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16. Abstract

This research collection is comprised of five separate studies supported entirely or in part under this grant. These studies are: (1) *Dynamic Visual Acuity at High Angular Velocities*, a preliminary study of differences between static and dynamic visual acuity and the significance of such changes with age; (2) *Thoughts on Elderly Driver Vision*. These two studies were preludes to A. Thompson Perry's present doctoral dissertation funded under this grant. (3) *Changes in Color Discrimination as a Function of Age*, by Frances A. Greene is a preliminary assessment of visual performance shifts with age. (4) *Spare Visual Capacity of Drivers*, by Laura K. Roush, R. Quinn Brackett, and Valmon J. Pezoldt has direct relevance to IVHS system design, and presents a methodology suitable for use in studying changes in driver workload capacity as a function of age. (5) *Visibility through Scatter*, by Bruce A. Wright relates losses in contrast sensitivity, typical with age, to sight distance on the highway.

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Studies in Aging Driver Needs for Mobility in an Automobile Oriented Region

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1. Dynamic Visual Acuity at High Angular Velocities
2. Thoughts on Elderly Driver Vision
3. Changes in Color Discrimination as a Function of Age
4. Space Visual Capacity of Drivers
5. Visibility through Scatter

Southwest Region University Transportation Center
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April 1992

FOREWORD

These five studies were performed under partial or full support of the Southwest Region University Transportation Center project "Aging Driver Needs for Mobility in an Authomobile Oriented Region" (RF712402) during the period of October 1989 to November 1990. The authors for each of these studies are identified in the appropriate sections that follow. Studies 1 and 2 were conducted entirely for the purposes of the project. Study 3 was supported by the project, but was also used as a graduate course project. Study 4 was conducted with very different objectives, i.e., the impairment produced by alcohol in young drivers, but was supported by the SWRUTC project for its contributions to methodologies development of use to the project. Study 5 was a masters thesis research project directed by the undersigned. Its findings are directly translatable into estimates of loss of visibility by drivers suffering from cataract or other eye disorders prevalent among older persons.

Rodger J. Koppa
Principal Investigator

TABLE OF CONTENTS

Note: Page references are to page numbers at bottom

Dynamic Visual Acuity
at
High Angular Velocities

A. Thompson Perry

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Dynamic Visual Acuity at High Angular Velocities

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Fourteen healthy young and middle aged drivers were tested for Static Visual Acuity (SVA) and Dynamic Visual Acuity (DVA) using the Contrast Vision Test System, a Modified Ortho-Rater, and a DVA test Station. Significant Correlations were found between the SVA tests, however, no significant Correlation was found between SVA and DVA scores. The mean size of the target needed for threshold resolution increases sharply above 90°/sec.

INTRODUCTION

One measure used in rating visual performance it that of acuity. Acuity is the ability to resolve small details. The evaluation of this ability is usually done in a static condition. That is neither the target or the observer is moving. This is called static visual acuity (SVA). There are various kinds of visual acuity. These are essentially threshold measurements where the reciprocal of the threshold is the measure of acuity. The first measure of threshold is the visibility threshold. That is how large must an object be in order to be seen. Another type of acuity is resolution acuity. This occurs when a target consists of two or more parts through which the background shows. The observers task is to detect the invading background. A third type of acuity is spatial or orientation acuity. The observers task is to determine the shape (round,triangle,etc.) of the target. Finally there is Vernier acuity. In this situation the observer must determine when two slightly offset lines are aligned.

However many tasks must be performed under dynamic conditions in which either the target or the observer or both are moving. Dynamic Visual Acuity (DVA) is the term used to describe this ability. Ludvigh and Miller first coined the term Dynamic Visual Acuity (1953).

The operation of any vehicle is one example of a situation in which DVA is required. Work by Burg(1967) has shown a significant correlation between DVA and driving performance as measured you reports of vehicle accidents. Evidence supporting this relationship was also reported by Shinar(1977). Reading(1968) reports that the DVA declines with age which also supports the earlier sighted work by Burg.

The correlation between SVA and DVA declines as the angular velocity increases (Slade,Burg,Knoll and Mathewson,1958). They report that between 60°/sec. and 120°/sec. no significant correlation is found.

OBJECTIVE

This study shall focus on the area between 60°/sec. and 120°/sec. in attempt to determine the manner in which the relationship between SVA and DVA deteriorates. Resolution acuity is the measure reported in the above studies and will be used in this investigation. To reduce the chances of confounding this investigation with age related decrements in DVA only young and middle aged subjects will be used.

METHOD

Subjects

Eight Female and Six Male graduate students or employees at Texas A & M University agreed to participate in this study. These subjects received no compensation for there services. They participated on an informed consent basis. All subjects were licensed drivers in the State of Texas. All were in good health and were free of noncorrected visual impairment.

Apparatus

A DVA test station was constructed by the experimenter. A 180° Panoramic Screen was constructed using poster board and white banner paper. The screen was constructed around the circumference of a half circle of 122 cm (48 inches) radius. A Photoelectric Rotary Pursuit Device Model 30014 (Lafayette Instrument Company) was placed at the middle of the screen with the center of rotation of the turntable at the exact center of the half circle.

A 35mm Ectagraphic Slide Projector Model AF2 (Eastman Kodak Inc.) equipped with a Kodak Projection Ectagraphic FF Zoom Lens (Eastman Kodak

Inc.) having a focal length of 100-150 mm and a speed of f 3.5 was placed on a table such that the projection beam passed above the turn table of the Rotary Pursuit Device and directly through the axis of rotation of that turntable.

A common mirror (15 cm x 30 cm) was supported in a hand made rest at such an angle to reflect the image projected from the slide projector on to the screen. The mirror and the rest were affixes to the turntable by paper backed adhesive tape.

A Modified Ortho-Rater (Bausch & Lomb) vision tester was used in this investigation. Test slides used were; Both Eye Distant Acuity FAR-3 (Bausch & Lomb), Right Eye Distant Acuity FAR-4 (Bausch & Lomb), and Left Eye Distant Acuity FAR-5 (Bausch & Lomb). Contrast sensitivity testing was accomplished by the use of the Vision Contrast Test System (Vistech consultants Inc., Model A).

Visual Stimulus Materials

Two 35mm resolution slides were made by the experimenter. Pictures were taken of Right Eye Near Acuity N-2 (Bausch & Lomb) and Left Eye Near Acuity N-3 (Bausch & Lomb) slides from the Modified Ortho-Rater set. Only the section of the slide containing the resolution checkerboard targets were used. Ectachrome 200 film (Eastman Kodak Inc.) and a Cannon Single-Lens Reflex Camera Model FTbn (Cannon Inc.) were used to make the stimulus slides. The N-2 Slide was designated Test Slide 1 (TS1) and N-3 was designated Test Slide 2 (TS2)

Experimental Design

This was a 2x2 design. One variable, Rotation, having two levels. Those levels were clockwise (CW) and counter-clockwise (CC). Clockwise is defined as the condition in which the target proceeds from the observers left to the observers right. Counter-clockwise is the case when the target proceeds from the observers right to the left.

The other variable, Angular Velocity, has six levels. Those levels are; 120°/sec., 105°/sec., 90°/sec.,75°/sec.,60°/sec., and 0°/sec. These values were chosen to investigate the region in which the relationship between SVA and DVA breaks down.

At the 0°/sec. level of angular velocity two other methods of measuring visual acuity were used, the Ortho-Rater and the Vision Contrast Test System, to provide a reference level for the DVA test station and to serve as a screening device for the test subjects to insure an adequate level of visual acuity.

Procedure

The participant was brought to the Human Factors Laboratory and placed in front of the Contrast Vision Test System and instructed in the task (see Appendix A). Upon completion of this measurement the subject was seated at a desk in front of the Modified Ortho-Rater and received the standard instructions for measurement on that device (see Appendix A). At this point the subject was asked to state which eye was dominant. If the subject did not know their dominant eye, they were asked to hold a cardboard tube like it was a telescope and to place it to the eye they would use to see through it. The preferred eye was observed and designated the dominant eye.

After completing these tasks, the subject was brought into the DVA test station and seated in a straight backed chair directly in front of the panoramic screen and closely adjacent to the Rotary Pursuit Device. The subject was instructed in the task (see Appendix A) and urged to sit with their head over the axis of rotation of the turntable. No time limit was imposed on the task and the subject was urged to guess in cases where they were unsure. A modified Method of Limits was used in attempting to determine the threshold of resolution. All trials started at the highest Angular Velocity and then the Angular Velocity was reduced in a stepwise manner. The last task was to test the limits of resolution with the turntable stopped and the target projected directly in front of the observer. At this point the Angular Velocity was increased to the highest level and the other test slide was projected. The test then proceeded as before. Upon completion of the second slide the subject was excused.

Four initial test conditions possible; CW/TS1, CW/TS2, CC/TS1, and CC/TS2. A random number table was used to distribute these conditions among the subjects in order to reduce the effects of fatigue or learning.

RESULTS

The mean visual angle resolved at the Angular Velocities 60°/sec. through 120°/sec. CC are displayed in Figure 1.

Insert Figure 1

There is no significant difference in the mean scores by Gender or Dominant Eye with the exception of CC120, $t\ (12) = 2.338, p < 0.04$. An examination of the Figure does revel a rapid increase in the visual angle of the target needed for resolution from CC90 to CC120 when compared to CC60 to CC90.

An examination of Figure 2 reveals a similar, although not as dramatic

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Insert Figure 2

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increase in the rate of change for the CW condition. There were no significant differences in the mean scores by Gender or Dominant Eye in the CW condition.

The scores at all levels of angular velocity and rotation were examined for a relationship using Pearsons Correlation Coefficient. The scores obtained from the Modified Ortho-Rater and the Contrast Vision Test System were also examined using this method. Significant correlations were found between the Modified Ortho-Rater and the Contrast Vision Test System, r = .642.p <.02. Additionally, a significant relationship was found between TS1 and TS2, r = .622,p<.02.

No significant correlation was found between any measure of SVA and DVA.

DISCUSSION

For young and middle aged subjects, 90°/sec. is the point at which visual targets must be markedly increased in size to be seen. The small sample size requires that the difference in male and female performance be regarded with caution. The lack of correlation between SVA and DVA coincides with the results in the literature. However, the lack of correlation at modest angular velocities may be a result of the sample size. Pearsons Correlation Coefficient is best used with a large number of samples.

RECOMMENDATIONS

This study should be repeated with a larger sample and a more varied one. The examination of the relationship of SVA and DVA for comparative populations of young, middle age, and elderly drivers is needed. A DVA test station with a smoother screen and better projection system is recommended.

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Burg,A. (1967). Relationship Between Vision Test Scores and Driving Records:General Findings. Institute of Transportation and Traffic Engineering, University of California, Los Angles.

Ludvigh,E.J. and Miller, J.W. (1953). A Study of Dynamic Visual Acuity. Joint Report #1 BuMed Research Project #NM 001 075.01.01

Reading,V. (1968). Disability Glare and Age. Vision Research, Vol.8, pp.207-214.

Shinar,D. (1977). Driver Visual Limitations, Diagnosis and Treatment. NHTSA, U.S. Department of Transportation.

Resolution Threshold
Clockwise Rotation

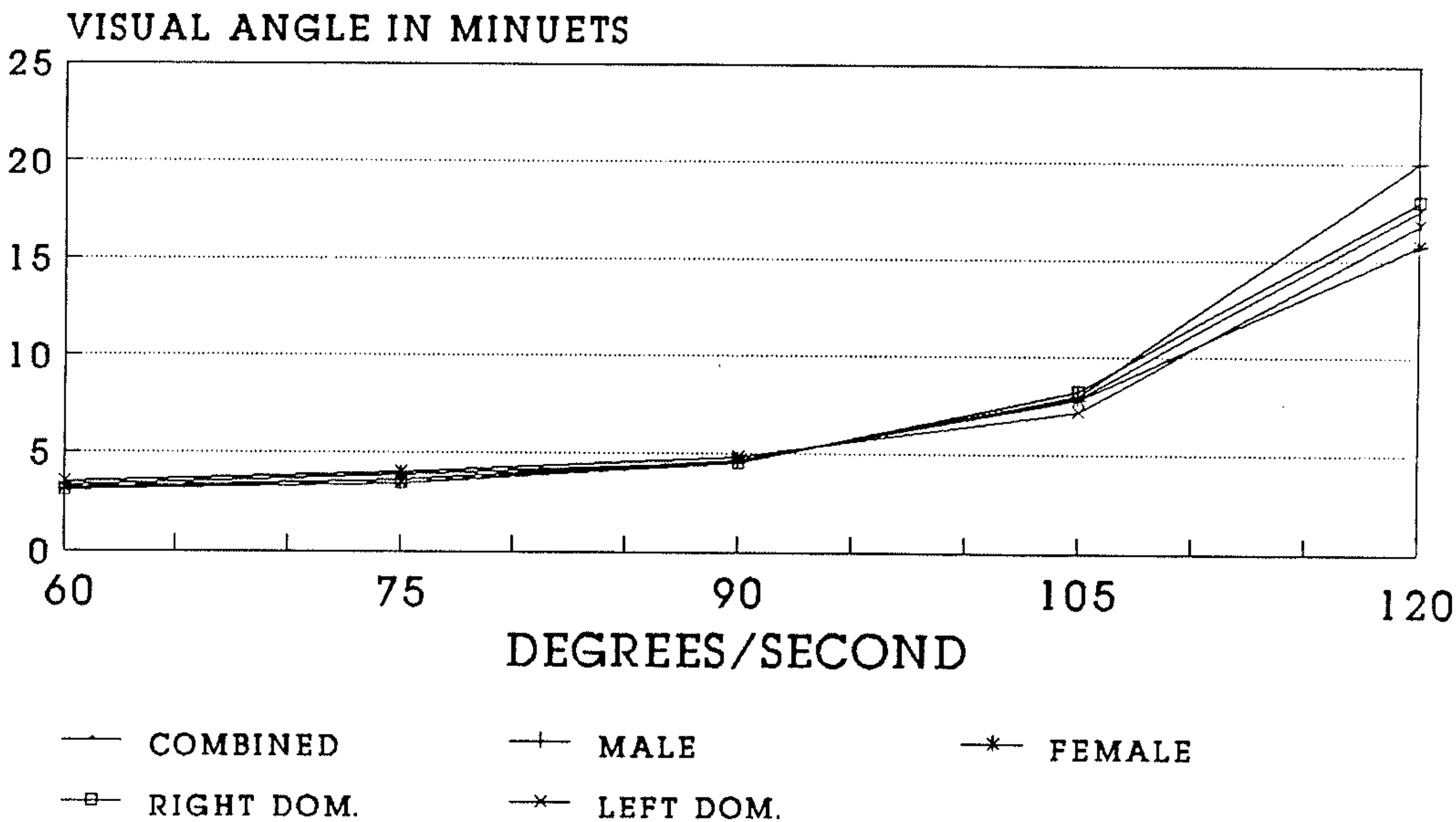

Figure 1

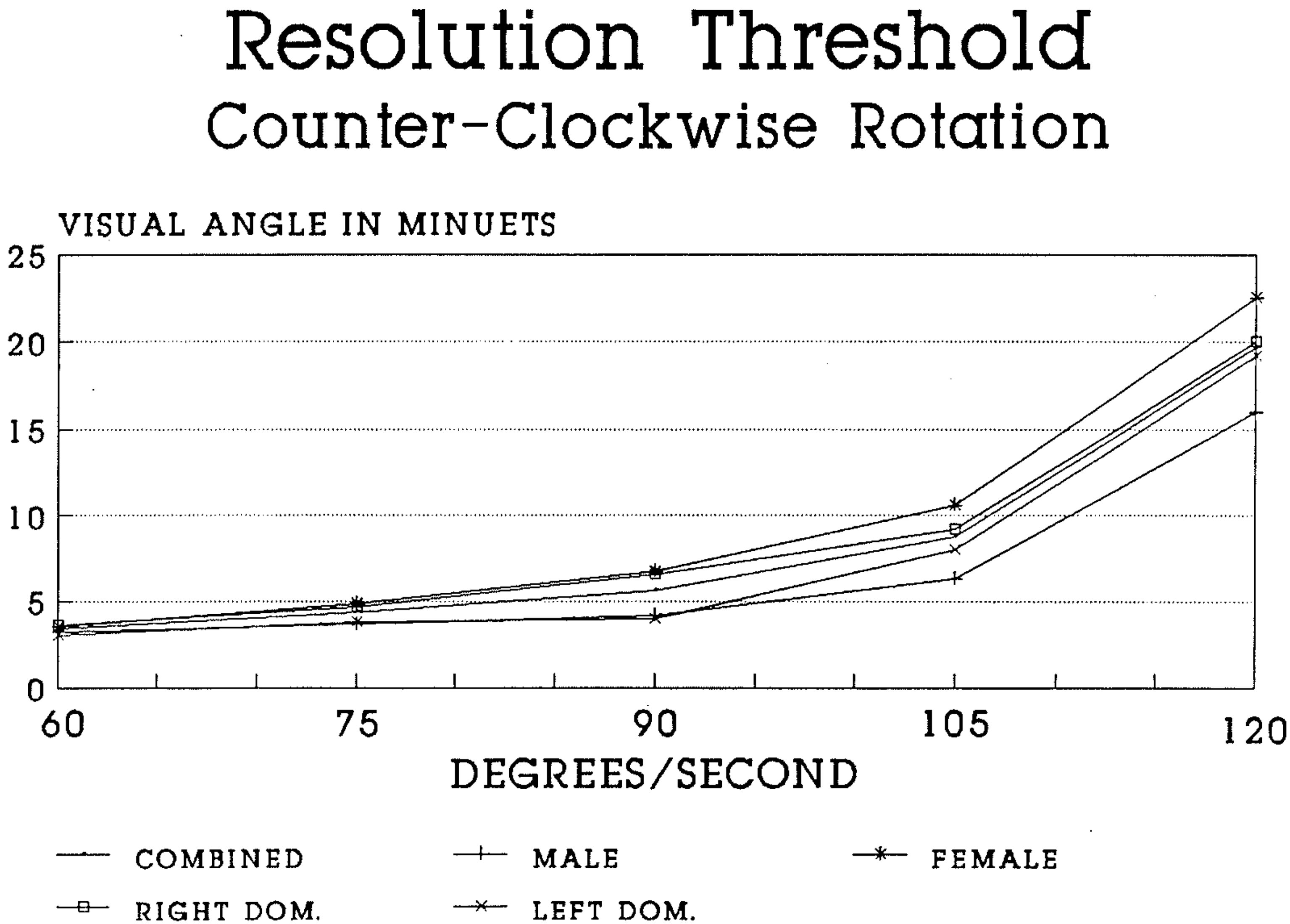
Resolution Threshold
Counter-Clockwise Rotation
VISUAL ANGLE IN MINUETS
25
20
15
10
5
0
60
75
90
105
120
DEGREES/SECOND
COMBINED
MALE
FEMALE
RIGHT DOM.
LEFT DOM.

Figure 2

Appendix A

Instructions for Contrast Sensitivity

You see in front of you a Contrast Sensitivity Test System. If you will look at the circles at the bottom will see that they have some lines or bars in them. They tilt to the left to the right, tilt to the left, or are vertical. This last one is blank and has no bars.

If you will look at the circles above you will see similar bars in some of them. Please start in Row A at Column One and tell me if you see any lines and which way they tilt. Now Row B, etc.

Instructions for the Ortho-Rater

(Insert Slide Far-3) In the big sign at the top, the No. 1 sign, do you see a black checkerboard on your right? In the No. 2 sign, where is the checkerboard? In no. 3?, 4?, 5?, etc.

Instructions for the Dynamic Visual Acuity Test

(Insert the familiarization slide into the Projector.) Please be seated in the chair in front of the mirror. You see a target similar to the ones you saw in the Ortho-Rater projected on the curved panorama screen in front of you. Your task will be similar to the task you had with the Ortho-

Rater. You will tell me where the checkerboard is located; top, bottom, right, or left.

The difference this time will be that the target will be moving. Please lean up as close over the mirror as you can. You may turn your head to track the target around the entire 180 degree panoramic screen. There is no time limit and you may guess if you are not sure of the placement of the target but try to be as accurate as rate as you can. Do you have any questions?

Raw Data

OBS	GENDER	AGE	CS	DOM	ORTHO	CW120	CW105	CW90	CW75	CW60	CW0	CC120	CC105	CC90	CC75	CC60	CC0
1	F	41	1.00	L	0.83	12	6.0	3.99	3.00	3.00	1.70	24	12.00	3.99	3.99	3.00	1.32
2	F	32	1.00	R	1.11	12	12.0	6.00	3.99	3.99	3.00	24	12.00	6.00	3.99	3.99	2.00
3	F	25	1.00	R	1.25	24	6.0	6.00	3.99	3.99	2.40	24	24.00	24.00	12.00	6.00	3.00
4	M	40	0.83	R	1.00	12	6.0	2.40	2.40	2.40	1.32	12	3.99	3.99	3.00	3.00	1.50
5	M	27	0.83	L	0.91	24	12.0	6.00	6.00	6.00	2.00	12	3.99	3.99	3.99	3.99	1.70
6	F	31	0.83	L	0.91	24	6.0	3.99	3.99	3.00	1.50	24	6.00	3.99	3.99	3.00	1.70
7	F	40	1.00	R	1.11	24	12.0	6.00	3.00	3.00	1.70	24	12.00	3.99	3.99	3.99	1.70
8	M	31	0.83	R	0.83	24	6.0	6.00	3.99	2.40	1.50	12	6.00	3.00	3.00	2.40	1.70
9	F	24	1.00	L	1.25	12	6.0	3.99	3.00	2.40	2.00	24	12.00	3.99	3.00	2.40	2.00
10	M	33	0.83	R	1.11	24	12.0	3.99	3.99	3.00	1.32	24	6.00	3.99	3.99	3.99	1.50
11	F	24	0.83	R	1.00	12	12.0	3.99	3.99	3.00	1.70	12	3.99	3.99	3.99	3.00	1.70
12	F	25	0.83	R	0.83	6	2.4	3.00	2.40	2.40	1.70	24	3.00	3.99	3.99	3.00	1.32
13	M	23	0.83	R	0.83	24	6.0	3.00	3.00	3.00	1.20	24	12.00	6.00	3.99	3.00	1.32
14	M	26	1.00	L	1.25	12	6.0	6.00	3.99	3.00	1.20	12	6.00	3.99	3.99	3.00	1.70

Thoughts on Elderly Driver Vision

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Thoughts on Elderly Drivers Vision

Tom Perry

A number of concepts come together in this discussion. They are static visual acuity (SVA), dynamic visually acuity(DVA), depth perception, information theory, and learning theory. Inherent in explaining the difference in driving styles of old versus young or middle age drivers in the lack of correlation and more particularly the difference in the slope of the functions of static visual acuity and dynamic visual acuity.

Evidence indicates that although there is a difference between SVA and DVA that these functions have roughly equal slopes for the young and even the middle age driver. However, for the older driver these functions become vary divergent. Although the SVA function acquires a slight negative slope, which is to some extent correctable by lenses, the DVA function becomes sharply negative and is not correctable by lens or any other means. Burg suggests that DVA is a function of central processes although this is disputed by others.

In all cases, without regard to age, as the angular velocity increases acuity decreases. This information seems intuitive. However what is not intuitive is that the older the person the greater the degradation for a given velocity. To put it another way, and possibly more germane to the task of driving, for the same level of acuity the slower must be the velocity of rotation for the older observer.

Now let us go to another thread of this discussion, information theory and learning theory. Information is defined as that which reduces uncertainty. In order to operate a vehicle a driver must have information. The primary channel for acquiring information for driving is vision. If the lack of information (uncertainty) is considered aversive, and I believe that studies support this conclusion, then information can be considered reinforcing. Learning theory shows that a person will have a greater probability of emitting those behaviors which have been reinforced. In addition the person will attend to the thing that is reinforcing and to those surroundings in the environment which have acquired secondary reinforcing properties.

With the above thoughts in mind, let us approach the driver in the vehicle at rest before entering the roadway. Visual acuity is the same in all directions. The only obstacles to vision are the structural members of the vehicle, the condition of the windshield and windows and maybe the frames of the drivers glasses. The flow of information in the visual channel is at its optimum level. As the vehicle begins to move the quality of visual information begins to change. Based on the concepts of the visual world there is now a flow of objects toward, past, and away from the observer. And what is more important is that the flow is not the same at all points in the world.

For the driver, what ever the age, DVA creates a Cone of Greatest Certainty (CGC) along a line parallel to the line of travel of the vehicle directly in front of the driver and directly behind the rear view mirror. Outside of the CGC the angular velocity becomes a significant factor in reducing visual acuity, and therefor increasing uncertainty, due to the mechanisms of DVA. Angular velocity is greatest along the lines perpendicular to the line of motion of the driver and therefor DVA causes the greatest reduction of acuity along that vista.

Another factor not to be neglected here is the fact that in a driving situation the objects either side of the road way do not remain at a fixed radius. Even stationary objects have a decreasing radius as the vehicle approaches until they reach a Closest Point of Approach (CPA) and then appear to recede. This phenomenon is compounded by moving objects such as other vehicles or pedestrians. This brings up the area of depth perception of the driver. Even objects in the CGC are approaching or receding and information regarding there distance is subject to the drivers ability to accurately determine relative distance and the rate of change of distance.

Like Mister A in Flat Land, let us return to the world of fixed radii. The boundary of the CGC is that radii at which the angularly velocity becomes so great that the level of visual information is below the level needed to make decisions which are reinforcing. This radii changes depending on a number of factors; level of riskiness of the driver, DVA of driver, and linear velocity of the vehicle. A driver, through lack of information regarding risk, conscious decision to accept risk, or personality style may decide to accept a relatively narrow CGC. Assuming the same perceived need for information, a driver with a poorer DVA will have a narrower CGC than a driver with a better DVA. Given the same DVA the driver of the slower vehicle will have a wider CGC than will the driver of the faster car. This point strikes to the heart of the matter regarding the driving styles of young, middle aged, and elderly drivers.

Implications of CGC

The CGC must be of sufficient size such that the driver is comfortable in operating the vehicle. In addition because the CGC is reinforcing it is attended to by the driver. These two points explain some significant behaviors of elderly drivers involved in accidents. But first we must understand how something becomes visible.

The three characteristics which control the visibility of an object are visual angle, illumination, and contrast. Visual angle relates to the apparent size of the object on the retina of the eye. Illumination of the object controls the amount of luminous flux which flows from the object to the rods and cones in the retina of the eye. Contrast is a function of the difference in the luminance of the object in relation to the luminance of the background surrounding the object.

The elderly driver has no control over the size, and therefor the visual angle, of the traffic signs, cars, street signs, or other objects that make up the world of the roadway. The visual angle of these objects can only be increased by approaching the object. This is a limited option because of the edge of the roadway. We speculate that this may be a partial explanation of the preference of older drivers for the curb lane in multi-lane roadways.

Illumination of the object is partially under the control of the driver in the form of headlights. This, however, is a two edged sword due to the presence of other vision defects common in the elderly like cataracts and floaters. Headlights, by design, are confined to the surface of the roadway and do little to illuminate overhead signs and objects to the side of the roadway. Illumination to the rear is only available via backup lights and is confined to the direct rear. Contrast of objects is out of the control of the driver.

Given that the three criteria for visibility are met by all the objects in the roadway environment, what can the elderly driver do to increase the CGC? The driver can control the angular velocity of the objects by approaching that optimum visual environment we started with. He can slow down or even stop. And that is what the elderly driver does.

Unfortunately this behavior has serious consequences. In the real world the elderly driver is not alone on the roadway. However, studies indicate that many elderly drivers try to approach this condition by driving at off peak hours. This driver is now traveling at a rate of speed which is significantly different than his fellow drivers. Studies by Brackett() have shown that drivers traveling at rates of speed beyond one standard deviation from the mean have a significantly increased probability of an accident. This could be a partial explanation of the number of rear-end accidents experienced by elderly drivers.

If the elderly driver has increased the CGC by whatever means available then he is receiving information he feels is sufficient to operate the vehicle. This information, by definition, reduces uncertainty and the discomfort associated with uncertainty. This reinforces the behavior of attending to the CGC. Attending to areas out side of the CGC decreases information and increases the discomfort associated with uncertainty. This serves as a discriminative stimulus for attending to the CGC. I speculate that the result of the focus of attention on the CGC along with the relatively narrow width of the CGC contributes to the reports that the older driver misses stop signs and contributes to other right-of-way accidents.

Changes in Color Discrimination as a Function of Age

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Changes in Color Discrimination as a Function of Age : Measured Using the Farnsworth-Munsell 100-Hue Test

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The Farnsworth-Munsell 100-hue test for general color discrimination was used to characterize color vision changes as a function of age. The acceleration in the aging process of the eye was accomplished using a special pair of glasses, manufactured for Dr Koppa, Texas Transportation Institute, to simulate the eyes of a 75 year old person. Test/retest scores of subjects not wearing and then wearing the old eye simulator glasses were obtained. A significant effect of age was found on color discrimination ability. However, no particular region of the color spectrum appears to be effected more than others. A general failing of discrimination across all colors was found.

INTRODUCTION

With advancing age, several physiological changes occur in the human eye. A condition known as presbyopia is an attribute of eyes of a 40 year old person. Presbyopia is a lack of accommodative power of the lens. The lens hardens with age and loses its elasticity, and hence, ability to accommodate. Therefore, the result is one's "arms not being long enough." Along with this hardening is an accompanying yellowing of the crystalline lens. This yellowing, coupled with the "floaters" in the vitreous humor of the eye, cut down on the transmission of light reaching the retina. Investigation of how this inevitable yellowing and reduction of light transmission to the retina affect color discrimination in older individuals is the focus of this research study.

The Farnsworth-Munsell 100-hue test (FM-100) is a commonly used color vision test to characterize both color anomalous vision, as well as color discrimination ability. This tool was developed by Dean Farnsworth, of Munsell Color Company, MacBeth, Division of Kollmorgen Corporation (1943). Farnsworth (1957) has acknowledged that

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This paper follows the style and format of Human Factors the scores from this test, designed to measure general color discrimination directly, are not expected to correlate directly with other tests of color vision, like the pseudo-isochromatic plates. The color plates, like Ishihara or Dvorine, can isolate only certain factors of color deficiency. Therefore, no correlation was derived between the subjects' color plate test scores and those obtained with the FM-100 hue test.

The FM-100 hue test has been used extensively in both clinical and industrial applications. Its primary uses are, first, to categorize persons with normal color vision into three classes color discrimination: superior, average and low ability, and second, to measure the zones of color confusion for persons with color anomalous vision. Some of its special applications have included: examination and selection of inspectors in the textile and paint industries, selection of applicants for vocational training, detection of poor color vision in salesmen, measurement of effects of medical treatments and, as an independent control on validity of other color vision tests.

The pseudo-isochromatic color plates are designed to test color imbalance (also erroneously referred to in the literature as "color blindness"). The 100-hue pattern will indicate the type of the imbalance, the color zones of best and poorest perception and the degree of color discrimination in those zones as compared to normals (Farnsworth, 1957).

METHOD

Subjects

The primary participants in this study were 12 unpaid volunteers between the ages of 21 and 47. All participants were either full-time undergraduate or graduate engineering students as Texas A&M University. All possessed self-reported 20/20

Snellen acuity, corrected if necessary.

Apparatus

The Farnsworth-Munsell 100-hue test was used as the test of color discrimination. The FM-100 test is comprised of 85 cylindrical plastic caps, each of which has a calibrated Munsell color chip recessed-mounted in it. The test, originally consisting of one hundred Munsell colored papers (hence the name 100-hue test), was pared down to represent a circuit of eighty-five, whose hue differences were "just noticeably different" in value (lightness) and chroma (saturation) for color normals. A plot of these 85 hues in Munsell color space is shown in Figure 1.

The caps are grouped into four separate boxes (quadrants) according to their basic hue. Quadrant 1 contains hues in the yellow through red part of the spectrum (572-610 nm). Quadrant 2 examines hues falling in the blue-green area through yellow-greens (497-571 nm). Quadrant 3 consists of hues in the blue through blue-green parts of the spectrum (472-496 nm). Finally, quadrant 4 contains hues in the red, and purple, through the blue portion of the spectrum (611-635 nm, along the "line of purples" joining the red and blue portions of the hue space, through 471 nm).

Prior to test administration, the order of the caps is randomized in each box. Observers are instructed to arrange the caps within each quadrant so that they form a regular color series between the two fixed hue caps, mounted at opposite ends of the box.

The second apparatus is a pair of optical glasses, (which will be termed "old eyes" for the remainder of this paper) manufactured for Dr R. Koppa, Human Factors Division, of the Texas Transportation Institute by Flanagan Spectacles, Inc. These

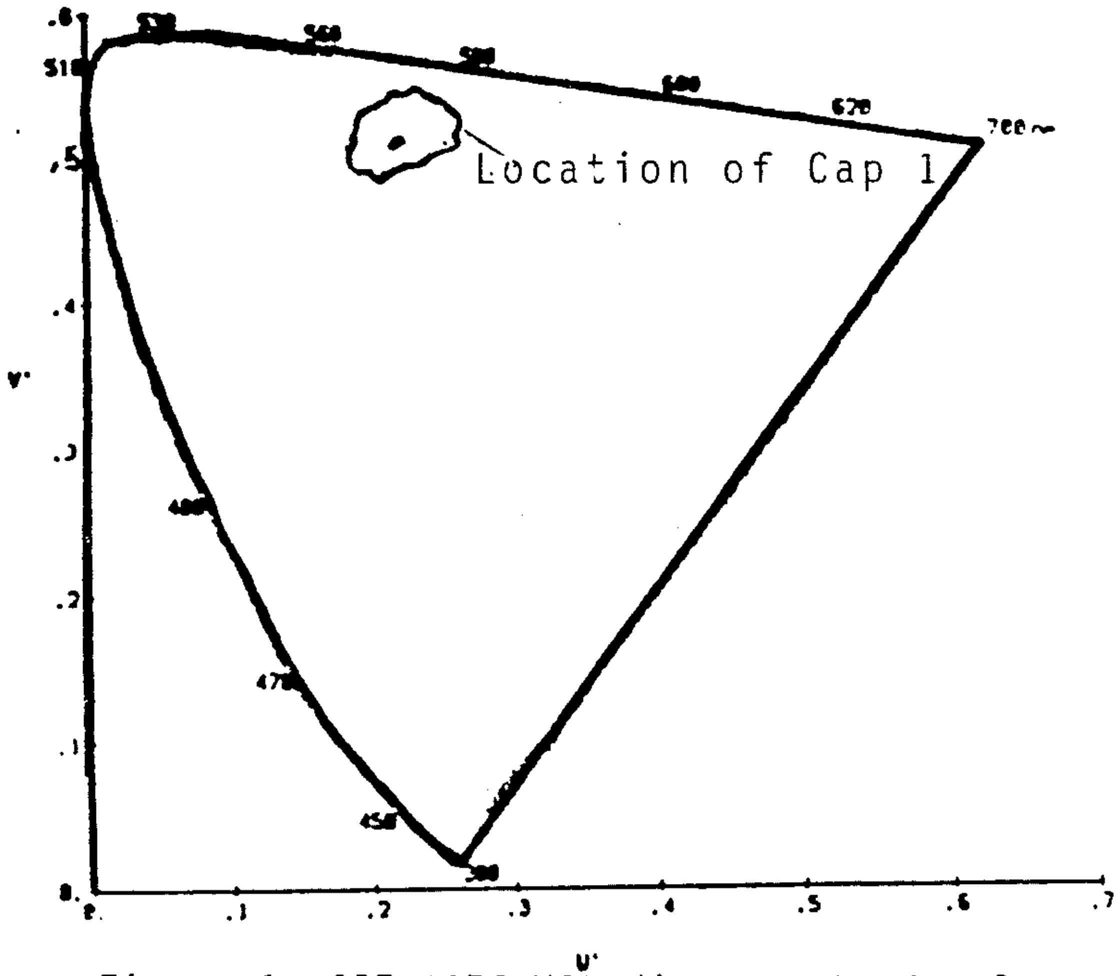


Figure 1. CIE 1976 UCS diagram showing location of FM-100 caps

glasses are specially designed to mimic the effects of aging on the eye. While wearing these glasses, the addition of roughly 35 years is made to the test subject's eyes. The glasses have the following optical characteristics: 50% transmissivity, -1 diopter correction (making the subject hyperopic, or farsighted), a yellowish-brown tint to approximate the yellowing of the crystalline lens.

Experimental Design

A repeated measures design was selected, using each subject as his own control. Due to the late addition of the old eyes condition, seven of the 12 subjects first performed the FM-100 hue test without the glasses, while the other five began the old eyes glasses. A test/retest set of scores was obtained for all 12 subjects. Each subject was administered the FM-100 test outside in the ambient environment. This setting was chosen so that the yellow and blue components of fluorescent lighting would not interfere with the results attributable to the old eyes glasses.

The order of presentation of the four boxes of color caps was counterbalanced across all subjects. The order of the color caps within each box was randomized such that no two caps were ever closer than four positions away from the next cap in the series. The complete experimental design is shown in Appendix A.

Instructions to the subjects were taken directly out of the FM-100 hue test manual (Farnsworth, 1957). The instructions to each subject are contained in Appendix B.

The FM-100 manual states in the "instructions to the subject" that it should take approximately two minutes to arrange each panel. The test clearly emphasizes that accuracy is much more important than speed, and as much time as is necessary should be allowed for everyone to complete the color test. Although test times were recorded for every subject, the data was not analyzed.

RESULTS

The standardized scoring procedure, along with a specialized data sheet, both supplied with the FM-100 test, were used to calculate error scores for each subject. At the end of each trial, the order series selected by the subject was recorded on the data sheet. This order and its difference from the correct series form the basis for computing error scores. The score for any cap is obtained by taking the sum of the differences between the number of that cap and the numbers of the caps adjacent to it. A single cap transposition results in an error score of 4, and a three-cap transposition error generates an error score of 8.

For example, a portion of a hypothetical recorded order of arrangement and its resulting error score derivation are illustrated below:

Correct	5	6	7	8	9	10	11	12	13	14
Recorded Order	5	6	7	8	13	11	9	10	12	14
Cap Score		2	2	6	7	4	3	3	4	
Sum of adjacent numbers		1+1	1+1	1+5	5+2	2+2	2+1	1+2	2+2	

Statistical significance of all effects reported herein was assessed using alpha = 0.05.

Plots of Color Confusions Within the Secondary Group (Not Tested with Old Eyes)

There was a secondary group of seven subjects, ranging in age between 20 and 54, who because of last-minute changes in the experimental design and their availability, were tested without the old eyes glasses. Within this group, two persons' scores reflect color anomalous vision. One subject, aged 35, tested as a blue-yellow deuteranope. The second subject, aged 54, displayed the hypothesized characteristic effects of the yellowing of the crystalline lens within the eye. It was the results of this person's test score which prompted the retest of the other subjects, wearing the old eyes glasses to reproduce the effects of advancing age on the eye. Plots of the data obtained for the two color anomalous persons in the secondary group are contained in Figures 2 and 3.

In the analysis of defective color vision, Farnsworth (1957) shows patterns of color defectiveness as being identified by bi-polarity (See Figure 4). Maximum errors cluster themselves in two regions which are nearly opposite one another on the color circle. Based on the interpretation guidelines provided by Farnsworth (1957), the analysis of this participant would classify him as having a severe degree of color vision defect in the blue/yellow regions of the spectrum. As can be seen in Figure 2, the blue-yellow deuteranope, has very few or even no color confusions in the purples, reds, greens or blue-greens. As a matter of fact, he has above average discrimination in those areas. The plot clearly reveals his primary zones of color confusion being in the yellows and blues (572-584 nm and 470-486 nm).

Figure 3 is a plot of the data of the 54 year old participant. This participant does not show the patterns of color confusions that would classify him as having a color anomaly (see Figure 4 for verification). This pattern of errors is more analogous to a person possessing very low color discrimination ability, due to the yellowing of the lens. Color confusions occur for this subject primarily in the purples. He also has trouble with blue-greens and some yellows (peaks near 485, 490 and 495 nm and 610-635 nm, plus purple-reds).

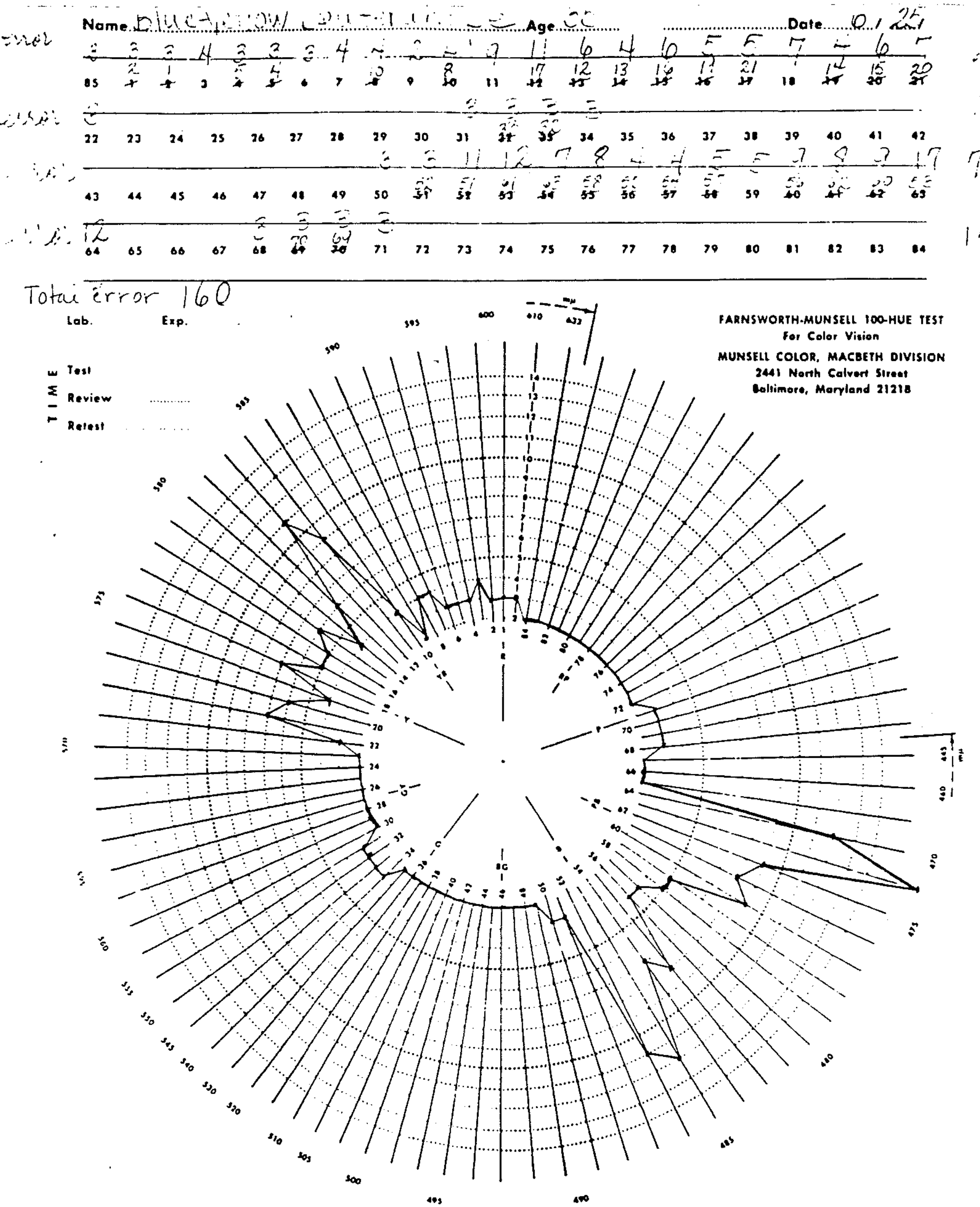


Figure 2. Plot of Blue/yellow deuteranope FM-100 Test error scores

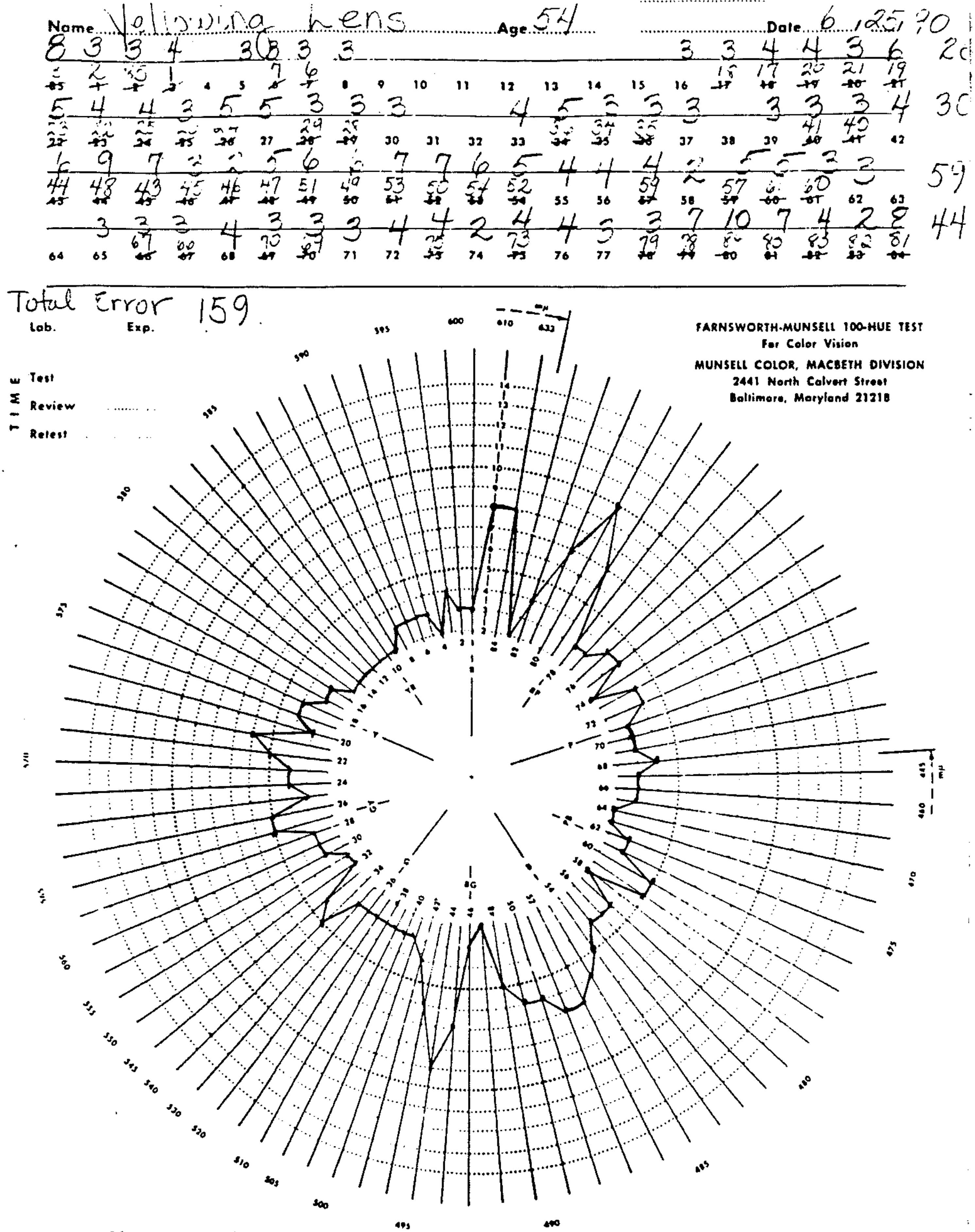
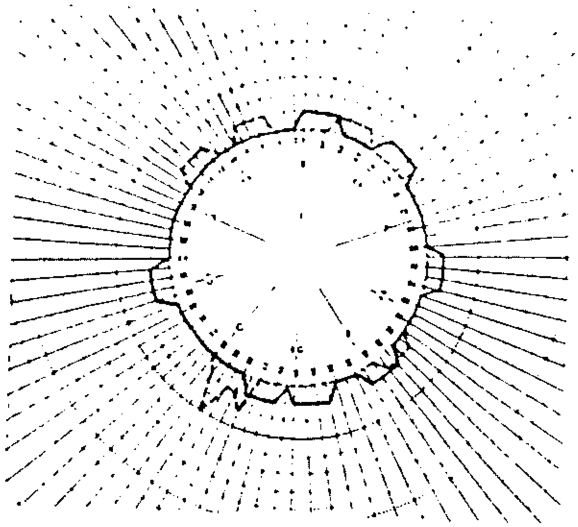
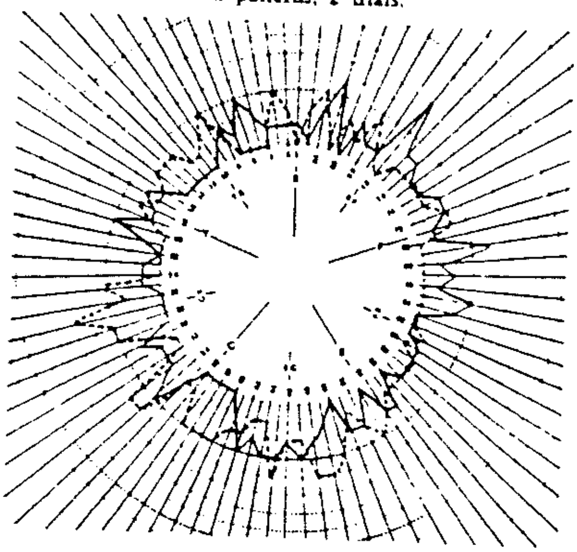


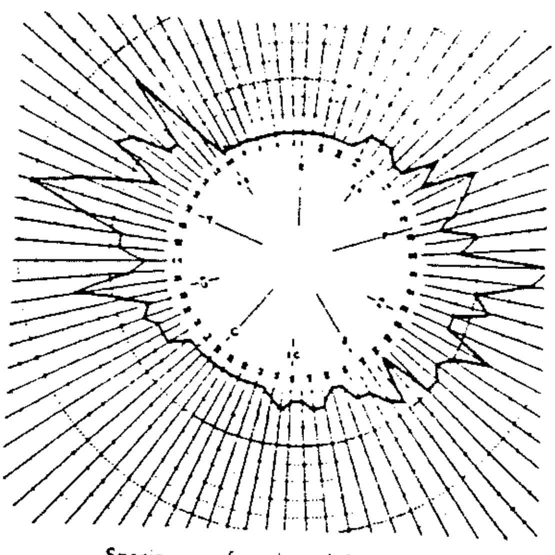
Figure 3. Plot of FM-100 Color Confusions for Subject with Yellcwing Lens



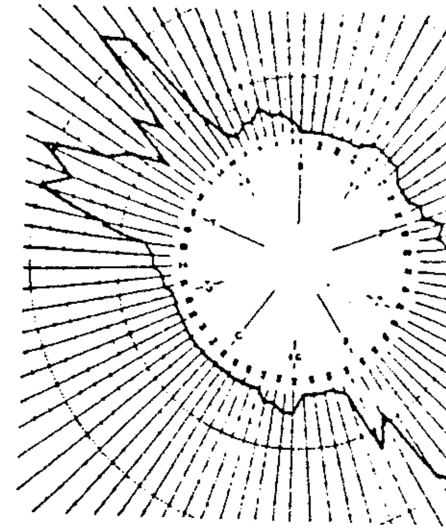
Specimens of normal, average, discrimination patterns, 2 trials.



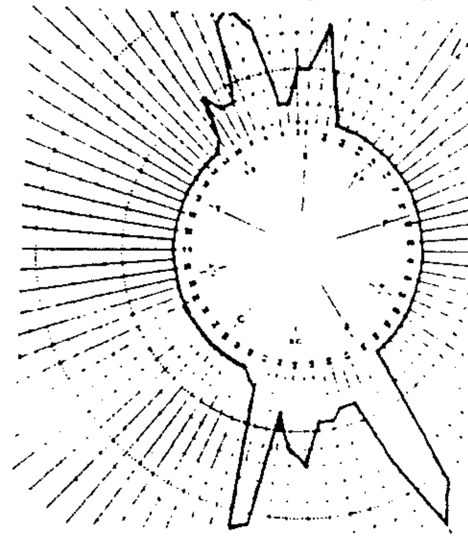
Specimens of normal, low discrimination pattern, 2 trials.



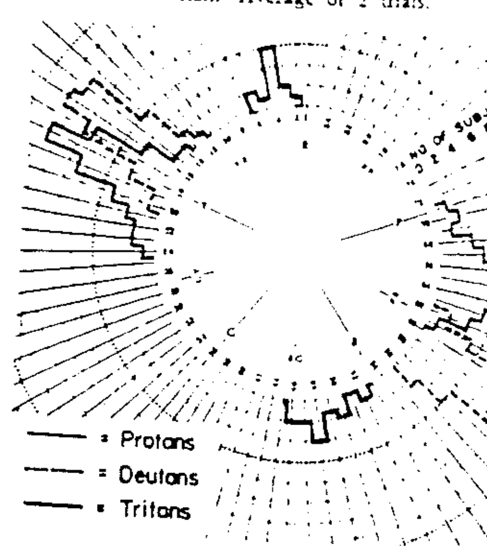
Specimen of color defective pattern; Protan. Average of 2 trials.



Specimen of color defective
Deutan. Average of 2 trials.



Specimen of color defective pa
Tritan. Average of 2 trials.



Distribution of mid-points from 112 te
on color defective subjects: 50 protans,
50 deutans and 12 tritans.

Figure 4. Examples of color confusion plots from FM-100 hue test

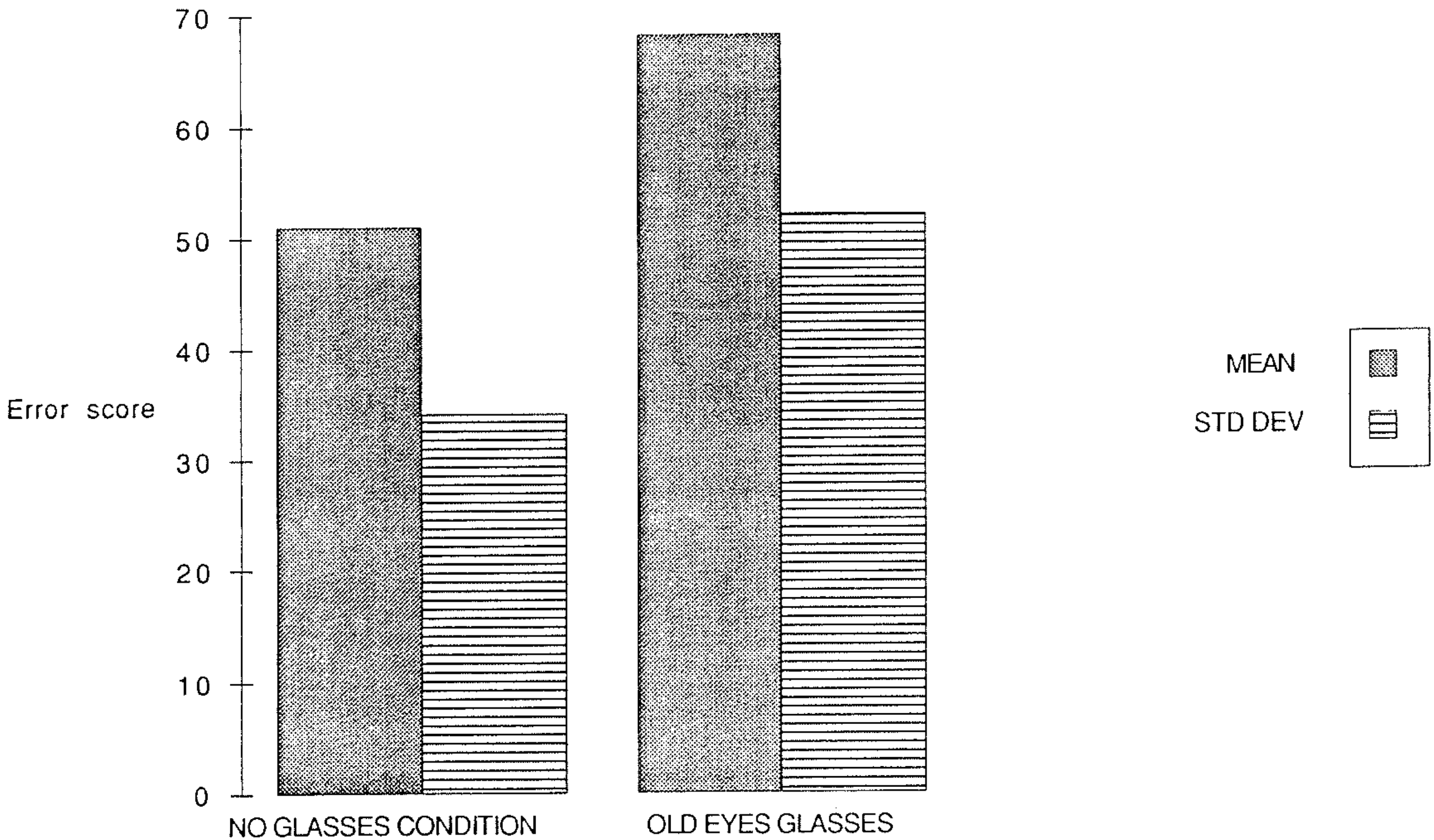


Figure 5. Means and standard deviations for treatment conditions

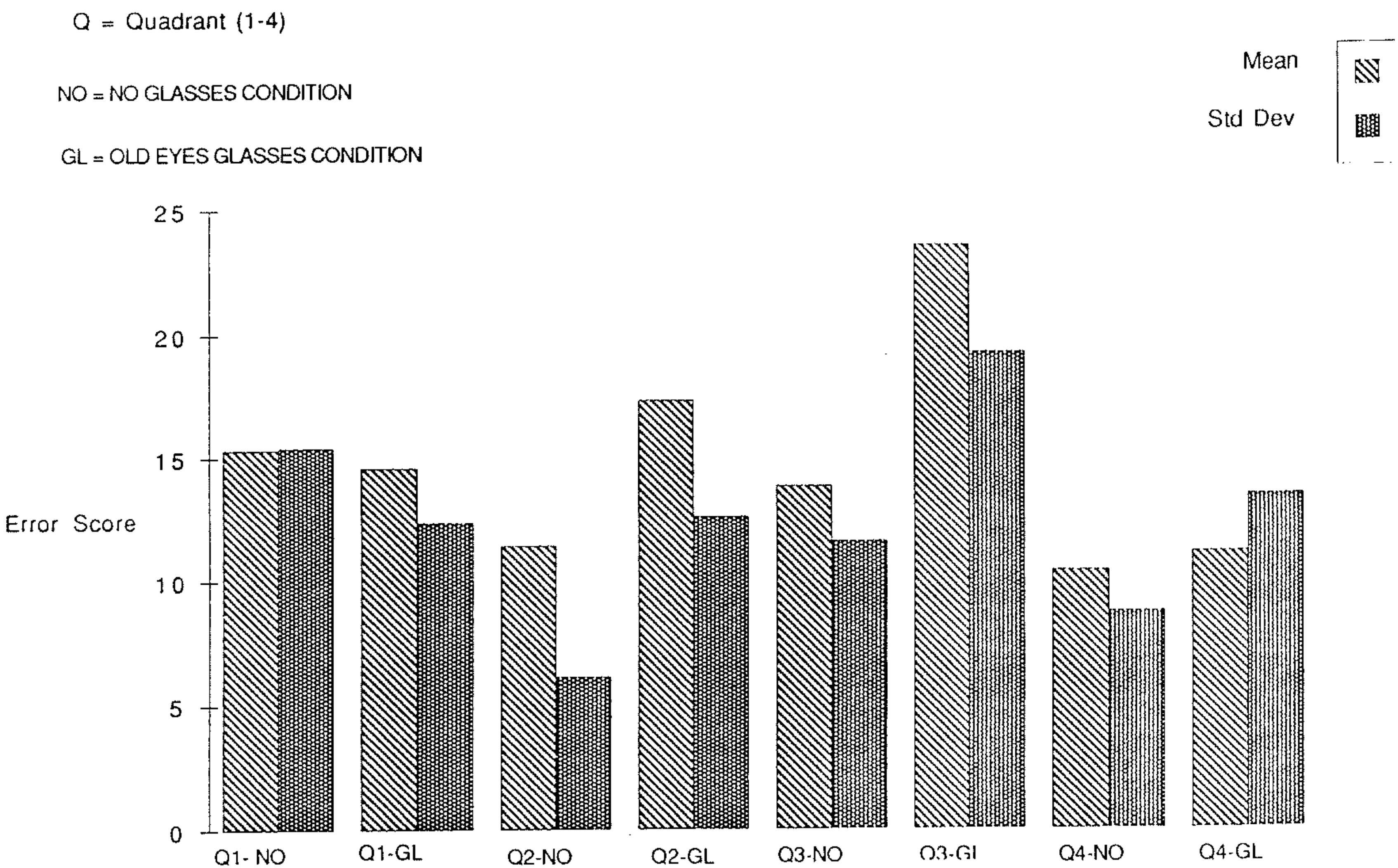


Figure 6. Quadrant x Treatment Means and Standard Deviations

Descriptive Statistics

According to Farnsworth (1957), total error score reveals discrimination ability. Superior discrimination has been found in about 16% of the population (exclusive of color defectives) and is defined as making between zero and four transpositions. In the primary group, tested under both treatment conditions, none of the 12 subjects could be categorized as having "**superior**" color discrimination. Only one of the seven subjects (14%) in the secondary group had superior color discrimination.

Average discrimination is defined as having a total error score between 20 and 100. Five of the seven participants (71%) in the secondary group fell within this category. The other two, of course, were the color anomalous subjects. In the primary group, while not wearing the glasses, 10 out of 12 or 83% fell into this range. While wearing the glasses, once again 10 out of 12 (83%) continued to have error scores in this range.

Low discrimination, according to Farnsworth (1957) defines 16% of the population (exclusive of color defectives) and their total error scores exceed 100. The tests reveal no region of large maximum or minimum sensitivity as found in the color defective patterns. None of the secondary group and only one out of 12 (8%) of the primary group fall into this category, either wearing the old eyes glasses or not.

Effect of Old Eyes Glasses

Table 1 shows the means and standard deviations of the total error scores wearing and not wearing the old eyes glasses. Table 2 shows the means and standard deviation of total error scores by quadrant of the hue circle, for each treatment condition. Figures 5 and 6 illustrate these results in histogram form.

TABLE 1
Overall means and standard deviations of total error scores with and without glasses

	OVERALL MEAN	STANDARD DEVIATION
WEARING NO GLASSES	51.000	34.0990
WEARING GLASSES	68.3333	52.0872

TABLE 2
Quadrant x treatment error score means and standard deviations

CONDITION	MEAN	STANDARD DEVIATION
Quadrant 1 - No Glasses	15.333	14.587
Quadrant 1 - With Glasses	15.417	12.362
Quadrant 2 - No Glasses	11.417	6.156
Quadrant 2 - With Glasses	17.333	12.601
Quadrant 3 - No Glasses	13.833	11.590
Quadrant 3 - With Glasses	23.583	19.247
Quadrant 4 - No Glasses	10.417	8.785
Quadrant 4 - With Glasses	11.167	13.469

ANOVA

A repeated measures analysis of variance (ANOVA) was conducted on the primary group, with and without the old eyes glasses, using the total error score generated on each FM-100 test as the dependent variable. Table 3 summarizes the results of the ANOVA.

TABLE 3
ANOVA table for repeated measures design

Source	df	Mean Square	F Value	Prob
Treatment (Glasses vs No Glasses)	1	408.375	8.24	0.0055
Subject	22	514.079	10.37	0.0001
Quadrant	3	254.819	5.14	0.0030
Treatment*Quadrant	3	125.153	2.52	0.0652

As can be seen from Table 3, wearing the old eyes glasses had a significant effect on the error score. In the treatment group (consisting of 11 out of 12 color normals), 9 out of 12 (75%) subjects' error scores worsened (got larger) when wearing the glasses. For only one of those nine subjects, did the resultant error score move him into the next lower discrimination category (as discussed above). All the other eight remained at the average discrimination level. For the one subject, his error score went from 98 without wearing the glasses to 115 with them, pushing him from the average into the low discrimination category.

The one color anomalous participant in the primary group (aged 23) was a blue-yellow deuteranope, although his degree of severity was not as marked as the other deuteranope from the secondary group. Figures 7 and 8 plot the error scores for the primary group's blue-yellow deuteranope without and with the old eyes glasses. First, observing total error score, the glasses increase it from 119 to 204. The quadrants most affected by the glasses for this participant are 2, 3 and 4 (yellows through purples). His color confusions are exaggerated while wearing the old eyes. In addition, color confusions in the purple and blue-purple areas of the spectrum are seen.

Error scores by quadrant were also significant. Overall error scores reflecting color discrimination, collapsing over treatment conditions, is differentially affected across the four quadrants. However, the interaction of treatment * quadrant was not significant, meaning that the glasses did not have a significant effect on the error scores within each quadrant of the test. Inspection of the raw data of treatment * quadrant shows that only quadrant 3 (the blues and blue-greens) showed a large increase in error score when wearing the glasses (13.8333 vs 23.5833). But the error

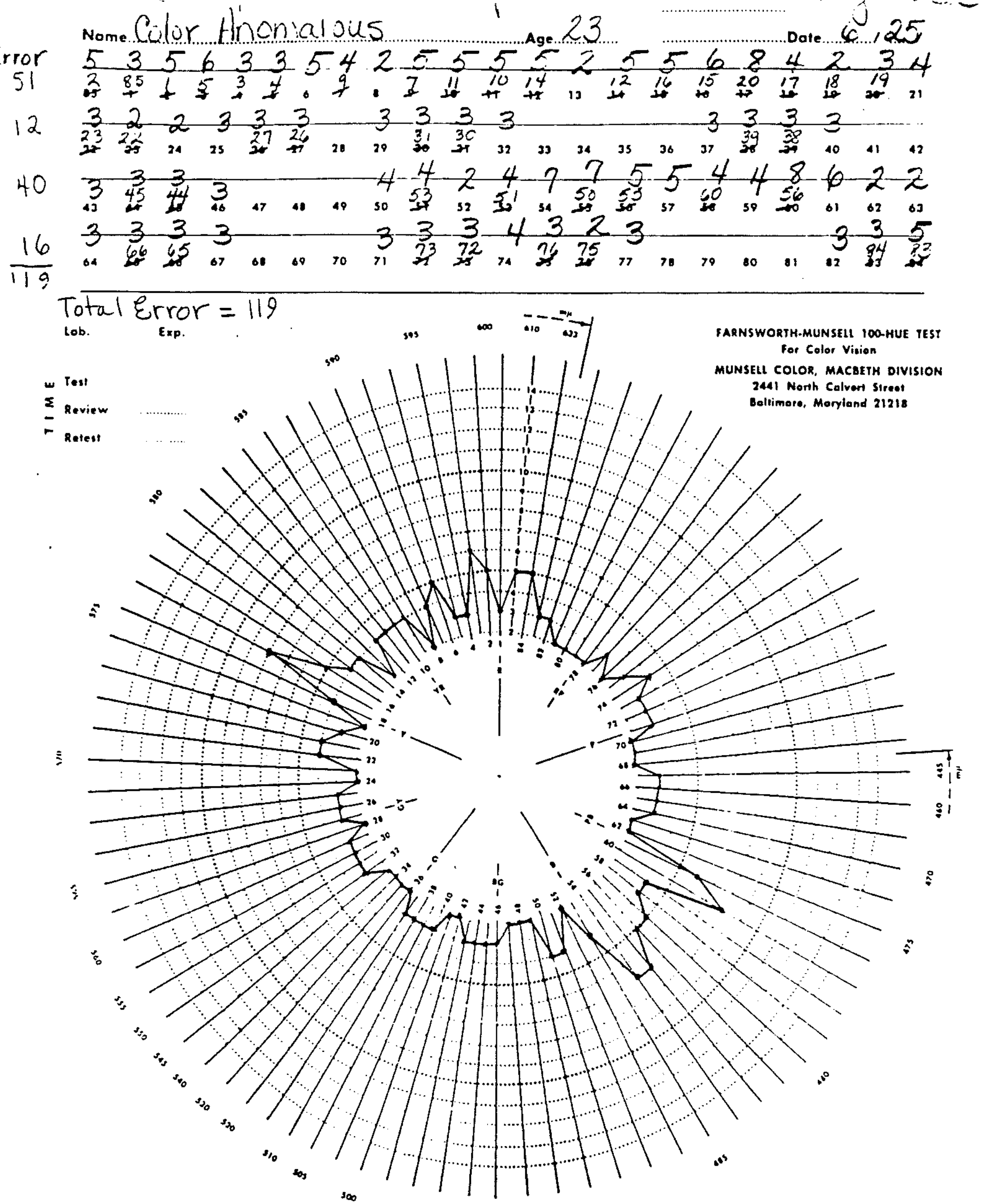


Figure 7. Plot of color confusions for blue/yellow deuteranope without the glasses

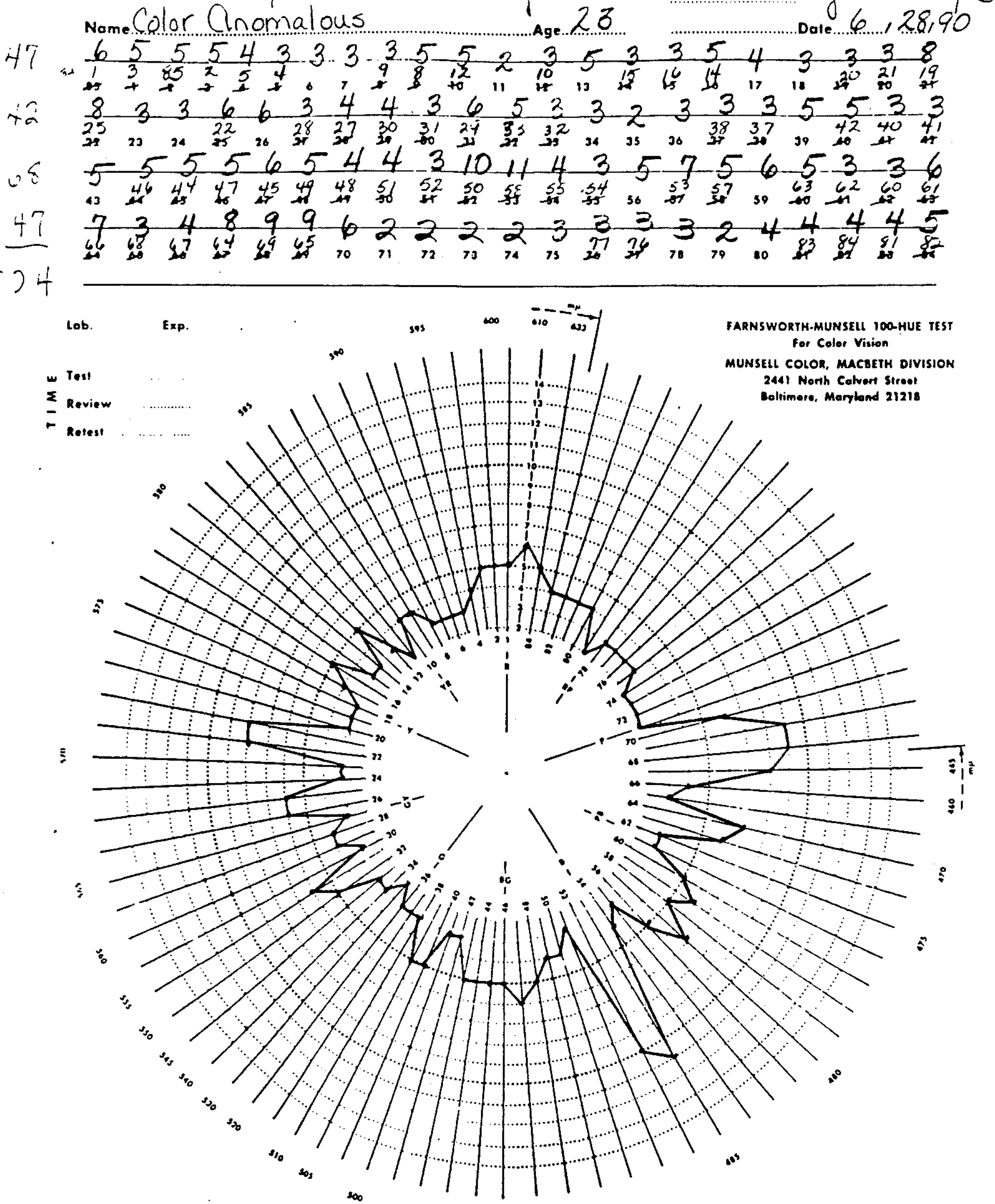


Figure 8. Plot of color confusions for blue/yellow deuteranope with old eyes glasses

score difference for this quadrant was not enough to make the overall interaction significant.

Other Independent Variables

The variables of sex and age were not examined. It is well-known that the occurrence of color deficiencies are statistically higher in males than in females. In the total participant population of 19, two males and no females were found to be color defective. Age was not systematically varied in this participant population. The ages of those whose scores improved when wearing the old eyes glasses were: 24, 31, and 39. The oldest subject, aged 47, was the only one whose error score while wearing the glasses pushed him into a lower color discrimination category.

GENERAL SUMMARY AND DISCUSSION

Color discrimination ability was significantly affected while wearing the old eyes glasses. In all but three cases, the error score on the Farnsworth-Munsell 100-hue test degenerated while wearing the glasses. These glasses were specially manufactured to simulate the eyes of a 75 year old person (if the participant is in his 40s). The glasses have the practical effect of adding 35 years to one's eyes, and hence to his color discrimination ability, as well.

Color discrimination deteriorates with age. For color normals, with average color discrimination ability, advancing age appears to have the outcome of lowering the sensitivity to all wavelengths. For color defectives, this aging process can have a more deleterious effect. Their color confusions are magnified with age.

Traffic engineers should be aware of this preliminary findings. If they are to design signs for elderly drivers, both color normals and defectives, the effect of aging on color discrimination ability must be considered when choosing colors for signs to be seen by this segment of drivers.

RECOMMENDATIONS

The sample size for this experiment was small and contained only one color defective male. Further research must be conducted using a much larger total population, comprised of a sizable number of color anomalous vision subjects. An improved characterization of the loss of color discriminability as a function of age for color normals with low, average and superior color discrimination must be determined. In addition, a substantial subject population of protanopes, deuteranopes and tritanopes must be tested for color discrimination loss as a function of increasing age. The heightened color confusions may vary according to type of color defective vision, and the initial degree of severity of that anomaly. The old eyes glasses are a perfect way to obtain the "elderly" population that is needed for this additional research, without attempting to find large numbers of older persons with and without color defective vision.

REFERENCES

Farnsworth, D. (1943). The Farnsworth-Munsell 100-hue and dichotomous tests for color vision. Journal of the Optical Society of America, 33, 568-578.

Farnsworth, D. (1957). Manual for the Farnsworth-Munsell 100-hue test for the examination of color discrimination. Baltimore, MD: Munsell Color, MacBeth, a Division of Kollmorgen Corp.

APPENDIX A

EXPERIMENTAL DESIGN*

SUBJECT NO.	QUADRANT ORDER FOR FM-100 HUE TEST
1	1 2 3 4
2	2 3 4 1
3	3 4 1 2
4	4 1 2 3
5	1 2 3 4
6	2 3 4 1
7	3 4 1 2
8	4 1 2 3
9	1 2 3 4
10	2 3 4 1
11	3 4 1 2
12	4 1 2 3

* The manual for administering the Farnsworth-Munsell 100-Hue Test expressly states that the order in which a subject completes the four boxes is not important, and they can be given in any order. However, the manual is quite explicit about randomizing the caps before giving the box to each subject to order in a regular color series.

APPENDIX B

INSTRUCTIONS TO PARTICIPANTS

"You will be performing the Farnsworth-Munsell 100-hue test for the examination of color discrimination. This test differs from the pseudo-isochromatic color plates, like the Dvorine ones we administered earlier in class, in that they can isolate certain factors of color deficiency, but do not measure general color discrimination directly as does the 100-hue test."

One case is opened lengthwise and placed before the examinee so that the empty, inclined panel to which the pilot caps are fixed is nearer to the subject. Then the following instructions are given:

"The object of the test is to arrange the caps in order according to color. Please transfer them from this panel (indicate) to this panel (indicate) and place them so they form a regular color series between these two fixed caps (indicate). It should take you about two minutes per panel. However, **accuracy is more important than speed - so you will be told when the two minutes are up but the panel will not be taken away from you.** **Arrange them as best as you can, but don't dawdle.** Do you understand?

Two additional notes, please try to handle the caps by the outside only, as they contain a calibrated Munsell color chip. Hand perspiration, dirt or smudging will render the test invalid for that chip, as the calibration will be destroyed with the addition of soil. Also, once you place the caps in an initial order, you are free to rearrange them as much as you want until you are happy with your color series you have formed. Remember, **accuracy is more important than speed. I want you to be as accurate as possible.**

If there are no further questions, - **Begin.**"

Spare Visual Capacity of Drivers

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R. Quinn Brackett
Valmon J. Pezoldt

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Texas Transportation Institute
The Texas A&M University System
College Station

Preface

This study was performed under funding from the Safety Education Program of the Texas A&M Department of Vocational, Technical and Industrial Education, and funding from the Southwest Region University Transportation Center. From the standpoint of the goals of the SWRUTC project, "Aging Driver Needs in an Automobile Oriented Region," this study provides a methodology for assessing the spare visual capacity of older drivers in upcoming research.

Rodger J. Koppa
Principal Investigator

SPARE VISUAL CAPACITY FOR YOUNG DRIVERS UNDER THE INFLUENCE OF ALCOHOL

INTRODUCTION

A driver extracts specific information from the environment in order to successfully guide a vehicle along a particular path. The information extracted concerns the orientation or direction of the path or roadway to be followed, the position of the vehicle relative to the path, and characteristics about that roadway which might influence the attention devoted to the guidance task. Attention devoted to the guidance task depends upon the estimations of the workload that will be imposed by the roadway path and conditions ahead. The higher the estimate of workload demand, the greater the attention allocated to the task. Workload estimates will vary as function of vehicle, vehicle speed, traffic, roadway geometry, lane width, etc. These estimates will also vary as a function of individual differences in ability and experience, and on physiological and psychological state or condition. Age is directly related to experience, consequently the estimates of young drivers are likely to be less accurate than those of older, more experienced drivers.

Underestimating the workload requirements of the guidance task, can lead a driver to allocate insufficient attention. Lack of adequate attention to the driving task, in turn, can result in errors and, possibly, crashes. Underestimating, the workload requirements of a roadway can occur when drivers, through lack of experience, fail to recognize characteristics of the roadway that require greater attention, when experienced drivers expect a lower workload that is required, when a drivers attention is distracted from the guidance task, or when drivers information processing abilities are impaired.

One type of impairment is the physiological condition of alcohol ingestion. Alcohol has been determined to degrade physical performance in blood-alcohol concentrations levels, but they involve higher order information processing such as decision making or judgement. Such degradations are difficult to demonstrate and hard to relate to the driving task. However, the effect of small amounts of alcohol will likely influence estimates of workload requirements of the roadway and subsequent decisions concerning the attention devoted to driving. It is likely that small amounts of alcohol will lead to underestimates of workload and result in a reduction of attention devoted to driving. This underestimation of workload should be particularly apparent in young drivers.

The objectives of this pilot study is to develop baseline measures of spare visual capacity for various driving tasks and conditions such as tangents and curves without traffic for a representative sample of young drivers under the age of twenty-four.

METHOD

Participants

Seven drivers, four male and three female, whose age ranged from 21 - 34 were selected for this study [Females: 21,23,& 28 yrs; Males: 22,23,27,& 34]. All participants possessed a valid drivers license and were paid for their participation.

Equipment

The Intoxilizer 4011-AS-A was used to monitor the breath alcohol levels of the participants. This equipment is regularly used by police departments to check the alcohol level of individuals. An instruction session was conducted by a College Station police sergeant well acquainted with the intoxilizer to properly train the experimenters with it's use.

Occlusion goggles were specifically designed and manufactured for the purpose of manually controlling the amount of vision an individual is allowed. These goggles were constructed from a pair of wrap-around plastic safety goggles on which a special substrate consisting of a thin liquid crystal layer was adhered. By applying an AC voltage to this goggle, transparency is induced. The wearer is able to activate the goggle, resulting in transparency at any time by tapping a tape switch located on the floorboard with the left foot. The system gives him/her only a brief glimpse (0.55 sec.) before the goggles fog again. The experimenter has an override switch which also clears the goggle for demonstration or if the driver becomes disoriented.

Wired into the goggle apparatus was a counter, timer, and strip chart recorder. These devices recorded the number of requests for sight, the total time duration for each trial, and the discrete time between each request. Measurements were recorded for every trial for each individual.

For safety, the vehicle used was specially equipped with an auxiliary brake placed on the passenger side of the front seat as well as two extra inside mirrors. One mirror acted as a supplemental rear-view mirror and the other to observe the driver's face. In addition to these safety precautions, the inboard experimenter was positioned such that they could instantaneously restore vision, stop the vehicle with the auxiliary brake, and seize the steering wheel if necessary.

A closed course was laid out on the runway complex at the Texas A&M Riverside Campus using traffic cones and painted lane markings. Two testing tracks were laid out. The first was a straight track 1/2 mile long, and the second track was approximately 1/3 mile long and contained a curve approx. (degree).

Procedure

Upon arrival the testing site, each participant was given a verbal description of the study and asked to complete a brief medical and consent form. The participants were told that the study was concerned with the amount of visual time individuals feel is necessary to successfully maneuver and automobile while under the influence of alcohol.

Once briefing was complete, the individual was requested to give a breath sample to provide a baseline reading and to acquaint them with how the apparatus worked. An instant breakfast was offered to the participant to help coat their stomach as they were requested to refrain from eating solid foods 12 hours prior to the study in order to facilitate acquiring accurate alcohol levels.

After the instant breakfast was consumed, the participant was driven to the testing site by an experimenter. Once at the site, the participant moved to the drivers seat for the final briefing session. The participant was encourage to adjust the mirrors, seat, and steering wheel to the most comfortable position. It was at this point that the experimenter introduced the occlusion goggles, its function and operation explained, and then demonstrated. The participant was then allowed to wear the goggles and become comfortable wearing them and activating the foot switch control. They were then instructed to drive around the runway complex to familiarized themselves with the automobile and while wearing the goggles before the testing commenced.

At the conclusion of the orientation session, the onboard experimenter initialized the counter and timer for the first test pass. The experimenter requested the driver to drive forward and attain a speed of 40 MPH and then maintain that speed with the use of the cruise control which had been preset by the onboard experimenter. The driver experienced the first occlusion when they passed through the first set of traffic cones marking the beginning of the test track. The driver was able to request glimpses of sight as he/she deemed necessary until the treatment has been driven through. Continuous recording of the data took place during this pass. The driver was then asked to bring the vehicle to a halt and to position the vehicle for the second testing track. The completion of both the tangent and curved test track is referred to as a single testing session. Each participant went through two to three testing sessions to collect a baseline reading while sober.

Once the initial treatments were completed by the participant, they were given a series of drinks consisting of 82% alcohol (Vodka) mixed with various fruit juices over the course of one hour. The BAC for each participant was monitored by a trained individual in the use of an Intoxilizer in order to gradually bring their alcohol level to 0.05, 0.08, and then 0.10 for subsequent testing.

Once the desired BAC level was achieved, the driver was directed to a new treatment, and the process continued until all intoxicated levels were attained.

Results

Table 1 demonstrates the percentage of time individuals were willing to drive without visual input. When looking across the mean for all individuals, it is noteworthy that the percentage of time visually occluded steadily as alcohol levels increase for both tracks.

Within the Tangent track, the occlusion time initially drops when the breath alcohol level moves from 17% when sober to 15% in the 0.043-0.059 category. After this initial drop, the percentage of occlusion time steadily increases until a mean of 48% occlusion time is reached at the legally intoxicated level of 0.100 .

Within the curve track, the occlusion time drops only when moving from the 0.043-0.059 category to the 0.062-0.067 group. The percentage change from sober to 0.100 intoxication level was a difference of 28% for total occlusion time.

TABLE 1. PERCENTAGE OF TIME EYES WERE CLOSED FROM TOTAL TIME

TANGENT

ID	0.000	0.043-0.059	0.062-0.067	0.080-0.089	0.100 +
1	5.99%	5.40%		7.08%	
2	6.47%	7.37%	3.71%		
3	22.54%	23.54%		33.95%	
4	2.41%	1.21%	2.70%		
5	28.57%	24.58%			
6	19.32%	27.19%		35.64%	50.45%
7	33.07%		45.12%		45.66%
MEAN	16.91%	14.88%	17.18%	25.56%	48.06%

CURVE

ID	0.000	0.043-0.059	0.062-0.067	0.080-0.089	0.100 +
1	3.72%	5.64%		4.38%	
2	4.46%	4.00%	3.79%		
3	9.57%	15.98%		13.87%	
4	2.10%	2.59%	2.88%		
5	17.15%	16.86%			
6	12.70%	26.67%		27.92%	38.29%
7	22.63%		26.47%		17.72%
MEAN	10.33%	11.96%	11.05%	15.39%	28.01%

CONCLUSION

Due to the limited size of this study, definitive conclusions cannot be made based on the data collected. The results do indicate, however, that different alcohol concentration levels do appear to have an impairing effect on individual's estimations of workload. Based on these findings, further study is warranted in this area.

Visibility Through Scatter

Bruce A. Wright

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Texas Transportation Institute
The Texas A&M University System
College Station

Preface

This study was conducted as a thesis for the degree of Master of Science in Industrial Engineering, under the title "Measurement of Visibility through Spray," (Wright, B.A., Texas A&M University, August 1990). The methodology and findings were designed by Captain Wright and me to be applicable to the older driver who has cataracts or other significant scatter of light through the optic train.

Rodger J. Koppa
Principal Investigator

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The ability of an operator of a motor vehicle to detect hazards is very dependent upon one's visual performance, ambient lighting levels, and atmospheric conditions. If that person is not able to obtain enough information because of inadequate lighting, rain, splash and spray, or some subtle visual impairment, a hazardous situation could escape detection. Static visual acuity is one measure of visual performance, however good acuity, by itself, cannot guarantee that a driver will be able to detect hazards in less than optimal viewing conditions.

Guyton (1981) describes the standard method for determining a person's static visual acuity as the Snellen line system. This system is based on a carefully printed chart with lines of high contrast letters which decrease in size toward the bottom of the chart. The chart is placed twenty feet away from the observer who is asked to read lines corresponding to "normal" visual acuity for the population. The results of the test are recorded as a Snellen number which is simply the ratio of two distances - that of one's own visual acuity to that of the "normal" person under ideal circumstances. For example, if a person is able to see the small (five minutes of visual arc) high contrast letters normally visible at 6 meters, he/she is said to have $^{6}/_{6}$ vision. In a paper relating vision capability to performance, Ginsburg (1983b) describes the Snellen system as testing only the optical characteristics of the eye, specifically foveal acuity, and that it is primarily a measure of visual quantity (size), <u>not</u> quality (size and contrast). Another method of vision testing is the Contrast Sensitivity Function (CSF).

The CSF, a recently developed vision assessment technique, is very different in nature from the Snellen acuity testing and Owsley, Sekuler, and Boldt (1981) have shown it to be much more able to accurately predict real world visual performance under less than ideal conditions. The CSF is a curve that describes an observer's threshold sensitivity to targets of different sizes. The Handbook of Perception and Human Performance (1986) provides the following definition:

> Contrast of a sinusoidal grating is the difference between its maximum and minimum luminances divided by their sum.
>
> $$C = \frac{L_{max} - L_{min}}{L_{max} + L_{min}}$$
>
> For a constant luminance, the amount of contrast needed to detect a grating, contrast threshold, varies as a function of its spatial frequency. The reciprocal of the threshold contrast needed for detection is contrast sensitivity. A plot of log sensitivity as a function of log spatial frequency is known as the contrast sensitivity function.

The CSF is similar in function to an audiogram, which plots the performance of the auditory system. Sekuler and Blake (1985, ch. 6) describes the CSF as testing the whole visual system, stating that one is able to detect faults in the optics of the eye as well as in the neural processing of the image by interpreting abnormalities of the plot.

According to Ginsburg (1983b), the brain converts the retinal image into a visual code based on the shape and contrast of the target. He states: "The contrast sensitivity tests use contrast and single spatial frequencies to measure sensitivity to complex targets. This technique describes the general filtering characteristics of vision, visual capability and performance in a quantitative manner." Each spatial frequency provides a piece of information about an object in much the same way that different audible frequencies make up the sensation of sound. Conceptually, the contrast sensitivity function can be described as representing many filters and receptive fields grouped together in channels. A channel describes a set of neurons which are able to respond to targets over a narrow range of spatial frequencies. These channels are mostly independent from one another and each channel has a different sensitivity (see figure 1). Each curve, or channel, describes the points at which the contrast of an object at a particular spatial frequency is just visible, and moving down the plot will increase contrast to make the object more visible. If any of the channels are impaired, for whatever reason, a decrease in visual performance will be realized. Additionally, Ginsburg (1983a) concluded: "Contrast losses resulting from HUD optics (owing to transmittance, glare, and reflections) were translated into detection range losses using previously collected field trial data that related differences in aircraft detection range of Air Force pilots to differences in their contrast sensitivity." Another conclusion was that "...any factor which reduces target contrast reduces target detection and recognition range". As a result of these findings, research has turned toward measurement of differences in real world visual ability.

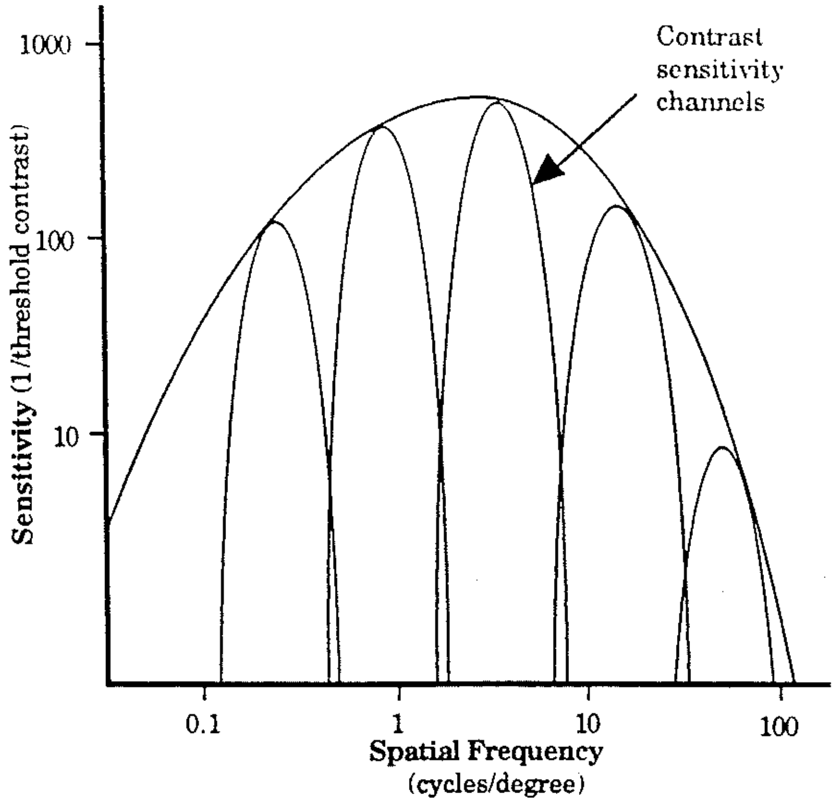

Figure 1. Contrast Sensitivity Channels

Evans and Ginsburg (1985) outline the application of the CSF to tasks of driving. It was shown that a random group of 20 drivers with $^6/_6$ visual acuity and ages ranging between 19 and 79 years displayed significant differences in the distances at which they were able to discriminate highway signs. The older group of subjects had significantly lower contrast sensitivity in certain spatial frequencies and they required a significantly larger symbol to determine if it denoted a four way "+" intersection or a "T" intersection (figure 2). The correlation between Snellen acuity and discrimination distance was <u>not</u> significant.

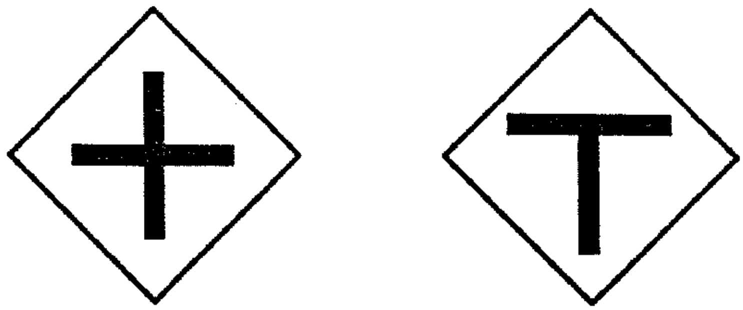

Figure 2. Highway Signs

The above references have shown that light transmissivity losses due to media in front of the eye (e.g., fog, rain, or spray) or resulting from deficiencies within the eye may be quantified using various visual assessment techniques. In this study, decreases in target identification distance were related to visual acuity changes induced by spray simulations.

Objectives

The objectives of this study were:

1. Relate two measures of visual performance (visual acuity and contrast sensitivity) in the laboratory to subjective field measures (target identification distance) at simulated levels of visibility.
2. Relate digitized images of targets videotaped through various levels of spray to simulated levels of obscuration.
3. Determine which measure of visual performance better relates to a driver's ability to identify an oncoming target in real-world situations.

METHOD

Independent variable

The independent variable in this study was the level of visual degradation imposed by simulated spray frames.

Measures

The dependent variables were the target detection distance, changes in the Snellen visual acuity, and CSF measures of visual performance through each level of simulated spray.

Participants

A total of 20 (12 male and 8 female) individuals participated in this experiment. The volunteer subjects were students or staff from Texas A&M University or associates of the experimenter. The younger group of 9 males and 7 females ranged in age from 22 to 40 years, the mean was 30.75 and the standard deviation was 5.29. The older group of 3 males and 1 female ranged in age from 59 to 64 years, the mean was 61.5 and the standard deviation was 2.08. Each subject possessed a valid drivers license, was in good health and free from any gross visual pathology. The experimenter determined the Snellen visual acuity and a CSF for each subject prior to field trials.

Apparatus

Several methods of simulating splash and spray obscuration were evaluated. A spray simulation was chosen because of the difficulties involved in accurately reproducing a given level of spray in an uncontrolled environment. It was judged that clear acetate document protectors adequately approximated the visual effect of splash and spray when viewing roadway scenes. A series of five 20 x 25 cm frames (designated s1 to s5) were built with one, two, four, six, or eight layers of acetate, respectively, sandwiched between two layers of glass. The visual effect of seeing through each of these frames was then digitized using a technique which was developed in another study (Koppa and Pezoldt, 1990) described below.

Appendix A describes in detail the relationship obtained by Koppa and Pezoldt between laser percent transmission and the digitized videotape Coefficient of Variation (CV). In general, a laser is used to excite a photodetector to measure light transmission over a specified distance based on zero (no light) and 100% (full illumination) calibrations prior to each run. The digitization process encodes an analog image by brightness into a file with numbers between 0 (dark) and 256 (white).

When the data from a digitized image file is plotted, the frequency distribution of brightness of a black/white (strong contrast) image such as a checkerboard has a bimodal distribution. The peak near the high end of the range of pixel brightness corresponds to the white checkers, and the peak at the lower end of the range corresponds to the black checkers. When some diffusing substance like a cloud or mist is interposed between the camera and the checkerboard, the resulting array of pixel brightnesses change, because the strong contrast of white and black checkers is greyed out. Hence the distribution changes shape and even begins to look like a bell-shaped curve with a mean brightness somewhat below the bimodal mean, and a much smaller standard deviation.

In order to express these graphic images mathematically, a Coefficient of Variation (CV) was employed. The CV is simply the standard deviation of brightness divided by its mean or average. The ratio of an experimental CV and the baseline CV multiplied by 100 yielded a Figure of Merit (FOM) analogous to the percentage of laser transmittance. The digitization results provided the following regression equation:

Digitize (CV) = 0.72(Laser percent transmission) + 8.09

A correlation of 0.85 was obtained between the laser percent transmission and digitized values of the same runs where 1.00 corresponds to a perfect relationship, and 0 to no relationship at all.

The resulting values for brightness obtained by Koppa et al are summarized in Table 1 in the results section. It should be noted that the brightness did not drop off very much as the obscuration increased, however the standard deviation indicating the level of contrast was reduced very rapidly. The resulting FOM for each of the frames related to how little visual information was actually transmitted through the frame to an observer's eyes or camera. This data was very representative of the effect the frames had on both measures of visual acuity as well as the target detection distance.

The laboratory phase of the experiment required that the visual acuity for each participant be tested with a wall mounted Snellen chart (Figure 3) at 6 meters (while wearing corrective lenses if appropriate). Additionally, contrast sensitivity was measured at five spatial frequencies

(86, 172, 344, 688, and 1032 cycles/radian) using the Vistech VCTS 6500 wall mounted chart (Figure 4) at the recommended distance of 3 meters. Luminance for each test procedure was normal room lighting (103-240 cd/m^2). These measurements were repeated while the subject looked through each of the five simulated spray levels and all information was transcribed to the Lab Data Sheet (Appendix B).

picture of snellen chart

Figure 3 Snellen Chart

picture of contrast sensitivity chart

Figure 4 Contrast Sensitivity Chart

The field trial phase of the experiment required that the subject be seated in a stationary automobile (a 1978 Oldsmobile Cutlass Salon) at a designated spot on the runway. The target automobile, a brown 1979 Pontiac Grand Am (Figure 5), was situated on the runway 1610 meters from the stationary car. The target vehicle was equipped with a fifth wheel and a digital distance display on top of the instrument panel (Figure 6). Hand held radios were carried in each car in order to report experimental information during the trial. The driver of the target vehicle recorded the distance traveled at each sighting on the Field Data Sheet (Appendix C).

photo of Pontiac (head-on)

Figure 5 Target Vehicle

photo of Pontiac digital display

Figure 6 Digital Distance Display

Procedure

Each participant met the experimenter at the drivers education classroom on the Texas A&M Riverside campus for the laboratory portion of the trial (Appendix D). Subjects were assigned identification numbers for experimental purposes as they completed the Participant Information Form (Appendix E). All participants were briefed on the methods and risks associated with the test procedure from the Subject Briefing Narrative (Appendix F). Next, visual acuity was measured with a standard Snellen eye chart, and contrast sensitivity was measured with the VCTS 6500 wall mounted chart following recommended test procedures. Each subject was comfortably seated at the appropriate distance and both measures repeated for each level of simulated spray. Each frame was held approximately 15 cm in front of the eyes and the results were immediately recorded on the Lab Data Sheet.

After the laboratory measurements were recorded, the field trials were performed on a 2135 meter runway at a former Air Force Base now known as the Texas A&M Riverside Campus. All trials took place between 9:00 A.M. and 4:00 P.M. under cloudy conditions to reduce variations in ambient lighting. The experimental procedure was the method of limits and each trial was sequenced through five increasing magnitudes of simulated spray and a control. Each subject was seated in the Cutlass at a pre-determined site on the runway. The windshield of the car and the glass in the frames were inspected before the trials to ensure they were clean. Upon receiving an appropriate radio signal, the target vehicle started toward the subject from a distance of 1610 meters and advanced at 16-24 KPH until the subject indicated he/she could identify it as a car. As the target car approached the subject from the opposite end of the runway, the subject was instructed to report by radio when he/she could discern the target vehicle first as an object, then identify it as a car. The experimenter in the target vehicle would stop and record the distance traveled as soon as the subject identified the target vehicle as a car. While the target vehicle was stopped, the subject would hold the first simulated spray frame about six inches in front of their eyes. The next radio message from the subject car would state whether the target car was seen as an object, then the target car would advance until it could be identified as a car again. If the subject could not identify the car as an object while it was stationary, the subject had to report when the car became an object as it moved forward. However, nearly every frame change resulted in an immediate report of the target car being an object. The start and stop procedure continued until there were no higher levels of spray and the whole process was repeated three times with the results being averaged and then subtracted from 1610 in order to obtain actual detection distances.

RESULTS

Snellen visual acuity data

The average Snellen visual acuity for the subject group was $^6/_5$ although the range was between $^6/_4$ and $^6/_8$. The Snellen ratio was reduced to a decimal value for the purposes of evaluation (Table 1). A plot of the resulting Snellen visual acuities for each frame is shown in Figure 7. As it can be seen, the average Snellen value decreased dramatically with increasing obscuration and the standard deviation decreased as well. The author had expected a more rapid drop in Snellen acuity with the top line ($^6/_{60}$) becoming unresolvable by slide s4. On the contrary, subjects were able to make out the fuzzy images reasonably well, and some were even able to read the $^6/_{30}$ line through frame s5. Each frame produced a drop in acuity of at least one Snellen line and several subjects were not able to see the top ($^6/_{60}$) line of the chart through s5. These data points were recorded as $^6/_{120}$ for computational purposes.

Contrast sensitivity data

The Contrast Sensitivity test produced a set of numbers (1-9) corresponding to the subject's sensitivity in each of five spatial frequencies (row A through E). The sum of those five values was chosen to represent a CS score for the purposes of evaluation (Table 1). The average sum of CS scores for the subject group was 30.15, although the minimum was 24 and the maximum was 35. The highest spatial frequencies (bottom rows of the contrast sensitivity chart) were the first to be degraded by the frames. The lowest spatial frequency (top row) was the

Table 1. Frame Results Summary

frame	Brightness Digitization				Distance		Snellen		Sum CS	
level	mean	S.D.*	CV	FOM	mean	S.D.*	mean	S.D.*	mean	S.D.*
base	142.46	60.53	0.42	1.00	1110.8	308.39	1.258	.258	30.15	3.41
s1	143.3	36.64	0.26	0.60	905.01	301.98	.828	.149	21	2.88
s2	138.31	25.38	0.18	0.43	622.88	231.08	.491	.172	14.95	2.11
s3	114.35	12.5	0.11	0.26	329.62	153.24	.288	.074	9.4	1.9
s4	102.36	7.14	0.07	0.17	106.93	52.44	.145	.051	3.05	0.88
s5	93.75	6.01	0.06	0.15	48.21	22.16	.072	.025	0.6	0.59

* = Based on (n-1)

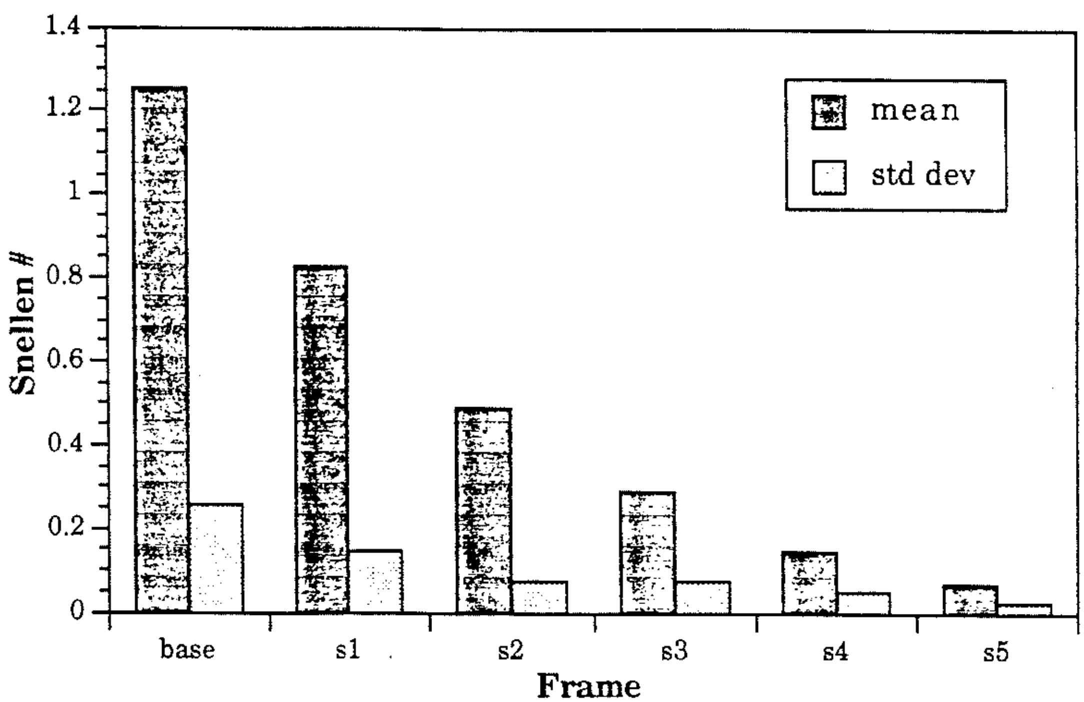

Figure 7. Snellen Visual Acuity by Frame

least affected by the frames. A plot of the resulting Contrast Sensitivity scores for each frame is shown in Figure 8. Here it can be seen that the available contrast through each consecutive frame was highly reduced and the standard deviation was reduced as well. This is what the author had expected and closely approximates the results of Evans and Ginsburg (1985) study of highway sign discriminability. The loss of high spatial frequency sensitivity brought about impairment of target detection ability at longer distances.

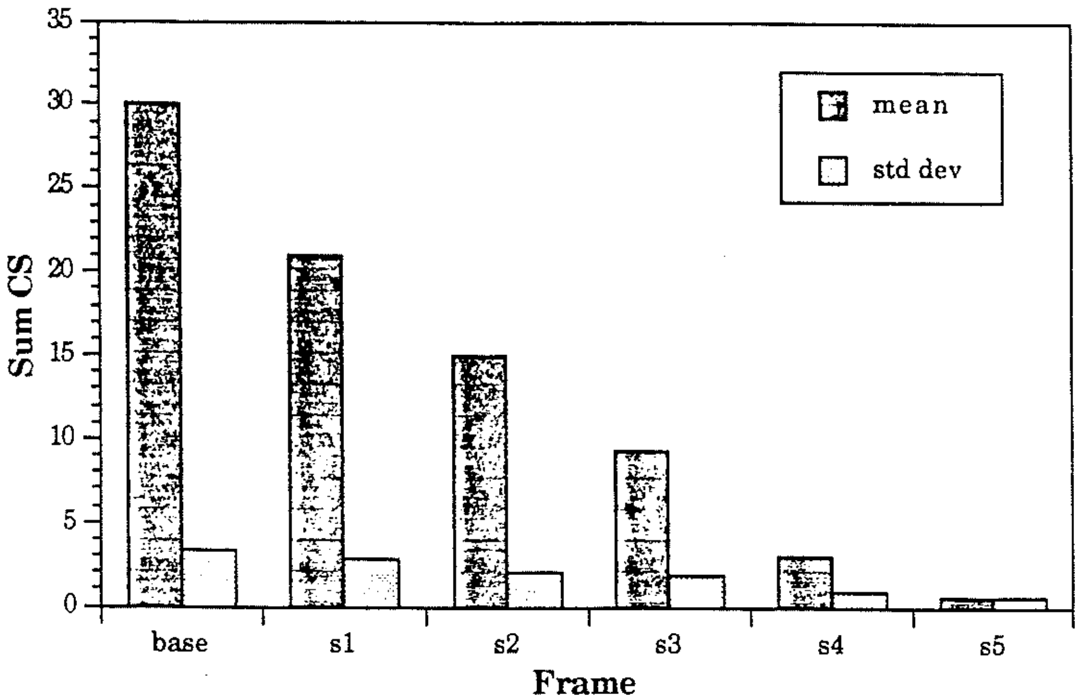

Figure 8. Sum CS Score By Frame

Identification distance data

The average baseline identification distance for the subject group was 1110 meters. The minimum identification distance was 584 meters, and the runway length limited the maximum to 1610 meters. Table 1 summarizes the mean and standard deviation for each of the frames with respect to target identification distances. A plot of the resulting identification distances for each slide is shown in Figure 9. As it can be seen, there were large decreases in detection distances for each slide and the variability among the reported distances for each slide decreased as well. The effect of age on target identification distance was not significant. The small sample size of the subject population is the most likely causes of this lack of significance. One additional factor which could not be effectively controlled was the criteria each subject used to judge the target vehicle as a car. It was obvious that some subjects did not need much visual information to call the image a car, while others required much greater amounts of information before making the call. This is reflected in the rather large standard deviations reported in Table 1. Each subject was instructed to maintain the same judgement criteria for calling the target a car throughout the trials, but the criteria were certainly different with different subjects.

Identification distance vs. visual performance regression data

The first objective of this experiment was to relate laboratory visual performance to target identification distance. A regression analysis was performed to determine that relationship. Both the Snellen and Sum CS Correlation Coefficients have shown a very high association with the response variable (identification distance). The author had expected a high correlation for the contrast sensitivity measure but the high correlation for the Snellen numbers was somewhat surprising. It is difficult to see any real difference in the predictive power of either

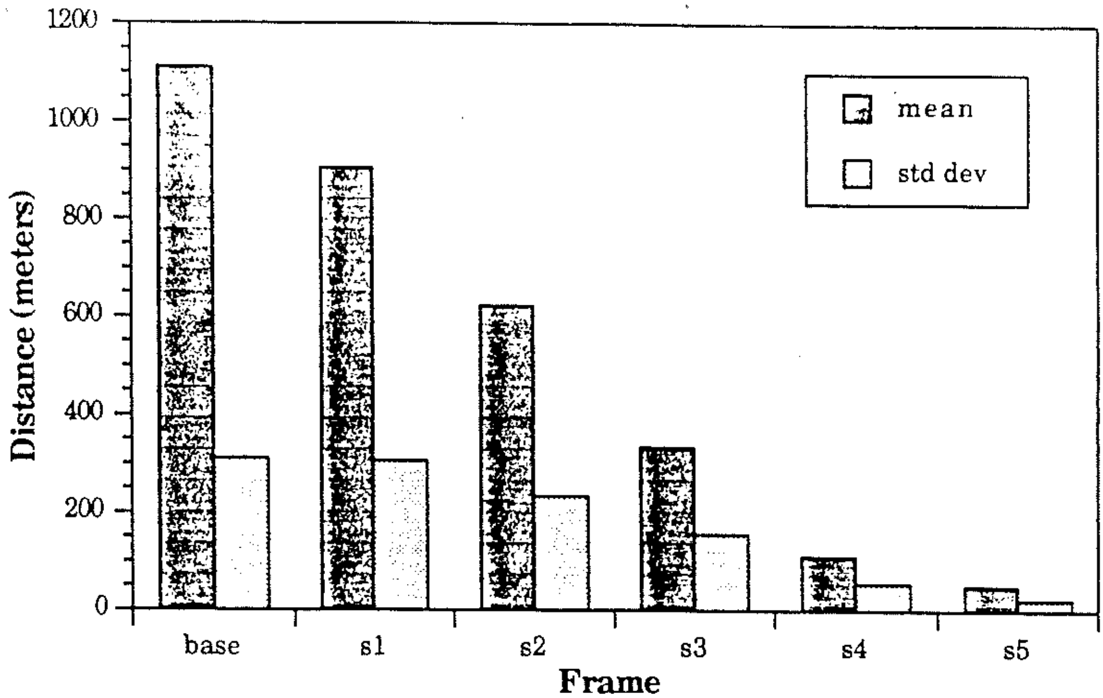

Figure 9. Identification Distances By Frame

measure of visual performance. Indeed, the following tables and figures of the Snellen and CS regressions show a striking resemblance to one another. Each measure produced nearly identical Correlation Coefficients and the scatter plots of distance against Snellen or Sum CS are nearly indistinguishable. Figure 10 is a scatter plot of the identification distances against Snellen acuity with the regression line fitted. Table 2 summarizes the regression output for identification distance vs. Snellen number. It is clear that the Snellen measure was highly associated with the identification distance ($r = 0.891$). The computed equation for the Snellen regression line is:

$$\text{Identification distance (meters)} = 911.916(\text{Snellen number})$$

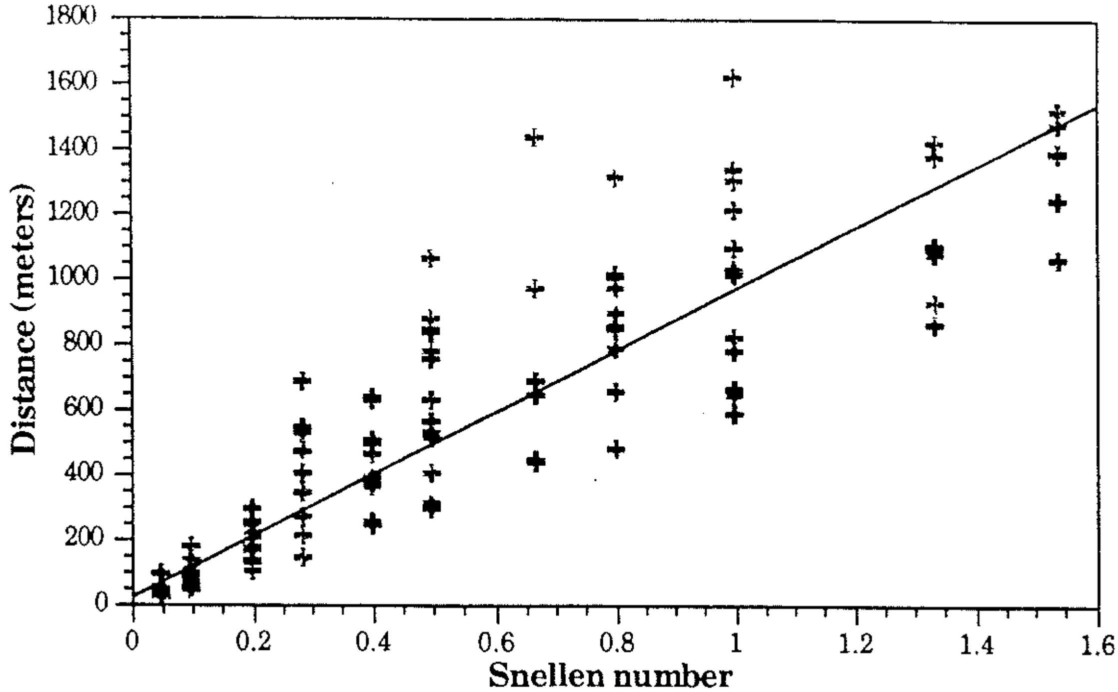

Figure 10. Identification Distance vs. Snellen Number

Table 2. Linear Regression, Detection Distance vs. Snellen Number

Linear Summary of Fit	
Rsquare	.7950
Root Mean Square Error	202.914
Correlation Coefficient	.891
Mean of Response	521.591
Observations (or Sum Wgts)	120

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	52.824	28.691	1.84	0.0681
Snellen	911.916	42.622	21.40	0.0000

Figure 11 is a scatter plot of the identification distances against Sum CS with the regression line fitted. Table 3 summarizes the regression output for identification distance vs. contrast sensitivity. This measure was also very highly correlated with target identification distance (r = .889). The computed equation for the Sum CS regression line is:

Identification distance (meters) = 37.847(Sum CS)

As far as the third objective of this study is concerned, the only apparent difference in the two visual assessment techniques is the time it takes to administer them, with the Snellen test taking less than half the time of the CS test. There does not seem to be any great advantage in one test over the other in predictive power of target identification distance.

Figure of merit data

Identification distance was highly correlated (r = 0.849) with the results of the digitization output (FOM) shown in Table 4. A scatter plot of that relationship is presented in Figure 12. The regression equation for this relationship is:

Identification distance = 1272.279(Figure of merit)

Both measures of visual performance are very highly correlated with the digitization processes resulting Figure of Merit (FOM). The correlation (r = 0.950) between the Snellen number and FOM through the frames is shown in Table 5 and the associated scatter plot is presented in

Figure 13. The computed equation for the relationship between Snellen and FOM is:

$$\text{Snellen number} = 1.3916(\text{Figure of merit}) - 0.091$$

The correlation ($r = 0.956$) between the Sum CS and FOM through the frames is shown in Table 6 and its associated scatter plot is presented in Figure 14. The computed equation for the relationship between Sum CS and FOM is:

$$\text{Sum contrast sensitivity} = 33.678(\text{Figure of merit}) - 1.458$$

All of the measures of brightness or visual performance are highly correlated with one another. The Figure of Merit is an electronically generated scale of relative brightness and contrast while the Snellen number represents more of a measure of size resolution for the eye, and the Sum CS is a measure of the eye's overall sensitivity to contrast over a particular range of spatial frequencies. It is gratifying to see that each of these methods for predicting target identification distances is well correlated with the others. If needed, laser percent transmission or a Figure of Merit may be used to predict visual acuity or contrast sensitivity as well as to determine potential target identification distances. The real advantage of this variety of predictive tools is in having the flexibility of employing whatever method is most suitable to the demands of the study.

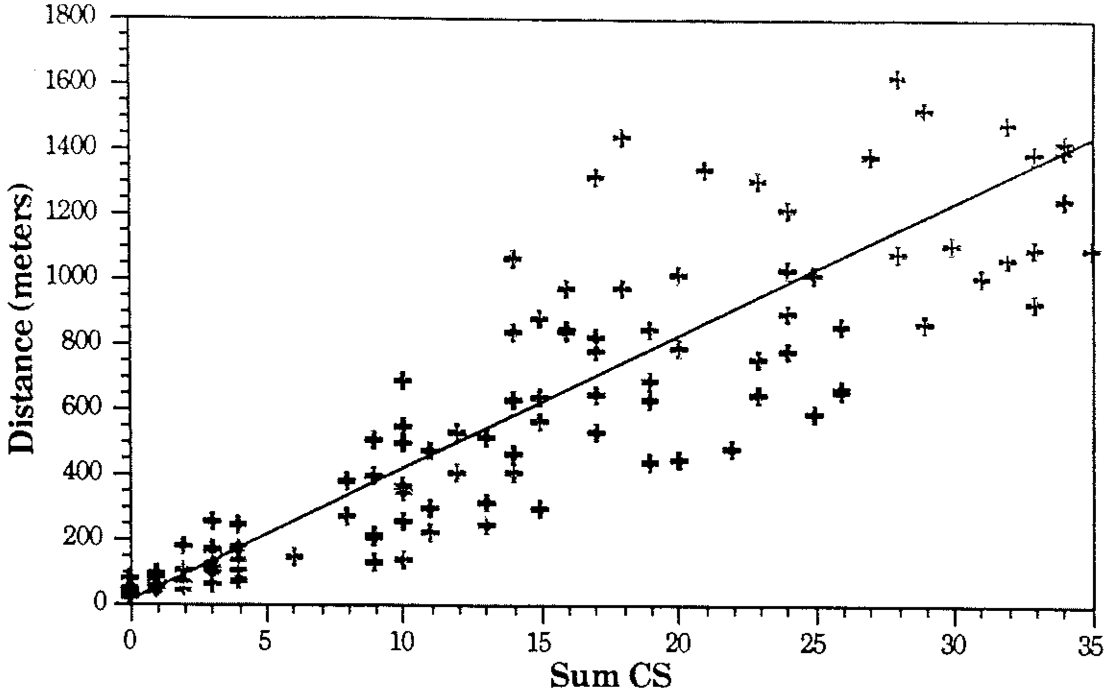

Figure 11. Identification Distance vs. Sum CS

Table 3. Linear Regression. Detection Distance vs. CS

Linear Summary of Fit	
Rsquare	.7916
Root Mean Square Error	204.583
Correlation Coefficient	.889
Mean of Response	521.592
Observations (or Sum Wgts)	120

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	22.328	30.077	0.74	0.4594
Sum CS	37.847	1.787	21.18	0.0000

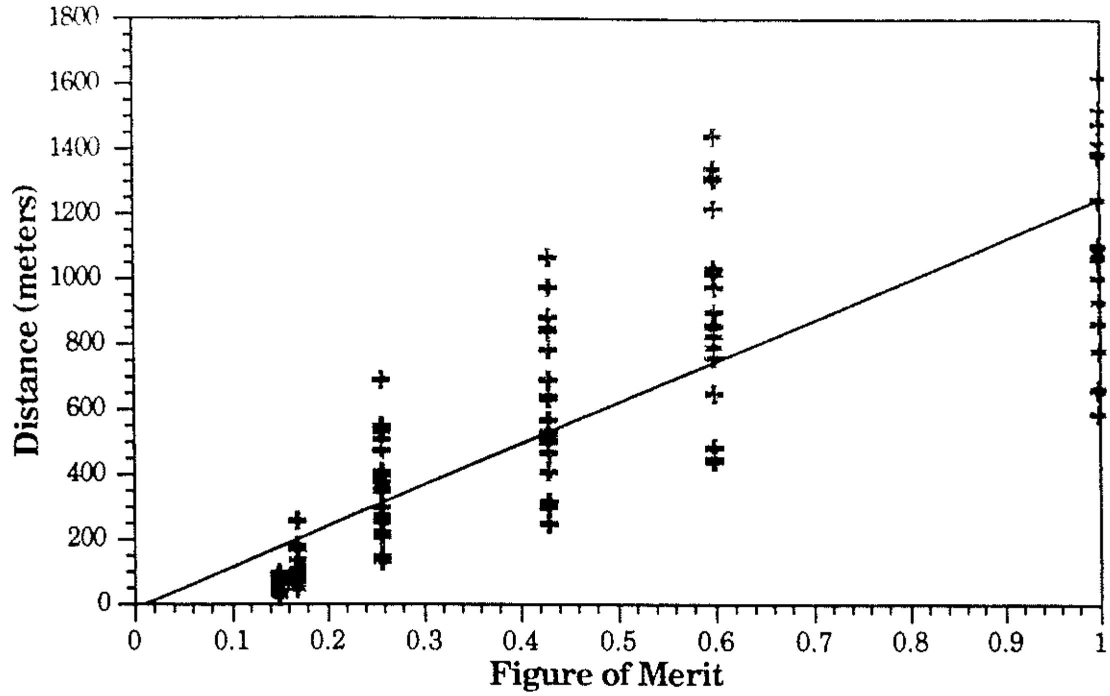

Figure 12 Identification Distance vs. Figure of Merit

Table 4 Linear Regression, Identification Distance vs. Figure of Merit

Linear Summary of Fit	
Rsquare	.7217
Root Mean Square Error	236.425
Correlation Coefficient	.849
Mean of Response	521.591
Observations (or Sum Wgts)	120

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-31.84573	38.2933	-0.830	.4073
FOM	1272.2698	72.7169	17.50	0.0000

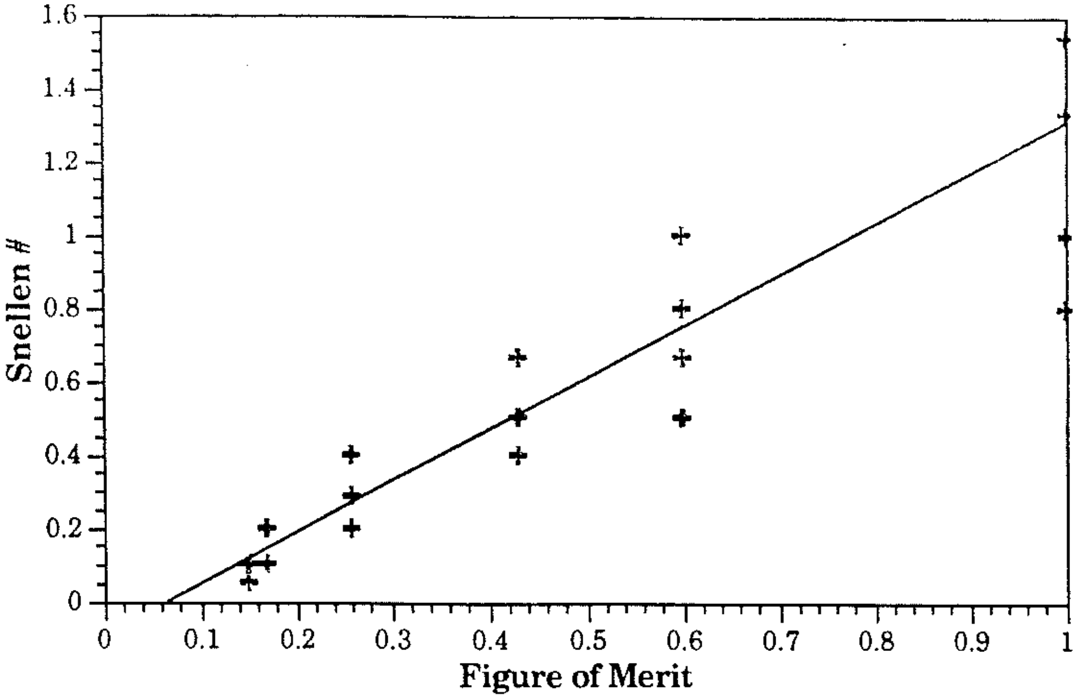

Figure 13 Snellen Number vs. Figure of Merit

Table 5 Linear Regression, Snellen Number vs. Figure of Merit

Linear Summary of Fit	
Rsquare	.9032
Root Mean Square Error	.1363
Correlation Coefficient	.9503
Mean of Response	.5140
Observations (or Sum Wgts)	120

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-.0912874	.022089	-4.13	0.0001
FOM	1.3915714	.041947	33.17	0.0000

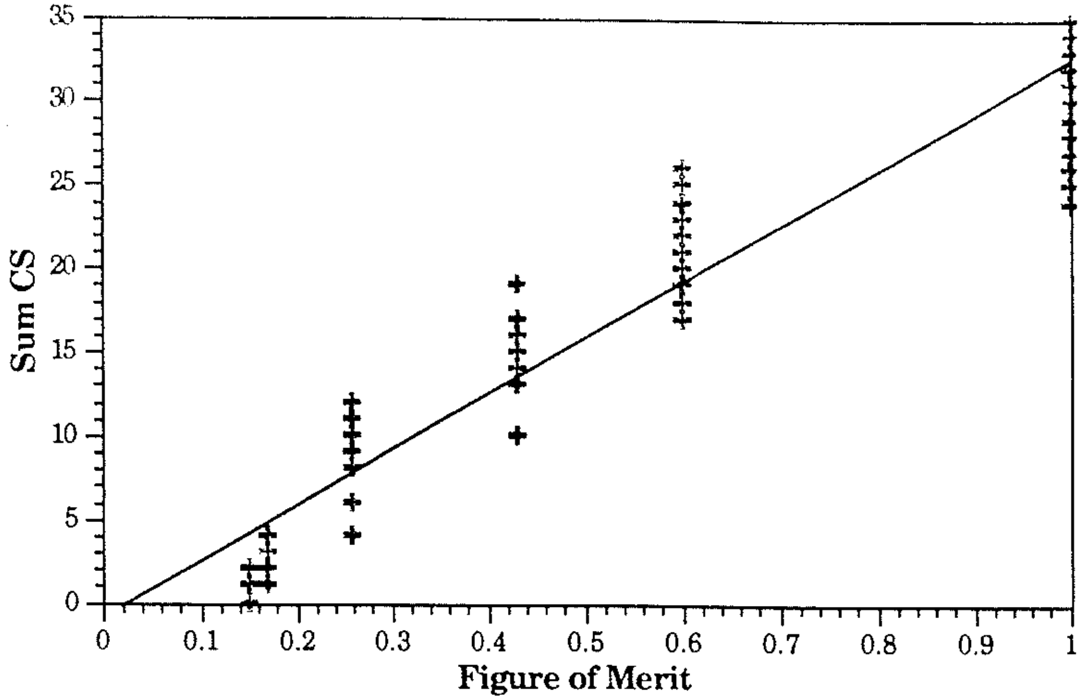

Figure 14 Sum CS vs. Figure of Merit

Table 6 Linear Regression, Sum CS vs. Figure of Merit

Linear Summary of Fit	
Rsquare	.9150
Root Mean Square Error	3.070
Correlation Coefficient	.956
Mean of Response	13.191
Observations (or Sum Wgts)	120

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-1.458463	.497335	-2.93	0.0040
FOM	33.678459	.944412	35.66	0.0000

CONCLUSIONS

The simulation of the visual effect produced by splash and spray by layering acetate document protectors was very successful. It seems that any matter which partially obstructs the clear viewing of a target will produce measurable decreases in visual acuity and this may be used to study target identification distances under less than ideal road conditions.

The correlation of both Snellen and Contrast Sensitivity measures with actual performance was great enough to warrant their use in future research into visibility impediments, such as heavy truck splash and spray. Since both vision assessment techniques were found to be very accurate in predicting target detection distance, the choice of a vision assessment method to use in future studies should be dictated by the availability of test equipment and time available for testing rather than any innate superiority of testing method. Further refinement of the target would probably gain even more accuracy. Specifically, if the target was simpler in its component spatial frequencies, there might be greater predictive power from the CS measure.

This research has supported earlier studies which demonstrated the validity of a video digitization method which can directly relate visibility through a spray cloud to a particular FOM. Researchers can confidently take CV ratios from transmissiometer readings or digitized videotape of spray or fog and relate them directly to target detection distances.

RECOMMENDATIONS

The video image digitization procedure and the resultant FOM used in this experiment provide an easy to use metric for comparisons of visual obscuration. Simple visual acuity tests may then be used to asses decrements in target discrimination. These techniques may then be applied to several areas of research, such as:

1. Evaluation of light losses through head up displays (HUD).
2. Evaluation of relative effects of window tinting films.
3. Evaluation of relative merit of traditional sunglasses vs. blue-blocker (amber) sunglasses.
4. Evaluation of the optical characteristics of embedded-wire heating element windshields.

Moreover, any area of research which investigates the effects of partial scattering of light on operator performance could benefit from the relatively simple techniques presented in this thesis.

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APPENDIX A

LASER % TRANSMITTANCE AND IMAGE DIGITIZATION

Excerpts from: Koppa, R., and Pezoldt, V. (1990). Development of a recommended practice for heavy truck splash and spray evaluation (Tech. Report, Project RF7143). College Station: Texas A&M University, Texas Transportation Institute.

2.1 Variations from Established Practice

...The laser transmissiometers are in the same location they have been since 1986, parallel to the test surface, with lasers [5 $^{mw}/_{cm^2}$ power] and photocells [essentially light meters] spaced 50 feet apart. The checkerboards originally used in 1984 have returned to the setup, although they have been moved from just uprange of the photocells to 100 feet downrange from the photocells. During the course of the project they were moved several times, in order to assure that the shadow of the vehicle did not fall on the checkerboards and ruin the image digigtization process. These checkerboards preclude visual estimates of the amount of spray that in one form or another were used in previous tests. The checkerboards block the view of the target at a distance as described by Koppa and Pendleton (1987). Hence the chase car with on-board observers was not used in this study.

Another change ... is the use of a digital computer to manage and reduce the data from each run, very shortly after the run is complete. The laser photocell outputs and outputs from the wind sensors are amplified and then go through an analog-digital conversion board in the small (8088 processor) personal computer that has been dedicated to splash and spray testing. A program in BASIC developed by R. A. Zimmer samples output at the rate of 25 seconds during a test interval with is initiated by the test vehicle interrrupting an infrared beam at the extreme uprange end of the 450 foot test surface. The computer times out 4 seconds later when the vehicle is clear of the test surface. Thus 100 observations are made of the sensor's ouput during the test interval. The laser transmissiometers are automatically calibrated by the test conductor's inputing a control character just before the vehicle breaks the IR beam. The calibration process consists of occluding the laser by means of a shutter, with the resulting low voltage output from the photocell designated 0 transmittance. When the shutter is opened and the beam thus unobstructed, the computer assigns the value 100 percent to the high voltage reading from the photocell.

After the test run, the computer writes the entire file of 100 observations to disk, togeather with time and date. Input on temperature, humidity, and vehicle speed is added by the test conductor. The program also provides summary information on the run. This consists of the lowest transmittance for each laser, with the wind direction and velocity at the calculated moment at which the vehicle reaches the laser beams. The file is in standard ASCII format, suitable for analysis by any standard statistical package.

2.2.5 Video Image Digitization

One objection to laser transmissiometer readings which has always been voiced is the very narrow beam which samples only a small fraction of the total spray cloud. Four sensors provide four very small samples of the cloud from which a generalized statement about the splash and spray performance of the vehicle must be made. A method for extracting data about the entire cloud which results in quantifiable measurements would appear to be very desirable, to either replace or supplement the laser setups. Also, lasers are delicate and temperamental, require a regulated power supply, and must be aligned very accurately.

Inspired by paper by Luyomba and Sheltons (1987), considerable effort was launched by TTI early in 1989 to develop a capability to extract information from a digitized television image of the spray cloud against a reference background. The 1984 MVMA tests used checkerboard reference surfaces to make both still and motion pictures of the spray cloud, but these data provided only qualitative area type information about splash and spray. Texas Transportation Institute funded an R&D effort by the Machine Vision Laboratory of the Texas Engineering Experiment Station to develop the necessary hardware and software to obtain a Figure of Merit analogous to the minimum laser transmittance which has been used for each sensor's response to the spray cloud during a run. The process begins with the 30 frame-a-second record made by an analog video cassette recorder. The camera feeding the signal is adjusted to disable automatic gain control (which essentially acts to optimize contrast, and thus defeats the purpose of image digitization to evaluate loss of image contrast).

The program (written in C for the 386 personal computer) is capable of storing six frames at any given time as an array of numbers corresponding to pixels, which are the "grain" in a television image. Each pixel brightness and location is stored as a separate entry. The analog frame image is grabbed by an A to D board, reduced to the array, and stored to memory. The brightness of each pixel is encoded by a number between 0 (dark) and 256 (white). When the file of pixels is plotted in a frequency distribution by brightness, a black/white strong contrast image such as a checkerboard looks like a bimodal distribution, as sketched in Figure A. There is a peak near the white end of the range of pixel brightness, corresponding to the white checkers, and another peak at the lower end of the range, corresponding to the black checkers. This distribution can be characterized by its mean or average pixel brightness value, and by the standard deviation or root-mean-square error around that mean value. If some substance like a cloud or mist is interposed between the camera and the checkerboard, the resulting array of pixel brightnesses changes, because the strong contrast of white and black checkers is greyed out. Hence the distribution changes shape and even begins to look like a bell-shaped curve with a mean brightness somewhat below the bimodal mean, and a much smaller standard deviation (Figure B). Thus the mean and standard deviation of a baseline high contrast image can be compared in some way with the mean and standard deviation of the same image obscured by a spray cloud to derive a figure of merit that says something about the quantity of spray being produced.

3.3 Image Digitization vs. Laser Transmissiometer

After many different approaches to deriving a figure of merit (FOM) from the data generated by the image digitization procedure briefly outlined in Section 2.2.5, the following rationale was developed. Since both the mean and the standard deviation change as the amount of spray interposed in the picture changes in density, a little-used quality control statistic known as the Coefficient of Variation (CV) was used as the quantity from which the Figure of Merit (FOM) was derived. The CV is simply the standard deviation divided by the mean or average. The ratio of the two CV's multiplied by 100 yields a FOM analogous to the percentage of laser transmittance. A correlation analysis (linear regression) between the two measures on the same runs yields a very high product moment correlation of 0.85 where as 1.00 is a perfect relationship, and 0 is no relationship at all. The two measures are evidently responsive to the same phenomena in the same way! The plot of the data and the associated analysis is provided in Figure 15 and Table 7 respectively.

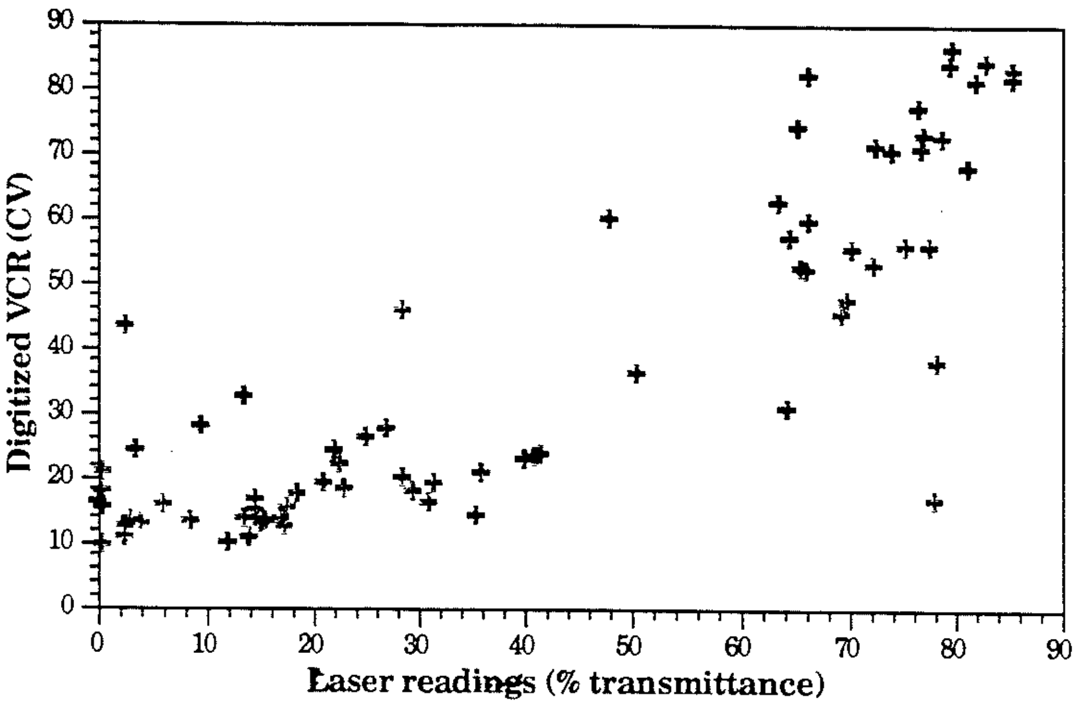


Figure 15. Digitization vs. Laser Percent Transmission

Table 7 Digitization vs. Laser Percent Transmission

Summary of Fit

Rsquare	.7326601
Root Mean Square Error	13.08477
Mean of Response	37.35109
Observations (or Sum Wgts)	73

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	33314.206	33314.2	194.5796
Error	71	12155.996	171.2	Prob > F
C Total	72	45470.202		0.0000

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	8.0851295	2.59752	3.11	0.0027
Laser	.72353417	.051869	13.95	0.0000

REFERENCES

Koppa, R., and Pendleton, O. (1987). Splash and spray test results (Tech. Paper 872279). Pennsylvania: Society of Automotive Engineers.

APPENDIX B

LAB DATA SHEET

Date ______________ Subject number ________

Contrast Sensitivity

Base line	Contrast level							
Row	1	2	3	4	5	6	7	8
A								
B								
C								
D								
E								

Slide 1	Contrast level							
Row	1	2	3	4	5	6	7	8
A								
B								
C								
D								
E								

Slide 2	Contrast level							
Row	1	2	3	4	5	6	7	8
A								
B								
C								
D								
E								

Slide 3	Contrast level							
Row	1	2	3	4	5	6	7	8
A								
B								
C								
D								
E								

Slide 4	Contrast level							
Row	1	2	3	4	5	6	7	8
A								
B								
C								
D								
E								

Slide 5	Contrast level							
Row	1	2	3	4	5	6	7	8
A								
B								
C								
D								
E								

Snellen Acuity

Base	Slide 1	Slide 2	Slide 3	Slide 4	Slide 5
20/	20/	20/	20/	20/	20/

APPENDIX C

FIELD DATA SHEET

Test date ____________ Subject number ____________

Sky conditions: Sunny Pt. cloudy Cloudy

Trial 1

Viewing Condition	ID as object (feet)	ID as car (feet)
BASE		
SLIDE 1		
SLIDE 2		
SLIDE 3		
SLIDE 4		
SLIDE 5		

Trial 2

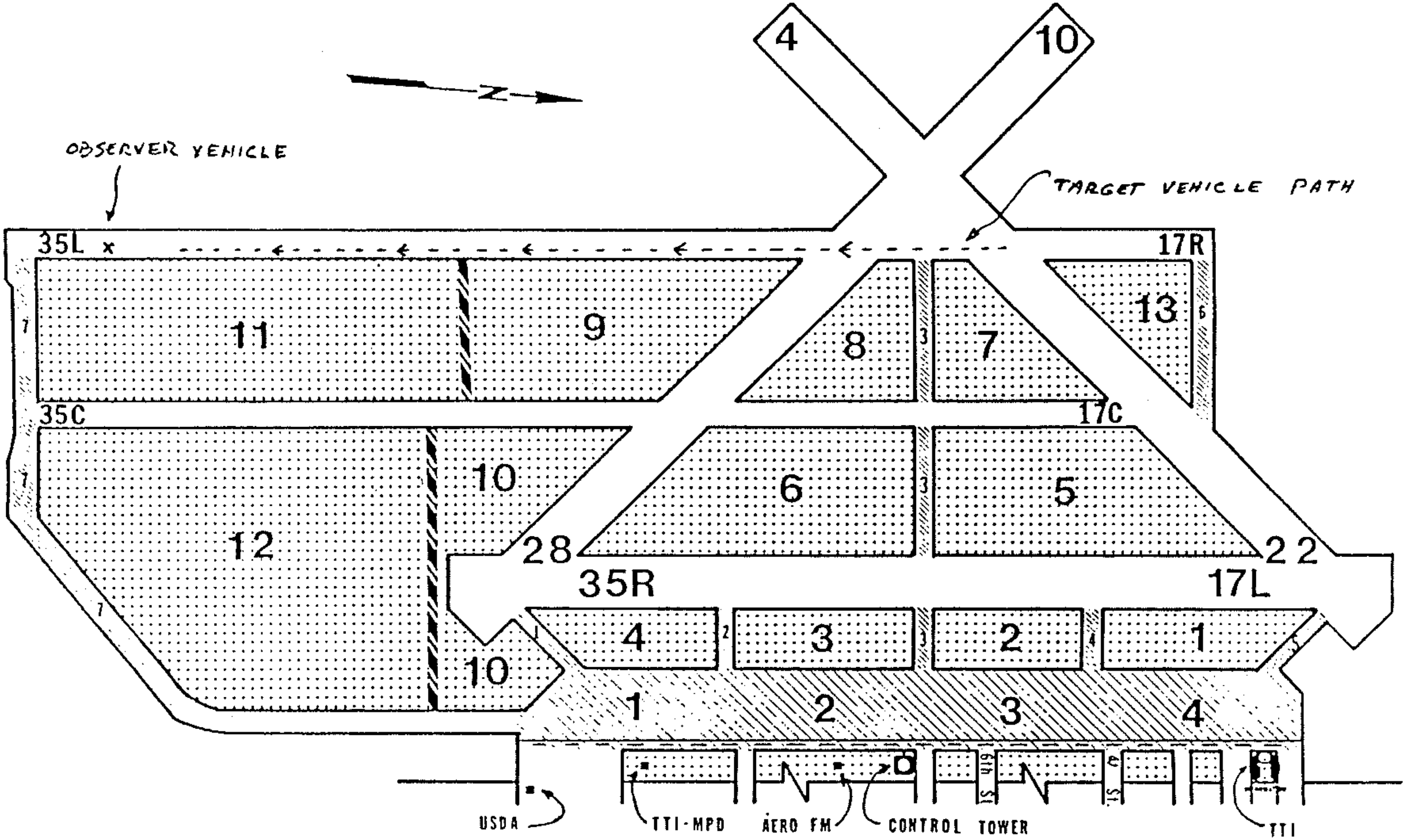
Viewing Condition	ID as object (feet)	ID as car (feet)
BASE		
SLIDE 1		
SLIDE 2		
SLIDE 3		
SLIDE 4		
SLIDE 5		

Trial 3

Viewing Condition	ID as object (feet)	ID as car (feet)
BASE		
SLIDE 1		
SLIDE 2		
SLIDE 3		
SLIDE 4		
SLIDE 5		

APPENDIX D

MAP OF TEXAS A&M RIVERSIDE CAMPUS



Map No. 4
Available in: 8½" x 11" (Not to Scal
36" x 24" (Not to Scal

Drawing not to scale
11/5/81 wlc

APPENDIX E

PARTICIPANT INFORMATION FORM

Participant Information Form

The following information is needed to enable TTI to study the results of todays experiment.

1. Name:____________________ ID Number: _____________

2. Date of birth: (mm/dd/yr) ____________________

3. How long have you been driving? _______________ years.

4. Do you wear glasses or corrective lenses? (circle one) yes no

APPENDIX F

SUBJECT BRIEFING NARRATIVE

Volunteer Briefing

First, your visual acuity will be measured with a standard Snellen eye chart, then contrast sensitivity will be measured with the chart supplied by Vistech Consultants, Inc. following recommended test procedures. Both measures will be repeated while looking through each slide of simulated spray. Second, we will move to the runway where the actual experimental measurements will be taken. You will be seated in a stationary automobile at the side of the roadway and instructed to look through the simulated spray slides at a target vehicle which will be advancing slowly. An assistant will be in the car to help you with the radio and the simulated spray slides.

Procedure: The target vehicle will start toward you from the extreme end of the runway (approx 1 mile) and will advance at 15 MPH. When you can see some object but cannot identify what it is, say: "**I see it**". When you can identify the object as an oncoming car, say: "**stop**". The car will remain stationary until you have the next slide of simulated spray is in place.

Appendix G Omitted

Pages 105-108

Information was incomplete due to file corruption.

APPENDIX H

TABULATION OF ALL DATA

Key to column headings and entries:

Subject:	Subject identification number.
Slide:	Frame of simulated spray.
Snellen:	Decimal value of measured Snellen acuity.
CS (A):	Level of contrast sensitivity in row A.
CS (B):	Level of contrast sensitivity in row B.
CS (C):	Level of contrast sensitivity in row C.
CS (D):	Level of contrast sensitivity in row D.
CS (E):	Level of contrast sensitivity in row E.
Sum CS:	Sum of values for rows A through E.
Raw d1:	Distance target vehicle traveled from starting point before subject identification in first trial.
Raw d2:	Distance target vehicle traveled from starting point before subject identification in second trial.
Raw d3:	Distance target vehicle traveled from starting point before subject identification in third trial.
Raw avg:	Average of raw (1 to 3) distances.
ID feet:	Computed identification distance from subject 5280 - Raw avg = ID feet.
ID meters:	Metric conversion of identification destance ID feet * 0.305 = ID meters.
m:	Missing value

Subject	slide	Snellen	CS (A)	CS (B)	CS (C)	CS (D)	CS (E)	Sum CS	raw d1	raw d2	raw d3	raw avg	ID feet	ID meters
1	base	1.33333	7	7	7	7	6	34	770	540	m	655	4625	1411
1	s1	1	6	6	5	4	3	24	2200	1650	m	1925	3355	1023
1	s2	0.5	6	5	3	2	0	16	2590	2450	m	2520	2760	842
1	s3	0.28571	5	5	2	0	0	12	3890	3250	m	3570	1710	522
1	s4	0.1	3	1	0	0	0	4	4730	4720	m	4725	555	169
1	s5	0.05	1	0	0	0	0	1	5010	4950	m	4980	300	92
2	base	1.33333	6	7	7	5	3	28	1790	1845	1690	1775	3505	1069
2	s1	1	5	5	4	2	1	17	2600	2680	2550	2610	2670	814
2	s2	0.5	5	5	3	0	0	13	3590	3630	3660	3627	1653	504
2	s3	0.28571	4	4	1	0	0	9	4600	4580	4640	4607	673	205
2	s4	0.1	3	1	0	0	0	4	5050	5060	5080	5063	217	66
2	s5	0.05	1	0	0	0	0	1	5180	5180	5210	5190	90	27
3	base	1.53846	6	7	7	7	6	33	680	810	m	745	4535	1383
3	s1	1	6	6	5	4	3	24	1230	1400	m	1315	3965	1209
3	s2	0.5	5	5	3	2	1	16	2450	2680	m	2565	2715	828
3	s3	0.28571	4	4	2	1	0	11	3675	3840	m	3758	1523	464
3	s4	0.2	2	1	0	0	0	3	4870	4880	m	4875	405	124
3	s5	0.1	1	0	0	0	0	1	5110	5100	m	5105	175	53
4	base	1	7	6	6	3	3	25	3530	3200	m	3365	1915	584
4	s1	0.66667	5	6	4	4	1	20	3860	3830	m	3845	1435	438
4	s2	0.5	5	5	3	0	0	13	4300	4280	m	4290	990	302
4	s3	0.2	5	5	1	0	0	11	4550	4630	m	4590	690	210
4	s4	0.1	3	1	0	0	0	4	5050	5040	m	5045	235	72
4	s5	0.05	0	0	0	0	0	0	5180	5180	m	5180	100	31
5	base	0.8	7	7	6	6	5	31	1870	2130	m	2000	3280	1000
5	s1	0.5	6	6	5	3	3	23	2600	3050	m	2825	2455	749
5	s2	0.4	5	5	3	1	0	14	3630	3950	m	3790	1490	454
5	s3	0.2	4	3	2	0	0	9	4425	4830	m	4628	653	199
5	s4	0.1	2	1	0	0	0	3	5110	5070	m	5090	190	58
5	s5	0.05	0	0	0	0	0	0	5200	5170	m	5185	95	29

Subject	slide	Snellen	CS (A)	CS (B)	CS (C)	CS (D)	CS (E)	Sum CS	raw d1	raw d2	raw d3	raw avg	ID feet	ID meters
6	base	1.33333	7	8	7	7	6	35	2190	1590	1350	1710	3570	1089
6	s1	0.8	6	7	6	4	3	26	2600	2500	2400	2500	2780	848
6	s2	0.5	6	6	4	3	0	19	3330	3340	3040	3237	2043	623
6	s3	0.28571	5	5	2	0	0	12	3930	3840	4140	3970	1310	400
6	s4	0.2	3	1	0	0	0	4	4840	4610	4845	4765	515	157
6	s5	0.1	1	0	0	0	0	1	5050	4950	5040	5013	267	81
7	base	1	7	7	7	6	6	33	2250	1060	1860	1723	3557	1085
7	s1	0.8	6	6	4	2	1	19	2470	2490	2650	2537	2743	837
7	s2	0.4	5	5	3	1	1	15	3230	3200	3220	3217	2063	629
7	s3	0.2	5	4	1	1	0	11	4420	4250	4350	4340	940	287
7	s4	0.1	3	1	0	0	0	4	4880	4870	4830	4860	420	128
7	s5	0.05	1	0	0	0	0	1	5090	5115	5130	5112	168	51
8	base	1.33333	6	7	5	5	4	27	1070	500	780	783	4497	1371
8	s1	0.8	6	5	4	2	1	18	2070	2220	2040	2110	3170	967
8	s2	0.4	5	5	3	1	0	14	3195	3170	3360	3242	2038	622
8	s3	0.28571	4	5	1	0	0	10	3740	4320	4460	4173	1107	338
8	s4	0.1	2	1	0	0	0	3	4940	4970	5080	4997	283	86
8	s5	0.05	0	0	0	0	0	0	5150	5190	5210	5183	97	29
9	base	1.33333	6	7	7	7	6	33	2500	1850	2450	2267	3013	919
9	s1	1	5	6	5	4	3	23	3160	3150	3250	3187	2093	638
9	s2	0.5	5	5	3	1	0	14	3795	4020	4150	3988	1292	394
9	s3	0.2	4	4	2	0	0	10	4800	4920	4810	4843	437	133
9	s4	0.1	1	1	0	0	0	2	5135	5160	5150	5148	132	40
9	s5	0.05	0	0	0	0	0	0	5250	5235	5230	5238	42	13
10	base	1	6	7	6	5	4	28	0	0	0	0	5280	1610
10	s1	0.66667	5	6	4	2	1	18	890	565	320	592	4688	1430
10	s2	0.5	5	5	3	1	0	14	2570	1480	1420	1823	3457	1054
10	s3	0.28571	5	4	1	0	0	10	3750	2550	2860	3053	2227	679
10	s4	0.2	2	1	0	0	0	3	4680	4460	4250	4463	817	249
10	s5	0.1	2	0	0	0	0	2	5130	5000	5070	5067	213	65

Subject	slide	Snellen	CS (A)	CS (B)	CS (C)	CS (D)	CS (E)	Sum CS	raw d1	raw d2	raw d3	raw avg	ID feet	ID meters
11	base	1.53846	7	6	7	5	4	29	110	570	260	313	4967	1515
11	s1	0.8	5	5	4	2	1	17	910	980	1070	987	4293	1309
11	s2	0.5	5	5	3	2	0	15	2120	2440	2730	2430	2850	869
11	s3	0.4	4	4	1	0	0	9	3600	3560	3800	3653	1627	496
11	s4	0.1	2	1	0	0	0	3	4980	4900	4920	4933	347	106
11	s5	0.05	1	0	0	0	0	1	5140	5125	5130	5132	148	45
12	base	1.53846	6	7	7	7	7	34	690	1000	500	730	4550	1388
12	s1	1	5	7	6	4	1	23	890	1200	1000	1030	4250	1296
12	s2	0.66667	5	6	3	2	0	16	2370	2010	1950	2110	3170	967
12	s3	0.28571	5	4	1	0	0	10	3670	3250	3610	3510	1770	540
12	s4	0.2	2	1	0	0	0	3	4810	4650	4840	4767	513	157
12	s5	0.1	1	0	0	0	0	1	5010	5015	5060	5028	252	77
13	base	1.53846	7	7	7	7	6	34	1750	1050	860	1220	4060	1238
13	s1	1	6	7	5	4	3	25	2430	2250	1300	1993	3287	1002
13	s2	0.66667	5	5	4	4	1	19	3150	3280	2740	3057	2223	678
13	s3	0.4	4	4	2	0	0	10	4150	4330	3880	4120	1160	354
13	s4	0.2	2	1	0	0	0	3	4870	4770	4630	4757	523	160
13	s5	0.1	1	0	0	0	0	1	5050	5040	5040	5043	237	72
14	base	1.33333	6	7	6	5	5	29	2900	2360	2160	2473	2807	856
14	s1	0.8	6	6	4	2	2	20	3050	2680	2420	2717	2563	782
14	s2	0.5	5	5	3	1	1	15	3750	3360	3250	3453	1827	557
14	s3	0.28571	3	4	1	0	0	8	4460	4320	4500	4427	853	260
14	s4	0.2	3	1	0	0	0	4	4940	4820	4810	4857	423	129
14	s5	0.1	1	0	0	0	0	1	5185	5070	5120	5125	155	47
15	base	1.33333	7	6	6	6	5	30	2000	2010	1000	1670	3610	1101
15	s1	0.8	6	6	4	2	2	20	2000	2280	1690	1990	3290	1003
15	s2	0.5	5	6	3	2	1	17	2550	3520	2160	2743	2537	774
15	s3	0.4	4	4	1	0	0	9	4260	4170	3620	4017	1263	385
15	s4	0.2	2	0	0	0	0	2	4830	4710	4630	4723	557	170
15	s5	0.1	0	0	0	0	0	0	5130	5030	4960	5040	240	73

Subject	slide	Snellen	CS (A)	CS (B)	CS (C)	CS (D)	CS (E)	Sum CS	raw d1	raw d2	raw d3	raw avg	ID feet	ID meters
16	base	1.53846	7	7	6	6	6	32	670	420	260	450	4830	1473
16	s1	1	6	6	4	2	3	21	1250	780	740	923	4357	1329
16	s2	0.5	5	5	3	1	0	14	3150	2000	2550	2567	2713	828
16	s3	0.4	4	2	2	0	0	8	4180	3840	4150	4057	1223	373
16	s4	0.2	1	1	0	0	0	2	4970	4970	4960	4967	313	96
16	s5	0.1	0	0	0	0	0	0	5110	5130	5110	5117	163	50
16	base	1	6	6	5	5	4	26	3480	2970	2950	3133	2147	655
17	s1	0.8	5	6	5	4	2	22	3960	3800	3450	3737	1543	471
17	s2	0.5	5	5	3	2	0	15	4460	4520	4060	4347	933	285
17	s3	0.2	4	4	1	0	0	9	4900	4970	4750	4873	407	124
17	s4	0.1	1	1	1	0	0	3	5120	5140	5060	5107	173	53
17	s5	0.05	0	0	0	0	0	0	5210	5220	5200	5210	70	21
18	base	1.53846	7	7	7	6	5	32	1630	1900	1940	1823	3457	1054
18	s1	0.8	6	6	5	4	3	24	1890	2570	2660	2373	2907	887
18	s2	0.5	5	5	4	2	1	17	3500	3600	3620	3573	1707	521
18	s3	0.4	4	4	2	0	0	10	4340	4580	4460	4460	820	250
18	s4	0.2	3	1	0	0	0	4	4860	5000	5010	4957	323	99
18	s5	0.1	1	0	0	0	0	1	5100	5140	5180	5140	140	43
19	base	1	6	6	5	4	3	24	2550	2800	2940	2763	2517	768
19	s1	0.66667	5	5	4	2	1	17	3060	3260	3250	3190	2090	637
19	s2	0.4	4	4	2	0	0	10	3830	3410	3820	3687	1593	486
19	s3	0.2	2	2	0	0	0	4	4710	4170	4630	4503	777	237
19	s4	0.1	1	0	0	0	0	1	5040	4970	5030	5013	267	81
19	s5	0.05	0	0	0	0	0	0	5190	5140	5170	5167	113	35
20	base	0.8	6	7	6	4	3	26	3110	3060	3300	3157	2123	648
20	s1	0.66667	5	6	5	2	1	19	3560	3900	4150	3870	1410	430
20	s2	0.4	4	5	3	1	0	13	4630	4310	4530	4490	790	241
20	s3	0.28571	3	3	0	0	0	6	4950	4730	4820	4833	447	136
20	s4	0.1	1	1	0	0	0	2	5100	5100	5030	5077	203	62
20	s5	0.05	0	0	0	0	0	0	5200	5200	5150	5183	97	29