On-Road Investigation of Fluorescent Sign Colors to Improve Conspicuity

by

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(ABSTRACT)

This thesis documents Phase III of a research program undertaken by the Virginia Transportation Research Council and the Virginia Tech Transportation Institute in cooperation with the 3M Company and the Virginia Department of Transportation for the evaluation of visual performance of retroreflective signs of various color combinations. Phase I was an off-road field experiment conducted to determine the best sign color combination, letter stroke width, and letter size for the emergency sign. Based upon the results of Phase I, three color combinations were chosen for testing (black on coral, black on light blue, and yellow on purple) against a baseline color combination of black on orange.

Phase II was conducted using an instrumented vehicle through a construction zone-related detour. Questionnaire data were also obtained. The independent variables of interest were sign color combination, age, and visibility condition. The findings of Phase II indicated that use of a color combination other than the traditional black on orange sign would improve driver performance and safety when used for trailblazing during critical incidents, especially when the incident route overlaps a work zone detour.

A serious limitation of Phases I and II is that the use of fluorescent colors was not evaluated. Anecdotal evidence suggests that the use of fluorescent colors on signs improves their conspicuity. The purpose of Phase III was to evaluate fluorescent sign color combinations for incident management trailblazing purposes. This study consisted of an on-road investigation using an instrumented vehicle over a 12.2-mile route in urban and rural areas of Montgomery County, Virginia. The following conclusions were made:

- A non-fluorescent yellow on non-fluorescent purple sign is least preferred by both older and younger drivers when compared to the other sign color combinations employed in this study.
- Both younger and older drivers have a preference for a black on fluorescent yellow-green sign.
- Fewer late braking maneuvers and fewer turn errors were recorded during daytime conditions than during nighttime conditions.
- Older drivers tended to register more late braking maneuvers than did younger drivers.

DEDICATION

If God is for us, who can be against us? He who did not spare His own Son, but delivered Him up for us all, how shall He not with Him also freely give us all things? Who shall bring a charge against God's elect? It is God who justifies. Who is he who condemns? It is Christ who died, and furthermore is also risen, who is even at the right hand of God, who also makes intercession for us. Who shall separate us from the love of Christ? Shall tribulation, or distress, or persecution, or famine, or nakedness, or peril, or sword? . . . Yet in all these things we are more than conquerors through Him who loved us (Romans 8:31-35,37).

If we say that we have no sin, we deceive ourselves, and the truth is not in us. If we confess our sins, He is faithful and just to forgive us our sins and to cleanse us from all unrighteousness (1 John 1:8-9).

We have been in many trials, but we have never yet been cast where we could not find in our God all that we needed. Let us then be encouraged to trust in the Lord for ever, assured that His ever lasting strength will be, as it has been, our anchor and stay.

This work is dedicated to my Lord and Savior, JESUS CHRIST.

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CHAPTER 1. INTRODUCTION

In the United States, as well as other developed areas of the world, congestion on roadways continues to grow. When road construction and traffic crashes occur, drivers must be diverted from primary routes to secondary road systems. When a traffic crash occurs within a construction zone the problem of navigating is compounded for drivers and incident management teams. Highway crews must then reroute drivers who are often confused while attempting to discern the typical black on orange "Emergency Detour" signs from orange and black construction zone signs (Neale, Barker, Dingus, and Brich, 1998).

The primary purpose of traffic signs is to provide information to the driver. Modern drivers are bombarded with a plethora of information that vies for their attention. Research by Agaki, Seo, and Motada (1996), Massie, Campbell, and Williams (1995), and Smith and Faulconer (1971), document the numerous and assorted signs which compete for driver attention. This amplifies the need for traffic signs that incorporate designs resulting in increased conspicuity. The influx of visual information presented to drivers is, at times, overwhelming. It is absolutely essential that the driver be presented information regarding navigation and safety in a manner that captures his attention (Haapaniemi, R., 1997; Hawkins, Picha, Rhodes, and Womack, 1997). The importance of attention in driving cannot be overemphasized. Research by Treat, et al. (1977) revealed that difficulties with perception, attention, and distraction are major human causes in over 40% of traffic accidents. Additional research by MacDonald and Hoffman (1991) concluded that the limited attentional capacity of drivers is a factor in sign recognition in visually complex and attention-demanding environments.

The ability to focus attention to the driving task while comprehending traffic sign information from complex visual scenes is important. As documented by Dewar (1993), "field dependence" is a driver characteristic that influences this ability. Dewar noted that drivers who are field-dependent have difficulty selecting relevant from irrelevant visual information and appear to be more easily distracted than those who are field-independent.

The literature on this matter is inconclusive regarding the relationship between field-dependence and traffic accidents. Research by Loo (1978) documents that field-dependent drivers are less skilled at detecting signs embedded in visual scenes. This further highlights the need for increased conspicuity in traffic signs.

When traffic is diverted through construction and work zones, the difficulties facing field-dependent drivers are compounded by embedding black on orange emergency detour signs in a visual scene that contains signs bearing the same color scheme (black on orange work zone signs). To provide enhanced traffic management in these situations, the most conspicuous sign colors need to be identified and incorporated in emergency detour signs. This will result in more effective traversing of motorists through unfamiliar detour routes (Pietrucha, 1993).

This research addresses the problem of trailblazing through an incident that overlaps a construction zone. Initiated by the Virginia Department of Transportation's (VDOT) Statewide Incident Management (SIM) Committee and the Virginia Transportation Research Council, the research was sponsored due to problems experienced when an incident detour marked with black on orange detour signs overlaps a construction detour marked with black on orange detour signs. Members of the SIM Committee noted that the inability of motorists to determine which sign to follow prompted the need for a unique sign color to trailblaze drivers around an incident. It was further thought that a unique sign color for an incident detour would reduce motorist confusion, increase driver comfort while navigating an unfamiliar area, and improve overall safety by reducing sudden stops and erratic maneuvers. This project, Phase III of a three-part effort (see Barker, Neale, and Dingus, 1998, for a discussion of the previous phases), examines the use of fluorescent signing materials for incident management trailblazing.

CHAPTER 2. LITERATURE REVIEW

The primary literature review for this research focused on studies involving fluorescent materials, but also included pertinent aspects of the driving population and traffic control devices. While research with fluorescent signing material has been conducted in the past, there have not been any on-road studies investigating the conspicuity of fluorescent signs. Previous research by Barker (1998) addresses the importance of conspicuity as it relates to the use of non-fluorescent signs and incident management trailblazing. Additional research (Dewar, 1988, 1989, 1993; Mace, 1988; U.S. Department of Transportation, 1983) describes necessary evaluation and design criteria for traffic signs, so these aspects will not be discussed herein.

Physiological Parameters Influencing Traffic Sign Design

Most equipment and systems are designed to be operated by a broad spectrum of people. In designing equipment for adjustability, it is typically the practice to provide for adjustments to cover the range from the 5^{th} percentile female to the 95^{th} percentile male (Sanders and McCormick, 1993). Alternatively, the worst-case scenario of drivers' needs must be factored into the design of traffic signs (Dewar, 1989). Consideration must be given to reduced visual acuity of older drivers (as well as visually impaired younger drivers), individuals with slow reaction times, and individuals with a greater than normal susceptibility to confusion due to information overload. Information contained in the *Traffic Control Devices Handbook* (U.S. Department of Transportation, 1983) addresses factors that must be considered in the overall design of traffic signs. These factors are important considerations that ultimately allow motorists to safely and effectively traverse the roadways. Use of fluorescent signing material has the potential to lessen the impact of adverse physiological effects brought on by the aging process.

Conspicuity

Conspicuity refers to "the property of an object that causes it to attract attention or to be readily located by search" (Cole and Hughes, 1984). Factors that influence conspicuity of a sign are characteristics of the sign and the environment in which it is used. Important sign-related variables that determine daytime conspicuity are the size of the sign, its contrast with the immediate surroundings, and the complexity of the background (Jenkins and Cole, 1986). Van Norren (1981) cited sign placement location, driver expectations, and frequency of occurrence of the sign as factors contributing to conspicuity. In addition, sign color and fluorescent materials exhibit the potential for improving conspicuity (Burns and Johnson, 1997; Zwahlen and Schnell, 1997).

According to Engel (1976), conspicuity can be viewed as being either *sensory* or *cognitive* in nature. Sensory conspicuity can be categorized as the degree of visual prominence afforded a sign by its crude sensory features (brightness, color, size, legibility) that combine to ensure that its message content is available at the preattentive level of processing. The cognitive conspicuity of a sign is based on its meaning, novelty, or relevance and will depend to a great extent on the psychological state of the driver, his purpose, and his expectations at the time (Jenkins and Cole, 1986).

Conspicuity, in the visual (sensory) context, can be defined as the attribute of an object that ensures its presence is noticed at the preattentive level of processing (Jenkins and Cole, 1986). It is essential that priorities be allocated to the enormous amount of information available in today's road environment. This is important so that the driver can direct his attention to only those items that are necessary for his purpose and safety. What information the driver considers important, and thus pays attention to, depends on the message of the sign and its relevance to him at the time. Therefore, some degree of preattentive processing of all available traffic environment information must occur so that the important information is not discarded but progresses to the stage of consciously being used. Information conveyed to drivers by traffic signs must be visually prominent, legible, and comprehensible at the preattentive level of processing. If not, it will not warrant attention and its importance cannot be evaluated.

Research by Zwahlen and Schnell (1997) tentatively concluded that to maximize daytime conspicuity for peripheral detection and recognition, highly conspicuous fluorescent colors (such as fluorescent yellow-green) along with a fairly large target size should be selected. Earlier research by Zwahlen and Vel (1994) concluded "designers of traffic signs, personal conspicuity enhancement items and devices, and roadside traffic control devices should consider the superior visual conspicuity properties of fluorescent colors (especially fluorescent yellow and fluorescent orange) and incorporate them in designs when the highest possible daytime target conspicuity is absolutely necessary." "Strong yellow-green" (SYG)[1] is one of the unassigned colors listed in the Federal Highway Administration's (FHWA's) "Manual on Uniform Traffic Control Devices" (Department of Transportation, 1988). Fluorescent yellow-green (FYG) is very promising since it is more conspicuous in low-light conditions than conventional yellow signing materials. The visible spectrum for color is between 370 - 730 nm. Peak wavelength sensitivity (scotopic, 507 nm; photopic, 555 nm) supports the outstanding visibility aspects of FYG (Cornsweet, 1970). The FHWA has sponsored numerous studies involving the evaluation of FYG signs that warn drivers of non-motorized hazards (Blakely, Clark, Dutt, and Hummer, 1996; Clark, Hummer, and Dutt, 1996; Dhar and Woodin, 1995; Dutt, Hummer, and Clark, 1997).

Previous investigations regarding the effects of color on sign conspicuity have generated mixed results. In a 1988 study, Olson concluded that all colors within a given family of materials are as effective as yellow with regard to sign conspicuity. Other researchers (Forbes, et al. 1968; Olson and Bernstein, 1979) have reported similar findings and concluded that color contrast has only a small effect on detection distance. Color contrast refers to the perceptual difference in two adjacent colors. It is related to traffic sign conspicuity and is of primary importance to daytime driving conditions. These studies support the notion that detection differences are more related to luminance contrast than to color contrast. Luminance contrast and contrast ratio, with regard to

[1] SYG is now referred to among practitioners and in this document as fluorescent yellow-green.

traffic signs, refer to light reflected from the sign, between two adjacent colors, and is of most importance during nighttime driving conditions. Contrast ratio is equal to L_{max} divided by L_{min}, where L_{max} is equal to luminance value of the brighter of two contrasting areas, and L_{min} equals luminance value of the darker of two contrasting areas. Gordon (1984) noted that if contrast between sign legend and sign background is too high, the legend will irradiate and sign legibility will be reduced. On-road studies comparing daytime and nighttime driver performance utilizing fluorescent signing material have not been conducted.

Age Related Factors

Some older drivers have disproportionate difficulty driving at night compared to younger drivers. This is due to a number of factors — reduced visual acuity; poor contrast sensitivity; less light being processed by the eyes of older persons; higher degree of glare sensitivity and slower recovery from glare due to headlights, advertising signs, and street lights; and reduced perception of color (Dewar, 1993; Evans and Ginsburg, 1985; Olson and Bernstein, 1979). Additionally, research has documented that older drivers often experience more stress than drivers of other age groups, resulting in a reduction of the attention they can direct to detecting, reading, and responding to traffic signs (Dewar, 1989, 1993; Hiatt, 1987; Mortimer and Fell, 1989). The physiological changes typically experienced by older drivers demand that the traffic control system provide drivers more information and additional time to respond. This is particularly important since growth in the elderly population continues to rise (National Research Council, 1988). As documented by Abrams and Berkow (1990), there are now more Americans over the age of 65 than under the age of 25. According to the U. S. Census Bureau (1990), there will be over 35 million people in the United States over the age of 65 by the year 2000. It is anticipated that by the year 2020, approximately 17% of the United States population will be 65 or older. This will result in over 50 million older persons being eligible to drive (Bishu, Foster, and McCoy, 1991).

As previously stated, many aspects of visual performance decline as individuals age. For instance, yellowing of the lens results in a significant reduction in light transmission thereby producing the need for higher contrast levels (Spence, 1989). Research has documented that older persons require higher levels of contrast to identify and discriminate traffic signs (Owsley and Sloan, 1987). Additionally, Richards (1966) reported that older participants exhibit an increased need for high contrast targets. Use of fluorescent signing material should assist drivers by providing higher contrast levels than are available using non-fluorescent materials.

Younger drivers experience problems of a different nature such as driving too fast in unsafe areas, not properly concentrating on the driving task, and "tunnel" vision. The predominant cause of problems experienced by young drivers is associated with inexperience and over-confidence.

Daytime versus Nighttime Driving Factors

It has been documented that nighttime driving carries a higher risk of being involved in a crash (Massie et al. 1995; Saunders, 1997). This is due to factors such as reduced visibility, fatigue, and elevated incidence of alcohol use. Massie et al. (1995) also reported data indicating that nighttime injury involvements per 100 million miles were nearly twice as prevalent as during daytime conditions, and nighttime fatal involvements exceeded four times the daytime fatalities. Glare from on-coming traffic has been shown to be a problem for drivers of all ages. One way to enhance sign visibility at night is through improvements in traffic sign design. This will ultimately result in improved night driving safety due to the increased conspicuity of the signs. Signing materials manufactured using colors not commonly found in the traffic environment should also increase conspicuity.

In recent years traffic signing research has explored the relationship between nighttime visibility performance and material properties (e.g., retroreflective brightness) (Goodspeed, Mercier, Paniati, and Simmons, 1995; Jenssen and Brekke, 1998; Zwahlen and Schnell, 1998). Nighttime visibility performance improves as a function of improvements to the retroreflective characteristics of signing material. The Manual on

Uniform Traffic Control Devices (MUTCD) requires that all signs intended for nighttime use must be reflectorized in a manner that portrays approximately the same shape and color under both day and night conditions (U. S. Department of Transportation, 1983, 1993). The majority of all traffic accidents, however, occur during daylight conditions when retroreflectivity has little influence on traffic sign visibility (Jenssen and Brekke, 1997). Considerably less research has been conducted on the relationship between daytime visibility performance and material properties (e.g., color, conspicuity in diffuse daylight). It has only been in the last few years that traffic signing materials combining fluorescence and high efficiency prismatic retroreflective optical designs suitable for long-term outdoor signing applications have become available (Gale, 1998; Hawkins and Carlson, 1999; Jenssen and Brekke, 1997).

Field studies have shown that fluorescent colors are detected with greater accuracy and are more conspicuous than their ordinary color counterparts (Burns and Johnson, 1997; Zwahlen and Vel, 1994). Based on its high visibility properties, fluorescent materials are now specified for a variety of safety signing and marking applications (BS EN 471, 1994; Zwahlen and Schnell, 1997). The expected daytime benefit of fluorescent traffic control devices is improved safety through earlier awareness of the driver to regulatory and hazard warning information. Driver comfort and driving smoothness may also increase due to better guidance resulting from early detection of traffic signs. Fluorescent traffic signs should benefit older drivers more than younger drivers due to the age related need for enhanced luminance and color contrast (Evans and Ginsburg, 1985; Olzak and Thomas, 1988; Richards, 1966; Spence, 1989).

Daytime photometric measurements of fluorescent retroreflective traffic signing materials have shown that fluorescent colors exhibit a higher daytime luminance than do the corresponding ordinary signing colors. Recent research has shown that daytime visibility of retroreflective signs is increased when fluorescent colors are used (Brekke and Jenssen, 1998). Nighttime visibility distances of fluorescent and non-fluorescent retroreflective signs are equivalent. An on-road study utilizing fluorescent signing material is needed to compare driver performance under both daytime and nighttime conditions.

Work Zone Applications and Considerations

Road construction and repair work present special challenges to both drivers and work crews. Work zone accident statistics attest to the critical need for safety improvements. One method by which traffic engineers have attempted to enhance work zone safety is by providing advance warning to assure that drivers are aware they are entering a road construction area. Increased traffic congestion has resulted in road construction during both day and night conditions. Work zone signs must be equally effective both day and night. Brekke and Jenssen (1998) reported significantly lower approach speeds to work zones where fluorescent signs were used. The literature shows that durable fluorescent orange sign sheeting is more conspicuous than standard non-fluorescent orange sheeting (Austin, et al. 1993). Prior to 1999, no one had yet demonstrated that greater conspicuity leads to operational changes or fewer accidents. To investigate that link, operational studies were conducted in seven long-term work zones in North Carolina that incorporated left-lane drops on multilane highways. Fluorescent orange signs were found to cause some changes in driver behavior. These changes were primarily positive in nature. With fluorescent signs, there were somewhat fewer traffic conflicts, the percentage of vehicles in the left lane at the midpoint was lower, and trucks moved out of the left lane sooner. There was a slight increase in mean speeds with the fluorescent signs, but this was not significant. Speed variances tended to decrease with fluorescent signs. Based on this research, Hummer and Scheffler (1999) recommended the use of fluorescent orange sheeting on work zone warning signs. Additional research with fluorescent materials is warranted to document driver performance with colors other than fluorescent orange.

Other Fluorescent Material Applications

Fluorescence has been defined as the phenomenon in which light energy of a relatively short wavelength is converted into visible light energy of a longer wavelength (Smith, 1981). Thus, fluorescent colors are brighter than ordinary colors due to the converting of light energy that is normally absorbed and wasted to visible light, which in turn reinforces the color intensity (Smith, 1981). Both fluorescent tape and reflective tape have been used successfully on "PASS WITH CARE" and "DO NOT PASS" signs. Fluorescent materials have also been shown to increase rail car conspicuity (Ford, Richards, and Hungerford, 1998).

Fluorescent yellow-green pedestrian crossing signs are increasingly appearing in school districts throughout the United States as well as along bike paths, playgrounds, and busy intersections (Brayshaw, 1998; Dhar and Woodin, 1995; Linck, 1996; 3M®, 2000; Voyles, 1999;). On June 18, 1998, the MUTCD was amended to allow optional use of fluorescent yellow-green for warning signs related to pedestrian, bicycle, and school applications. Other uses of fluorescent materials include: bike helmets; motorcycle accessories; clothing for joggers, cyclists, and pedestrians; backpacks; apparel for road construction crews; and apparel for firefighters (Reflexite®, 2000; Zwahlen and Schnell, 1977). These uses of fluorescent materials reinforce the potential benefits of using fluorescent materials in the manufacture of traffic signs.

Summary

The previously described concepts support the notion that use of fluorescent signing materials would increase conspicuity of traffic signs and should enhance highway safety through earlier detection of roadway information. Also addressed were issues associated with physiological challenges experienced by older drivers. These concepts are particularly applicable to construction work zones (CWZs). CWZs present unique challenges to drivers. CWZs are also a major cause of concern for highway and safety engineers. Although CWZs constitute only a very small fraction of the total roadway miles, they are the sites of an increasing number of roadway accidents each year. In an attempt to respond to this problem, the traffic safety industry has provided brighter retroreflective signing materials to increase CWZ nighttime visibility. The equally essential need for increased daytime visibility has led traffic engineers to experiment with fluorescent colors in the CWZ (Austin, Burns, and Pavelka, 1993; Brekke and Jenssen, 1997). Even though fluorescent colors exhibit outstanding visibility under all daylight driving conditions, they have never achieved widespread acceptance in outdoor signing applications. The principal objection has been the extremely poor color stability of fluorescent signing materials. In the past, a typical fluorescent roadway sign lost most, if not all, of its color within the first year. In many instances, this time period is reduced to weeks or months. Due to recent improvements in the stability of fluorescent colorant systems, durable fluorescent traffic signing materials are now available (Burns and Johnson, 1997). These new materials effectively combine retroreflective optics and fluorescent colorants in a single construction capable of providing both daytime and nighttime enhanced visibility performance. Signs manufactured using these new traffic control materials will be highly visible whether it is day, night, dawn, dusk, or inclement weather conditions. Older drivers, in particular, will benefit from the enhanced conspicuity of signs manufactured using retroreflective optics and fluorescent colorants.

Previous research (Barker, 1998) resulted in a recommendation not to use the traditional black on orange emergency detour sign to trailblaze a route through a construction zone. Barker's research suggested that future studies evaluate the use of fluorescent colors for incident management purposes and was influential in determining the choice of sign color combinations utilized in this study.

CHAPTER 3. RESEARCH OBJECTIVES

The primary objective of this research was to investigate the use of fluorescent colors for incident management trailblazing. This included obtaining field data utilizing full-size (0.610 m by 0.762 m, or 24 inch by 30 inch) test signs featuring black on fluorescent yellow-green (FYG), fluorescent yellow on fluorescent purple (FYP), black on fluorescent coral (FC) (fluorescent "hot - pink"), and non-fluorescent yellow on non-fluorescent purple (YP) sign colors. Non-fluorescent yellow on non-fluorescent purple was used in a previous study (see Barker, 1998) and was utilized in this study as a baseline for comparative purposes. Driver participation in this research was analyzed to:

- Study the conspicuity of the experimental sign color combinations relative to the traffic environment under normal traffic conditions, with respect to driver age and day and night visibility conditions.
- Evaluate the readability, understandability, and overall preference of the experimental sign color combinations under normal traffic conditions, with respect to driver age and day and night visibility conditions.

Based upon the literature and previous research, results of this research are expected to:

- Yield sign color recommendations capable of affording greater conspicuity under both day and night conditions.
- Lead to increased driver awareness of traffic route information and enhanced driver comfort due to earlier detection of signs and better readability.
- Benefit older drivers due to a reduction in stress while navigating through an incident.
- Ultimately result in a recommendation leading to a national standard for sign color combinations for incident management purposes.

This research was conducted with two primary goals in mind. The first goal was to investigate driver performance over a route blazed with fluorescent signs. The second goal was to investigate driver impressions and preferences regarding the fluorescent signs using a post drive questionnaire.

Experimental Hypotheses

- Hypothesis 1: Drivers will express a greater preference for the black on fluorescent yellow-green sign than the other sign color combinations.
- Hypothesis 2: Turn errors and late braking maneuvers will be more prevalent during nighttime than daytime conditions due to behavioral changes and the characteristics associated with fluorescent colors.

CHAPTER 4. METHODS AND MATERIALS

Experimental Design

This study utilized a 4 X 2 X 2 (Sign Color by Age by Visibility Condition) between factor design. Table 1 portrays the assignment of drivers who participated in the study. Drivers were included in either a Younger (18 -34) or Older (55 and older) age category. Male and female drivers were randomly assigned between Daytime and Nighttime conditions. Each driver was shown one test sign configuration and was exposed to one viewing condition, as indicated in Table 1 (see Appendix A for a description of participant assignments). All participants drove along the same experimental route in urban and rural areas in Montgomery County, Virginia (see Appendix B for a map of the route).

Table 1. Experimental assignment of participants.

Sign Color Combination	Younger Drivers		Older Drivers		Totals
	Daytime	Nighttime	Daytime	Nighttime	
Black on Fluorescent Yellow-Green	5	6	4	5	20
Non-Fluorescent Yellow on Non-Fluorescent Purple	6	6	6	5	23
Black on Fluorescent Coral	6	6	6	6	24
Fluorescent Yellow on Fluorescent Purple	6	6	6	6	24
Totals	23	24	22	22	
	47		44		91

Independent Variables

- *Sign Color Combination.* The four experimental sign color combinations included Fluorescent Yellow-Green (FYG), Non-fluorescent Yellow on Non-fluorescent

Purple (YP) (used as a baseline for comparisons between Phase II and Phase III), Fluorescent Coral (FC), and Fluorescent Yellow on Fluorescent Purple (FYP).

- *Age.* Two age groups of drivers were used: younger drivers (18 - 34 years) and older drivers (55 and older).
- *Visibility Condition.* Participants drove either during the day or night. Forty-five of the participants observed the test signs during daytime sessions. Daytime test sessions began no earlier than one hour after sunrise and no later than one hour before sunset. During the course of the study, all sign color combinations were observed under both clear and cloudy/partly cloudy conditions. Forty-six participants observed the test signs during nighttime sessions. Only the low-beam headlights of the test vehicle were used to illuminate the test signs. Nighttime test sessions began no sooner than one-half hour after sunset. All data collection occurred in fair weather, i.e., no precipitation.

Controlled Variables

- *Gender.* Gender was controlled such that an approximately equal number of male and female drivers were assigned and tested under daytime and nighttime conditions, respectively.

Dependent Variables

The in-vehicle data collection system provided the capability to store data on a computer in the form of one line of numerical data every 0.1 seconds during a data run. The videotape record provided by the cameras' views was time-stamped and synchronized with the computer data stream so that post-test data reduction and data set merging could be performed in the laboratory. All vehicle data collection records were time-stamped to an accuracy of +/- 0.1 seconds. The specific measures collected were as follows:

- *Average Vehicle Velocity/Velocity Variance.* Research indicates that velocity maintenance is a sensitive measure of changes in the amount of attention demanded by secondary driving tasks (Monty, 1984). A change in vehicle velocity can also be used to indicate the point where a driver receives information about a detour or a change in speed limit.

- *Late Braking Reaction.* Braking behavior can also provide a sensitive measure of performance (Monty, 1984). If drivers are inattentive, the brake must be depressed harder and the resulting deceleration is greater than in a normal attention situation. In addition, an abrupt maneuver can be indicative of a driver receiving or processing information late about an upcoming maneuver. A late reaction was operationally defined by a brake position found to be more than two standard deviations from the mean brake position during the course of a sign event. A sign event began when a sign came into view and ended when the experimental vehicle passed the sign.
- *Longitudinal Acceleration/Deceleration Measures and Braking Data.* The pattern of acceleration and braking data is an indication of driver inattention to the forward roadway.
- *Lateral Acceleration Measures*. Abrupt lateral maneuvers, such as large steering reversals, are indicative of a vehicle that is off the center lane track due to driver inattention. Lateral acceleration measures are highly correlated to driver steering input and are therefore used to highlight large magnitude corrections.
- *Steering Wheel Position Variance*. Research has shown that changes in driver steering behavior occur when driver attention changes (Wierwille and Gutman, 1978). In normal, low-attention circumstances, drivers make continuous, small steering corrections to correct for roadway variance and driving conditions. These corrections typically range from two to six degrees. As attention or workload demands increase, the number of these corrections decreases, requiring a larger input to correct the vehicle's position. Therefore, an increase in the variance of steering wheel position indicates high attention or workload requirements.
- *Number of Wrong and Missed Turns*. The experimenter collected this data during the experimental trial. The number of wrong turns is an indication of whether the signs are being detected, recognized, and understood by the driver. A wrong turn event was defined as a turn taken when no directional information was provided to indicate a required turn. A missed turn event was defined as a required turn that was not taken

when indicated by a sign. In the event that a wrong turn and a missed turn occurred for the same sign site, only one error was counted.

- *Subjective Acceptance and Preference Measures*. This data was collected via a subjective questionnaire to assess the driver's impressions and preferences about the TEST ROUTE signs.

Although the vehicle recorded all of the above listed parameters, previous research conducted by Barker (1998) found that only late braking reaction was a sensitive measure of test sign conspicuity. Therefore, analysis was performed only on late braking, number of wrong and missed turns, and questionnaire data.

Participants

The intent was to have 96 participants in order to have six subjects per experimental cell. However, due to sign vandalism during the first phase of the study (black on fluorescent yellow-green) and hardware issues during the second phase (non-fluorescent yellow on non-fluorescent purple), 91 drivers actually participated in this study. Forty-seven participants were between the ages of 18 and 34 (younger drivers), and forty-four participants were between the ages of 55 and 83 (older drivers). Drivers were recruited via a number of different methods: flyers posted at local merchants in the Montgomery County area; flyers posted at various locations on the Virginia Polytechnic Institute and State University campus; announcements using senior citizen list serves; and contact with area churches and clubs. Drivers received $15 compensation for participating in the approximately one hour-long study.

Each participant was required to: (1) be a licensed driver; (2) drive a minimum of twice a week; (3) pass a health-screening questionnaire; and (4) have a minimum visual acuity of 20/40, wearing corrective lenses if necessary.

Apparatus

The primary apparatus used in the study were: (1) a vision tester; (2) an instrumented automobile; (3) the test signs located along the test route; and (4) a post-drive questionnaire. These are described in the following sections.

Titmus® II Vision Tester

This device was used to screen participants for visual acuity at a far distance. The device included a Landholt broken ring test for visual acuity. The level of visual acuity was determined by the participant's ability to locate and identify the unbroken ring in each of the numbered targets.

Automobile

A 1995 Oldsmobile Aurora was used as the experimental vehicle for all participants. This was the same vehicle used in the previous two phases of this research (Barker, 1998). The instrumentation in the vehicle provided the means to unobtrusively collect, record, and reduce a number of data items, including measures of attention demand, measures of navigation performance, safety-related incidents, and subjective opinions of the participants. The system consisted of video cameras to record pertinent data events, an experimenter control panel to record time and duration of events and information on an MS display, sensors for the detection of variations in driving performance and behavior, and a custom analog-to-digital interface and computer to log the data in the required format for analysis. A detailed description of the components of the vehicle can be found in Appendix C.

Experimental Sign Design

There were four experimental sign colors tested in this study. Other sign design parameters were the same across colors tested. The signs read "TEST" on the first line and " ROUTE" on the second line. The specified dimensions for each sign were 0.610 m (24 in) tall by 0.762 m (30 in) wide; however, the actual signs measured 24 inches by 29 inches following the manufacturing process. It is typical for manufactured signs to be slightly different from the specified parameters. Remaining specifications are shown in Figure 1. A photograph of the experimental sign color combinations is shown in Figure 2.

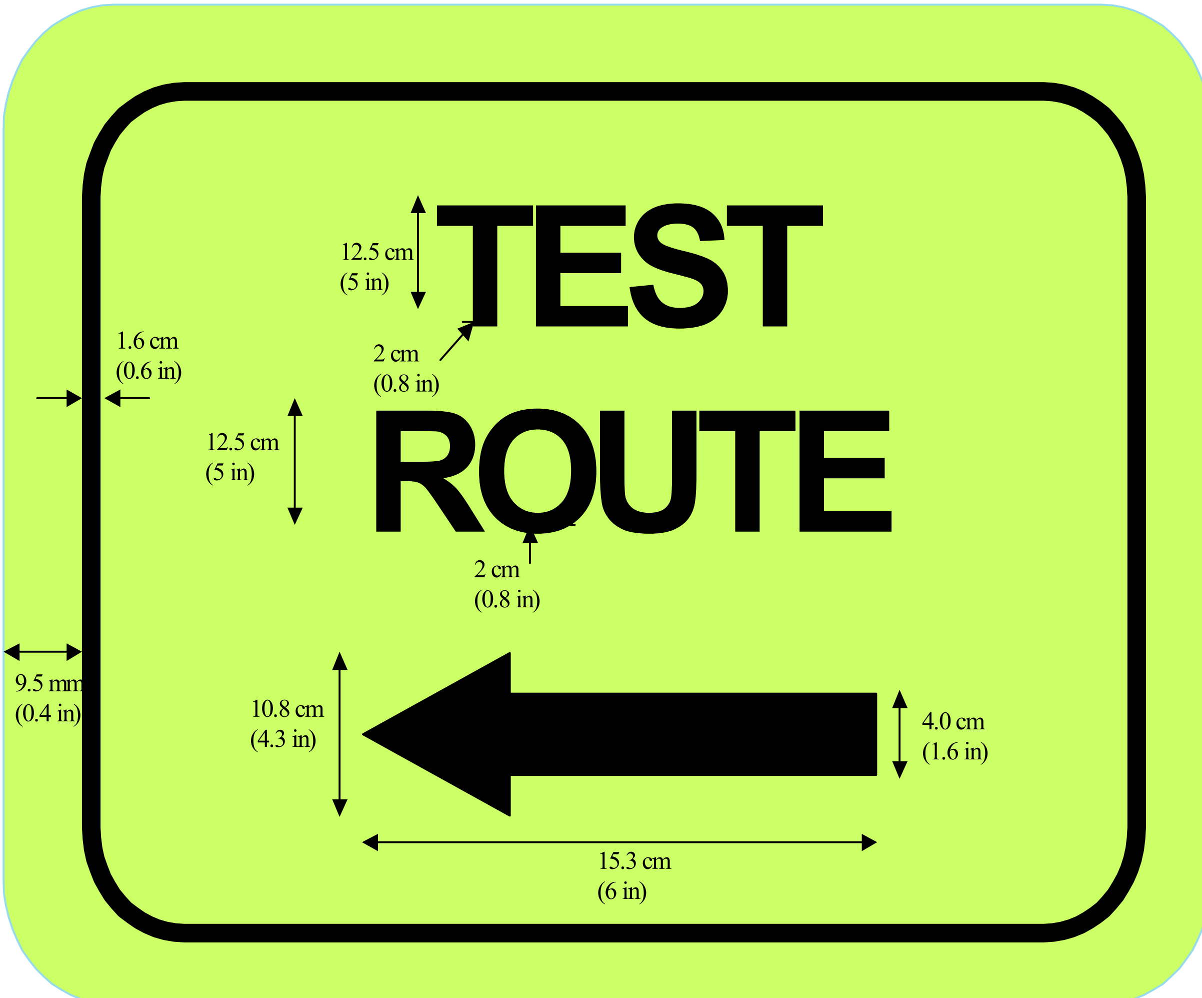

Figure 1. Experimental TEST ROUTE sign specification.

Figure 2. The experimental test signs (clockwise from top left: black on fluorescent yellow-green, non-fluorescent yellow on non-fluorescent purple, fluorescent yellow on fluorescent purple, and black on fluorescent coral).

The inks used in the manufacture of these signs were made specifically for this study and were not mass-produced. Table 2 contains Commission International d'Eclairge (CIE) Notations for the actual experimental signs used in the study. The measurements were taken in the Displays and Control Laboratory in Whittemore Hall on the Virginia Polytechnic Institute and State University campus. Appendix D contains a description of the equipment and procedures utilized in obtaining the CIE notations listed in Table 2. Luminance contrast ratios for the measurements found in Table 2 are listed in Table 3.

Table 2. CIE notation for the experimental signs.

Sign Color	CIE Y(%) cd/m^2	CIE x	CIE y
Fluorescent Yellow-Green	137.0	.424	.563
Black arrow	1.72		
Fluorescent Purple	12.8	.480	.233
Fluorescent Yellow arrow	87.9	.537	.457
Fluorescent Coral	43.2	.564	.309
Black arrow	1.63		
Non-Fluorescent Purple	8.30	.351	.218
Non-Fluorescent Yellow arrow	46.7	.539	.454

Table 3. Contrast ratios for experimental signs.

Sign Color	CIE Y (%)	Contrast Ratio*
Black on Fluorescent Yellow-Green	1.72 137.0	79.7
Black on Fluorescent Pink	1.63 43.2	26.5
Fluorescent Yellow on Fluorescent Purple	87.9 12.8	6.9
Non-Fluorescent Yellow on Non-Fluorescent Purple	46.7 8.3	5.6

*A larger number denotes a greater contrast.

Nighttime photometric measurements were taken to quantify the difference in luminance among the four sign color combinations under a simulated driving situation. This was done in an effort to better understand the driver performance and driver preferences associated with each sign. The methodology utilized during the simulated driving situation was as follows: A 1997 Ford Taurus was placed 280 feet from the mounted sign. An LMT photometer was used to measure the luminance of each sign. The photometer was positioned in front of the vehicle between the headlights and was set to a height of 3.5 feet above the pavement in line with the driver's eye.

The signs were manufactured in the same lot as those used in the actual on-road tests. Each sign was mounted at a height of 5 feet above the surface of the road and 6 feet from the edge line to the nearest edge of the sign. The signs were placed perpendicular to the roadway and upright (i.e., no twist, tilt, or rotation). The corresponding entrance and observation angles calculated for the left headlamp to the center of the signs were 3.23˚ and 0.34˚, respectively. The calculated entrance and observation angles for the right headlamp to the center of the signs were 2.41˚ and 0.70˚, respectively. The average observation angle for the signs at this distance was calculated to be 0.52˚.

For each sign, three luminance measurements were taken in four areas of the background (upper left corner, upper right corner, lower right corner, and lower left corner). A luminance measurement of the directional arrow was also made to determine the contrast between the legend and background for each sign. In addition, illuminance measurements were taken at the sign face in the same areas in which the luminance measurements were made. Appendix D provides the photometric measurements taken in the field and the retroreflectivity measurements made with a handheld ART-920 retroreflectometer (see Appendix D; Tables D-1, D-2, D-3).

The Culpeper District Sign Shop of the Virginia Department of Transportation (VDOT) manufactured each of the signs used in this study. Each test sign manufactured for this phase of the research was 0.610 m (24 in) by 0.762 m (30 in) and had 125-mm (5-

in) Series D letters. The test signs used 3M's Scotchlite™ Diamond Grade Visual Impact Prismatic (VIP™) reflective sheeting. This sheeting was selected because of its ability to remain highly retroreflective when large observation angles exist, and yet it performs equally well at long distances. A large observation angle is usually created when a vehicle is within 60.96 m (200 ft) of a sign. This situation is typical of the driving conditions found in urbanized areas. The test route used in this research had a cross section of urbanized and rural driving conditions. This sheeting was ideal for both situations.

The FYG signs required no special manufacturing requirements. They employed the traditional silk screening process. The non-reflective black legend and border were inked directly onto the fluorescent yellow-green sign blank. The FC (hot pink) signs required an extra step in the manufacturing process. These signs were constructed by overlaying the experimental film onto Diamond Grade VIP™ white retroreflective sheeting. The film required the technician to butt splice the material twice to cover the entire sign face. Once the overlay film was applied, the technician then inked the non-reflective black legend and border using the traditional screening process. The FYP sign also used an experimental overlay film over the Diamond Grade VIP™ white retroreflective sheeting, but the legend and border were Diamond Grade VIP™ fluorescent yellow retroreflective sheeting. The process required only one butt splice in the overlay film. The legend and border required the technician to hand cut each letter and piece for the border and apply the respective pieces by hand. The YP signs used purple ink over white Diamond Grade VIP™ retroreflective sheeting. The legend and border were Diamond Grade VIP™ yellow retroreflective sheeting. The white sheeting was flood coated with the purple ink. The legend and border required the technician to hand cut each letter and piece for the border and apply the respective pieces by hand.

Although three of the four sign color combinations required additional steps in the manufacturing process, none of the procedures were abnormal for the technicians in VDOT's sign shop. It should be noted that the overlay films that were provided by 3M were manufactured strictly for experimental use on this project and they do not represent typical 3M quality, handling characteristics, or color uniformity.

Twenty-three experimental signs were posted along the route. To the extent possible, sign panels were supported on standard signposts. Exceptions were sign panels that, due to the urban location constraints, were mounted on existing posts (light, utility, etc.). Each sign panel was oriented approximately perpendicular to the direction of travel, facing the observation vehicle, as is normal practice. Sign supports were located on the right shoulder of the road in all but three locations. Deviations from the Manual for Uniform Traffic Control Devices (MUTCD) specifications were due to requirements to be compliant with existing traffic sign locations at those sites.

Post-test Questionnaire

The post-test questionnaire to gather subjective opinion data is shown in Appendix E. The first three questions on the survey asked the driver to *rate* the sign they had just seen on the test route in terms of visibility, ease of identifying and understanding the directional information, and usefulness of the sign information. It is important to note that these questions asked the driver to make a relative judgment of the sign they had seen on the test route; that is, the drivers had only seen one sign color to this point and could not judge the sign color as it compared to the other sign colors.

Questions 4, 5, and 6 on the survey asked the drivers to *rank* the four sign colors based on viewing 16.5 cm x 29.2 cm samples of the sign material. Drivers were asked to rank the signs in terms of visibility, readability, and overall preference under indoor fluorescent lighting conditions. It is important to note that the drivers did not have the opportunity to see the signs with varying levels of daytime light, such as might occur with a changing sun position, or during nighttime viewing conditions, in which case the effect of headlights could dramatically change the appearance of the signs. However, Questions 4, 5, and 6 did allow for an absolute judgment of sign colors; that is, the drivers could look at the four sign colors together and decide which they most and least preferred.

Procedure

Participants who responded to a recruitment flyer were initially screened over the telephone regarding age, gender, driving frequency, and general health (Appendix F). If determined to be eligible, participants were scheduled for testing. Participants were instructed to meet experimenters at the Virginia Tech Transportation Institute (VTTI) in Blacksburg, Virginia. Upon arrival, participants were given an overview of the study, and asked to review and complete the informed consent form (Appendix G). Next, they were asked to complete the health-screening process (i.e., complete part 2 of the questionnaire (Appendix F). Following this, a vision test and a color vision test were administered using the Titmus® II vision tester (Appendix H). After these tasks were completed, participants were escorted to the test vehicle. The vehicle's windshield was cleaned prior to each testing session. While the car was in park, the experimenter reviewed general information concerning the operation of the test vehicle (e.g., lights, seat adjustment, mirrors, and windshield wipers; see Appendix I). Participants were then asked to operate each control and set it for their driving comfort. When the participants felt comfortable with the controls, the experimenter briefly described the driving task. Participants had to maneuver the test vehicle through several turns to get out of the VTTI facility. If the drivers indicated that they felt comfortable with the car, the test route began.

The experimental protocol required two experimenters as well as the participant to be in the vehicle. The experimenter seated in the front passenger seat gave initial navigational instructions, served as the safety officer, flagged events in the data set using the event flagger, and recorded the events corresponding to the flagged data on a data sheet. Only unplanned external events, such as a preceding car slowing suddenly or pedestrians or animals on or crossing the roadway, were flagged during the data collection session; the 'planned' sign events were marked manually during later data analysis. The second experimenter was seated in the back seat and monitored the data collection computer. The low-beam halogen headlights were used during nighttime driving conditions.

At the beginning of the test route, participants were instructed to look for and follow the signs that read "TEST ROUTE" (the sign color was not mentioned). Participants were told that these signs marked a predetermined route of approximately 12.2 miles in length. Participants were also instructed that all test signs would contain the same text legend, and that each sign would contain a directional arrow to indicate the route to be followed. While following the directions provided by the signs, participants were instructed to obey the traffic laws and to drive safely. If a wrong turn was made, the experimenter allowed the driver to complete the turn and then immediately directed him/her back to the prescribed route.

The study was conducted in Montgomery County, Virginia, along both urban and rural roadways. The route began at the intersection of Transportation Research Drive and Industrial Park Road in Blacksburg and then proceeded along South Main Street (Business 460) to downtown Blacksburg. After a series of three turns, the route proceeded out of town on East Roanoke Street and Harding Avenue. The route then followed Route 723 (Lusters Gate Road) to Route 1260 and returned to Blacksburg on Route 681 (Nellies Cave Road) (see Appendix B).

The test route was approximately 19.6 km (12.2 mi) long. The roadways along the test route were both two-lane and four-lane roads with marked lanes. Some rural sections of the route outside of the Blacksburg town limits had few sources of illumination other than occasional private homes or businesses. Following completion of the test route, participants drove back to the VTTI and completed the post-drive questionnaire (see Appendix E). Participants were then debriefed and compensated for their time. The total time for the experiment averaged approximately one hour.

CHAPTER 5. RESULTS & DISCUSSION

All statistical analyses were conducted using the SAS® 6.12 software package. As is typical of field experiments, some data cells were not filled. Therefore, all analyses of variance (ANOVAs) were performed by running a General Linear Model (GLM) Procedure. The traditional ANOVA procedure is designed for use on balanced data sets. The term *balanced data* implies that the same number of response observations exist for each combination of classification variables. A traditional ANOVA would not produce valid results in this instance since the data for this study is unbalanced. Instead, a "PROC GLM" was used. This procedure is designed to compute analysis of variance for unbalanced data (Littell, Freund, and Spector, 1991). For this experiment, a 0.05 significance level was used (95% probability that the reported results reflect actual differences). Non-parametric tests were performed where appropriate.

This research was conducted with two primary goals in mind: (1) investigate driver performance over a route blazed with fluorescent signs and (2) investigate driver impressions and preferences regarding the "TEST ROUTE" signs. The following discussion will focus on the degree to which these goals were addressed.

As stated earlier, the primary purpose of traffic signs is to provide information to the driver. The influx of visual information presented to drivers is, at times, overwhelming. It is absolutely essential that the driver be presented information regarding navigation and safety in a manner that captures his/her attention. Otherwise, driver errors and late reactions will occur.

Driving Performance Variables

Late Braking Maneuvers

A late braking maneuver was operationally defined as an incident requiring a brake pedal depression that exceeded two standard deviations from the mean brake position to slow to make a turn during the course of a sign event. A sign event began when a sign came into view and ended when the experimental vehicle passed the sign.

Only one sign event (shown in Appendix B as site number 18) had enough late braking maneuvers to evaluate (one other sign event resulted in one late braking maneuver). Seventeen of eighty-two drivers demonstrated late braking reactions at site number eighteen. Table 4 lists the frequency of late braking by sign color at this site. Due to the small expected frequencies in each cell, a proper application of the chi-square test could not be performed. The occurrences of late braking were distributed over the four sign colors in a manner resulting in little difference between the signs. Four late braking maneuvers occurred with the FYG sign; three with the YP sign; five with the FC sign; and five with the FYP sign. It is noteworthy that fourteen of the seventeen late braking maneuvers were attributed to drivers in the older category while younger drivers committed only 3 late braking maneuvers (see Table 5). Also of interest is the fact that thirteen of the seventeen late braking maneuvers occurred during conditions of darkness (see Table 6). Statistically there is no difference in driver performance among the four signs (due perhaps to the novelty of the sign colors), but it is noteworthy that no late braking maneuvers occurred with the FYG sign during daytime conditions. Subjective data revealed that this sign was considered to be more visible than the other signs. Additionally, laboratory and field measurements support the subjective data obtained from participants regarding the FYG sign.

Table 4. Frequency of late braking at Woodland Hills sign (#18).

Sign Color Combination	No Late Reaction Observed	Late Reaction Observed
Black on Fluorescent Yellow-Green	16	4
Non-Fluorescent Yellow on Non-Fluorescent Purple	18	3
Black on Fluorescent Coral	15	5
Fluorescent Yellow on Fluorescent Purple	16	5

Table 5. Frequency of late braking at Woodland Hills sign (#18) by age.

Sign Color Combination	Older Drivers	Younger Drivers
Black on Fluorescent Yellow-Green	2	2
Non-Fluorescent Yellow on Non-Fluorescent Purple	3	0
Black on Fluorescent Coral	4	1
Fluorescent Yellow on Fluorescent Purple	5	0

Table 6. Frequency of late braking at Woodland Hills sign (#18) by visibility.

Sign Color Combination	Daytime	Nighttime
Black on Fluorescent Yellow-Green	0	4
Non-Fluorescent Yellow on Non-Fluorescent Purple	1	2
Black on Fluorescent Coral	2	3
Fluorescent Yellow on Fluorescent Purple	1	4

Analysis of Wrong and Missed Turns

Assessment for Sign Color

Wrong and missed turns were consolidated and analyzed together as turn errors. Table 7 shows the frequency of correct turns and turn errors listed by sign color. A wrong turn event was defined as a turn taken when no directional information was provided to indicate a required turn. A missed turn event was defined as a required turn that was not taken when indicated by a sign. In the event that a wrong turn and a missed turn occurred for the same sign event, only one error was counted. Note that there was only one incorrect turn event (wrong or missed turns) for the fluorescent yellow-green and the non-fluorescent yellow on non-fluorescent purple signs.

Table 7. Overall frequency of turn errors by sign color combination.

Sign Color Combination	Correct Turns	Incorrect Turns
Black on Fluorescent Yellow-Green	459	1
Non-Fluorescent Yellow on Non-Fluorescent Purple	517	1
Black on Fluorescent Coral	548	4
Fluorescent Yellow on Fluorescent Purple	549	3

The locations at which the turn errors occurred were examined to determine if underlying causes might possibly be responsible for the turn errors. The turn errors occurred at three different rural locations. Each location was at a "T" intersection and the signs were posted past the intersection, not before the intersection, as is normally the case. It is noteworthy that all the late braking maneuvers occurred at two of these same signs. Also noteworthy is that only one other intersection had a similar sign placement. While no turn errors were made at this intersection, several drivers experienced confusion and made comments regarding the placement of the sign. The sign being referenced is Sign #2[2], which was located across the road at a "T" intersection, not on the right hand side of the road prior to the intersection. It can be concluded that drivers in this study experienced problems when signs were not located on the right-hand side of the road environment.

During the course of this research, only nine turn errors were committed out of a total of 2082 opportunities to make a turn error. This is a very small percentage (0.004). Younger and older drivers made a similar number of incorrect turns for each sign color. It should be noted that seven of the nine turn errors were committed at night. Anecdotal evidence supports the results discussed thus far—the frequency of driver errors increase as visibility conditions decrease. It should be noted that the locations where late braking and turn errors were committed were similar. As mentioned previously, each location was at a "T" intersection. The signs at these sites were located after the intersection, not prior to the turn. This fact may have led some drivers to assume that no turn was required at these sites, hence, the documented late braking maneuvers and turn errors. Seven of the nine turn errors were committed at site 18 (the late braking site). It should also be acknowledged that the sign at site 18 was mounted on a signpost below an existing sign. This reduced the distance that the sign was visible to drivers. Site 18 was located in a rural section of the route. Advance turn signs were not utilized in this study. It is very possible that the lack of advance turn signs, coupled with the roadway geometry and sign placement, were causal factors in the turn errors and late braking maneuvers that were committed.

One turn error was committed at site 17. The arrow on the sign at this site was vertical, indicating the route proceeded straight ahead. The turn error at this site was

[2] Sign #2 was located at the intersection of Industrial Park Road and South Main Street. The sign was posted below an existing traffic sign.

committed by an 83-year-old male driver who acknowledged that he was slightly confused and assumed that a turn was to be made. The location of this site is at a "T" intersection with the sign located approximately 60 feet past the intersection. This particular turn error occurred at night with the FYG sign. This was the only turn error made with this sign color combination. There were no late braking maneuvers during the daytime with the FYG sign and the only turn error occurred during a nighttime event.

Assessment for Age

Table 8 contains the frequency of turn errors by driver age and sign color combination. Once again the results violate the assumption of normality for small expected frequencies and an appropriate application of the chi-square test is not possible. The results indicate that both younger and older drivers committed approximately the same number of turn errors. Statistically there is no difference in driver performance between younger and older drivers.

Table 8. Frequency of turn errors by driver age and sign color combination.

Sign Color Combination	Younger Drivers	Older Drivers
Black on Fluorescent Yellow-Green	0	1
Non-Fluorescent Yellow on Non-Fluorescent Purple	0	1
Black on Fluorescent Coral	1	3
Fluorescent Yellow on Fluorescent Purple	3	0

Assessment for Visibility Condition

Table 9 contains the frequency of turn errors by visibility condition and sign color combination. Again, the small expected frequency count does not allow a proper chi-square test to be conducted. The results indicate that more turn errors occurred during nighttime conditions than daytime conditions. Anecdotal data would lead one to expect that the fluorescent colored signs would have out performed the non-fluorescent sign during daytime conditions. Again, the novelty of the sign colors is most likely responsible for the lack of statistical difference in driver performance among the sign colors.

Table 9. Frequency of turn errors by visibility condition and sign color combination.

Sign Color Combination	Daytime	Nighttime
Black on Fluorescent Yellow-Green	0	1
Non-Fluorescent Yellow on Non-Fluorescent Purple	0	1
Black on Fluorescent Coral	1	3
Fluorescent Yellow on Fluorescent Purple	1	2

Table 10 is listed below to provide a breakout of the frequency of correct turns and incorrect turns as demonstrated by daytime drivers.

Table 10. Frequency of correct turns and incorrect turns for daytime drivers.

Sign Color Combination	Correct Turns	Incorrect Turns
Black on Fluorescent Yellow-Green	207	0
Non-Fluorescent Yellow on Non-Fluorescent Purple	270	0
Black on Fluorescent Coral	275	1
Fluorescent Yellow on Fluorescent Purple	275	1

Similarly, Table 11 is listed to indicate the frequency of correct turns and incorrect turns as demonstrated by nighttime drivers.

Table 11. Frequency of correct turns and incorrect turns for nighttime drivers.

Sign Color Combination	Correct Turns	Incorrect Turns
Black on Fluorescent Yellow-Green	252	1
Non-Fluorescent Yellow on Non-Fluorescent Purple	247	1
Black on Fluorescent Coral	273	3
Fluorescent Yellow on Fluorescent Purple	274	2

Taken together, the information contained in Tables 10 and 11 indicates no statistical difference between sign colors with regard to frequency of correct and incorrect turns. Again, it is thought that the novelty of the sign colors employed in this study resulted in similar results for driver performance with both the non-fluorescent and the fluorescent signs.

Driver Preference Data

For survey questions 1, 2, and 3, the participants only rated the sign they saw while driving (refer to the section "Post-test Questionnaire" and Appendix E). The number of participants who viewed each sign color was unequal; therefore the number of drivers rating each sign was unequal. The number of drivers making each rating is specified in the tables as "N = *number*. " Means and standard deviations are also specified.

Survey Question #1: How Visible was the Test Detour Sign Relative to the Environment?

This question asked participants to rate the visibility of the experimental TEST ROUTE sign they had seen on the test route using a Likert-type scale of one to five, with one meaning not visible and five meaning extremely visible (see Appendix E). ANOVAs were performed on the mean ratings for this question.

For the assessment by sign color, the mean scores are shown in Table 12. An analysis for sign color (see Appendix J, Table J-1) revealed that the ratings were significantly different from one another (F (3,75) = 6.73, p = 0.0004). Based on the mean ratings, drivers in the FYG and FC groups thought the experimental sign they had seen was very to extremely visible. Drivers in both the FYP and YP groups rated the experimental sign they had seen as moderately to very visible. A Tukey pairwise comparison (see Figure 3) revealed that the FYG and FC signs were rated as significantly more visible than the YP sign. The FYP sign was not rated significantly different from the other signs. Figure 3 graphically depicts the results of the Tukey pairwise comparisons.

Table 12. Survey question 1 mean ratings for assessment by sign color.

Sign Color Combination	Mean*/STD	# of Obs.
Black on Fluorescent Yellow-Green	4.43/0.48	N=20
Non-Fluorescent Yellow on Non-Fluorescent Purple	3.65/0.63	N=23
Black on Fluorescent Coral	4.25/0.72	N=24
Fluorescent Yellow on Fluorescent Purple	3.96/0.61	N=24

* 1 = not visible, 5 = extremely visible

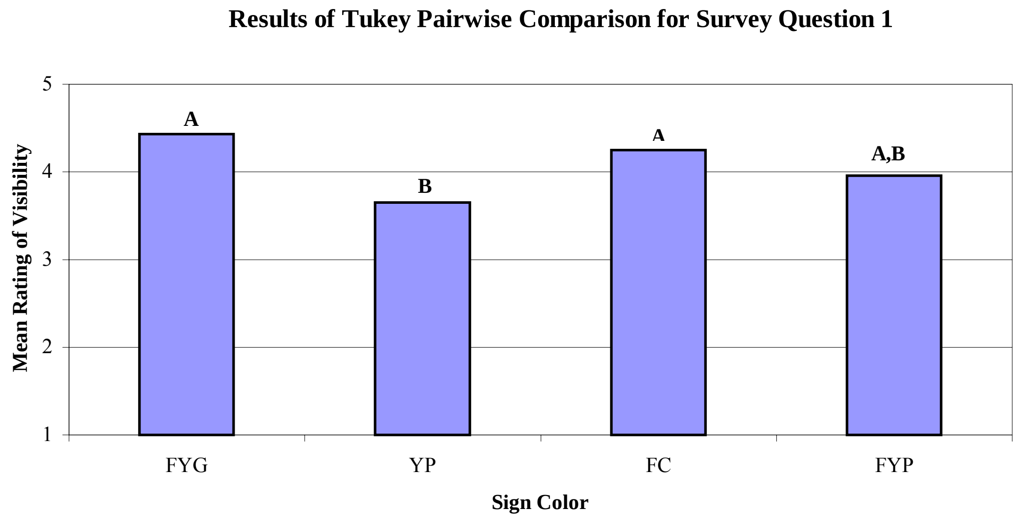

Figure 3. Results of Tukey pairwise comparison (means with the same Tukey letter grouping are not significantly different).

For the assessment by age, the mean ratings for older and younger drivers are shown in Table 13. An analysis of variance for age-related differences (see Appendix J, Table J-1) revealed that the ratings by younger and older drivers were not significantly different for each sign color. Based on the mean ratings for each group, younger and older drivers did not rate the visibility of the signs differently; that is, both younger and older drivers thought that the experimental sign they saw was moderately to very visible.

Table 13. Survey question 1 mean ratings for assessment by age.

Sign Color Combination	Younger Mean/STD (Number)	Older Mean/STD (Number)
Black on Fluorescent Yellow-Green	4.50/0.48 (N=11)	4.33/0.47 (N=9)
Non-Fluorescent Yellow on Non-Fluorescent Purple	3.67/0.62 (N=12)	3.64/0.64 (N=11)
Black on Fluorescent Coral	4.33/0.94 (N=12)	4.17/0.37 (N=12)
Fluorescent Yellow on Fluorescent Purple	4.00/0.82 (N=12)	3.92/0.28 (N=12)

* 1 = not visible, 5 = extremely visible

For the assessment by visibility condition, the mean ratings for daytime and nighttime drivers are shown in Table 14. No significant differences were found for the two-way age by sign color, visibility condition by sign color, or age by visibility condition interactions, and no significant difference was found for the three-way age by visibility condition by sign color interaction. An analysis of variance for differences in ratings between daytime versus nighttime drivers (see Appendix J, Table J-1) revealed no significant difference. The mean rating for daytime drivers was 4.14 while the mean rating for nighttime drivers was 3.98. This indicates that the signs were rated just slightly more visible during the daytime than at night, but not at a level approaching significance.

Table 14. Survey question 1 mean ratings for assessment by visibility condition.

Sign Color Combination	Daytime Mean/STD (Number)	Nighttime Mean/STD (Number)	
Black on Fluorescent Yellow-Green	4.61/0.46 (N=9)	4.27/0.45 (N=11)	
Non-Fluorescent Yellow on Non-Fluorescent Purple	3.58/0.49 (N=12)	3.73/0.75 (N=11)	
Black on Fluorescent Coral	4.58/0.49 (N=12)	3.92/0.76 (N=12)	
Fluorescent Yellow on Fluorescent Purple	3.92/0.49 (N=12)	4.00/0.71 (N=12)	

* 1 = not visible, 5 = extremely visible

<u>Survey Question #2: How Easy was it to Identify, or Understand, the Directional Information Provided by the Test Signs?</u>

This question asked participants to rate the directional information on the experimental TEST ROUTE sign they had seen while driving. The Likert-type rating scale ranged from one to five, with one meaning not easy and five meaning extremely easy (see Appendix E). An ANOVA was performed on the mean ratings for this question.

Almost all of the participants commented that the turn arrows on the signs were too small to identify the directional information until fairly close to the sign. The arrow icons on the test route signs were approximately one-half the size of the arrow icons used on normal detour signs. Participants noted that the signs were very conspicuous and could be detected from an acceptable distance, but the arrows, due to their small size, required a closer approach to ascertain the directional information. Comments about the small size of the arrows were perhaps prompted because the signs were visible from such great distances that the drivers wanted to see the directional information sooner. Similar comments regarding the size of the arrows were documented during Phase II of this research (Barker, 1998).

An analysis for visibility condition (see Table 15 and Appendix J, Table J-2) revealed no significant difference between the overall rating by daytime and nighttime drivers. The results, however, do indicate a significant difference in mean ratings of the interaction between sign color and visibility condition, $F(3,75) = 3.50$, $p = 0.0195$. Results of a Tukey post-hoc analysis revealed a significant difference in mean ratings by daytime and nighttime drivers who observed the black on fluorescent coral sign (see Figure 4). A significant difference in mean ratings by daytime and nighttime drivers did not exist with the other sign color combinations.

Table 15. Survey question 2 mean ratings for assessment by visibility condition.

Sign Color Combination	Daytime Mean/STD (Number)	Nighttime Mean/STD (Number)
Black on Fluorescent Yellow-Green	4.11/0.74 (N=9)	3.55/0.66 (N=11)
Non-Fluorescent Yellow on Non-Fluorescent Purple	2.75/1.16 (N=12)	3.45/0.99 (N=11)
Black on Fluorescent Coral	3.75/0.83 (N=12)	2.58/0.95 (N=12)
Fluorescent Yellow on Fluorescent Purple	3.50/1.26 (N=12)	3.58/1.32 (N=12)

* 1 = not easy, 5 = extremely easy

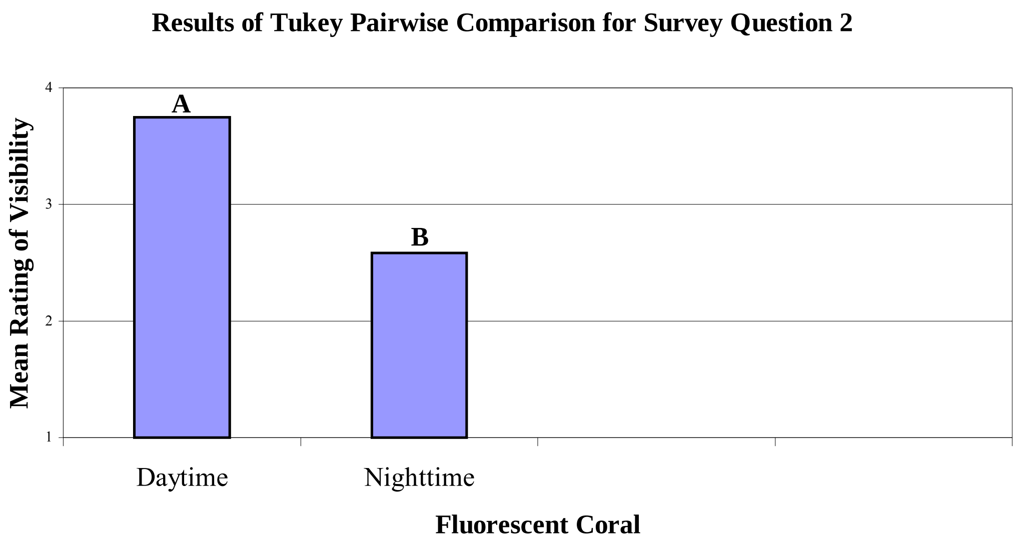

Figure 4. Results of Tukey pairwise comparison.

An analysis for age differences (Table 16 and Appendix J, Table J-2) revealed that the ratings by younger and older drivers were significantly different, $F(1,75) = 7.35$, $p = 0.0083$. The results indicate that older drivers rated the signs significantly easier to identify than did younger drivers. Based on the mean ratings by each group, younger drivers tended to rate the signs moderately easy to identify and older drivers thought that the experimental sign they saw was very easy to identify. This difference in mean ratings could possibly be attributed to anecdotal evidence documenting visual degradation associated with the aging process. In other words, enhancements in the manufacturing process (fluorescence and retroreflective optics) prompted older drivers to rate these signs easier to identify than did younger drivers.

Table 16. Survey question 2 mean ratings for assessment by age.

Sign Color Combinations	Younger Mean/STD (Number)	Older Mean/STD (Number)
Black on Fluorescent Yellow-Green	3.45/0.78 (N=11)	4.22/0.42(N=9)
Non-Fluorescent Yellow on Non-Fluorescent Purple	2.67/0.94 (N=12)	3.55/1.16 (N=11)
Black on Fluorescent Coral	3.00/1.08 (N=12)	3.33/1.03 (N=12)
Fluorescent Yellow on Fluorescent Purple	3.33/1.18 (N=12)	3.75/1.36 (N=12)

* 1 = not easy, 5 = extremely easy

The overall mean scores for question 2 are shown in Table 17. No significant differences were found for the two-way age by sign color or age by visibility condition interactions, and no significant difference was found for the three-way age by visibility condition by sign color interaction. An analysis for sign color (see Appendix J, Table J-2) revealed that the ratings were not significantly different from one another (p = 0.0783). This indicates a probable difference between sign colors at 92%. Based on this, a Tukey pairwise comparison was conducted at a level of significance of 0.1, resulting in no significant differences at this level. The results, however, did indicate that participants in the FYG group rated this sign easier to identify and understand than did the participants in the other groups. The mean results indicate that the directional information on the FYG sign was rated easier to identify than the directional information on the other signs.

Table 17. Survey question 2 mean ratings for assessment by sign color.

Sign Color Combination	Mean*/STD	# of Obs.
Black on Fluorescent Yellow-Green	3.80/0.75	N=20
Non-Fluorescent Yellow on Non-Fluorescent Purple	3.09/1.14	N=23
Black on Fluorescent Coral	3.17/1.07	N=24
Fluorescent Yellow on Fluorescent Purple	3.54/1.29	N=24

* 1 = not easy, 5 = extremely easy

Survey Question #3: How Useful Would You Find this Type of Sign Design for Providing Temporary Directional/Detour Information While Driving?

This question referred to the experimental TEST ROUTE sign that participants had seen on the test route (see Appendix E). Drivers were asked to rate the sign they had seen using a Likert-type scale of one to five, with one meaning the information was not useful and five meaning the information was extremely useful. ANOVAs were performed on the mean ratings for this question. No significant differences were found for the two-way age by sign color, visibility condition by sign color, or age by visibility condition interactions, and no significant difference was found for the three-way age by visibility condition by sign color interaction.

An analysis for sign color (see Table 18 and Appendix J, Table J-3) revealed that the ratings were not significantly different from one another (p = 0.0727). This indicates a probable difference between sign colors at 93%. Based on this, a Tukey pairwise comparison was conducted at a level of significance of 0.1, resulting in no significant differences at this level. Once again, participants in the FYG group rated the sign they had seen as more useful that participants in the other groups.

Table 18. Survey question 3 mean ratings for assessment by sign color.

Sign Color Combination	Mean*/STD	# of Obs.
Black on Fluorescent Yellow-Green	4.25/0.70	N=20
Non-Fluorescent Yellow on Non-Fluorescent Purple	3.43/1.21	N=23
Black on Fluorescent Coral	3.75/0.88	N=24
Fluorescent Yellow on Fluorescent Purple	3.67/1.18	N=24

* 1 = not useful, 5 = extremely useful

An analysis by age group (see Table 19 and Appendix J, Table J-3) revealed that the ratings by younger and older drivers were not significantly different for each sign color. Based on the mean ratings by each group, both younger and older drivers thought that the experimental sign they saw was moderately to very useful for providing detour information.

Table 19. Survey question 3 mean ratings for assessment by age.

Sign Color Combination	Younger Mean/STD (Number)	Older Mean/STD (Number)
Black on Fluorescent Yellow-Green	4.18/0.83 (N=11)	4.33/0.47 (N=9)
Non-Fluorescent Yellow on Non-Fluorescent Purple	3.33/1.11 (N=12)	3.55/1.30 (N=11)
Black on Fluorescent Coral	3.42/0.95 (N=12)	4.08/0.64 (N=12)
Fluorescent Yellow on Fluorescent Purple	3.58/1.19 (N=12)	3.75/1.16 (N=12)

* 1 = not useful, 5 = extremely useful

An analysis by visibility condition (see Table 20 and Appendix J, Table J-3) revealed that the ratings were not significantly different for daytime drivers as compared to nighttime drivers. Both daytime and nighttime drivers found the signs to be moderately to very useful for detour information.

Table 20. Survey question 3 mean ratings for assessment by visibility condition.

Sign Color Combination	Daytime Mean/STD (Number)	Nighttime Mean/STD (Number)
Black on Fluorescent Yellow-Green	4.56/0.50 (N=9)	4.00/0.74(N=11)
Non-Fluorescent Yellow on Non-Fluorescent Purple	3.17/1.07 (N=12)	3.73/1.29 (N=11)
Black on Fluorescent Coral	4.17/0.69(N=12)	3.33/0.85(N=12)
Fluorescent Yellow on Fluorescent Purple	3.75/1.01 (N=12)	3.58/1.32 (N=12)

* 1 = not useful, 5 = extremely useful

Questions 1, 2, and 3 requested that the participants rate the sign that they had seen while navigating the test route. Note that ratings were made without having seen the other experimental sign colors. For the assessment by sign color across the three ratings, non-fluorescent yellow on purple was consistently rated least preferred among the four sign color combinations. Both the younger and older drivers who used the fluorescent yellow-green sign to navigate tended to rate that sign higher than younger and older drivers who used the other sign colors. Driver preference for black on fluorescent yellow-green may result from the high contrast for this sign (see Table 3). Field measurements indicate the background of the fluorescent yellow-green sign provided the highest luminance, on average, 380.5 cd/m^2 , as compared to the other signs (see Table D-3). This was more than 4.5 times the luminance of the next brightest sign (non-fluorescent purple). The non-reflective black directional arrow provided a luminance of 219 cd/m^2, which produced a luminance contrast of 1:1.7 between the legend and background. The retroreflectivity values for this sign paralleled its luminance (see Table D-2). That is, the background of this sign yielded the highest coefficient of retroreflection (R_A) for any of the signs evaluated, 427.8 cd/lx/m^2 at the 0.2/-4 geometry. The legend yielded an R_A of 0.5 cd/lx/m^2, as expected.

The results from the first three survey questions indicate that across every mean rating for all analyses, the lowest rating was a 2.67 and the highest was a 4.61, with most ratings falling between 3.60 to 4.20. This indicates that the signs were typically rated in the category of very visible, identifiable, and useful. The fluorescent yellow-green sign was consistently rated much higher than the other three sign colors. Based on the results of these three questions, the following trends were observed:

- The fluorescent yellow-green and fluorescent coral signs were rated more visible, easier to understand, and more useful by daytime drivers than nighttime drivers. Again, this supports the anecdotal evidence that indicates the superior daytime characteristics of fluorescent sign colors.

- Older drivers rated the fluorescent yellow-green and the non-fluorescent yellow on non-fluorescent purple signs more understandable (easier to identify directional information) than did younger drivers.

- Even though the results of questions 2 and 3 do not indicate that a significant difference exists, the participants consistently rated the FYG sign as more understandable and more useful than the other sign color combinations.

<u>Survey Question #4: Rank the Sample Signs in Order of Preference for Visibility Along the Roadway, by Sign Color.</u>

Question 4 on the post-test questionnaire (see Appendix E) asked participants to rank the four sign color combinations in order of preference for visibility along the roadway after being shown samples of the signs. For the purposes of analysis, the most preferred sign for visibility was equated to a numerical value of one, and the least preferred sign was equated to a numerical value of 4. A Friedman two-way analysis of variance by ranks was used to analyze the data.

An analysis to determine if the drivers ranked the sign colors differently was significant, $F_r(3,N=91)=202.71>F_{tab}(alpha=0.05,df=3)=7.82$, $p = 0.000$ (see Table 21 for rank sums). Pairwise comparisons (see Appendix J, Table J-4) revealed that all signs were ranked significantly different from all other signs.

Table 21. Survey question 4 mean rankings for assessment by sign color.

Sign Color Combination	Rank Sum
Black on Fluorescent Yellow-Green	108
Non-Fluorescent Yellow on Non-Fluorescent Purple	344
Black on Fluorescent Coral	191
Fluorescent Yellow on Fluorescent Purple	267

An analysis by age group was conducted to determine if there was a significant difference in rankings of visibility between the younger and older drivers (see Table 22 mean scores). The result was not significant, indicating that younger and older drivers, based on viewing the sign samples, did not rank the visibility of each sign color differently.

Table 22. Survey question 4 mean rankings for assessment by age.

Sign Color Combination	Younger	Older
Black on Fluorescent Yellow-Green	1.2	1.2
Non-Fluorescent Yellow on Non-Fluorescent Purple	3.8	3.7
Black on Fluorescent Coral	1.9	2.3
Fluorescent Yellow on Fluorescent Purple	3.0	2.8

*1 = most visible, 4 = least visible

Survey Question #5: Rank the Sample Signs in Order of Preference Based on How Easy You Feel the Signs are to Read.

As with question 4, drivers were shown sign color samples of the four TEST ROUTE sign color combinations and asked to rank them in order of preference regarding readability (see Appendix E). Again, the most preferred sign was equated to a numerical value of one, and the least preferred sign was equated to a numerical value of 4. An analysis of variance by ranks to determine if the drivers ranked the sign colors differently was significant, $F_r(3,N=91)=168.55>F_{tab}(alpha=0.05,df=3)=7.82$, p = 0.000 (see Table 23 for rank sums). Pairwise comparisons (see Appendix J, Table J-5) revealed that all comparisons were ranked significantly different from each other except FC vs. FYP.

Table 23. Survey question 5 mean rankings for assessment by sign color.

Sign Color Combination	Rank Sum
Black on Fluorescent Yellow-Green	111
Non-Fluorescent Yellow on Non-Fluorescent Purple	333
Black on Fluorescent Coral	213
Fluorescent Yellow on Fluorescent Purple	253

An analysis was conducted to determine if there was a difference between rankings given by younger and older drivers (see Table 24 for mean scores). The result was not significant, indicating that younger and older drivers did not rank the readability of each sign color sample differently.

Table 24. Survey question 5 mean rankings for assessment by age.

Sign Color Combination	Younger	Older
Black on Fluorescent Yellow-Green	1.2	1.2
Non-Fluorescent Yellow on Non-Fluorescent Purple	3.6	3.7
Black on Fluorescent Coral	2.3	2.4
Fluorescent Yellow on Fluorescent Purple	2.8	2.7

*1 = most easy to read, 4 = least easy to read

Survey Question #6: Rank the Sample Signs in Order of Overall Preference for Use on Signs Providing Temporary Directional/Detour Information.

For this question (see Appendix D), drivers were shown sign color samples of the four TEST ROUTE sign color combinations. The participants were then asked to rank the signs in order of overall preference for providing temporary directional/detour information. Again, the most preferred sign was equated to a numerical value of one, and the least preferred sign was equated to a numerical value of four. A Friedman two-way analysis of variance by ranks was used to analyze the data.

An analysis to determine if the drivers ranked the sign colors differently was significant, $F_r(3,N=91)=165.42>F_{tab}(alpha=0.05,df=3)=7.82$, $p = 0.000$ (see Table 25 for rank sums). Pairwise comparisons (see Appendix J, Table J-6) revealed that all signs were ranked significantly different from all other signs.

Table 25. Survey question 6 mean rankings for assessment by sign color.

Sign Color Combination	Rank Sum
Black on Fluorescent Yellow-Green	119
Non-Fluorescent Yellow on Non-Fluorescent Purple	338
Black on Fluorescent Coral	203
Fluorescent Yellow on Fluorescent Purple	250

An analysis was also conducted to determine if there was a difference between rankings given by younger and older drivers (see Table 26 for mean scores). The result was not significant, indicating that there was not a difference between younger and older drivers for sign preference.

Table 26. Survey question 6 mean rankings for assessment by age.

Sign Color Combination	Younger	Older
Black on Fluorescent Yellow-Green	1.3	1.3
Non-Fluorescent Yellow on Non-Fluorescent Purple	3.7	3.7
Black on Fluorescent Coral	2.2	2.2
Fluorescent Yellow on Fluorescent Purple	2.7	2.8

*1 = most preferred, 4 = least preferred

The results of the pairwise comparisons for questions 4, 5, and 6 indicate that a significant difference exists between the FYG sign as compared to each of the other signs. This is supported by data collected during both the laboratory and field measurements.

To answer questions 4, 5, and 6 on the post-test questionnaire, participants looked at color samples of all four signs. They were then asked to rank the four colors in terms of visibility, readability, and overall preference from highest to lowest. Note that these questions were not analyzed by visibility condition since survey respondents could not make comparisons for daytime versus nighttime conditions.

Reviewing the results, it can be seen that the non-fluorescent yellow on purple sign was consistently ranked the lowest across questions 4, 5, and 6 by both younger and older drivers. Both the younger and older drivers tended to favor the fluorescent yellow-green sign. The fluorescent yellow-green sign was ranked first across all three questions. The order of preference was fluorescent yellow-green, fluorescent coral, fluorescent yellow on fluorescent purple, and non-fluorescent yellow on non-fluorescent purple for Questions 4, 5, and 6. It is noteworthy that this is the same order as the contrast ratios derived from laboratory measurements of the actual signs (see Table 3).

CHAPTER 6: CONCLUSIONS, RECOMMENDATIONS, AND FUTURE RESEARCH DIRECTIONS

Conclusions

The primary goal of this research study was to evaluate fluorescent sign color combinations to improve conspicuity of incident management traffic signs. The evaluation of driver responses to various sign color combinations was examined with respect to age and visibility conditions. Anecdotal data would lead one to expect superior driver performance data attributable to the fluorescent signs. This was not the case. There were negligible driver performance differences between the four signs. This finding is most likely due to the novelty effect of the sign colors employed in this study. The following conclusions were made:

1. Both younger and older drivers have a preference for a black on fluorescent yellow-green sign.
2. A non-fluorescent yellow on non-fluorescent purple sign is least preferred by both older and younger drivers when compared to the other sign color combinations employed in this study.
3. Fewer late braking maneuvers and fewer turn errors were recorded during daytime conditions than during nighttime conditions.
4. Older drivers tended to register more late braking maneuvers than did younger drivers.

Recommendations

Results of the survey questionnaire clearly indicated the preference by participants for the fluorescent yellow-green sign. Both laboratory and field measurements support this finding. Overall, the FYG sign provided the highest luminance and retroreflectivity for its background. In fact, its background luminance was more than 4.5 times that of the next brightest sign, (YP), and almost 9 times that of the FYP sign. The trends in the data indicate that fewer turn errors and fewer late braking maneuvers occur during daytime conditions than during nighttime conditions. This provides strong evidence as to the superior daytime characteristics of fluorescent signs and in particular, the FYG sign color. The following recommendations are made:

- Based upon results from this study, FYG should be utilized for trailblazing during critical incident management situations. While driver performance data indicate no significant differences between the four sign colors tested, subjective data clearly indicates that FYG is preferred for visibility, readability, and overall preference.
- If FYG is deemed inappropriate for trailblazing purposes based upon its current designation as a sign color for non-motorized hazards (pedestrian crossings), use of FC should be considered.
- Larger arrows should be utilized on emergency detour signs. Most of the participants commented on the small size of the arrows employed on the signs in this study. Larger arrows will enhance the readability aspects of emergency detour signs. This is especially pertinent with regard to the FYG sign. This sign was so bright that the arrow was more difficult to distinguish due to the halation effect.

Limitations of this Research and Directions of Future Research

1. As previously mentioned, the test signs in this study employed directional arrows that were approximately one-half the size of the standard arrows on detour signs. Larger arrows would have certainly increased the readability provided by these signs.
2. Based on observations, videotapes of the participants during the test drives, and comments made by participants during debriefing, it is very likely that an *observer effect* may have biased some of the drivers' typical behavior. Several of the participants did indicate that they had driven more cautiously than under normal circumstances.

3. While none of the participants indicated that they had driven the route, most of them had seen some of the signs. The route did not change over the approximate two-month period during which the driving portion of the study was conducted. It should also be noted that news media coverage of this study was highlighted approximately halfway through the two-month period in which participants were being recruited. It is possible that this situation may have affected the results documented here, but there are no indications supportive of this theory.

4. This study did not evaluate driver responses in reduced visibility conditions associated with weather (e.g., fog, precipitation). Anecdotal evidence suggests that the use of fluorescent colors on signs greatly improves their conspicuity in low-level daylight conditions and reduced visibility during daylight conditions brought on by fog and precipitation. Future research should investigate driver response to fluorescent signs in reduced visibility conditions associated with weather.

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APPENDICES

APPENDIX A. PARTICIPANT INFORMATION

Table A-1. Participant information for black on fluorescent yellow-green sign.

Visibility Condition	Gender (M/F)	Age (years)
Day	M	29
Day	M	62
Night	M	24
Day	F	57
Night	F	22
Night	M	19
Day	M	67
Night	F	77
Night	M	83
Day	F	69
Night	F	22
Night	F	25
Day	F	19
Day	M	20
Night	M	67
Day	F	21
Day	F	27
Night	F	74
Night	M	22
Night	M	67

Table A-2. Participant information for non-fl yellow on non-fl purple sign.

Visibility Condition	Gender (M/F)	Age (years)
Day	M	25
Night	F	58
Night	M	26
Day	F	58
Day	M	58
Day	M	32
Night	F	22
Night	F	25
Day	F	24
Day	M	63
Night	M	25
Night	M	27
Day	F	61
Day	F	24
Night	M	56
Night	M	65
Day	M	26
Day	M	74
Day	F	24
Night	F	30
Day	F	73
Night	M	78
Night	F	69

Table A-3. Participant information for black on fluorescent coral sign.

Visibility Condition	Gender (M/F)	Age (years)
Night	F	69
Night	F	21
Day	F	20
Day	M	30
Night	F	65
Night	M	34
Day	M	76
Night	F	62
Night	M	25
Day	M	23
Day	M	28
Night	M	73
Night	M	19
Day	M	70
Night	F	32
Night	F	30
Day	F	21
Day	F	68
Day	M	73
Night	M	67
Night	M	75
Day	F	22
Day	F	67
Day	F	64

Table A-4. Participant information for fl yellow on fl purple sign.

Visibility Condition	Gender (M/F)	Age (years)
Day	F	79
Day	F	73
Day	M	70
Night	F	64
Night	F	63
Day	M	80
Day	F	23
Day	M	20
Day	M	24
Night	M	78
Night	F	21
Day	F	71
Day	M	77
Day	M	23
Day	F	25
Day	F	21
Night	M	72
Night	F	20
Night	M	23
Night	F	70
Night	M	65
Night	M	26
Night	M	23
Night	F	26

APPENDIX B: MAP OF TEST ROUTE AREA

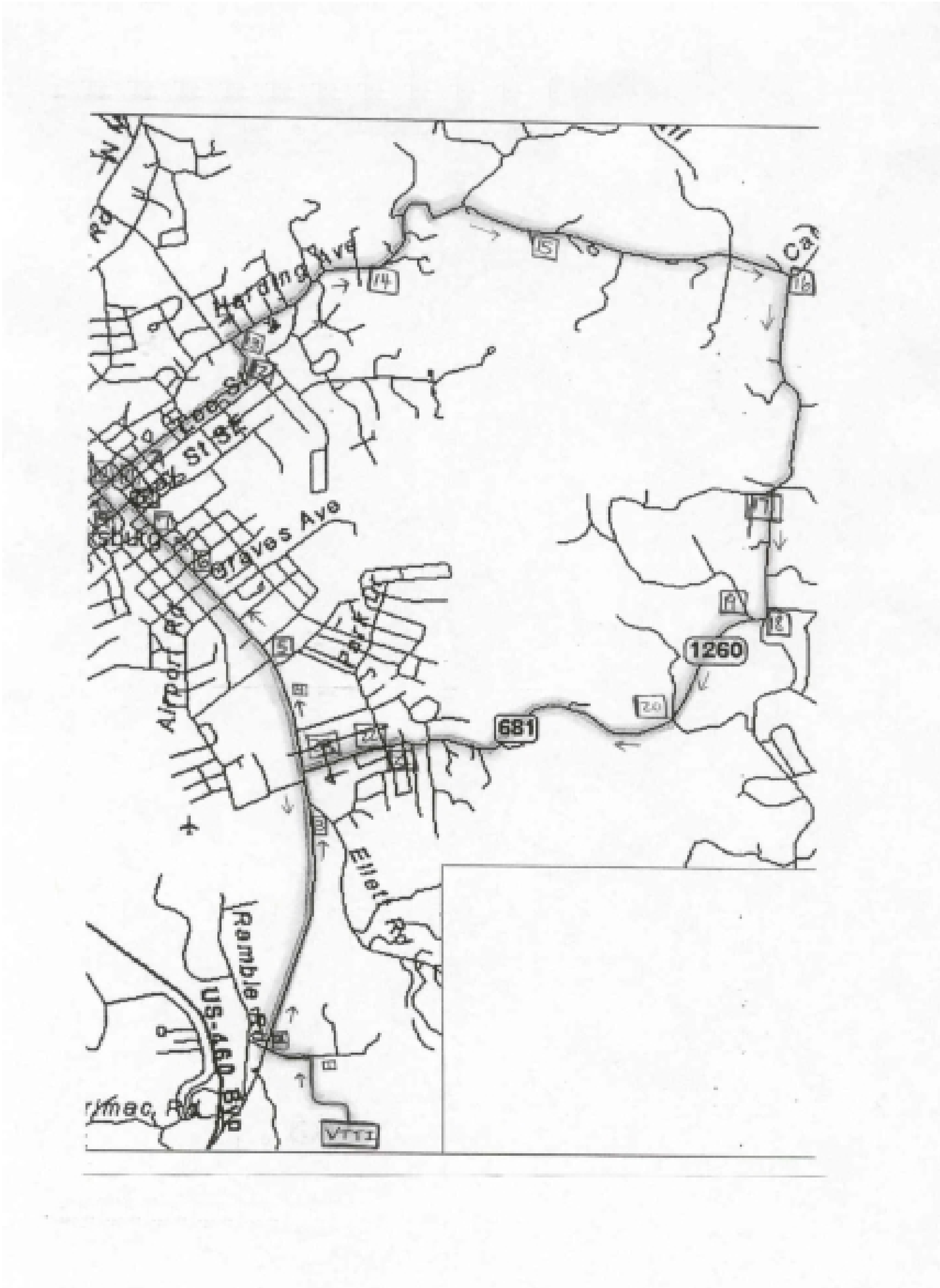

Figure B-1. Map of test route area.

Figure B-2. Sample sign posting.

Figure B-3. Sample sign posting.

APPENDIX C: DESCRIPTION OF THE INSTRUMENTED VEHICLE

A 1995 Oldsmobile Aurora was used as the experimental vehicle for all participants. The instrumentation in the vehicle provided the means to unobtrusively collect, record, and reduce a number of data items, including measures of attention demand, measures of navigation performance, safety-related incidents, and subjective opinions of the participants.

Forward-View Camera

The forward-view camera provided a wide view of the forward roadway without substantial distortion. The camera had an auto-iris and provided a high-quality picture in all but the most severe daylight glare conditions. The forward-view camera was located in the center rear-view mirror and did not obscure any part of the driver's view of the roadway or impair his/her use of the mirror. The forward-view camera served to collect relevant data from the forward scene (e.g., traffic density, signs and markers, and headway).

Multiplexer and PC-VCR

A quad-multiplexer was used to integrate up to four camera views and place a time stamp onto a single videotape record. A PC-VCR received a time stamp from the data collection computer and displayed the time stamp continuously on the multiplexed view of the videotaped record. In addition, the PC-VCR had the capability to read and mark event data provided by the data collection computer and perform high-speed searches for event marks. The PC-VCR operated in an S-VHS format so that each multiplexed camera view would have 200 horizontal lines of resolution.

Data Collection Computer

The data collection computer provided reliable data collection, manipulation, and hard drive storage under conditions present in a vehicle environment. The computer had a 16-channel analog-to-digital capability, standard QWERTY keyboard, and a 9-inch diagonal color monitor. Computer memory and processing capabilities included: 12 megabytes RAM, a 1.2 gigabyte hard drive, and a Pentium processor.

Sensors

The steering wheel, speedometer, accelerator, and brake were instrumented with sensors that transmitted information about position of the respective control devices. The steering wheel sensor provided steering position data accurate to within +/- 1 degree.

The brake and accelerator sensors provided brake position to within +/- 0.1 inch. An accelerometer provided acceleration readings in the lateral and longitudinal planes of the vehicle. The accelerometers provided values for vehicle acceleration and deceleration up to and including hard braking behavior, as well as intense turning. These sensors provided signals that were read by the A/D interface at a rate of 10 times per second.

Experimenter Control Panel and Event Flagger

A custom experimenter control panel was located in the vehicle and allowed the experimenter to record the occurrence of test sign events or other unplanned events in the data set by push-button input.

Video/Sensor/Experimenter Control Panel Interface

A custom interface was used to integrate the data from the experimenter control panel, driving performance sensors, event flagger, and speedometer with the data collection computer. In addition, the interface provided a means to accurately read and log the time stamp from the PC-VCR to an accuracy of +/- 0.1 second. The time stamp was coded such that a precise location could be synchronized from any of the videotaped records to the computer data record for post-test laboratory reduction and file integration.

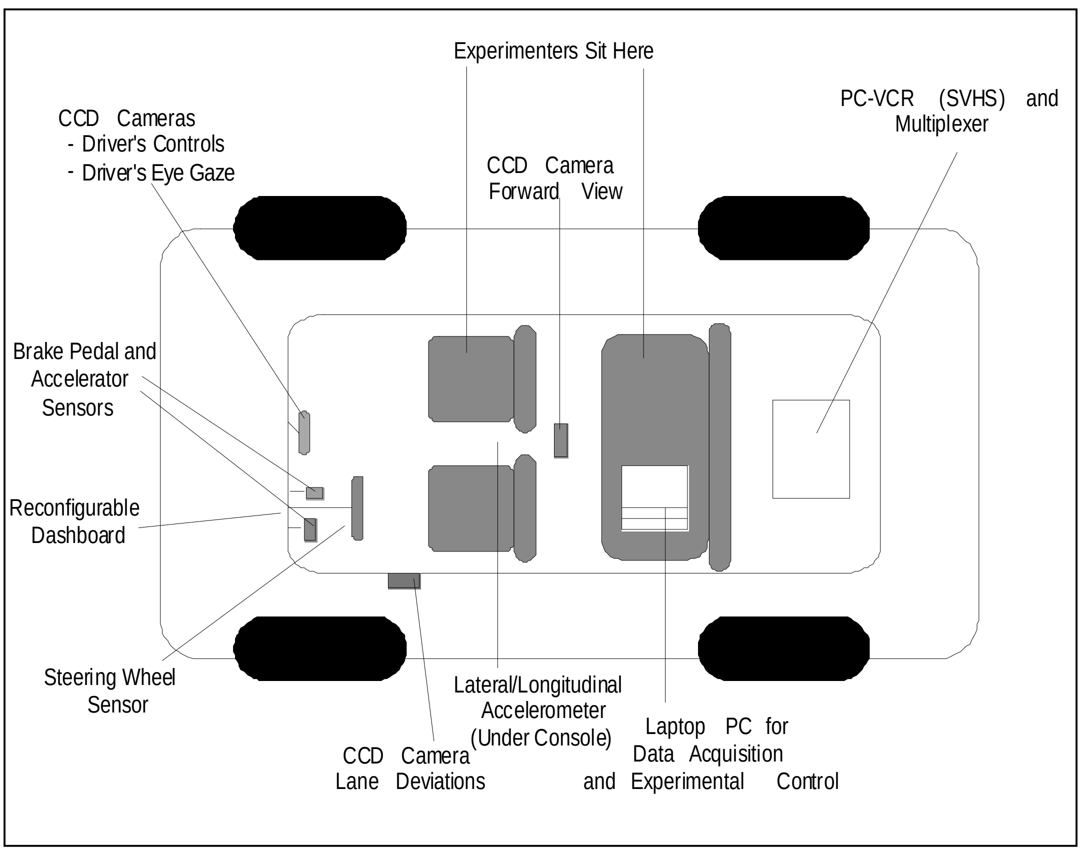

Figure C-1.   Diagram of the instrumented vehicle.

Safety Apparatus

The test vehicle had the following safety apparatus provided as part of the instrumented vehicle system:

- All data collection equipment was mounted such that no hazard was posed to the driver.
- Participants were required to wear the lap and shoulder belt restraint system. The vehicle was equipped with a driver-side and passenger-side airbag supplemental restraint system.
- The vehicle had an experimenter's brake pedal mounted in the front passenger side.
- The vehicle had a fire extinguisher, first aid kit, and cellular phone, for emergency use.
- None of the data collection equipment interfered with the driver's normal field-of-view.
- Emergency protocol was established prior to testing.

APPENDIX D: APPARATUS AND PROCEDURES FOR LAB MEASUREMENTS AND RESULTS OF FIELD MEASUREMENTS

The primary apparatus used in obtaining the laboratory measurements contained in Table 2 included the following: (1) Minolta CS-100 chroma meter; (2) Minolta T-1 Illuminance meter; and (3) Macbeth® Spectralight® II lighting booth.

Minolta CS-100 Chroma Meter

A Minolta CS-100 tristimulus color chroma meter was used to obtain non-contact luminance measurements (chromaticity vales in Yxy) of the signs used in study 2.

Iluminance Meter

A Minolta T-1 illuminance meter was used to obtain illuminance measurements of the conditions in the lighting booth. The measuring range for this device is 0.019 to 900 lx (0.019 to 990 ft-c).

Macbeth® Spectralight® II lighting booth

The Macbeth® Spectralight® II lighting booth was used to simulate a typical daytime viewing condition for signs used in Phase III. The lighting booth was used to produce an average day lighting condition of 572 lux (measured vertically, i.e., parallel to the color sign).

Procedure

For this study, measurements were taken only during simulated daylight since we were interested in color contrast. Color contrast is related to the perception of color differences and is very important during daylight conditions. Measurements were taken approximately 1 meter from the sign samples. The vertical illumination from the Macbeth Spectralight II lighting booth was approximately 572 lux located 64 cm above the sample signs. Contrast calculations were derived using the following formula: C ratio= L max/L min, where L max is the maximum luminance and L min is the minimum luminance in cd/m2.

Table D-1. Telephotometer readings.

LMT TELEPHOTOMETER READINGS (cd/m^2)
(taken at 280 ft. with a 6' aperture)

	NON-FLOURESCENT PURPLE			
Reading	**UR**	**LR**	**UL**	**LL**
1	74.7	95.3	69.7	83.1
2	81.8	99.8	71.7	82.9
3	84.3	97.8	72.2	83.6
AVG	**80.3**	**97.6**	**71.2**	**83.2**
STDEV	**5.0**	**2.3**	**1.3**	**0.4**
Yellow Legend - 152 (2' aperture)				

	FLOURESCENT PURPLE			
Reading	**UR**	**LR**	**UL**	**LL**
1	43.3	41.7	44.0	43.0
2	45.1	41.5	40.8	44.5
3	44.3	45.6	39.4	44.5
AVG	**44.2**	**42.9**	**41.4**	**44.0**
STDEV	**0.9**	**2.3**	**2.4**	**0.9**
Flourescent Yellow Legend - 115 (2' aperture)				

	FLOURESCENT YELLOW-GREEN			
Reading	**UR**	**LR**	**UL**	**LL**
1	342	427	324	420
2	362	441	324	416
3	354	438	322	397
AVG	**353**	**435**	**323**	**411**
STDEV	**10.1**	**7.4**	**1.2**	**12.3**
Black Legend - 219 (2' aperture)				

	FLOURESCENT CORAL-HOT PINK			
Reading	**UR**	**LR**	**UL**	**LL**
1	59.1	97.1	67.0	90.8
2	64.5	99.1	66.0	83.9
3	61.7	90.3	67.3	95.2
AVG	**61.8**	**95.5**	**66.8**	**90.0**
STDEV	**2.7**	**4.6**	**0.7**	**5.7**
Black Legend - 43.0 (2' aperture)				

UR = Upper Right side of sign
LR = Lower Right side of sign
UL = Upper Left side of sign
LL = Lower Left side of sign

Table D-2. Retroflectivity measurements.

RETROREFLECTIVITY MEASUREMENTS (cd/lx/m^2)
Readings taken with an ART-920 at 0.2/-4 degrees

	NON-FLOURESCENT PURPLE			
Reading	**UL**	**UR**	**LR**	**LL**
1	115	132	134	117
2	119	130	133	108
3	116	128	135	116
AVG	**117**	**130**	**134**	**114**
STDEV	**2**	**2**	**1**	**5**
Arrow - 400				

	FLOURESCENT PURPLE			
Reading	**UL**	**UR**	**LR**	**LL**
1	37	45	28	46
2	35	41	56	46
3	30	43	49	47
AVG	**34**	**43**	**44**	**46**
STDEV	**4**	**2**	**15**	**1**
Arrow - 303				

	FLOURESCENT YELLOW-GREEN			
Reading	**UL**	**UR**	**LR**	**LL**
1	418	422	443	430
2	425	413	444	429
3	416	437	440	416
AVG	**420**	**424**	**442**	**425**
STDEV	**5**	**12**	**2**	**8**
Arrow - 0.5				

	FLOURESCENT CORAL-HOT PINK			
Reading	**UL**	**UR**	**LR**	**LL**
1	138	123	141	143
2	128	99	79	151
3	126	152	135	158
AVG	**131**	**125**	**118**	**151**
STDEV	**6**	**27**	**34**	**8**
Arrow - 0.5				

UR = Upper Right side of sign
LR = Lower Right side of sign
UL = Upper Left side of sign
LL = Lower Left side of sign

Table D-3. Illuminance readings.

RIMENTAL INCIDENT MANAGEMENT SIGN COLOR S

ILLUMINANCE READINGS (lx) USING A MINOLTA T-10

	UL	LL	UR	LR
Non-flourescent purple	0.85	1.29	1.04	1.40
Flourescent purple	1.03	1.37	1.09	1.54
Flourescent yellow-green	1.08	1.47	1.19	1.51
Flourescent Coral	1.01	1.46	1.18	1.57

UL = Upper Left side of sign
LL = Lower Left side of sign
UR = Upper Right side of sign

APPENDIX E: POST-TEST QUESTIONNAIRE

VIRGINIA TECH TRANSPORTATION INSTITUTE
SIGN CONSPICUITY STUDY

User Survey

Participant ID: _______________	Date: ___________

Please read the following questions and circle the number that best describes how you feel.

1. How visible was the "test route" sign relative to the environment?

1	2	3	4	5
Not visible	Somewhat Visible	Moderately visible	Very visible	Extremely visible

2. How easy was it to identify, or understand, the directional information provided by the test signs?

1	2	3	4	5
Not easy	Somewhat easy	Moderately easy	Very easy	Extremely easy

3. How useful would you find this type of sign design for providing temporary directional/detour information while driving?

1	2	3	4	5
Not useful	Somewhat useful	Moderately useful	Very useful	Extremely useful

User Survey (continued, Page 2)

Participant ID: ___________	Date: ____________

Please answer the following questions using the sign samples provided by the experimenter.

Please use the color definitions provided with the sign samples.

Black on Fluorescent Yellow-Green
Non-Fluorescent Yellow on Non-Fluorescent Purple
Black on Fluorescent Coral
Fluorescent Yellow on Fluorescent Purple

4. Please rank the signs in order of preference for visibility along the roadway, or how well you feel the signs would stand out from the environment and other signs along the roadway. Use the following definitions of visibility to rank the sign samples:

Most visible ______________________________
More visible ______________________________
Somewhat visible ______________________________
Least visible ______________________________

5. Please rank the signs in order of preference based on how easy you feel the signs are to read. Use the following definitions of readability to rank the sign samples.

Most readable ______________________________
More readable ______________________________
Somewhat readable ______________________________
Least readable ______________________________

6. Please rank the signs in order of overall preference for use on signs providing temporary directional/detour information. Use the following definitions of preference to rank the sign samples.

Most preferred ______________________________
More preferred ______________________________
Somewhat preferred ______________________________
Least preferred ______________________________

APPENDIX F: INITIAL CONTACT AND SCREENING FORMS

VIRGINIA TECH TRANSPORTATION INSTITUTE
SIGN CONSPICUITY STUDY
INITIAL CONTACT SCRIPT (BY PHONE OR IN PERSON)

INTERVIEWER:*I am conducting an on-the-road study of traffic signs for my graduate research at Virginia Tech. The purpose of this research project is to evaluate traffic signs of varying colors and design parameters to determine which signs produce the greatest visibility distance during day and night conditions on dry pavement, as well to evaluate driver behavior relative to use of these signs.*

During the course of this experiment you will be asked to perform the following tasks:

1. *Complete a short demographic survey (over the phone).*
2. *Read and sign an Informed Consent Form.*
3. *Complete a simple vision test and color vision test.*
4. *Complete a brief health-screening questionnaire.*
5. *Listen to the instructions regarding the task that you will be performing.*
6. *Read general information about the operation of the experimental vehicle.*
7. *Participate in a training session in which you will learn about the operation of the experimental vehicle.*
8. *Perform one experimental drive with the vehicle over a pre-determined route in which data will be collected.*
9. *Answer questions regarding your subjective assessment of the signs displayed during your drive.*

At the end of the experimental run, you will drive back to the original location, be paid for your time, and debriefed. The total experiment time will be approximately 1 hour.

Would you be interested in participating?

POTENTIAL PARTICIPANT: YES or NO

INTERVIEWER:*As part of the experiment, I need to ask you a few questions. Your answers will help me determine if I can include you as a participant in my study and if so, it will also help me group and sort the data from the study. This data will not be associated with your name, and will be treated confidentially*.

See following pages.

VIRGINIA TECH CENTER FOR TRANSPORTATION RESEARCH
SIGN CONSPICUITY STUDY

INITIAL CONTACT SCREENING QUESTIONNAIRE AND BACKGROUND INFORMATION (BY PHONE)

Participant's Name:________________________________ Date of Birth:________________
Participant's Phone No.:_______ Gender: M or F
Eligibility Status:_____________________ Date and Time:______________________

For office use:	**Participant ID: ________**

NOTE TO INTERVIEWER: The initial screening consists of two parts: 1) demographic information and 2) health screening. Ask the participant the following questions and record his/her responses. If the participant does not have a valid driver's license, thank the person for his/her time and explain that this criterion must be met in order to participate. If the participant reveals a health condition that disqualifies him/her from safe participation in this study, thank the person for his/her time and explain that he/she is not eligible to participate for safety reasons.

PHONE INTERVIEWER: As *part of the study, I need to ask you a few questions. Your answers will determine your eligibility for this study. This data will not be associated with your name, and will be treated confidentially*.

(1) To participate, you need to have a valid driver's license. Do you have a valid license?

YES NO

(2) How many times per week do you drive?

4+ 2-3X 1X <1X

(3) Approximately how many miles do you drive per year?

1 ❑ Under 2,000
2 ❑ 2,000 - 7,999
3 ❑ 8,000 - 12,999
4 ❑ 13,000 - 19,999
5 ❑ 20,000 or more

PHONE INTERVIEWER: If participant is eligible, then conduct the health screening.

See following pages.

VIRGINIA TECH TRANSPORTATION INSTITUTE
SIGN CONSPICUITY STUDY
Health Screening Questionnaire - Part I

Participant ID: ________

NOTE TO INTERVIEWER: This is a two-part questionnaire. The first part may be completed during initial screening process. The second part must be completed and signed immediately prior to participation in the study.

1. Are you in good general health? Yes No

   If no, please list any health-related conditions you are experiencing or have experienced in recent past.

   ____

   ____

2. Have you, in the last 24 hours, experienced any of the following conditions?

Inadequate sleep	Yes	No
Unusual hunger	Yes	No
Hangover	Yes	No
Headache	Yes	No
Cold symptoms	Yes	No
Depression	Yes	No
Allergies	Yes	No
Emotional upset	Yes	No

3. Do you have a history of any of the following?

   Visual Impairment Yes No
   (If yes, please describe.)

   ____

   ____

   Hearing Impairment Yes No
   (If yes, please describe.)

   ____

   ____

   Seizures or other lapses of consciousness Yes No
   (If yes, please describe.)

   ____

   ____

   Any disorders similar to the above or that would impair your driving ability?
   Yes No
   (If yes, please describe.)

   ____

   ____

4. If you are female, are you pregnant? Yes No

5. List any prescription or non-prescription drugs you are currently taking.

   ____

   ____

VIRGINIA TECH TRANSPORTATION INSTITUTE
SIGN CONSPICUITY STUDY

INITIAL CONTACT SCREENING QUESTIONNAIRE AND BACKGROUND INFORMATION (CONT'D)

Participant ID: ________

PHONE INTERVIEWER: If participant is eligible based on results of background information and health screening...*Now I'd like to schedule a time when you can come out to the Virginia Tech Transportation Institute for the study*.
If participant is not eligible based on results of health screening...*Thank you for your time; unfortunately you are not eligible for this particular study due to safety considerations. Would you be interested on being put on a participant list for future studies?*

A. Schedule a time DATE AND TIME:________________________________

PHONE INTERVIEWER: If participant is eligible based on results of background information and health screening...*Do you have transportation to the Virginia Tech Transportation Institute, or do you need transportation. We can arrange for someone to pick you up and return you home afterwards*. If yes...*Please you give me directions to the place where we will pick you up.*

____

____

____

____

PHONE INTERVIEWER: Also, *please refrain from drinking alcohol for the 24 hours before the experiment. Is this all right with you?* YES__________NO__________

PHONE INTERVIEWER: I *will call to remind you of when the experiment is scheduled. This reminder will occur approximately 24 hours before your appointment. At that time I will also include directions to the field laboratory if necessary. Thank you! I'll see you* <insert date and time>.
Comments:
____
____
____
____

Time Preference: DAY NIGHT

VIRGINIA TECH TRANSPORTATION INSTITUTE
SIGN CONSPICUITY STUDY

Health Screening Questionnaire - Part II

Participant ID: ________

NOTE TO INTERVIEWER: This is a part 2 of a two-part questionnaire. This part must be completed and signed immediately prior to participation in the study.

6. List any prescription or non-prescription drugs you have taken in the last 24 hours.

   ____
   ____
   ____

7. List the approximate amount of alcohol (beer, wine, fortified wine, or liquor) you have consumed in the last 24 hours.

   ____
   ____

8. List the approximate amount of caffeine (coffee, tea, soft drinks, etc.) you have consumed in the last 6 hours.

   ____
   ____

9. Are you taking any drugs of any kind other than those listed in questions 5 or 6?

   Yes No

______________________________ ______________________________
Signature Date

APPENDIX G: INFORMED CONSENT FORM

VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of the Project: *On-road Investigation of Fluorescent Colors to Determine Improvements of Conspicuity for Traffic Signs*
Investigators: Richard L. Anders and Dr. Vicki L. Neale

I. THE PURPOSE OF THIS RESEARCH

The purpose of this research project is to evaluate specific traffic sign designs relative to a current sign design standard in an on-road field study. This research continues the evaluation of previously determined color and letter size combinations, and will investigate the visibility and conspicuousness, relative to the current sign design standard, of the sign designs that resulted in the greatest legibility distances during the previous parts of this research program. Participants will drive an instrumented vehicle along a predetermined route in a normal traffic situation, and will follow the directional information provided by the test signs. For safety considerations, data collection will occur when on dry pavement and an experimenter will be present in the car during the data collection session. The results of this study will help traffic engineers to design more visible, conspicuous, and legible traffic signs based on the color and design parameter information obtained. The study involves 96 observers of varying age and gender.

II. PROCEDURES

During the course of this experiment you will be asked to perform the following tasks:

1. Complete a short demographic survey (over the phone).
2. Read and sign an Informed Consent Form.
3. Complete a simple vision test and color vision test.
4. Complete a brief health-screening questionnaire.
5. Listen to the instructions regarding the task that you will be performing.
6. Read general information about the operation of the experimental vehicle.
7. Participate in a training session in which you will learn about specific features of the experimental vehicle.
8. Perform one experimental drive with the vehicle over a pre-determined route in which data will be collected.
9. Answer questions regarding your subjective assessment of the signs displayed during your drive.

At the end of the experimental run, you will drive back to the original location, be paid for your time and debriefed about the research. The total experiment time will be approximately 1 hour.

It is important for you to understand that we are evaluating the traffic signs, not you. Therefore, we ask that you perform to the best of your abilities. If you ever feel frustrated in attempting to read a test sign, just remember that this is the type of thing that we need you to comment on. The information and feedback that you provide is very important to this project.

III. RISKS

There are some risks or discomforts to which you are exposed in volunteering for this research. These risks are:

(1) The risk of an accident normally associated with driving an automobile in light or moderate traffic, as well as on straight and curved roadways.
(2) Possible fatigue due to the length of the experiment. If you deem it necessary, rest breaks will be provided.
(3) You will be videotaped by cameras while driving the vehicle. Due to this fact, you will be asked not to wear sunglasses. If this at any time during the course of the experiment impairs your ability to drive the vehicle safely, please so notify the experimenter.

The following precautions will be taken to ensure minimal risk to you:

(1) An experimenter will monitor your driving and will ask you to stop if they feel the risks are too great to continue. However, as long as you are driving the research vehicle, it remains your responsibility to drive in a safe, legal manner.
(2) You will be required to wear the lap and shoulder belt restraint system while in the car. The vehicle is also equipped with a driver's side and passenger's side airbag supplemental restraint system.
(3) The vehicle is equipped with an experimenter brake pedal if a situation should warrant braking and you fail to brake.
(4) The vehicle is equipped with a fire extinguisher, first-aid kit, and a cellular phone.
(5) If an accident does occur, the experimenters will arrange medical transportation to a nearby hospital emergency room. You will be required to undergo examination by medical personnel in the emergency room.
(6) All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard to you in any foreseeable case.
(7) None of the data collection equipment interferes with any part of your normal field of view present in the automobile.

IV. BENEFITS OF THIS RESEARCH

There are no direct benefits to you from this research other than payment for participation. No promise or guarantee of benefits is made to encourage you to participate. Your participation will provide baseline data for visibility and conspicuousness of highway traffic signs composed of various design parameters and colors. This may have a significant impact on highway traffic sign effectiveness when these color combinations and design parameters are employed, as well as on driving safety. Ultimately, the results of these data may significantly affect highway traffic signing as specified by the Virginia Department of Transportation and the Federal Highway Administration.

V. EXTENT OF ANONYMITY AND CONFIDENTIALITY

The data gathered in this experiment will be treated with confidentiality. Shortly after participation, your name will be separated from your data. A coding scheme will be employed to identify the data by participant number only (e.g., Participant No. 1). You will be allowed to see your data and withdraw the data from the study if you so desire, but you must inform the experimenters immediately of this decision so that the data may be promptly removed. At no time will the researchers release the results of this study to anyone other than individuals working on the project without your written consent.

VI. COMPENSATION

You will receive $15.00 total for your participation in this study. This payment will be made to you at the end of your voluntary participation in this study for the portion of the study that you complete.

VII. FREEDOM TO WITHDRAW

As a participant in this research, you are free to withdraw at any time for any reason. If you choose to withdraw, you will be compensated for the portion of time of the study for which you participated. Furthermore, you are free not to answer any questions or respond to any research situations without penalty.

VIII. APPROVAL OF RESEARCH

This research has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Virginia Tech Transportation Institute.

IX. PARTICIPANT'S RESPONSIBILITIES

If you voluntarily agree to participate in the study, you will have the following responsibilities: To be physically free from any illegal substances (alcohol, drugs, etc.) for 24 hours prior to the experiment, and to conform to the laws and regulations of driving or public roadways.

X. PARTICIPANT'S PERMISSION

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project. If I participate, I may withdraw at any time without penalty. I agree to abide by the rule of this project.

____

Participant's Signature   Date

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

Richard L. Anders, Investigator	(540) 231-1564
Vicki L. Neale, Principal Investigator	(540) 231-1514
Thomas A. Dingus, Director, VA Tech Trans. Institute	(540) 231-1502
H. T. Hurd, Chair, IRB	(540) 231-5281

APPENDIX H. VISION AND COLOR TEST SCRIPTS

VIRGINIA TECH TRANSPORTATION INSTITUTE
SIGN CONSPICUITY STUDY – VISION TEST AND COLOR VISION TEST

Participant ID: ______________	Date: __________

After the participant has read and signed the consent form...
(1) Administer "Health Screening Questionnaire" if not previously done.

NOTE TO EXPERIMENTER: Due to safety considerations, the participant must be in general good health, not be taking any medication that would adversely affect his/her driving ability (e.g., antihistamine), not have been drinking, and not be pregnant.

(2) Follow me, and I'll administer a vision test that is required of all participants.

EXPERIMENTER: Take the participant to the area containing the Titmus II Vision Tester. Have the participant sit down and place his or her forehead against the headrest trigger so the illumination in the unit is activated and the GREEN "READY" indicator on the control panel is lit. Set the dial to #2 at the yellow indicator (far). Make sure the participant is wearing any glasses or contacts necessary for distance vision (as in for driving).

Read to participant: Look *at the first target: is the ring at the TOP broken like the other rings, or is it unbroken?*

EXPERIMENTER: Let participant answer TOP, BOTTOM, LEFT, or RIGHT. {Answers are on the score sheet.} *Where is the unbroken ring in target #2? #3? #4?* Continue until the subject misses two consecutive answers. When the participant misses one, but answers the next one correctly, continue until the subject misses two consecutive answers. Record the acuity of the last target that he or she gets correct.

Acuity score: ______________

EXPERIMENTER: Set the dial to #6 at the yellow indicator (far).

Read to participant: Next *I'll administer a color vision test that is required of all participants. Do you see a numeral in circle A? What numeral do you see?*

EXPERIMENTER: Repeat for circles B, C, D, E, and F. The correct response for circle F would be no number. Eight digits are displayed in a total of six circles.

- Normal: 8 digits correct.
- Mild deficiency: 5 or more digits correct.
- FAIL: less than 5 digits correct. Record on line below number of letters or numbers correctly identified and the score (normal, mild deficiency, or fail).

Color test score: ______________

<u>SCORING</u>
In order for the participant to continue with the study, the participant must:

A. Have a visual acuity of 20/40 or better.
B. Pass "Health Screening Questionnaire". For Question 3, look for impairments that might adversely affect one's ability to drive.
C. Regarding the color vision, several participants should have some form of color deficiency (mild or fail) as demonstrated by the color vision test criteria. Remaining participants should have normal color vision.

APPENDIX I. SCRIPTS OF TEST INSTRUCTIONS AND PROCEDURES

VIRGINIA TECH TRANSPORTATION INSTITUTE
SIGN CONSPICUITY STUDY

Experimenter's Instructions Script

1. INTRODUCTIONS and INSTRUCTIONS

A. Greet Participant

B. Informed Consent Form

- *Give participant a copy of the informed consent form to read.*
- *Answer any general questions the participant might have about the study.*
- *Have participant sign and date the informed consent form.*
- *Give participant a copy of the informed consent form.*

C. Verify Driver's License

- *Have participant show a valid driver's license.*

D. Health, Medication, and Drug Questionnaire

- *Give participant a copy of the health, medication, and drug questionnaire to complete.*
- *Have participant sign and date the health, medication, and drug questionnaire.*
- *Review questionnaire to ensure that participant is fit to take part in the study.*

E. Vision Test and Color Vision Test

EXPERIMENTER: "Before we go out to the vehicle, I need to give you a vision test. This is a requirement of all participants of this study."

- *Administer vision test and color vision test per instructions provided by Vision and Color Tests' Scripts.*
- *Review results of both tests to ensure that participant is fit to take part in the study.*
- *If passes (at least 20/40 and meets required level of color vision), then go out to vehicle and continue with study. If fails, pay for time and excuse from study.*

2. ORIENTATION SESSION

A. Initial Briefing

Experimenter: "Do you have any questions at this point?"

- *Answer any general questions the participant might have.*

Experimenter: "Before we proceed, I would like to inform you that I will be reading from a script during much of our time together. This ensures that I will not forget to tell you anything. So, if I sound extremely formal at times, please understand that this is a requirement of the study."

"In order to make the experience as objective as possible as well as safe, I'd like to review a few points before we start driving."

"First, we will be driving over a predetermined and marked route. This route will be in the Montgomery County area. Signs that indicate "TEST ROUTE" and a directional arrow mark the route. These signs will guide your direction of travel."

B. Task Training

EXPERIMENTER: "Your task is to follow the test signs until told that you have reached the final destination. I am not allowed to provide you with any other directional information."

"Do you have any questions?"

- *Answer any questions the participant might have.*

C. Vehicle Briefing

- *Open front driver side door for the participant and have him or her get into the driver's seat.*
- *Get into front passenger seat.*

EXPERIMENTER: "Before we begin, I would like to take a few minutes to familiarize you with this vehicle."

"Since the controls in this car may be different from those in your vehicle, I would like to give you a chance to become familiar with the controls. When I point out the location of each, please operate it."

- *Say name of each control and have subject operate it.*

EXPERIMENTER and PARTICIPANT:

1. WINDSHIELD WIPERS
2. LIGHTS

3. HORN
4. TURN SIGNALS
5. STEERING WHEEL ADJUSTMENT LEVER
6. LEFT AND RIGHT OUTSIDE REARVIEW MIRRORS
7. SEATS

EXPERIMENTER: "Now I would like you to adjust the seat and steering wheel so that you are in a comfortable driving position. Make sure that you can see the entire instrument panel through the steering wheel. Please fasten your seat belt."

EXPERIMENTER: "Now please adjust the side and rear-view mirrors to your liking."

- *Make sure the following system settings are achieved:*
  1. Connect all computer cables.
  2. Power on display computer.
  3. Power up data collection computer.
  4. Load videocassette.
- *Have participant start the engine.*

3. PRACTICE SESSION

EXPERIMENTER: "If you are comfortable, we can begin. As you maneuver out of the parking lot you will get a feel for the driving and handling characteristics of this vehicle."

- *At the intersection of Transportation Research Plaza and Transportation Research Drive ascertain if participant is comfortable with the handling qualities of the vehicle; if so, then continue on to the test route. If not, then go back and allow the participant to drive around the parking area again."*

4. TEST DRIVE

EXPERIMENTER: "During your upcoming drive, you will be following a predetermined route that is marked by a series of TEST ROUTE signs."

"Your primary responsibility is to safely operate the vehicle, obeying all traffic laws. Other responsibilities are: Follow the directional information provided by all TEST ROUTE signs; follow the directions of all safety advisory and warning signs. There are no other tasks associated with this study."

"Do you have any questions regarding these tasks? Please note that I will not be allowed to answer questions during the drive. Also, I will not be allowed to talk with you during the drive other than to tell you when you have passed the last sign."

- *Answer general questions.*

"Are you ready to begin the test drive?"

Data Collection

- *Prepare data collection equipment.*
  1. *Enter subject number.*
  2. *Enter gender.*
  3. *Enter color blindness status.*
  4. *Enter input condition, i.e., sign number, visibility condition (day or night).*
  5. *Begin data collection.*

5. POST-TEST, DEBRIEFING, AND PAYMENT

- *Return to the VTTI.*
- *Administer the User Survey.*
- *Answer any questions the participant may have about the study in general.*
- *Pay participant. Make certain that both you and the participant sign and date the payment log sheet.*
- *Thank the participant for taking part in the study.*

Experimenter Protocol

Tasks

The experimenter that rides in the passenger seat has three primary responsibilities They are as follows:

1. Operate the safety brake (**to be used only in the event of an emergency**). The emergency brake is a foot-operated brake located in the front passenger area.

2. Flag unplanned events. Flag any event where the driver is required to react (or should react and neglects to). Unplanned events are naturally occurring events that happen during he drive. Examples of unplanned events include a car braking sharply in front of the participant, a dog running across the road, a car merging toward the participant, etc.

3. The experimenter must have a thorough understanding of the route and all turns. Information is provided to the participant regarding when the test route begins and when the final sign has been negotiated.

APPENDIX J: STATISTICAL TABLES FOR SURVEY QUESTIONS

Significant p or z values are indicated by an asterisk in the right hand column.

Table J-1. Analysis of variance table for survey question #1.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Sign Color	3	7.8450	2.6150	6.73	0.0004*
Age	1	0.3057	0.3057	0.79	0.3779
Visibility Condition	1	0.8982	0.8982	2.31	0.1325
Sign Color X Age	3	0.0593	0.0198	0.05	0.9847
Sign Color X Visibility Condition	3	2.4483	0.8161	2.10	0.1072
Visibility Condition X Age	1	0.0140	0.0140	0.04	0.8498
Sign Color X Age X Visibility Condition	3	2.432	0.8107	2.09	0.1090
Error	75	29.1333	0.3884		
TOTAL	90	43.1358			

Table J-2. Analysis of variance table for survey question #2.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Sign Color	3	7.8875	2.6292	2.36	0.0783
Age	1	8.1969	8.1969	7.35	0.0083*
Visibility Condition	1	1.1793	1.1793	1.06	0.3070
Sign Color X Age	3	1.2774	0.4258	0.38	0.7663
Sign Color X Visibility Condition	3	11.7106	3.9035	3.50	0.0195*
Visibility Condition X Age	1	0.5337	0.5337	0.48	0.4911
Sign Color X Age X Visibility Condition	3	2.0319	0.6773	0.61	0.6121
Error	75	83.6000	1.1147		
TOTAL	90	116.4173			

Table J-3. Analysis of variance table for survey question #3.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Sign Color	3	7.8908	2.6303	2.42	0.0727
Age	1	1.9653	1.9653	1.81	0.1828
Visibility Condition	1	1.3571	1.3571	1.25	0.2674
Sign Color X Age	3	1.0886	0.3629	0.33	0.8009
Sign Color X Visibility Condition	3	6.1322	2.0441	1.88	0.1402
Visibility Condition X Age	1	0.0659	0.0659	0.06	0.8062
Sign Color X Age X Visibility Condition	3	2.6669	0.8890	0.82	0.4881
Error	75	81.5333	1.0871		
TOTAL	90	102.7001			

Table J-4. Pairwise comparisons for survey question 4, assessment by sign color.

Sign Color Background	Difference between Rank Sums $z(\alpha=0.05, \#c=6)=2.638$, $z_{critical} = 45.95$
Yellow-Green vs Non-Fl Y/P	236*
Yellow-Green vs Coral	83*
Yellow-Green vs Fl Y/P	159*
Non-Fl Y/P vs Coral	153*
Non-Fl Y/P vs Fl Y/P	77*
Coral vs Fl Y/P	76*

***significant difference, $z_{calculated} > z_{critical}$**

Table J-5. Pairwise comparisons for survey question 5, assessment by sign color.

Sign Color Background	Difference between Rank Sums $z(\alpha=0.05, \#c=6)=2.638$, $z_{critical} = 45.95$
Yellow-Green vs Non-Fl Y/P	222*
Yellow-Green vs Coral	102*
Yellow-Green vs Fl Y/P	142*
Non-Fl Y/P vs Coral	120*
Non-Fl Y/P vs Fl Y/P	80*
Coral vs Fl Y/P	40

***significant difference, $z_{calculated} > z_{critical}$**

Table J-6. Pairwise comparisons for survey question 6, assessment by sign color.

Sign Color Background	Difference between Rank Sums $z(\alpha=0.05, \#c=6)=2.638$, $z_{critical} = 45.95$
Yellow-Green vs Non-Fl Y/P	219*
Yellow-Green vs Coral	84*
Yellow-Green vs Fl Y/P	131*
Non-Fl Y/P vs Coral	135*
Non-Fl Y/P vs Fl Y/P	88*
Coral vs Fl Y/P	47*

***significant difference, $z_{calculated} > z_{critical}$**

VITA

Richard Lee Anders

Mr. Rick Anders is a career Civil Service employee with over 28 years of Federal service. His current assignment is Chief of the U. S. Army Research Laboratory Field Office at Fort Gordon, Georgia. Mr. Anders earned a Bachelor of Science degree from the U. S. Naval Academy and has extensive experience as a Navy combat pilot. Prior to retirement from the Naval Reserve in December 1999, his most recent Naval Reserve assignment was as an air combat plans officer on the staff of the Commander, U. S. Sixth Fleet in the Mediterranean Sea. Presently he is pursuing a Master of Science degree in Industrial and Systems Engineering, Human Factors option, at the Virginia Polytechnic Institute and State University.

Upon graduation from the Naval Academy in 1976, Mr. Anders entered Navy flight training in Pensacola, Florida. Mr. Anders earned his wings and was designated a Naval Aviator in October 1977. He has accumulated over 3500 flight hours in a variety of aircraft (P-3, T-34, T-28, S-2, A-4, and Grumman American Trainer). As a Patrol Plane Commander/Mission Commander he was qualified to conduct missions anywhere in the world. He holds the following FAA ratings: single engine, multi-engine, land, instrument, commercial, and Airline Transport.

After transitioning to the Naval Reserve in 1982, Mr. Anders was employed as a reliability and maintainability engineer at the Naval Air Systems Command in Arlington, Virginia. While at NAVAIR he supported the following programs: AV-8B Harrier, SH-60B, H-53, Hellfire Missile, HARM Missile, and numerous avionics programs. Mr. Anders accepted a position with the Army Research Laboratory in 1988. He has extensive experience conducting field tests for prototype combat identification systems.