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Pavement Markings and Delineation for Older Drivers

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FOREWORD

The proportion of the driving population over age 65 is growing significantly. Older motorists can be expected to have problems driving at night, given the known changes in their sensory, perceptual, cognitive, and psychomotor performances. Based on their own recognition of these decreased functional capacities, many older drivers limit their nighttime driving.

Pavement markings and delineation devices serve an important function for the nighttime driver. They provide a preview of roadway features that are ahead and also give the driver information about his lateral position on the roadway, which, in turn, helps the driver track or steer his vehicle. Improvements in these types of devices could help increase the mobility of older drivers at night.

The research documented in this report identified the information needs of older drivers and evaluated the situations in which older driver performance might be improved by enhanced pavement markings and delineation treatments. Based on this information, a range of enhanced treatments was developed and the effectiveness of these treatments was determined. Finally, the costs and benefits associated with selected treatments were analyzed and recommendations regarding the use of these treatments were made.

The information contained in this report should be of interest to highway designers, traffic engineers, and highway safety specialists involved in the design and operation of highway facilities.

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Office of Safety and Traffic Operations,
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16. Abstract

The objectives of this project were: (1) to identify the needs of older drivers and to evaluate the situations in which older driver performance might be improved through enhanced pavement markings and delineation; (2) to identify the range of potentially useful enhanced treatments; (3) to determine the effectiveness of those treatments judged to be most useful for the older driver; and (4) to assess the costs and benefits of the treatment shown to be most effective.

Following a literature review to identify older driver deficiencies, 25 delineation/pavement marking treatments (including several "control" treatments) were identified for testing. A laboratory simulator study was used as a means to determine the most effective among the group. The treatments shown to produce better recognition distance, along with several control treatments, were then subjected to field testing.

The field tests were conducted on a closed test track facility, and recognition distance and visual occlusion time were used as dependent measures. Of the 66 subjects who participated in the field study, half were over 65 years of age and half were 45 years of age or less. All subjects were involved in both types of measures.

Following the field test performance assessment, the treatments were subjected to a cost benefit analysis and recommendations were made regarding the treatments that could benefit older drivers.

This volume is the first in a series. The other volume is: FHWA-RD-95-118: Executive Summary

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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1. INTRODUCTION

The first objective of the project was to identify the needs of older drivers and to evaluate the situations in which older driver performance might be improved by enhancing pavement markings and delineation. This objective was satisfied through (1) a review and evaluation of existing background material on older driver deficiencies, (2) a review of selected delineation treatment evaluations, and (3) an analysis of accident data to determine over representation of older drivers in specified situations.

The second objective of the project was to identify the range of potentially useful enhanced treatments. This objective was met by first identifying the range of existing delineation devices and pavement marking materials, along with those under development by manufacturers. The characteristics of these materials and devices were then evaluated relative to known older driver deficiencies in various situations. This resulted in the identification of potentially useful treatments that can be implemented with current technology and manufacturing processes.

The third objective was to determine the effectiveness of treatments judged to be most useful for the older driver. This was done via laboratory/simulator testing. Based on the preliminary simulation results, the most effective treatments were then evaluated in controlled field tests.

2. BACKGROUND

INTRODUCTION

The proportion of the driving population over age 65 has grown significantly within the last 10 years and is growing larger every day. Older motorists can be expected to have problems driving at night given the known changes in their sensory, perceptual, cognitive, and psychomotor performance. Based on their own recognition of these decreased functional capacities, many older drivers limit their nighttime driving.

Pavement markings and delineation devices serve important functions for the nighttime driver. They provide a preview of roadway features ahead and give the driver information about the vehicle's lateral position on the roadway. Improvements in these types of devices could help increase the safety and mobility of older drivers at night. Safety can be enhanced by providing better preview and tracking information, and mobility can be increased by providing a visual environment that is more comfortable for the older driver; thus, leading to more frequent night travel.

REVIEW OF OLDER DRIVER DEFICIENCIES

The declining functional capacities of older individuals can be categorized into sensory, perceptual, cognitive, and psychomotor performance. It is expected that the sensory, perceptual, and, to a lesser extent, cognitive and psychomotor deficiencies might be moderated by improvements in delineation and marking treatments.

Sensory/Perceptual Deficiencies

Several visual functions show age-related decrements. One primary visual function that declines with age is visual acuity. The research literature on visual capabilities has consistently identified acuity decrements among older test subjects. The decline occurs slowly at first, beginning at approximately age 45, but accelerates after age 60 or 70.[1,2] Ten percent of men and women between the ages of 65 and 74 have uncorrected acuity worse than 20/30, compared to 30 percent over the age of 75.[3] The late decline in acuity can be attributed to pathologic factors, and only a small loss can be attributed to "normal aging."[4]

As described in one recent comprehensive review[5], many of the recent reports are in agreement that age-related declines in acuity—particularly under low-luminance conditions—are of primary importance in traffic control design considerations where the performance of older drivers is an issue.[5] As noted in a report by Lindholm, objects subtending a small visual angle are generally processed more slowly than larger features of the environment and are also more difficult to detect and fixate upon.[6] Such problems for older drivers may be further magnified by (apparent) target speed, focusing operational concerns on roadways with higher design speeds. This concern is also supported by tests of dynamic visual acuity. This measure, among all visual measures, shows the most consistent relationships to driving record. Fox points out that dynamic acuity correlations for accident involvement are strongest for drivers over age 50 and under age 25.[7]

Given the control exercised by licensing agencies (i.e., the requirement for 20/40 corrected acuity to obtain a license), acuity deficiencies are not expected to be a major issue with regard to continuous pavement markings (e.g., centerlines or edgelines) or repetitive delineation treatments (e.g., a series of post delineators). However, increases in size of delineation devices that include a legibility component (e.g., the directional component of chevrons [< or >] or the head size of arrows) could be important in providing earlier discrimination of curve direction.

Contrast sensitivity has also been found to decline with age.[8] This finding has more recently been confirmed in a random screening of approximately 13,000 Pennsylvania motorists, as described by Decina et al.[9] For older drivers, there are two compounding problems. Under constant viewing conditions, older observers have lower contrast sensitivity. Further, for a given reduction in ambient light levels, older driver performance deteriorates to a much greater degree than has been observed for younger drivers. A 60-year-old driver requires 2.5 times the contrast (i.e., target luminance minus background luminance divided by the background luminance [Lt - Lb / Lb]) needed by a 23-year-old driver.[10] With regard to delineation is an investigation of age-related differences in the required contrast for pavement delineation. A recent study by Staplin et al. showed that older drivers required a level of contrast 20 to 30 percent higher than a young/middle-aged comparison group. The study also showed an increase in within-group variability of performance among subjects over age 65.[5] The differences were found to be exaggerated in the presence of glare. However, the experimental sample was a self-selected group of older drivers with visual capabilities superior to the older driver population as a whole. The study also involved a comparison of contrast sensitivity measures obtained using alternative subject recruitment strategies.[5] These data suggest a self-selection bias leading to a possible underestimation in the technical literature of the magnitude of contrast sensitivity problems among older drivers.

Contrast sensitivity is a general functional ability and, with regard to delineation, is an age-related deficiency that is more important than acuity. Whereas acuity tests the ability to resolve detail (i.e., high spatial frequency targets), typically at high contrast levels, contrast sensitivity tests measure the detection/recognition of targets at low and intermediate spatial frequencies under conditions of poor contrast with the visual background. This distinction is clearly relevant to real-world tasks where delineation is a primary information source. Discrimination of the boundaries of the driving lanes often involves only slight differences in the obtained luminance of the road surface versus the shoulder or surrounding land. In such instances, the "edge information" is less sharply defined than the critical detail in, for example, a character on a highway sign or an acuity chart test stimulus.

Slower dark adaptation among older drivers, as well as slower recovery of retinal sensitivity after glare (glare recovery) and a diminished ability to see against glare (glare sensitivity), were emphasized in a review of visual functions and driving performances by North.[11] While significant correlations between measures of these functions and accident experience have yet to be demonstrated, an inevitable consequence of such age-related deficiencies is an increased reliance on delineation elements for path guidance by older drivers under nighttime conditions, particularly when driving against oncoming traffic. Sources of both long preview and instant-to-instant steering control cues are critical to older drivers under these circumstances; therefore, a special case for larger, brighter, and/or redundant delineation treatments on two-lane highways can be made.

Another potentially important visual decrement in older drivers is a decline in the visual field.[4] Changes in the visual field can be measured as a reduction in field area for different target sizes and intensities, or as an elevation in threshold values at distinct locations within the field limits. Given the variations in the offset of roadside delineators, such findings argue for testing the effects of increasing the brightness of such devices as a possible means to overcome deficiencies associated with a reduction in the visual field.

Further justification for a heavy emphasis on brightness in improving delineation is provided by the results of dark adaptation studies. Several studies have shown a progressive elevation of both rod and cone thresholds with age, with an accelerated loss above the age of 60.[4,12] As rod and cone thresholds increase, more light is needed to bring important tasks above the cone limit. Even at night, most visual information is processed by the cone, or daylight, system. The rod system alerts the driver to a weaker signal to which the driver may then be oriented. The implication of a loss in rod sensitivity is that a brighter peripheral signal would be needed (e.g., a brighter roadside delineator) and any stimuli falling below the threshold would be ignored. Depending upon its color,[4] a traffic control device may need to be 10 to as much as 100 times brighter to be perceived in the driver's periphery. More specifically, Zwahlen has shown that the recognition distance of a reflectorized target is 47 to 59 percent of the average foveal recognition distance when the target is at a 10-degree peripheral angle.[13] At a 30-degree peripheral angle, recognition distance was found to decline to 25 to 33 percent of the foveal recognition distance. Based on the results of the study, Zwahlen concludes that ". . . in a situation where drivers approach or negotiate a curve at night, where reflectorized objects or targets will become visible for the first time probably in the periphery of a drivers visual field, and where there is a need for early detection, the reflectivity of the target should be increased to ensure timely recognition, information processing, and decision making, and appropriate control actions."[13] While the Zwahlen study does not focus on older drivers, it can be assumed that age-related contrast sensitivity and visual field deficiencies make increases in brightness even more important for the older driver group.

Overall, the research findings having the greatest bearing on age differences in drivers' ability to acquire and use information provided by roadway delineation are: a decline in spatial contrast sensitivity, reduced dark adaptation ability, and a heightened sensitivity to glare (slower recovery and stronger masking effects).

Cognitive Deficiencies

Many changes in cognitive capabilities have been found to occur with aging. These changes are associated with changes in the frontal lobes, the area that controls behaviors such as arousal and attention, visuo-spatial skills, visual search behavior, memory functions, and complex problem solving. Generally, the age-related deficiencies in cognitive functions result in a general increase in processing time related to several specific cognitive difficulties, as described below. Another specific deficit is the ability of older drivers to rapidly discriminate more important from less important information in a driving scene. While such cognitive deficiencies are important in the design of an overall driver information system, most of them are not as relevant to the design of pavement marking and delineation treatments as they are to the design and deployment of signs. However, signs, markings, and delineation interact within the overall driver information system and these interactions become more important in more complex urban situations. Some age-related cognitive deficiencies are discussed in the following sections.

Older adults have been shown to have difficulty refocusing after an immediate attentional shift.[14,15] This may cause problems when the older driver has to scan many signs to find information or to perform other maneuvers that require reorientation of attention. However, it is believed that for guidance and tracking at nonintersection locations, the critical demands on a driver are principally on the visual system.

There are relatively few age-related studies on complex divided-attention or time-sharing task performance (e.g., situations in which the driver has to concurrently monitor vehicle position, scan signing, and respond to changes in traffic flow). The existence of an age-related deficit may depend on the complexity of the task. For example, in a signal detection study, where signals were equated for target strength for older and younger subjects, no significant age differences were found in accuracy of response to multiple signals.[16] However, with more complex tasks that contain a memory component, age effects were more pronounced.[17,18] Age-related deficits have also been shown in a study of time-sharing between two skilled behaviors.[19] Given the existing studies, it is difficult to equate the complexity of the driving task to the tasks used in the studies that showed age-related deficits. As a result, conclusions regarding age differences in complex time-sharing must await further research.

Optimizing attention is separate from time-sharing efficiency and is thought to depend most strongly upon the development of automatic attention responses.[20,21] The development of automatic responses appears to be an acquired skill that is task/situation specific.[22] Therefore, the goal of preserving and reinforcing the acquired automatic responses of older drivers to traffic control elements must assume importance in the design or redesign of any driver information system.

The integration of sensory information over time and the ability to manipulate information for decision making and problem solving are functions for which memory is crucial. Measures of working memory address the amount of information a person can remember during ongoing processing of events, or the ability of a person to retrieve information from memory during concurrent cognitive processing. The importance of "working memory" lies in its interaction with decisional and response-selection functions. These functions are critical to the driving task, as information must be constantly sampled and stored temporarily as the basis for planning of downstream maneuvers. Age-related performance deficits associated with older persons include declines in storage capacity, reduced processing efficiency, and impaired coordination of storage and processing of information.[23,24] As with most of the other cognitive areas, the importance of these deficiencies increases as the driving environment becomes more complex.

Next, possible problems with delineation usage among older drivers are suggested by age decrements in visual search/scanning capabilities and information extraction as documented in the work of Fisk (it should be noted that the Fisk study did not use traffic control stimuli or driving scenes for the research).[25] More specific attention to information extraction in a driving scene was provided in a study by Staplin et al.[5] This study showed that older drivers were at a disadvantage in acquiring "most critical" messages conveyed by traffic signs in a visually complex highway environment. It seems reasonable to generalize this finding to delineation elements, at least as far as object markers and barriers marking the location of discrete roadway hazards are concerned. Also, it seems reasonable to expect that older drivers will experience exaggerated difficulty in rapidly discerning the correct travel path in construction and maintenance zones, mainly because they must respond to temporary pavement markings that often are in competition with preexisting striping and/or misleading informal cues provided by variation in the surface characteristics of the road, shoulder, or median.

In a study related to "useful field of view," Ball et al. showed that older test subjects performed more poorly on a task requiring concentration on a central task with concurrent detection and recognition of peripheral stimuli.[26] The results showed that older subjects exhibited a constriction in field size at recognition thresholds for various stimuli. In view of the work of Zwahlen, the Ball results take on some practical significance.[13,27] As described in more detail later in this report (under the heading of "Roadside Delineators"), Zwahlen found that the peripheral detection ability, or the recognition distance for suprathreshold reflectorized targets, decreases considerably as the peripheral visual detection angle increases. He also found that the negative effects can be offset by increasing the reflectivity or specific intensity of the retroreflective target.

To summarize, the age-related cognitive deficiencies are not expected to have a major influence on delineation treatments. While they cannot be ignored, most of the deficits documented are more highly related to the overall driver information system than to delineation, per se.

Psychomotor Deficiencies

Turning to a consideration of differences in psychomotor capabilities between young/middle-aged and older drivers, a widely reported finding in gerontological research describes an increase in response time for older subjects across a broad range of speeded tasks.[5] However, the specific psychomotor deficits observed depend on the nature of the response required. For example, while reaction time has been shown, in general, to slow with age, brake reaction time is slowed by only 0.1 s for a 75-year-old as compared to a 25-year-old.[28,29,30] Psychomotor deficiencies are not directly applicable to delineation. However, treatments chosen to overcome sensory and cognitive deficiencies should act to inform older drivers earlier and, therefore, avoid the need for a quick motor response to changes in roadway features.

Summary of Older Driver Deficiencies

The diminished capabilities described previously must be considered in relation to specific information needs while also taking into account the time (distance) in which those needs must be satisfied. The information needs may be loosely contrasted according to the discrimination of continuous versus discrete roadway features—that is, the perception and recognition of the boundaries of the traveled way as opposed to a discrete location that must be avoided (e.g., an island, barrier, or abutment) or to a path selection that must be acted upon (e.g., a ramp gore, pavement width transition point, or intersection). Further, delineation must provide information that results in recognition of roadway features both at "long" preview distances (5 to 8 s of travel time) and at more immediate proximities (within 1 s of travel time) where attention is directed toward instant-to-instant vehicle control responses. These multiple needs are most likely to be met with various combinations of markings and surface and roadside delineation treatment elements. It would appear, on the basis of the older driver deficiencies, that the needs can most adequately be met by improvements in brightness and size of the individual delineation and marking elements.

DELINEATION AND MARKING TREATMENTS

This section provides a review of the research on delineation and marking treatments. While little of the research is specifically related to the older driver, it identifies treatments shown to be useful to the driving population at large. The first part of the section ("General Considerations") provides reviews of some of the more general studies and of delineation and marking treatments. The second part ("Treatment-Specific Considerations") describes studies that are specific to various types of treatments. The second part is subdivided into the specific types of treatments or treatment components that could be combined to provide upgraded treatments that might be effective in overcoming older driver deficiencies.

General Considerations

Robinson reported that drivers age 65 and older account for the second highest per capita incidence of vehicular fatalities.[44] He points out that while the increased fatality record is due in part to the drivers' reduced physiological and cognitive factors, other factors are also involved. The other factors include environmentally controllable factors such as the condition of roadways, lane markings, and signs. Based on presentations and discussions at the "Workshop on the Highway Mobility and Safety of Older Drivers and Pedestrians" in 1985, Robinson makes the following general safety recommendations: install brighter signs, signals, and road markings; gain a better understanding of driving deficiencies in the elderly and find cost-effective ways to compensate for these deficiencies; make more widespread and better use of pavement markings and delineation systems, including reflectorized guard rails; use traffic control devices that are uniform in appearance, brightness, placement, and meaning across the country; establish minimum levels of brightness and reflectivity for traffic control devices, both for new installations and for those that are in service, so highway maintenance personnel will know when replacement or rehabilitation is required; increase sensitivity to sign clutter and information overload and reduce the introduction of unnecessary complexities in signs; improve motorist information systems, including all forms of traffic control devices, especially in terms of reaction time and visual capabilities.[44]

A general review by Deacon discusses previous research results dealing with several delineation techniques; those which he concluded would ". . . more favorably affect the older driver than possibly more average segments of the driving population."[32] His summary of previous research is oriented toward the crash benefits of various delineation techniques, whereas most of the research presented under the separate treatment categories is oriented toward specific aspects of driving performance or visibility. The conclusions of Deacon are reviewed in the appropriate subsections that follow.

Treatment-Specific Considerations

Surface Treatments

The literature on surface treatments/pavement markings includes paint stripes, smooth and textured stripes of materials such as thermoplastics and epoxy, raised pavement markers (RPM's), and ceramic buttons. Because these treatments have different visibility characteristics under various conditions and can be enhanced along different dimensions, each is discussed separately.

Pavement Markings

Pavement markings can be enhanced in four ways: increased brightness, increased width, increased thickness, and the addition of structure to "thick" applications. Stripes of increased thickness (whether structured or not) have an advantage in wet weather because the material is more likely to protrude above the level of surface water and to provide a degree of retroreflectivity greater than that provided by thinner applications of paint. Also, the commercially available structured stripes (tapes) are brighter than other marking treatments, even under dry conditions. This is due to the ability of the "vertical" element of the structure to reflect more light than a horizontal surface.

From the standpoint of crash benefits, Deacon found that highways with centerlines had lower crash rates than those without delineation treatment.[32] For example, application of a painted centerline to two-lane sections without prior delineation was found to reduce the overall crash rate by up to 1.5 crashes per million vehicle miles. The reduction was approximately 30 percent for the entire sample of highways. He also found that the application of edgelines generally resulted in a decrease in crash rates. The reduction was greatest for tangent sections, averaging approximately 0.7 crashes per million vehicle miles.

Freedman et al. showed significant performance decrements for 65-year-old drivers, as compared with 35-year-old drivers, in the visibility distance of 101.6-mm (4-in) pavement stripes on a simulated wet roadway.[30] More recently, Staplin et al. confirmed the need for higher levels of line brightness for older drivers.[5] In this simulator study, line brightness was continuously varied within a 40-step range in a method of limits. Apparent (scaled) driver-target separation distance was varied at two levels: 30.5 m and 61 m (100 ft and

200 ft). The target was defined as the distance to curve (i.e., the edge and centerline striping at the point where the downstream curvature began in the roadway scene). The dependent variable was the target contrast level at which a driver could correctly detect the roadway heading with 100 percent confidence. Results of the study showed that, for the geometrics tested, significantly brighter striping was required by older drivers to reliably discern the curving direction of the roadway.

The empirical data from the Staplin study were supplemented with focus group sessions with older drivers. Four of the changes that the focus groups identified as making their driving easier were delineation-related: introduction of painted and reflectorized curbs and edgelines where none exist, and effective maintenance where already in place; more widespread use of raised pavement markers to delineate lane boundaries and the edge of the roadway; more frequent repainting of faded lane lines and other pavement markings; and use of corrugated pavements to provide redundant cues for center line and roadway edge delineation.

Based on the general delineation/marking literature, one characteristic of stripes that appears promising is the increase of the width of stripes, at least on roadways 6.7 m (22 ft) or more in width. However, whether the wide stripes should be used as a general treatment or as a spot treatment on curves is open to question. A survey of State highway agencies by Wright et al. found that engineers believe that treatments such as chevrons, delineators, and warning signs are more effective than markings for spot improvements at curves.[31]

Deacon, in reviewing much of the most recent striping research as it relates to older drivers, concludes that ". . . at least until more conclusive crash data become available, 203.2-mm (8-in) edgelines should be used instead of standard, 101.6-mm (4-in) edgelines on two-lane, rural highways.[32] Deacon goes on to point out that while ". . . this finding is not based on benefits to older drivers, older drivers will share—probably proportionally more—the safety benefits with others who travel these highways during periods of impaired visibility."[32]

In addition to the assumption that a wider stripe will provide greater visibility distances and be more conspicuous to older drivers, there is evidence from a study by Hughes et al. that 203.2-mm (8-in) edgelines offer the potential for cost-effective application.[33] This conclusion is based on the finding that for 203.2-mm (8-in) edgelines to be a cost-effective replacement for 101.6-mm (4-in) edgelines when the daily traffic exceeds 1,000 vehicles, crashes need to be reduced by only 0.7 percent.

While the use of a wide edgeline is conceptually attractive for improving older driver performance, the complete operational and safety benefits are not clear. For example, Hall reported that wide edgelines do not reduce the incidence of run-off-the-road (ROR) accidents, nor do they reduce the incidence of such accidents at night or on curves.[34] A study by Cottrell also showed that the use of wide edgelines does not reduce the risk of accidents on curves or at night.[35] Concerning both the Cottrell and the Hall studies, Lum and Hughes point out that ". . . because of the number of miles sampled in their studies was small, researchers are hesitant to accept their finding."[36] In spite of his findings about accident incidence, Cottrell does state in his conclusions that ". . . it can be argued that the use of wide edgelines only in the vicinity of curves, while retaining conventional edgelines on tangents, would be an effective spot improvement." However, only one stripe-width study specifically attended to the older driver population that would be most likely to benefit from such a treatment. This study, conducted by Potter Industries in conjunction with an American Association of Retired People (AARP) group and reported in *Better Roads,* showed that 87 percent of the older drivers rated 203.2-mm (8-in) edgelines as more visible, brighter, and superior to standard-width edgelines.[37]

Although the evidence regarding the effectiveness of wide edgelines is equivocal, it appears logical that such a treatment is likely to overcome some deficiencies of the older driver. An important issue with respect to stripe width is the lane widths on which the 203.2-mm (8-in) lines should be applied to reduce accidents. Deacon, for example, suggests that on narrower roadways, raised pavement markers or post-mounted delineators should be used instead of wide edgelines.[32]

Structured Lines

There are relatively little data available on the effects of structured (profiled) lane lines on driver performance. However, the structure, despite how it is designed, does increase brightness under wet and dry conditions and has the additional advantage of providing vibrotactile and aural feedback to the driver if an encroachment of the line occurs.

The only study of structured lines that was found was by Blaauw and Padmos.[38] The authors showed that the two types of structured-line treatments that were tested had higher coefficients of retroreflective luminance and resulted in longer visibility distances than a typical paint stripe and a thermoplastic stripe that were tested, especially on wet pavements. It was further shown that new RPM's provide greater visibility distances than structured lines, but after 22 months of wear both types of structured lines are comparable to the RPM's.

Raised Pavement Markers

Raised pavement markers have received widespread use because they provide better long-range delineation than conventional painted lines, particularly under wet conditions. When used on a road edge, they also provide brighter peripheral cues, which could be advantageous to the older driver for path guidance. One major problem with RPM's is that they rapidly lose their initial retroreflectivity.

No research was found on age-related evaluations of RPM's; however, other useful data relating to the general driving population were found. Deacon found that highways with raised pavement marker centerlines had lower crash rates than those with painted centerlines.[32] The average reduction in crash rates was approximately 0.5 crashes per million vehicle miles. As noted previously, Deacon oriented his review of research toward delineation and marking treatments that he felt would aid the older driver more than younger age groups.

An RPM spacing study of particular relevance was conducted by Blaauw, who tested several RPM patterns on both tangents and curves using a visual occlusion technique.[40] White RPM's were used for the tests. The spacing distance between the markers was based on the 3.0/6.1-m (10/30-ft) pattern typically used in the Netherlands. Spacing distances were approximately 12.2 m, 24.4 m, and 36.6 m (40 ft, 80 ft, and 120 ft) for RPM's at the left, center, and right, respectively. A fourth condition tested consisted of a 3.0/9.1-m (10/30-ft) spacing for the center markers, in combination with a 12.2-m (40-ft) spacing for the left and right markers. In another study reported in the same paper, combinations of RPM's and post-mounted delineators were tested. All delineation patterns were tested on 200-m (656-ft) radii curves, 1000-m (3281-ft) radii curves, and tangent sections. It was found that, in general, the mean occlusion time decreases and driving performance deteriorates when less delineation information is present per unit of road length. This was particularly true for the 200-m (656-ft) radius curves, where even the 24.4-m and 36.6-m (80-ft and 120-ft) spacings led to speed reductions and lane errors. Based on these results, it was recommended that on curves of this severity, the spacing of RPM's be restricted to 12.2-m (40-ft) spacings. In general, no differences between treatments were observed for the more gentle 1000-m (3281-ft) radius curves.

Based on the overall results, Blaauw makes the following recommendations: (1) RPM's exclusively at the center are favorable for lateral vehicle control inside the lane (short-range delineation), but are less adequate for preview information on the lane to be followed (long-range delineation), therefore it is necessary to delineate both lane boundaries; (2) delineation at the center can be realized with RPM's; (3) delineation at the outside of the traffic lane can be realized with RPM's at the location of the lane boundary or with post-mounted delineators spaced laterally at 1.5 m (5 ft)—both configurations are equally efficient, and post-mounted delineators at an approximate 3.7-m (12-ft) spacing are less efficient; and (4) RPM's at the location of the center and/or lane boundaries have to be applied with a maximum spacing distance of 12.2 m (40 ft) on a 200-m (656.2-ft) radii curve or 24.4 m (80 ft) on straight sections.[40] Of note regarding the results of the study is the fact that visual occlusion time was found to be a sensitive criterion for the various delineation patterns tested.

In another RPM study, Zwahlen evaluated various RPM spacings on freeway tangent sections and on ramps that were approximately 304.8-m (1000-ft) long with a curvature of 24 degrees.[41] The RPM spacings evaluated on the ramps were 3.8 m, 7.6 m, and 15.2 m (12.5 ft, 25 ft, and 50 ft) along the outer edgeline. These spacings were evaluated against a no-RPM condition. It was found that the addition of RPM's at any of the above spacings did not substantially improve driver performance. However, it must be recognized that the ramps on which the tests were conducted were of the cloverleaf type and, therefore, the exit speeds were most likely lower than can be expected on most two-lane rural roadways.

Roadside Delineators

Because of its increasing use throughout the country, and because it accommodates different types of sheeting in varying amounts and different designs, the roadside delineation device of primary interest in the current study is the flat, flexible post. The general accident data have shown that the installation of post-mounted delineators lowered crash rates for sections with or without edgelines.[42,43] Deacon[32] found that installation of post-mounted delineators lowered crash rates for sections with or without edgelines. The reduction in crash rates resulting from the installation of these delineators averaged 1.0 crashes per million vehicle miles. Thus, given the lane width restrictions for the use of enhanced (e.g., wider) edgelines, post-mounted delineators can be an important device for lower functional classification roadways.

Conclusions from the research by Zwahlen emphasize the need for study of the relative effectiveness of increased luminance or size on post retroreflectivity, particularly for two-lane rural roads that are not wide enough to accommodate edgeline striping.[27] Zwahlen investigated the ability of drivers to detect an approaching reflectorized target at night both foveally and at the peripheral visual angles of 10, 20, and 30 degrees. It was found that at a 10-degree peripheral angle the average recognition distance was 47 to 59 percent of the average foveal recognition distance. At a 30-degree peripheral angle, this distance declines to 25 to 33 percent of the average foveal recognition distance. Based on the results described above, Zwahlen conducted another study to investigate the importance of peripheral visual detection in the night driving environment.[13] As he points out, the curve-tangent and tangent-curve sections are frequent on two-lane rural highways, and, therefore, relatively large peripheral detection angles are common for reflectorized targets that become visible for the first time in the periphery of the visual field. In this study he found that the peripheral detection ability, or the recognition distance for suprathreshold reflectorized targets, decreases considerably as the peripheral visual detection angle increases. It was found, however, that the effects can be offset by increasing the reflectivity or specific intensity of the retroreflective target. Based on the study results, Zwahlen recommends that in cases where the target will become visible in the periphery of the visual field and where there is a need for early detection, the reflectivity of the target should be increased to ensure timely recognition. Considered together with older driver deficiencies in peripheral vision, reductions in the useful field of view and the reduction in contrast sensitivity, the Zwahlen results suggested that the post-delineator brightness and design should be included as a variable in the current study.

OLDER DRIVERS AND ACCIDENTS

Maleck and Hummer analyzed more than 50,000 police-reported accidents on Michigan Interstate and trunkline highways in 1982 and found that older drivers (age 65 and older) are overrepresented in the following accident categories: urban accident involvement (but not rural accident involvement); total and injury accident involvement; right-angle, left-curve, head-on, and parking-backing accident involvement (extreme overrepresentation); and rear-end and pedestrian-cyclist accident involvement (slight overrepresentation).[45]

McKelvey et al. have reported on accidents in Michigan.[47] They showed that the increase in relative accident involvement is greater for older women than for older men. They also showed that there is a higher accident involvement for older drivers on non-Interstate routes than on Interstate routes, and they thought this could be associated with the influence of highway design features. They further examined the non-Interstate accidents and found that the highest elderly driver relative accident involvement occurred on roadways other than U.S. and State routes, suggesting that "certain highway design features—perhaps alignment or lane width—may have a more significantly adverse effect on the accident potential for older drivers in comparison to other drivers."

In an attempt to identify the inappropriate driving behaviors (IDB's) of older drivers who were involved in accidents, Mason et al. performed analyses of accident data collected from the Pennsylvania Accident Record System for the years 1984 through 1986.[46] The specific IDB's that elderly drivers display include: turns at intersections; slow driving; improper use of acceleration lanes; failure to yield right of way; disregard of traffic control devices; and IDB's associated with indecision.

As part of the same study, Mason et al. conducted interviews with older drivers to identify why certain IDB's occur in this group. Driver responses as to the reasons for IDB's being associated with elderly drivers include: lack of perception; driver taxation beyond capabilities; inexperience (especially women); lapse of attention; reduced courtesy; night-vision problems (especially women); driving too slowly; fatigue; apathy; failing senses; and pharmaceuticals and their side effects.

In addition to the aforementioned published research, the study team conducted some analyses of a data base from accident analysis research that Hughes et al. had conducted in a recent study of edgeline widths.[33] The data base consisted of approximately 402 km (250 mi) of two-lane, rural roadway sections in Maine. Accident data were compiled for the roadway sections from 1986 through 1988. The resulting data base contained more than 1,800 accident records. Cross-tabulation summaries were generated for the following variables: single-vehicle and multiple-vehicle accidents; roadway alignment; road surface conditions; light conditions; and intersections and nonintersections. The cells were stratified by age groups: a younger group of age 25 to 54, and an older driver group of 65 and over.

These cross tabulations were then subjected to a chi-square analysis to determine if there was a significant difference in the proportion of accidents associated with the two age groups. It should be noted that only accident frequency was analyzed; exposure was not included in the analysis.

The only cross tabulation that showed any evidence of the two age groups not being independent was the daytime, multiple-vehicle accident category stratified by roadway surface condition (dry versus wet versus ice/snow/slush). Based on a very limited sample size, it appears that the older driver does not exhibit accident frequencies different from the 25- to 54-year-old driver in terms of the following variables: tangents versus curves, dry versus wet road conditions, level versus rolling/mountainous terrain, and intersections versus nonintersections. However, these findings were not related to presence, absence, or type of delineation.

POTENTIAL ENHANCEMENTS TO AID OLDER DRIVERS

A need for improved delineation practice to accommodate older drivers can be asserted on the basis of multiple and compounding functional deficits linked to advancing age. Visual and cognitive diminished capabilities among older drivers result in a situation in which members of this user group—allowing for broad individual differences—perceive path guidance cues later and process the information less efficiently than their younger counterparts.

To address difficulties older drivers have with the present system of delineation elements, the research was directed toward brighter materials, larger target sizes, redundant and/or multidimensional cues using combinations of elements, and novel designs or configurations of elements. The various combination of elements and changes in design were considered to have the potential to enhance the conspicuity and comprehensibility of delineation/marking treatments. Delineation/marking improvements for older drivers must take into account the need for both "long preview" and instant-to-instant path guidance and must also provide information about the full range of continuous and discrete roadway features experienced in highway and freeway operations. Only if these goals are met will the mobility of older drivers be increased; particularly in nighttime driving situations. Further, to the extent that the information systems can be designed to compensate for known deficiencies, the mobility can be increased without the penalty of decreased safety.

The review of background material, including delineation and marking research findings and the deficiencies of older drivers, has led to the identification of treatments that will hopefully meet the goal of increasing the mobility of older drivers. Further, the treatments tested can be implemented with existing materials.

3. TREATMENTS EVALUATED

The identification of delineation and marking treatments considered to have some potential to improve older driver performance was completed in two steps. First, each member of the research team was provided with a technical memorandum summarizing the older driver deficiencies and other delineation/marking treatment-related material obtained during the background material review. Each member was also given a set of treatment specification and ranking forms. Following the completion of the forms, the group met to discuss the enhanced treatments that had been identified and to provide a final listing of treatments. This process is described in greater detail in appendix A.

Based on the review of past research and the considerations of the panel, the following treatments were chosen for the initial evaluation. In addition to the treatment description, the rationale for choice of each treatment is described. It should be noted that some of the treatments do not constitute enhanced treatments, but are representative of currently used treatments and, therefore, serve as a basis of comparison for the enhanced treatments.

- <u>Treatment 1: 101.6-mm (4-in) yellow centerline at inservice brightness level of 100 mcd (referred to as ISBL)</u>

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL with no other devices. This treatment served as a baseline condition for a two-lane rural road. It provided limited alignment preview information and single line (left edge of the traveled path) lateral position reference information that could be used by the driver to steer the vehicle.

- <u>Treatment 2: 101.6-mm (4-in) yellow centerline at ISBL and a 101.6-mm (4-in) white edgeline at ISBL</u>

  The second treatment was a 101.6-mm (4-in) yellow centerline at ISBL and a 101.6-mm (4-in) white edgeline at ISBL. This treatment served as a baseline condition for a rural freeway. It provided limited alignment preview information and two-line (both edges of the traveled path) lateral position information to be used for steering input.

- <u>Treatment 3: 101.6-mm (4-in) yellow centerline at ISBL and a 203.2-mm (8-in) white edgeline at ISBL</u>

  The third treatment was a 101.6-mm (4-in) yellow centerline at ISBL and a 203.2-mm (8-in) white edgeline at ISBL. This treatment provided a bigger edgeline. It also provided limited alignment preview information and two-line lateral position information to be used for steering input. It is believed that this is a more visible device for the older driver. It is also a good choice from a cost effectiveness standpoint, since it is much cheaper to make a stripe wider than it is to make it brighter.

- Treatment 4: 101.6-mm (4-in) yellow centerline at ISBL and a 101.6-mm (4-in) white edgeline at brightness level 2

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL and a 101.6-mm (4-in) white edgeline with a brightness level that was somewhat greater than an ISBL. This treatment addressed the increased contrast thresholds of the older driver and provided a starting point for the range of changes in brightness that the panel expressed an interest in testing in this study. The brighter line was used in an effort to provide better alignment preview information along with two-line lateral position information.

- Treatment 5: 101.6-mm (4-in) yellow centerline at ISBL and a 101.6-mm (4-in) white edgeline at brightness level 3

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL and a 101.6-mm (4-in) white edgeline with an brightness level that was somewhat greater than the brightness of the edgeline used in treatment 4. The material used for this treatment was 3M Diamond tape. This treatment addressed the increased contrast thresholds of the older driver and provided a middle point for the range of changes in brightness tested in this study. The texture of the diamond tape gave some mild auditory and vibrotactile feedback to the driver if it was crossed. This tape could also be considered a low profile structured tape since a portion of the waffle pattern is a raised reflective surface relative to an approaching driver. Again, the brighter, raised line was used in an effort to provide better alignment preview information along with two-line lateral position information.

- Treatment 6: 101.6-mm (4-in) yellow centerline at ISBL and a 101.6-mm (4-in) white edgeline at brightness level 4

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL and a 101.6-mm (4-in) white edgeline with an brightness level that was greater than the brightness of the 3M Diamond tape used in treatment 5. The material used for this treatment was a structured tape that provides a brightness near the maximum of what is commercially available. This treatment addressed the increased contrast thresholds of the older driver and provided an upper point for the range of changes in brightness tested in this study. The texture of the structured tape also gave some auditory and vibrotactile feedback to the driver if it was crossed. Again, the brighter, raised line was used in an effort to provide a better preview of the alignment along with two-line lateral position information.

- Treatment 7: 101.6-mm (4-in) yellow centerline at ISBL and a 203.2-mm (8-in) white edgeline at brightness level 2

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL and a 203.2-mm (8-in) white edgeline with an brightness level that was somewhat greater than an ISBL. This treatment addressed the increased contrast thresholds of the older driver by providing a bigger and brighter pavement marking that could be used for moment to moment guidance by the driver using a two-line system. It was felt that a bigger, brighter line would also allow the driver to preview the alignment a little better. This treatment also provided another reference point for the range of changes in brightness.

- Treatment 8: 101.6-mm (4-in) yellow centerline at ISBL and a 203.2-mm (8-in) white edgeline at brightness level 3

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL and a 203.2-mm (8-in) white edgeline with a brightness level that was somewhat greater than the brightness of the edgeline used in treatment 7. Again, the material used to obtain delta two brightness was the 3M Diamond tape. This treatment addressed the contrast threshold problems of the older driver and provided a second middle point for the range of changes in brightness tested in this study. The 3M Diamond tape is a textured tape and it gave some mild auditory and vibrotactile feedback to the driver if it was crossed. Again, the brighter, raised, waffle line was used in an effort to provide better alignment preview information along with lateral position information from a two-line system.

- Treatment 9: 101.6-mm (4-in) yellow centerline at ISBL and a 203.2-mm (8-in) white edgeline at brightness level 4

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL and a 203.2-mm (8-in) white edgeline with an brightness level that was greater than the brightness of the 3M Diamond tape used in treatments 5 and 8. A structured tape that provides the maximum brightness from what is commercially available was used for this treatment. This treatment addressed the increased contrast thresholds of the older driver and provided an upper point for the range of changes in brightness tested in this study. The texture of the structured tape also gave some auditory and vibrotactile feedback to the driver if it was crossed. Again, the brighter, raised line was used in an effort to provide a better preview of the alignment along with two-line lateral position information.

- Treatment 10: 101.6-mm (4-in) yellow centerline at ISBL with yellow RPM at ISBL and standard spacing

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL with yellow RPM at ISBL placed at standard spacing. This was treatment 1 with RPM added. This was an enhanced one-line system that gave increased alignment preview and moment to moment lateral position guidance. The RPM addressed the contrast problem of the older driver by making the centerline brighter in the areas where the RPM were placed. While the alignment preview was not as great as it would have been if the test vehicles were using high-beam headlights, it was felt that it would still be an improvement over treatment 1 conditions.

- Treatment 11: 101.6-mm (4-in) yellow centerline at ISBL and a 101.6-mm (4-in) white edgeline at ISBL with white RPM at ISBL and standard spacing

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL and a 101.6-mm (4-in) white edgeline at ISBL with 101.6-mm (4-in) wide white RPM at ISBL placed at a standard spacing. This was treatment 2 with RPM added on the edgeline. This enhanced two-line system gave increased alignment preview and moment to moment lateral position guidance. The RPM addressed the detection contrast threshold problems of older drivers by making the edgeline brighter in the areas where the RPM were placed. While the alignment preview was not as great as if the test vehicles were using high beam headlights, it was thought that it would be an improvement over treatment 2 conditions.

- Treatment 12: 101.6-mm (4-in) yellow centerline at ISBL and a 203.2-mm (8-in) white edgeline at ISBL with 203.2-mm (8-in) wide white RPM's at ISBL and standard spacing

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL and a 203.2-mm (8-in) white edgeline at ISBL with 203.2-mm (8-in) wide white RPM at ISBL placed at standard spacing. This was treatment 3 with 203.2-mm (8-in) RPM's added on the edgeline. This two-line system enhancement also gave increased alignment preview and moment to moment lateral position guidance. The wide RPM again addressed the detection contrast threshold problems of older drivers by making the edgeline brighter in the areas where the RPM were placed. While the alignment preview was not as great as it might have been if high beam headlights were used, it was felt that it would be an improvement over treatment 3 conditions.

- Treatment 13: 101.6-mm (4-in) yellow centerline at ISBL with yellow RPM at ISBL and standard spacing and a 101.6-mm (4-in) white edgeline at ISBL with white RPM at ISBL and standard spacing

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL with yellow RPM at ISBL placed at standard spacing and a 101.6-mm (4-in) white edgeline at ISBL with white RPM at ISBL placed at standard spacing. This was treatment 3 with RPM added on the centerline and edgeline. This was also an enhanced two-line system that gave increased alignment preview and moment to moment lateral position guidance. Again, the RPM addressed the detection contrast threshold problems of older drivers by making both the centerline and edgeline brighter in the areas where the RPM were placed. As with treatments 10 and 11, the alignment preview was not as great as if the test vehicles were using high beam headlights; however, it was thought that it would be an improvement over treatment 3 conditions.

- Treatment 14: 101.6-mm (4-in) yellow centerline at ISBL and chevrons with high intensity retroreflective sheeting at ISBL and standard spacing

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL and chevrons with high intensity retroreflective sheeting at ISBL placed at standard spacing. This was treatment 1 with the addition of chevrons. This was a two-line system with one of the lines being an off-road line. This treatment gave good moment to moment control because of the centerline and good alignment preview because of the chevrons. The panel felt that the chevron is an effective device and should be used more frequently. This treatment acted as a baseline for using chevrons on two-lane rural roads.

- Treatment 15: 101.6-mm (4-in) yellow centerline at ISBL, a 101.6-mm (4-in) white edgeline at ISBL, and chevrons with high intensity retroreflective sheeting at ISBL and standard spacing

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL, a 101.6-mm (4-in) white edgeline at ISBL, and chevrons with high intensity retroreflective sheeting at ISBL placed at standard spacing. This was treatment 2 with the addition of chevrons. This was a three-line system with one of the lines being an off-road line. This treatment gave good moment to moment control because of the path defined by the centerline and edgeline, and good alignment preview because of the chevrons. This treatment acted as a baseline for using chevrons on rural freeways.

- Treatment 16: 101.6-mm (4-in) yellow centerline at ISBL and a standard post delineator at ISBL and standard spacing

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL and a standard post delineator at ISBL placed at standard spacing. This was treatment 1 with the addition of standard post mounted delineators. This was a two-line system with one of the lines being off of the road. This treatment gave good moment to moment control because of the centerline and good alignment preview because of the delineators. However, based on the unpublished work done by DeJaiffe, there was concern that there could be problems with these types of devices. This treatment acted as a baseline for using delineators on rural freeways.

- Treatment 17: 101.6-mm (4-in) yellow centerline at ISBL and a standard post delineator brighter retroreflective sheeting

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL and a standard post delineator, at standard spacing, at a brightness level that is higher than the ISBL. This was treatment 1 with the addition of brighter post mounted delineators. This was a two-line system with one of the lines being off of the road. This treatment gave good moment to moment control because of the centerline and good alignment preview because of the delineators. The brighter delineators addressed the contrast problems of older drivers. As stated before, there was concern that there could be problems with these types of devices.

- Treatment 18: 101.6-mm (4-in) yellow centerline at ISBL and a fully retroreflectorized standard post delineator at ISBL and standard spacing

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL and a standard post delineator that was fully retroreflectorized from the top of the post to the ground level with a brightness level that was ISBL placed at standard spacing. This was treatment 1 with the addition of a fully retroreflectorized post mounted delineator. This was a two-line system with one of the lines being off of the road. This treatment gave good moment to moment control because of the centerline and good alignment preview because of the delineators. By tieing the delineators to the ground level it was hoped that the problems cited by DeJaiffe would disappear.

- Treatment 19: 101.6-mm (4-in) yellow centerline at ISBL and a fully retroreflectorized standard post delineator with brighter retroreflective sheeting

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL and a standard post delineator that was fully retroreflectorized from the top of the post to the ground level with a brightness level that was somewhat greater than the brightness used for treatment 18 placed at standard spacing. This was treatment 1 with the addition of a brighter than standard, fully retroreflectorized post mounted delineator. This was a two-line system with one of the lines being off of the road. This treatment gave good moment to moment control because of the centerline and good alignment preview because of the delineators. It was felt that the use of the brighter material would address the contrast detection threshold problems experienced by older drivers. Again, by tieing the delineators to the ground level it was hoped that the problems cited by DeJaiffe would disappear.

- Treatment 20: 101.6-mm (4-in) yellow centerline at ISBL and T-post delineators at ISBL and standard spacing

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL with a T-post delineator at ISBL placed at standard spacing. This was treatment 1 with the addition of a T-post. The T-post was a standard flat delineator post where the top of the post was covered with retroreflective material to full post width and a thin strip of retroreflective material ran from the bottom of the retroreflectorized top portion of the post down the length of the post to ground level. This was a two-line system with one of the lines being off of the road. This treatment gave good moment to moment control because of the centerline and good alignment preview because of the T-post delineators. It was felt that the tie-in of the point of retroreflected light at the top of the post down to ground level would address the direction reversal problems associated with delineators cited by DeJaiffe.

- <u>Treatment 21: 101.6-mm (4-in) yellow centerline at ISBL, a 101.6-mm (4-in) white edgeline at ISBL, and T-post delineators at ISBL and standard spacing</u>

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL with a 101.6-mm (4-in) white edgeline at ISBL and a T-post delineator at ISBL placed at standard spacing. This was treatment 2 with the addition of T-posts. This was a three-line system with one of the lines being off of the road. Again, this treatment gave good moment to moment control because of the centerline and good alignment preview because of the T-post delineators. It was hoped that the tie-in of the point of retroreflected light at the top of the post down to ground level would address the delineator direction reversal problem.

- <u>Treatment 22: 101.6-mm (4-in) yellow centerline at ISBL with yellow RPM at ISBL and standard spacing and T-post delineators at ISBL and standard spacing</u>

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL with a yellow RPM at ISBL and a T-post delineator at ISBL placed at standard spacing. This was treatment 10 with the addition of T-posts. This was a two-line system with one of the lines being off of the road. Again, this treatment gave good moment to moment control because of the centerline and good alignment preview because of the RPM and T-post delineators. It was felt that the tie-in of the point of retroreflected light at the top of the post down to ground level would address the delineator direction reversal problem.

- <u>Treatment 23: 101.6-mm (4-in) yellow centerline at ISBL and T-post delineators brighter retroreflective sheeting and standard spacing</u>

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL with a T-post delineator with a brightness level that was greater than the brightness of the T-posts used in treatments 21 and 22 placed at standard spacing. This was a two-line system with one of the lines being off of the road. Again, this treatment gave good moment to moment control because of the centerline and good alignment preview because of the T-post delineators. The increased brightness level of the T-post delineators addressed the contrast threshold problems of the older driver. It was felt that the tie-in of the point of retroreflected light at the top of the post down to ground level would deal with the direction reversal problem sometimes seen with standard delineators.

- <u>Treatment 24: 101.6-mm (4-in) yellow centerline at ISBL, a 101.6-mm (4-in) white edgeline at ISBL, and T-post delineators with brighter retroreflective sheeting and standard spacing</u>

  This treatment was a 101.6-mm (4-in) centerline at ISBL with a 101.6-mm (4-in) white edgeline at ISBL and a T-post delineator with a brightness level that was greater than the brightness of the T-posts used in treatments 21 and 22 placed at standard spacing. This was a three-line system with one of the lines being off of the road. Again, this treatment gave good moment to moment control because of the centerline and good alignment preview because of the T-post delineators. It also improved older driver detection of the third line of the system because of the increased contrast ratio of the brighter T-post. It was felt that the tie-in of the point of retroreflected light at the top of the post down to ground level would also address the delineator direction reversal problem.

- Treatment 25: 101.6-mm (4-in) yellow centerline at ISBL with yellow RPM at ISBL and standard spacing and T-post delineators with brighter retroreflective and standard spacing

  This treatment was a 101.6-mm (4-in) yellow centerline at ISBL with a yellow RPM at ISBL and a T-post delineator at a brightness level that was somewhat greater than the brightness used for treatments 21 and 22 placed at standard spacing. This was a two-line system with one of the lines being off of the road. Again, this treatment gave good moment to moment control because of the centerline and good alignment preview because of the RPM and T-post delineators. It was felt that the tie-in of the point of retroreflected light at the top of the post down to ground level would address the delineator direction reversal problem.

The above treatment descriptions are shown in tabular form in table 1. Note that in table 1, references made to "standard" refer to guidelines in the MUTCD.[50] The term "wide" in reference to spacing of post-mounted delineators or RPM's indicates that the spacing was twice the "standard" spacing recommended in table III-1 (page 3D-3) of the MUTCD. For example, for the 152.4-m (500-ft) radius curves used in the study, the spacing between delineation units was 39.6 m (130 ft) rather than the 19.8 m (65 ft) recommended in the table. With regard to the term "standard" as applied to the design of post delineators, all posts were 121.9 mm (48 in) high, and the delineation material associated with the term "standard" was 457.2 mm (18 in) of retroreflective sheeting. Treatment 1, identified in table 1, is referred to as the control treatment elsewhere in this report. However, the experimental design allows for the comparison of each treatment with every other treatment.

Table 1. Summary of treatments tested in simulator experiments.

	CENTER LINE				EDGE LINE				ROAD EDGE			
Treat. #	Mat'l/Device	Color	Brightness *	Spacing **	Mat'l/Device	Color	Brightness	Spacing	Mat'l/Device	Color	Brightness	Spacing
1	4 in. tape	Yellow	Level 1	N/A	None				None			
2	4 in. tape	Yellow	Level 1	N/A	4 in. tape	White	Level 1	N/A	None			
3	4 in. tape	Yellow	Level 1	N/A	8 in. tape	White	Level 1	N/A	None			
4	4 in. tape	Yellow	Level 1	N/A	4 in. tape	White	Level 2	N/A	None			
5	4 in. tape	Yellow	Level 1	N/A	8 in. tape	White	Level 2	N/A	None			
6	4 in. tape	Yellow	Level 1	N/A	4 in. structured	White	Level 3	N/A	None			
7	4 in. tape + RPM	Yellow	Level 1	MUTCD	None				None			
8	4 in. tape + RPM	Yellow	Level 1	Wide	None				None			
9	4 in. tape	Yellow	Level 1	N/A	4 in. tape + RPM	White	Level 1	MUTCD	None			
10	4 in. tape + RPM	Yellow	Level 1	Wide	4 in. tape + RPM	White	Level 1	Wide	None			
11	4 in. tape	Yellow	Level 1	N/A	4 in. tape + RPM	White	Snowplowable	MUTCD	None			
12	4 in. tape + RPM	Yellow	Level 1	MUTCD	4 in. tape + RPM	White	Level 1	MUTCD	None			
13	4 in. tape + RPM	Yellow	Level 1	MUTCD	4 in. tape + RPM	White	Level 1	Wide	None			
14	4 in. tape	Yellow	Level 1	N/A	None				Standard Chevron	Std.	Hi-Intensity	MUTCD
15	4 in. tape	Yellow	Level 1	N/A	4 in. tape	White	Level 1	N/A	Standard Chevron	Std.	Hi-Intensity	MUTCD
16	4 in. tape	Yellow	Level 1	N/A	None				Low Mount. Chevron	Std.	Hi-Intensity	MUTCD
17	4 in. tape	Yellow	Level 1	N/A	4 in. tape	White	Level 1	N/A	Low Mount. Chevron	Std.	Hi-Intensity	MUTCD
18	4 in. tape	Yellow	Level 1	N/A	None				Standard Flat Post	White	Hi-Intensity	MUTCD
19	4 in. tape	Yellow	Level 1	N/A	4 in. tape	White	Level 1	N/A	Standard Flat Post	White	Hi-Intensity	MUTCD
20	4 in. tape	Yellow	Level 1	N/A	None				Full Reflect. Flat Post	White	Hi-Intensity	MUTCD
21	4 in. tape	Yellow	Level 1	N/A	None				Full Reflect. T-post	White	Hi-Intensity	MUTCD
22	4 in. tape	Yellow	Level 1	N/A	4 in. tape	White	Level 1	N/A	Full Reflect. T-post	White	Hi-Intensity	MUTCD
23	4 in. tape + RPM	Yellow	Level 1	MUTCD	None				Full Reflect. T-post	White	Hi-Intensity	MUTCD
24	4 in. tape	Yellow	Level 1	N/A	None				Full Reflect. T-post	White	Eng. Grade	MUTCD
25	4 in. tape	Yellow	Level 1	N/A	4 in. tape	White	Level 1	N/A	Full Reflect. T-post	White	Eng. Grade	MUTCD

1 in = 2.54 cm

Notes: * Brightness levels are representative of "inservice" levels.
** Wide spacing of RPM's refers to doubling of the spacing between each RPM.

4. LABORATORY SIMULATION STUDY

As noted previously, the empirical studies were begun in the laboratory. The laboratory program was developed to serve as a screening procedure designed to select an economically viable number of the best treatments to test in the controlled field study. Given the realism and the validity of the simulation program, a large number of treatments could be evaluated at a relatively low cost. Further, the laboratory situation allowed the program to be conducted in a relatively short period of time, as compared to the time it would have taken to evaluate the same number of initial treatments in the field.

The simulation study was conducted to measure age differences in the responses of drivers to a baseline condition versus a range of enhanced delineation treatments and to identify treatments that showed the greatest relative increases in effectiveness for older drivers. A simulator using cinematically projected nighttime driving scenes (described in the following "Methodology" section) was used for the evaluations. The results of this study are presented on the following pages.

METHODOLOGY

A repeated-measures research design was used for the laboratory simulator study. The independent variables for this research were delineation treatment and driver age (group). Delineation treatment was a within-subjects variable: all test subjects generated responses to each level of this variable included in the study. Two levels of a blocking variable, headlight illumination, were also tested: low-beam headlight illumination and high-beam illumination. The two levels of this variable were completely crossed with the delineation treatment variable.

Driver age group was a between-subjects variable with three levels: young/middle-aged (18 to 45), young-old (65 to 74), and old-old (75 and over).

The experimental situation was a large-screen (front windshield view) laboratory driving simulator. With this approach, subjects could perform responses to a large number of treatments under controlled viewing conditions that preserved real-world size and perspective cues, presenting the same visual information for any given pavement marking or delineation treatment to all subjects with a high degree of image resolution. The simulator employed a 35-mm cinematic projector to display filmed stimulus scenes. The apparatus included in the simulator configuration is diagrammed in figure 1.

A total of 25 distinct delineation/pavement marking treatments (a baseline treatment and 24 enhanced treatments) was studied. The baseline treatment was a 4-in-wide yellow centerline at a representative "in service" level of brightness with no edgeline or off-road delineation elements. The 24 enhanced treatments varied according to the presence/absence of edgeline and off-road elements and the characteristics (material, color, brightness, and/or

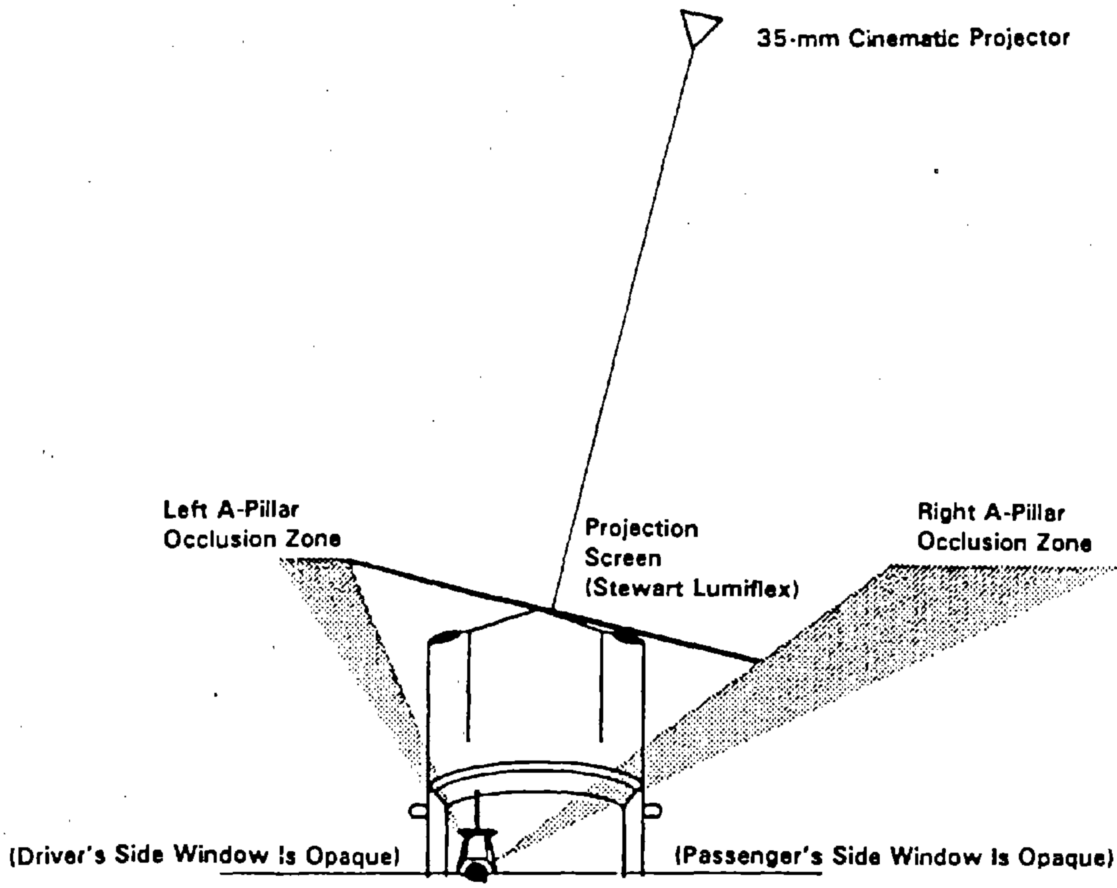

Figure 1. Simulator configuration for laboratory study.

spacing) of those elements. The full set of treatments (numbered 1 through 25) included in the laboratory study are given in chapter 3.

Within the set of treatments 1 through 25, four blocks of treatment conditions, based on shared information elements, were defined: (1) treatments with neither an edgeline on the pavement surface or any off-road elements, (2) treatments including an edgeline but no off-road elements, (3) treatments including off-road elements but no edgeline, and (4) treatments including both edgeline and off-road elements. These treatment blocks are composed of treatments numbered T1 through T25 as follows: block 1 (treatments 1, 7, and 8); block 2 (treatments 2, 3, 4, 5, 6, 9, 10, 11, 12, and 13); block 3 (treatments 14, 16, 18, 20, 21, 23, and 24); and block 4 (treatments 15, 17, 19, 22, and 25). All treatments within a given block were applied to the same type of road feature (curve) at the identical location on the test track. This blocking scheme also served as the starting point for subsequent analyses of treatment effectiveness and treatment-by-age interactions.

The primary dependent measure in the laboratory study was downstream roadway feature recognition. This measure was collected under dynamic stimulus presentation conditions (i.e., during a simulated traversal of a roadway marked/delineated with a specific experimental treatment). The recognition measure was obtained for all 25 treatments (see table 1). In addition, a subjective scaling of relative treatment effectiveness was obtained for each treatment from each subject to complement the roadway feature recognition measure.

Specifically, recognition of the direction of a downstream horizontal curve was measured for the full set of marking/delineation treatments (T1 through T25) under nighttime/low-beam and nighttime/high-beam visibility conditions. In all cases, subjects performed brake pedal depression responses in the simulator to signify that they had detected a downstream curve and could identify its direction while maintaining stable performance on a concurrent tracking task (discussed below). It was emphasized to each subject that he or she must be able to discern with 100-percent confidence the nature of the downstream feature before responding. The resulting recognition distance for correct responses was the measure of effectiveness for this dependent variable, with accuracy data also recorded as a manipulation check.

The means of translating a driver's response in the simulator into a recognition distance depended upon isolating a specific frame number on a cinematic test stimulus (film track), which in curve defined a specific separation distance from the target roadway feature at the time of filming. Telemetry information, which coded the position of the filming vehicle at all times as it approached the roadway feature, permitted the later frame-by-frame specification of the response distance measure. Identifying a particular frame at the time of response was accomplished by means of reading the Society of Motion Picture and Television Engineers (SMPTE) time code laid down on an optical sound track of the film. This time code provided a means of identifying any given frame number as it was projected in the simulator. A personal computer used to record data in the laboratory was used to monitor the time code information from the projector and, at the instant of a subject's brake pedal depression response, determined which frame he or she was viewing when the response was made. The individual's simple reaction time (RT) could then be factored out to yield a corrected recognition latency measure. It should be noted that the RT had been measured earlier to derive the in-car pedal depression latency for a series of signals presented as hood-mounted LED actuations. These data were then used to correct the latencies.

The accuracy of the distance measure of effectiveness (MOE) obtained as described above was +/- 0.518 m (1.7 ft), given the filming vehicle speed of approximately 56.3 km/h (35 mi/h) and the film speed of 30 frames/sec.

When a subject made his or her brake pedal (recognition) response, the screen went blank—i.e., the stimulus scene was instantly removed from view. A verbal description of the direction of curve ahead was then provided by the subject and recorded in the subject's data file by the experimenter, thus determining response accuracy. At this time, the subjective scaling of treatment effectiveness was performed on each trial. This is described later in this section.

As noted earlier, a tracking task was incorporated into the simulator test protocol in conjunction with the curve recognition MOE. This task was designed with particular ecological considerations in mind, i.e., subsidiary task parameters were established such that demands for a driver's shared attention resources and psychomotor (steering) control capabilities realistically represented those associated with actual travel over an identical section of highway under identical conditions.

A low-wattage laser pointer focused a red spot of light on the dynamic stimulus display (driving scene) approximately 15.2 m (50 ft) in front of the vehicle. The subject's task was to keep this spot on the roadway centerline as he or she "drove" in the simulator. Excursions of the pointer dot were not scored; however, subjects were told that tracking accuracy was important to this laboratory evaluation of delineation effectiveness without being informed that tracking performance was not being recorded.

The stimulus materials for the laboratory study were prepared through the process of applying individual delineation treatments and combinations of treatments, as described in tables 1 and 2, on a .40-km (.25-mi) section of test track (with the PC for right and left 7-degree horizontal curves 348.1 m [1142 ft] from the starting point). Then each treatment was filmed under high- and low-beam headlight illumination at night. The contractor's Pavement Durability Research Facility in Pennsylvania was used for the filming of treatment conditions; no peripheral features providing informal delineation cues were visible on the section of the track where filming occurred. A 35-mm Panavision camera with anamorphic lens was used for filming, thus providing a wide-angle view (approximately 73 degrees) with good detail (scene texture) at infinity while also preserving correct perspective-in-depth for the viewer. The camera lens was wide open (largest F-stop) during filming. A filming vehicle with a stable platform was used to provide a precise, rigid camera mount. The film stock was Kodak 500 ISO (35 mm), pushed one stop during processing to present brighter images of the nighttime driving scene.

After filming, preparation of cinematic stimuli involved the production of answer prints from the 35-mm negatives, including SMPTE time code on an optical sound track to identify each frame. The finished answer print was then divided into separate programs corresponding to nighttime/low-beam and nighttime/high-beam conditions and, within each program, the included treatments (except for the baseline test condition) were randomized. The low-beam and high-beam programs were each further divided into two reels: the first and last halves of the randomized sequence of 24 treatments (i.e., excluding the baseline treatment). On test trials, the baseline treatment was always inserted as trial number 1 in each program, then one of the two possible orders of the remaining 24 treatments was presented to a subject and distributed equally within each age group.

Nighttime dummy test drives were also filmed on the test track using scenes not included in any test trials. This footage allowed subjects to practice on the simulated driving and tracking task prior to actual data collection. The dummy footage was produced as an additional program (approximately 5 min in length) and was mounted on a separate reel for projection in the laboratory.

SUBJECT SAMPLE CHARACTERISTICS

The sample size for this research was 45 subjects, 15 each from the young/middle-aged, young-old, and old-old driver test groups. Young/middle-aged subjects ranged in age from 18 to 45, with a mean and median age of 30.1 and 30, respectively. Young-old subjects were aged 65 to 74, with mean and median equalling 68.5 and 68. Old-old subjects were 75 and older, with mean and median equalling 79.9 and 80.

The test sample was recruited through face-to-face contacts with licensed drivers at Pennsylvania photo license (renewal) centers, where the date of birth determines who walks through the door within any biweekly period. This approach has been shown to yield a more representative sampling of older driver (visual) capabilities, relative to the placement of newspaper advertisements or appeals to large audiences (e.g., AARP chapters) for paid test subjects. Each individual recruited at the license renewal centers was offered a cash payment of $40 for the visit to the laboratory.

SUBJECT SCREENING PROCEDURES

Subject screening procedures evaluated static acuity under low luminance (mesopic visibility: 5 cd/m^2) and contrast sensitivity using Snellen and Vistech (VCTS 6500) wall charts, respectively, plus immediate memory span and block design using sub-tests of the revised Wechsler Adult Intelligence Scale (WAIS-R). No outliers denoting possible pathological conditions were identified; thus, no prospective test subjects were excluded from participation in the study. Results of the visual screening procedures, which are of particular interest given the present research objectives, are summarized in the form of group averages in table 2.

TEST PROTOCOL

The test protocol in this study was conducted for one subject at a time, with all data (including screening) for that subject collected during a single visit to the laboratory. As noted above, for half the subjects in a given age group, one of the two possible orders of test trials within each program (visibility condition) was presented; the other half received the other presentation order. However, all subjects first completed data collection for the low-beam program, followed by the high-beam program, to allow for visual adaptation to conditions of increasing stimulus (scene) luminance.

Table 2. Results of visual screening procedures for test subjects.

Visual Performance Measure	Driver Age Group		
	18-45	65-74	75 +
Snellen (Static) Acuity	20/29	20/40	20/51
Vistech Test Patch - Correct Orientation Responses by Spatial Frequency			
1.5 cycles/degree	4.3	3.7	2.4
3.0 cycles/degree	3.4	3.3	2.1
6.0 cycles/degree	2.1	1.2	0.3
12.0 cycles/degree	0.7	0.2	0.1
18.0 cycles/degree	0.3	0.2	0.1

Upon a subject's arrival at the data collection site, the immediate memory span and block design measures were obtained. The instructions for the visual screening were then presented during a period allowing for dark adaptation. Following the adaptation period, the screening data were collected in the darkened laboratory. Next, an introduction to the dynamic simulator display and practice with the tracking task were provided. After a criterion period of 1 min with stable tracking performance and verbal confirmation of readiness from the subject, the sequence of actual test trials for that subject was begun. Varying amounts of practice as required from one individual to another were allowed. The times required to reach the criteria ranged from approximately 2 min for the younger subjects and up to 5 min for the slowest older subjects.

After a subject's curve recognition response on each trial, a subjective assessment of relative treatment effectiveness was obtained. Each study participant was asked to assign a number from 1 to 100 to denote the effectiveness of the markings and delineators in conveying downstream curve directional information on each trial. For the first trial—the baseline condition—subjects were told that this scene contained the lowest level of delineation information; they were thus encouraged to rate all other treatments in relation to the baseline. The amount of time between the completion of a subject's curve recognition response and the subjective rating of treatment effectiveness was consistently less than 30 s. All subjective responses were based on subjects' memory of the just-completed trial.

RESULTS

Objective Results

The results of the laboratory simulation study are reported in the form of descriptive statistics that first summarize response accuracy and then recognition distance for correct responses by treatment, driver age group, and headlight beam condition. Inferential statistical tests for significance of differences noted in selected data sets and blocks of treatments follow. This section concludes with an interpretation of the present findings and a discussion of their implications for design of the subsequent field experiments to be conducted in this research project.

Tables 3 and 4 show the distribution of correct, incorrect, and no response outcomes on the laboratory test trials for the low-beam and high-beam conditions, respectively, for each age group, and for all 25 delineation/marking treatments examined in the study. The results for the two older-driver groups are presented both separately and as an aggregate value ("all old").

It is apparent that many subjects, especially drivers in the older age groups, failed to respond correctly on trials where treatments conveying the least visual information (i.e., pavement markings only) were presented, especially when viewed under high-beam illumination. This outcome may best be attributed to limitations inherent in the filming and stimulus display procedures, as discussed below. Under low-beam illumination conditions, consistently high proportions of correct responses were observed for subjects in all age groups, with isolated exceptions (see treatment 8 data in table 3). Since a relatively high proportion of incorrect responses were obtained under high-beam conditions, the resulting data are judged to be less reliable. For this reason, the conclusions are based primarily on the low-beam data.

Results for the primary MOE—distance of correct recognition responses—are displayed in tables 5 and 6, again organized by illumination condition (low beams versus high beams), driver age group, and treatment number. When inspecting these tables it is important to remember that the indicated values under high-beam conditions were derived from very few data points for selected trial types (see table 4). In all cases, the distance values presented are corrected to take individual differences in simple reaction time into account; that is, the latency associated with each recognition decision by a given subject was separated from the latency associated with the psychomotor component of the brake pedal depression in the simulator by subtracting out a simple RT value for each person based on a preexperimental measure of this capability.

Though it occurred only rarely, it should also be noted that two default values for recognition distance are incorporated into the data presented in tables 5 and 6. If a subject performed a (correct) response that was so quick that a distance farther from the PC than the filming vehicle's starting position was indicated, that individual's RT correction was applied and a maximum recognition distance of 347.6 m (1140.5 ft) upstream of the PC was entered into the data analysis file. At the other extreme, if a subject made a correct verbal response

Table 3. Summary of response accuracy by driver age group and treatment (low-beam conditions).

Treatment Number

	1			2			3			4			5		
Age Group	C	I	NR	C	I	NR	C	I	NR	C	I	NR	C	I	NR
Young/middle-aged	11	4	0	15	0	0	15	0	0	15	0	0	14	1	0
All old	24	5	1	26	4	0	28	2	0	30	0	0	26	3	1
young-old	13	2	0	14	1	0	15	0	0	15	0	0	13	2	0
old-old	11	3	1	12	3	0	13	2	0	15	0	0	13	1	1

	6			7			8			9			10		
Age Group	C	I	NR	C	I	NR	C	I	NR	C	I	NR	C	I	NR
Young/middle-aged	15	0	0	15	0	0	14	1	0	14	0	0	8	7	0
All old	26	2	2	30	0	0	18	6	5	27	2	1	20	8	1
young-old	15	0	0	15	0	0	12	1	1	14	0	1	10	4	0
old-old	11	2	2	15	0	0	6	5	4	13	2	0	10	4	1

	11			12			13			14			15		
Age Group	C	I	NR	C	I	NR	C	I	NR	C	I	NR	C	I	NR
Young/middle-aged	15	0	0	14	1	0	0	0	0	14	1	0	15	0	0
All old	25	3	1	29	1	0	4	4	0	25	4	1	27	1	1
young-old	13	2	0	15	0	0	1	1	0	14	1	0	13	1	0
old-old	12	1	1	14	1	0	3	3	0	11	3	1	14	0	1

	16			17			18			19			20		
Age Group	C	I	NR	C	I	NR	C	I	NR	C	I	NR	C	I	NR
Young/middle-aged	13	2	0	15	0	0	14	1	0	15	0	0	15	0	0
All old	26	4	0	27	3	0	24	6	0	27	2	1	27	2	1
young-old	14	1	0	13	2	0	12	3	0	14	1	0	13	2	0
old-old	12	3	0	14	1	0	12	3	0	13	1	1	14	0	1

	21			22			23			24			25		
Age Group	C	I	NR	C	I	NR	C	I	NR	C	I	NR	C	I	NR
Young/middle-aged	14	1	0	14	1	0	15	0	0	13	2	0	15	0	0
All old	30	0	0	27	3	0	29	1	0	27	3	0	27	3	0
young-old	15	0	0	13	2	0	14	1	0	13	2	0	13	2	0
old-old	15	0	0	14	1	0	15	0	0	14	1	0	14	1	0

C = correct, I = incorrect, NR = no response

Table 4. Summary of response accuracy by driver age group and treatment (high-beam conditions).

Treatment Number

	1			2			3			4			5		
Age Group	C	I	NR	C	I	NR	C	I	NR	C	I	NR	C	I	NR
Young/middle-aged	7	3	5	10	2	3	8	6	1	15	0	0	14	1	0
All old	7	6	17	14	7	8	14	6	10	17	2	1	30	0	0
young-old	3	2	10	8	4	2	7	4	4	14	1	0	15	0	0
old-old	4	4	7	6	3	6	7	2	6	13	1	1	15	0	0

	6			7			8			9			10		
Age Group	C	I	NR	C	I	NR	C	I	NR	C	I	NR	C	I	NR
Young/middle-aged	15	0	0	15	0	0	14	0	1	14	1	0	11	4	0
All old	28	1	1	27	2	0	11	7	12	21	6	3	25	4	1
young-old	15	0	0	13	1	0	8	2	5	10	4	1	13	1	1
old-old	15	1	1	14	1	0	3	5	7	11	2	2	12	3	0

	11			12			13			14			15		
Age Group	C	I	NR	C	I	NR	C	I	NR	C	I	NR	C	I	NR
Young/middle-aged	15	0	0	14	0	0	15	0	0	15	0	0	15	0	0
All old	28	1	1	25	1	3	29	1	0	28	2	0	28	2	0
young-old	14	0	1	12	1	1	14	1	0	14	1	0	14	1	0
old-old	14	1	0	13	0	2	15	0	0	14	1	0	14	1	0

	16			17			18			19			20		
Age Group	C	I	NR	C	I	NR	C	I	NR	C	I	NR	C	I	NR
Young/middle-aged	15	0	0	15	0	0	15	0	0	15	0	0	15	0	0
All old	27	3	0	24	5	1	27	2	1	29	1	0	27	2	11
young-old	15	0	0	15	0	0	14	1	0	15	0	0	13	1	0
old-old	12	3	0	9	5	1	13	1	1	14	1	0	14	1	

	21			22			23			24			25		
Age Group	C	I	NR	C	I	NR	C	I	NR	C	I	NR	C	I	NR
Young/middle-aged	15	0	0	14	0	0	15	0	0	13	1	0	14	1	0
All old	22	8	0	27	3	0	29	0	1	24	4	1	24	5	1
young-old	11	4	0	14	1	0	15	0	0	12	2	0	11	3	1
old-old	11	4	0	13	2	0	14	0	1	12	2	1	13	2	0

C = correct, I = incorrect, NR = no response

Table 5. Mean and standard deviation values (ft) for recognition distance (low-beam conditions).

Treatment Number

	1		2		3		4		5	
Age group	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**
Young/middle	35.0	27.3	207.0	58.5	238.9	21.9	251.0	106.6	227.8	32.8
All old	32.5	31.7	179.4	71.9	217.5	59.6	220.6	116.4	194.4	127.3
Young-old	27.4	29.8	177.0	91.2	205.0	43.1	244.8	159.5	161.3	85.0
Old-old	38.7	34.4	182.2	46.9	232.0	73.7	196.5	37.3	227.6	155.5

	6		7		8		9		10	
Age group	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**
Young/middle	379.6	87.9	271.4	135.7	194.6	27.5	259.6	203.4	390.0	56.3
All old	364.5	85.8	212.4	160.2	172.6	78.4	153.4	173.5	342.2	48.9
Young-old	326.1	56.7	245.7	204.1	171.8	93.0	155.6	191.2	315.3	40.6
Old-old	417.0	93.2	179.2	95.8	174.2	43.2	151.1	160.0	369.1	42.4

	11		12		13		14		15	
Age group	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**
Young/middle	291.0	53.6	354.5	63.7	410.8	91.8	557.6	327.5	785.7	317.9
All old	276.2	107.4	296.9	64.6	332.1	125.2	267.7	151.5	597.7	322.3
Young-old	300.0	116.7	273.0	55.1	307.6	139.1	228.6	60.9	559.3	281.2
Old-old	250.5	94.5	322.5	66.1	360.8	105.4	317.6	213.2	633.5	263.3

	16		17		18		19		20	
Age group	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**
Young/middle	617.1	389.5	579.0	311.0	824.4	363.7	767.8	411.9	699.8	461.4
All old	224.4	137.9	284.7	245.0	463.6	375.8	465.2	356.1	323.3	373.5
Young-old	198.9	67.0	251.6	150.2	277.7	241.1	350.6	250.9	243.0	269.7
Old-old	254.2	190.2	315.6	311.7	649.7	401.1	588.7	418.1	398.1	446.7

	21		22		23		24		25	
Age group	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**
Young/middle	584.5	432.8	703.6	337.2	844.5	369.2	278.2	199.6	822.1	405.2
All old	353.5	298.1	498.6	278.7	601.3	339.2	279.4	332.6	541.0	324.8
Young-old	222.1	86.9	446.0	205.3	551.8	320.6	253.4	278.3	379.7	160.1
Old-old	484.9	373.7	547.5	333.5	650.9	361.8	303.6	385.4	690.9	370.3

Table 6. Mean and standard deviation values (ft) for recognition distance (high-beam conditions).

Treatment Number

	1		2		3		4		5	
Age group	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**
Young/middle	199.4	29.7	82.5	106.1	243.0	116.8	284.5	37.2	297.5	32.4
All old	132.5	91.3	18.2	66.2	89.7	125.2	263.5	37.6	268.5	31.2
Young-old	127.2	109.9	31.5	87.7	107.1	134.3	259.9	33.7	261.6	29.8
Old-old	136.5	92.7	0.5	0.0	72.5	123.4	267.4	42.6	275.4	32.3

	6		7		8		9		10	
Age group	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**
Young/middle	362.5	40.4	302.5	85.5	254.1	57.3	236.5	50.7	450.0	23.9
All old	356.7	63.8	256.2	119.0	161.5	120.6	131.5	97.2	431.3	55.3
Young-old	340.4	43.1	231.3	55.1	157.5	99.2	98.9	104.5	427.0	32.5
Old-old	375.6	79.3	279.4	156.0	172.5	195.1	161.0	84.1	436.0	74.0

	11		12		13		14		15	
Age group	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**
Young/middle	398.1	56.7	661.8	48.7	297.4	81.5	936.8	27535	880.2	332.8
All old	347.533	62.8	596.7	86.2	251.6	79.9	605.6	308.0	523.0	304.0
Young-old	339.1	61.7	576.8	53.5	207.4	52.6	473.5	162.3	404.5	151.1
Old-old	355.9	65.2	615.1	107.2	293.0	80.2	737.8	364.8	641.5	372.7

	16		17		18		19		20	
Age group	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**
Young/middle	786.1	372.6	670.9	362.0	816.1	430.0	849.3	374.6	817.0	451.8
All old	295.1	252.1	301.0	332.4	334.5	412.7	565.9	367.3	506.7	410.1
Young-old	210.1	93.7	162.4	81.5	184.9	229.8	367.0	179.3	310.5	255.3
Old-old	401.5	342.0	532.1	458.3	495.7	507.6	779.1	401.9	689.1	449.4

	21		22		23		24		25	
Age group	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**
Young/middle	756.5	351.7	820.2	346.8	803.8	416.8	456.8	214.8	931.5	320.5
All old	508.6	362.0	453.9	372.1	496.5	360.1	255.2	226.1	636.7	331.8
Young-old	357.6	243.2	300.6	196.5	321.7	192.4	186.0	142.8	464.5	210.1
Old-old	659.8	407.3	619.0	448.6	683.8	408.0	324.5	275.9	782.5	352.3

C = correct, I = incorrect, NR = no response

to the experimenter but, for whatever reason, failed to depress the brake pedal in the simulator before the stimulus scene was terminated, a minimum curve recognition distance of 0.15 m (0.5 ft) upstream of the PC was entered into the data file for that trial. These data substitutions were required for no more than 1 of the 15 responses within an age group, and only for isolated trial types.

For purposes of visual inspection, the mean recognition distances for low-beam trials are shown in figures 2, 3, and 4. Figure 2 shows only the combined older (age >65) group. Figure 3 shows the comparison of older (combined) and younger groups. Figure 4 shows the older driver group means within each of the four experimental treatment blocks. As described previously, there were four blocks of treatment conditions, based on shared information elements. The block definitions are as follows: (1) treatments with neither an edgeline on the pavement surface or any off-road elements, (2) treatments including an edgeline but no off-road elements, (3) treatments including off-road elements but no edgeline, and (4) treatments including both edgeline and off-road elements.

Inferential statistical tests were performed under low- and high-beam conditions to evaluate the effects of age group, delineation treatment, and potential group-by-treatment interactions for each of the four blocks of trials described earlier. The General Linear Models (GLM) procedure in SAS was used for this purpose, with results corrected to calculate F-values for main effects of groups using the mean square error term derived by SAS for the subjects-within-group nesting factor. Where effects of delineation treatment were indicated, post-hoc Scheffé tests were performed to localize the source of significant differences. This procedure evaluated the recognition distance for each treatment in a given analysis block and for every possible paired comparison among treatments to determine if it was different from each of the other treatments included in the block. Also, it may be noted that the responses of the two older driver groups were aggregated for comparison to the young/middle-aged group in these analyses to facilitate the development of practical recommendations for engineering practice provided later in this project.

The results of the GLM analyses for low-beam conditions are shown in tables 7 through 10 for analysis blocks 1 through 4, respectively. Tables 11 through 14 present results of the GLM analyses for the high-beam conditions (blocks 1 through 4). The results presented in these tables reveal consistent main effects of delineation treatment under low-beam illumination for all four analysis blocks, plus a reliable effect of subject age group in blocks 2, 3, and 4. A significant interaction of delineation treatment and age group was noted only in block 3, where treatments included off-road elements but no edgeline on the pavement surface. The localization of these effects is explored later in this report through application of Scheffé post-hoc tests.

The reported results for the Scheffé procedure are based on the performance of all subjects within a given block of treatments. A constant alpha of .05 was used to derive the critical F-value in these tests. It should be emphasized that the Scheffé test is more conservative than some other tests; it controls the type I experimentwise error rate (falsely concluding that an effect is significant) while allowing a higher type II error rate (failing to detect a significant effect). Its application to these data reflects the intent to examine all

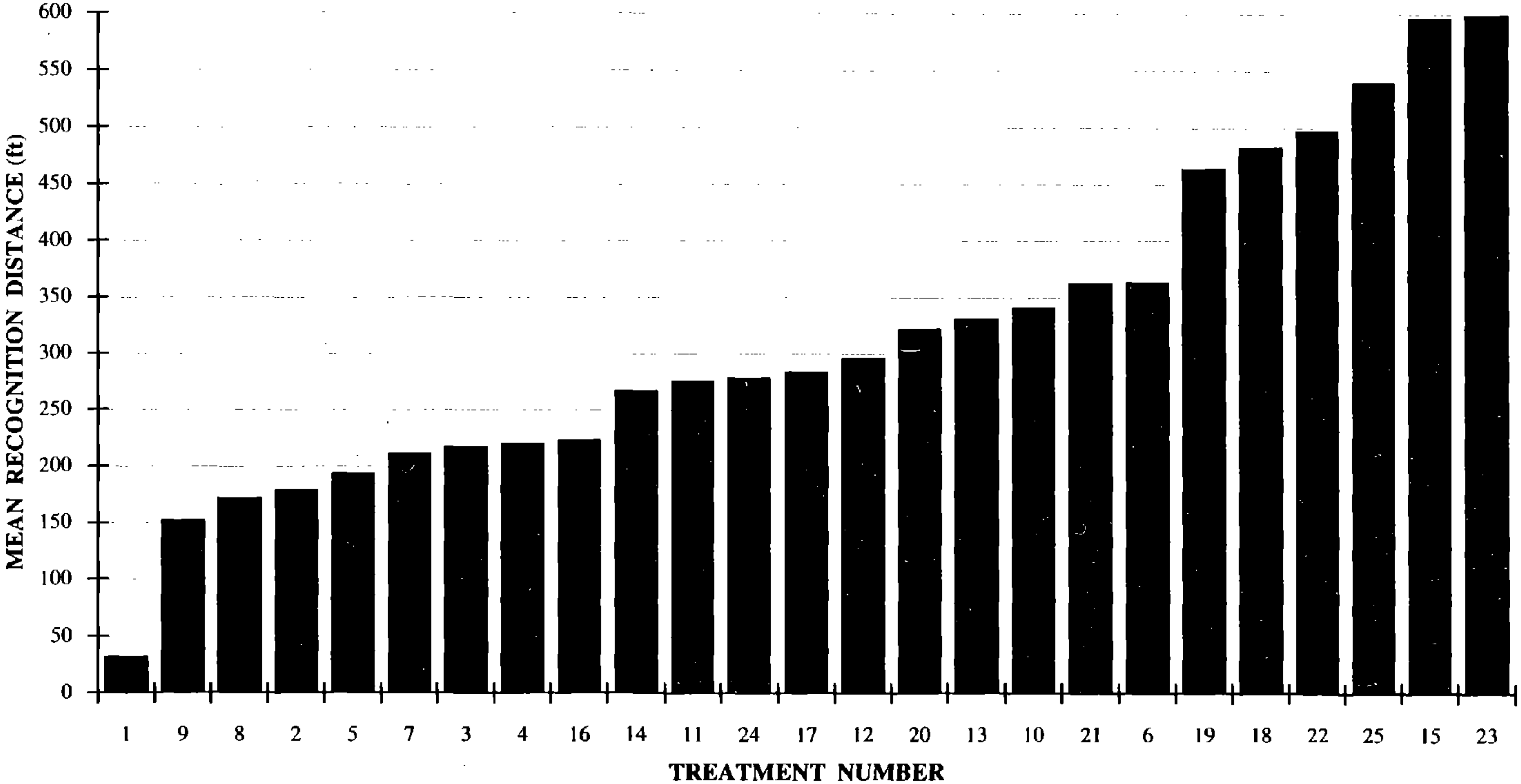

Figure 2. Mean recognition distance (low beams—older subjects).

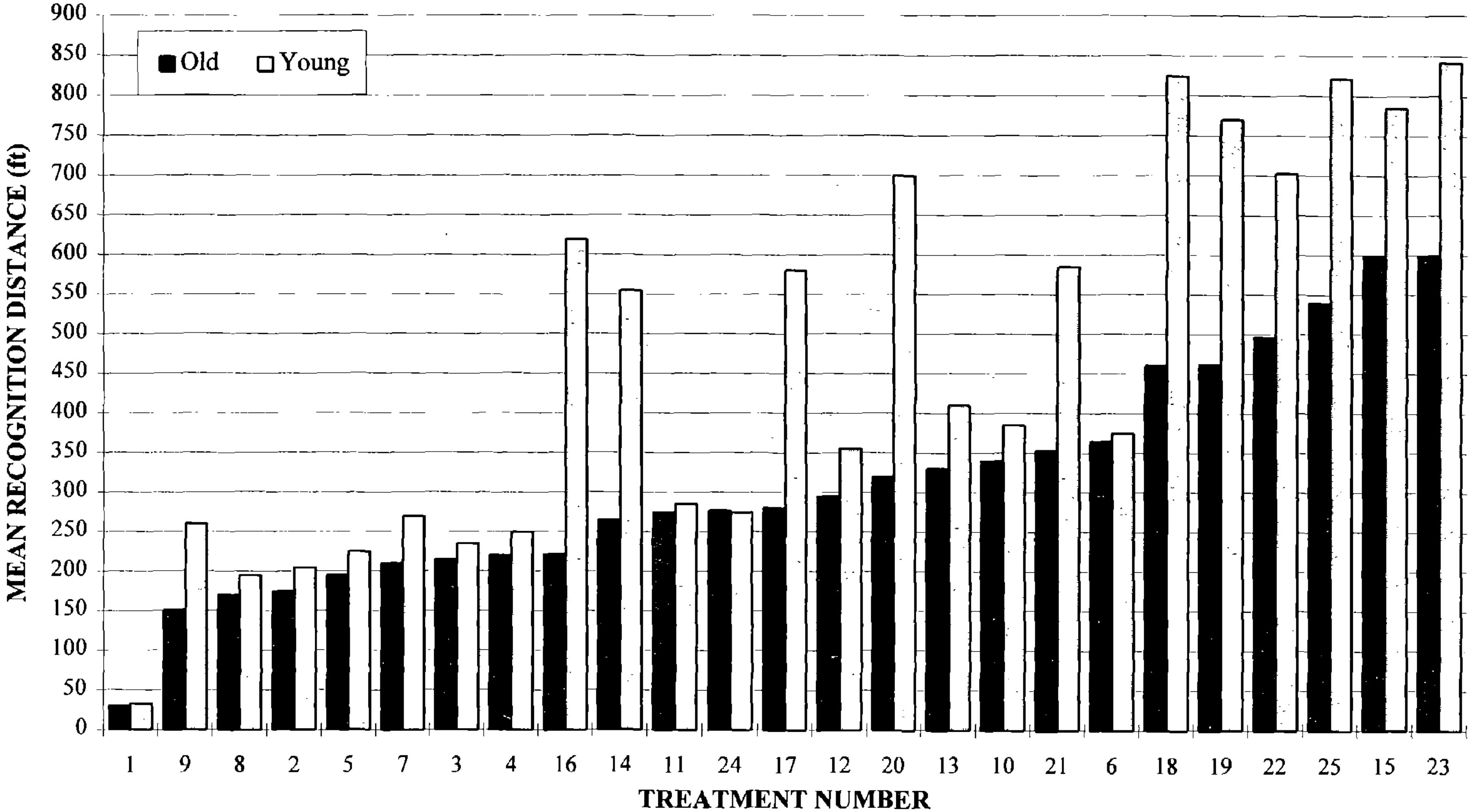

Figure 3. Mean recognition distance (low beams-old versus young).

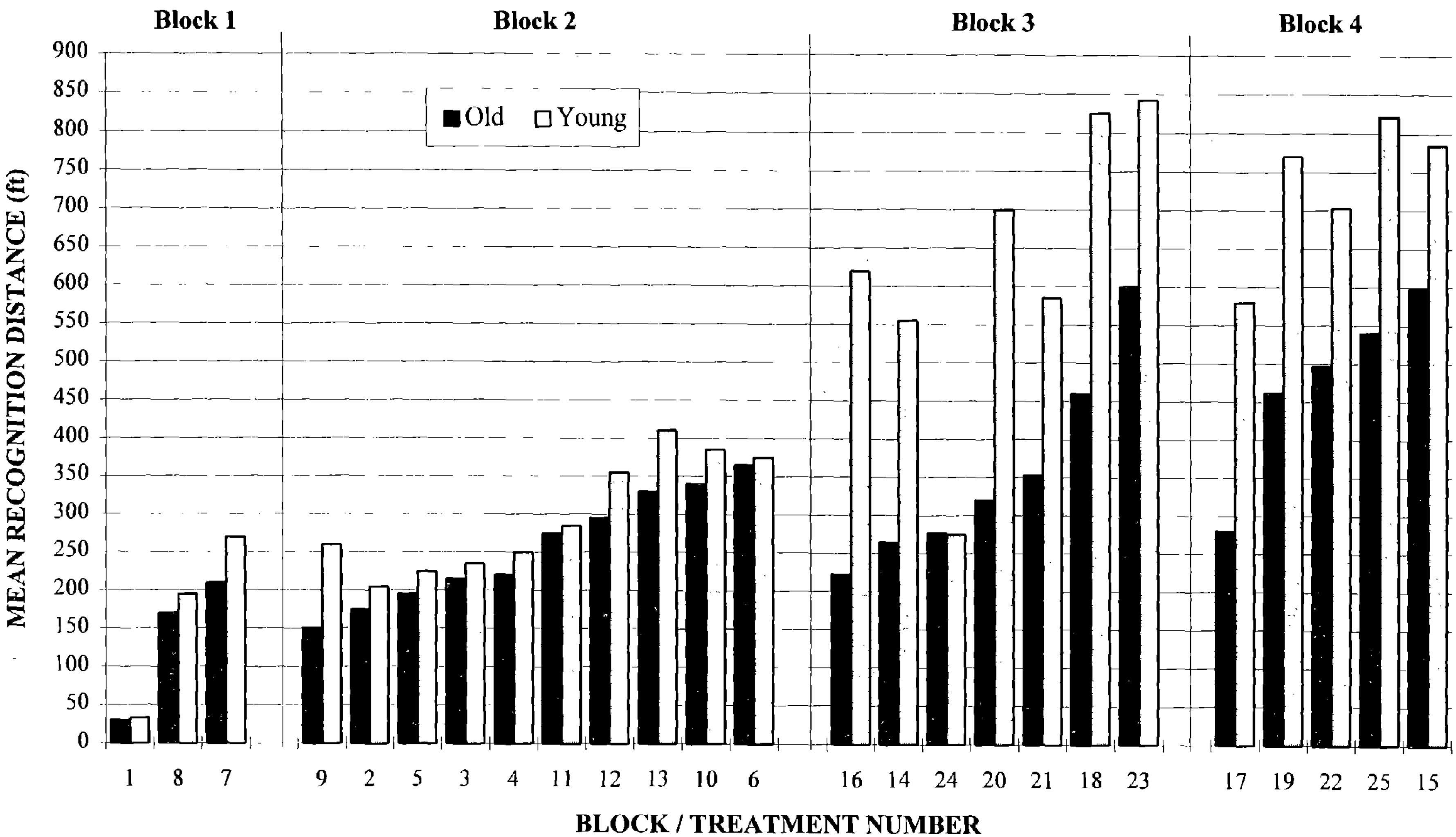

Figure 4. Mean recognition distance by treatment block (low beams-old verssus young).

Table 7. GLM analysis for treatments 1, 7, and 8
(block 1—under low-beam conditions).

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
Age group	1	13420.7	13420.7	0.46	n.s.
Treatment	2	527519.4	263759.7	2451.00	.0001
Age X treat.	2	15604.0	7802.0	0.72	n.s.
Error	64	688782.6	10762.2		
Subject (Grp)	43	1253558.5	29152.5		

n.s. = not significant

Table 8. GLM analysis for treatments 2-6 and 9-13
(block 2—low-beam conditions).

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
Age group	1	133016.7	138826.9	4.52	.05
Treatment	9	1810078.4	231947.2	21.2	000.1
Age X Treat.	9	90323.7	10912.0	1.06	n.s.
Error	342	3244972.4	9488.2		
Subject (Grp)	43	1264055.2	29396.6		

n.s. = not significant

Table 9. GLM analysis for treatments 14, 16, 18, 20, 21, 23, and 24
(block 3—low-beam conditions).

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
Age group	1	4409753.9	4409753.9	11.23	.01
Treatment	6	4568819.2	761469.8	14.1	.0001
Age X Treat.	6	901474.5	150245.7	2.78	.0125
Error	228	12309550.8	53989.2		
Subject (Grp)	4	16886043.0	392698.6		

Table 10. GLM analysis for treatments 15, 17, 19, 22, and 25 (block 4—low-beam conditions).

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
Age group	1	3286757.8	3286757.8	8.97	.01
Treatment	4	1424594.3	356148.5	10.11	.0001
Age X Treat	4	89217.8	22304.4	0.63	n.s.
Error	156	5492927.9	35211.1		
Subject (Grp)	43	15753308.7	366356.0		

n.s.=non-signifcant

Table 11. GLM analysis for treatments 1, 7, and 8, (block 1—high-beam conditions).

Source	DF	Type III SS SSS	Mean Sq.	F Value	Pr > F
Age group	1	38885.3	38885.3	2.65	n.s.
Treatment	2	90550.2	45275.1	13.73	.0001
Age X Treat.	2	1596.5	798.2	0.24	n.s.
Error	34	112122.5	3297.7		
Subject (Grp)	41	602126.3	14686.0		

Table 12. GLM analysis for treatments 2-6, 7, 9, and 10-13 (block 2—high-beam conditions).

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
Age group	1	227951.2	227951.2	16.55	.001
Treatment	2	6923149.4	769238.8	13.73	.0001
Age X Treat	2	109205.9	12133.9	0.24	.0002
Error	309	1032046.8	3339.9		
Subject (Grp)	43	592388.3	13776.4		

Table 13. GLM analysis for treatments 14, 16, 18, 20, 21, 23, and 24 (block 3—high-beam conditions).

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
Age group	1	7541380.7	754130.7	12.0	.01
Treatment	6	3133178.2	522196.3	17.78	.0001
Age X Treat.	6	382152.3	63692.0	2.17	.0469
Error	230	6756046.2	29374.1	0.24	
Subject (Grp)	43	26994910.4	627788.6		

Table 14. GLM analysis for treatments 15, 17, 19, 22, and 25 (block 4—high-beam conditions).

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
Age group	1	4765025.4	4765025.4	10.02	.01
Treatment	4	1355725.4	338931.3	18.09	.0001
Age X Treat.	4	16729.2	4182.3	0.22	n.s.
Error	152	2848375.2	18739.3		
Subject (Grp)	43	20348907.6	473230.4		

pairwise comparisons among treatment conditions of possible interest—a situation that inflates the experimentwise error rate.

The main effect of treatment in the block 1 analysis was localized by the Scheffé test to the baseline condition. Treatment 1 (see table 1) was significantly different than both treatments 7 and 8, while treatments 7 and 8 were not significantly different from each other (F-crit = 3.14; df = 64). These results are summarized in table 15, with asterisks denoting significant differences.

Table 15. Scheffé results
(block 1—low beams).

Comparison Between Treatment Numbers	Difference Between Means
7 versus 8	22.4
7 versus 1	198.7*
8 versus 7	-22.4
8 versus 1	176.4*
1 versus 7	-198.7*
1 versus 8	-176.4*

*Significant difference observed.

In block 2, the Scheffé test (F-crit = 1.91; df = 342) indicated that treatment 2 was significantly different from treatments 6, 10, 11, 12, and 13, but not significantly different from treatments 3, 4, 5, or 9. Treatment 3 was significantly different from treatments 6, 10, 12, and 13 only. Treatment 4 was significantly different from treatments 6, 10, and 13 only. Treatment 5 was significantly different from treatments 6, 10, 12, and 13 only (an identical outcome to the one observed for treatment 3). Treatment 9 was significantly different from treatments 6, 10, 11, 12, and 13, but not different from treatments 2, 3, 4, or 5. Treatment 10 was significantly different from treatments 2, 3, 4, 5, and 9, but not different from treatments 6, 11, 12, or 13. Treatment 11 was significant different from treatments 2, 6, and 9 only. Treatment 12 was significantly different from treatments 2, 3, 5, and 9 only. Treatment 13 was significantly different from treatments 2, 3, 4, 5, and 9, but not different from treatments 6, 10, 11, or 12. These results are summarized in table 16, with asterisks denoting significant differences between treatment pairs.

In block 3, the Scheffé test (F-crit = 2.14; df = 228) indicated that treatments 14, 16, and 24 were significantly different from treatments 18 and 23 only (under low-beam illumination). Treatment 18 was significantly different from treatments 14, 16, and 24, but not different from treatments 20, 21, or 23. Treatments 20 and 21 were significantly different from treatment 23 only. Treatment 23 was significantly different from all other

Table 16. Scheffé results for block 2, low beams.

Comparison between treatment numbers	Difference between means	Comparison between treatment numbers	Difference between means
6 versus 13	27.4	4 versus 6	-157.6*
6 versus 10	32.5	4 versus 13	-130.1*
6 versus 12	74.5	4 versus 10	-125.0*
6 versus 11	106.6*	4 versus 12	-83.1
6 versus 4	157.6*	4 versus 11	-51.0
6 versus 3	163.3*	4 versus 3	5.7
6 versus 5	182.3*	4 versus 5	24.6
6 versus 9	198.6*	4 versus 9	41.0
6 versus 2	199.8*	4 versus 2	42.1
13 versus 6	-27.4	3 versus 6	-163.3*
13 versus 10	5.0	3 versus 13	-135.9*
13 versus 12	47.0	3 versus 10	-130.8*
13 versus 11	79.1	3 versus 12	-88.9*
13 versus 4	130.1*	3 versus 11	-56.7
13 versus 3	135.9*	3 versus 4	-5.7
13 versus 5	154.8*	3 versus 5	18.9
13 versus 9	171.2*	3 versus 9	35.2
13 versus 2	172.3*	3 versus 2	36.4
10 versus 6	-32.5	5 versus 6	-182.3*
10 versus 13	-5.0	5 versus 13	-154.8*
10 versus 12	41.9	5 versus 10	-149.7*
10 versus 11	74.0	5 versus 12	-107.8*
10 versus 4	125.0*	5 versus 11	-75.7
10 versus 3	130.8*	5 versus 4	-24.6
10 versus 5	149.7*	5 versus 3	-18.9
10 versus 9	166.1*	5 versus 9	16.3
10 versus 2	167.2*	5 versus 2	17.5
12 versus 6	-74.5	9 versus 6	-198.6*
12 versus 13	-47.0	9 versus 13	-171.2*
12 versus 10	-41.9	9 versus 10	-166.1*
12 versus 11	32.1	9 versus 12	-124.1*
12 versus 4	83.1	9 versus 11	-92.0*
12 versus 3	88.9*	9 versus 4	-41.0
12 versus 5	107.8*	9 versus 3	-35.2
12 versus 9	124.1*	9 versus 5	-16.3
12 versus 2	125.3*	9 versus 2	1.1
11 versus 6	-106.6*	2 versus 6	-199.8*
11 versus 13	-79.1	2 versus 13	-172.3*
11 versus 10	-74.0	2 versus 10	-167.2*
11 versus 12	-32.1	2 versus 12	-125.3*
11 versus 4	51.0	2 versus 11	-93.2*
11 versus 3	56.7	2 versus 4	-42.1
11 versus 5	75.7	2 versus 3	-36.4
11 versus 9	92.0*	2 versus 5	-17.5
11 versus 2	93.2*	2 versus 9	-1.1

treatments in block 3, except treatment 18. These results are summarized in table 17, with asterisks denoting significant differences between treatment pairs.

In block 4, the Scheffé test (F-crit = 2.43; df = 156) revealed clear-cut results showing that, under low-beam illumination, treatments 15, 19, 22, and 25 were all significantly different from treatment 17, but not from each other. Conversely, treatment 17 was shown to be significantly different from every other treatment included in this analysis block. These results are summarized in table 18, with asterisks denoting significant differences between treatment pairs.

Turning to a consideration of laboratory study findings under high-beam illumination conditions, the Scheffé test for block 1 (F-crit = 3.26; df = 34) localized the treatment effect to treatment 7. Treatment 7 was significantly different from treatments 1 and 8, while treatments 1 and 8 were not different from each other. These results are summarized in table 19, with asterisks denoting significant differences between treatment pairs.

In the analysis of block 2 data under high-beam illumination, the Scheffé test (F-crit = 1.91; df = 309) results were as follows. Treatments 2, 10, and 12 were significantly different from every other treatment included in this block, including each other. Treatments 6 and 11 were significantly different from every other treatment in block 2, except each other. Similarly, treatments 3 and 9 were significantly different from every other treatment in this analysis block, except each other. Treatment 4 was significantly different from every other treatment except treatments 5 and 13; treatment 5 was significantly different from every other treatment except treatments 4 and 13; and treatment 13 was significantly different from every other treatment except treatments 4 and 5. These results are summarized in table 20, with asterisks denoting significant differences between treatment pairs.

In block 3, the Scheffé test (F-crit = 2.14; df = 230) indicated that treatment 14 was significantly different from treatments 16, 18, and 24, but not different from treatments 20, 21, or 23 under high-beam conditions. Treatment 16 was found to be significantly different from all other treatments except treatments 18 and 23. Treatment 18 was significantly different from treatments 14 and 24 only. Treatments 20 and 21 were significantly different from every other treatment—including each other—except treatments 16 and 24. Treatment 23 was significantly different from treatment 24 only, and treatment 24 was significantly different from every other treatment included in this analysis block. These results are summarized in table 21, with asterisks denoting significant differences between treatment pairs.

In block 4, the Scheffé test (F-crit = 2.43; df = 152) revealed that treatments 15 and 22 both were significantly different from treatments 17 and 25 under high-beam conditions, but not different from treatment 19 or from each other. Treatment 17 was significantly different from all other block 4 treatments, while treatment 19 was significantly different from treatment 17 only. Finally, treatment 25 was significantly different than every other treatment in block 4 except treatment 19. These results are summarized in table 22, with asterisks denoting significant differences between treatment pairs.

Table 17. Scheffé results for block 3, low beams.

Comparison between treatment numbers	Difference between means
23 versus 18	89.6
23 versus 20	228.3*
23 versus 21	259.1*
23 versus 14	314.3*
23 versus 16	330.8*
23 versus 24	407.1*
18 versus 23	-89.6
18 versus 20	138.7
18 versus 21	169.5
18 versus 14	224.7*
18 versus 16	241.2*
18 versus 24	317.5*
20 versus 23	-228.3*
20 versus 18	-138.7
20 versus 21	30.8
20 versus 14	86.0
20 versus 16	102.5
20 versus 24	178.7
21 versus 23	-259.1*
21 versus 18	-169.5
21 versus 20	-30.8
21 versus 14	55.1
21 versus 16	71.6
21 versus 24	147.9
14 versus 23	-314.3*
14 versus 18	-224.7*
14 versus 20	-86.0
14 versus 21	-55.1
14 versus 16	16.5
14 versus 24	92.7
16 versus 23	-330.8*
16 versus 18	-241.2*
16 versus 20	-102.5
16 versus 21	-71.6
16 versus 14	-16.5
16 versus 24	76.2
24 versus 23	-407.1*
24 versus 18	-317.5*
24 versus 20	-178.7
24 versus 21	-147.9
24 versus 14	-92.7
24 versus 16	-76.2

Table 18. Scheffé results
(block 4—low beams).

Comparison between treatment numbers	Difference between means
15 versus 25	23.4
15 versus 19	91.5
15 versus 22	96.2
15 versus 17	275.0*
25 versus 15	-23.4
25 versus 19	68.1
25 versus 22	72.8
25 versus 17	251.5*
19 versus 15	-91.5
19 versus 25	-68.1
19 versus 22	4.6
19 versus 17	183.4*
22 versus 15	-96.2
22 versus 25	-72.8
22 versus 19	-4.6
22 versus 17	178.7*
17 versus 15	-275.0*
17 versus 25	-251.5*
17 versus 19	-183.4*
17 versus 17	-178.7*

Table 19. Scheffé results
(block 1—high beams).

Comparison between treatment numbers	Difference between means
7 versus 8	59.3*
7 versus 1	106.8*
8 versus 7	-59.3*
8 versus 1	47.4
1 versus 7	-106.8*
1 versus 8	-47.4

Table 20. Scheffé results for block 2, high beams.

Comparison between treatment numbers	Difference between means	Comparison between treatment numbers	Difference between means
12 versus 10	183.0*	4 versus 12	-349.0*
12 versus 11	254.9*	4 versus 10	-165.9*
12 versus 6	261.3*	4 versus 11	-94.1*
12 versus 5	342.3*	4 versus 6	-87.7*
12 versus 4	349.0*	4 versus 5	-6.7
12 versus 13	352.8*	4 versus 13	3.7
12 versus 9	446.6*	4 versus 9	97.5*
12 versus 3	474.5*	4 versus 3	125.5*
12 versus 2	575.0*	4 versus 2	226.0*
10 versus 12	-183.0*	13 versus 12	-352.8*
10 versus 11	71.8*	13 versus 10	-169.7*
10 versus 6	78.2*	13 versus 11	-97.8*
10 versus 5	159.2*	13 versus 6	-91.4*
10 versus 4	165.9*	13 versus 5	-10.4
10 versus 13	169.7*	13 versus 4	-3.7
10 versus 9	263.5*	13 versus 9	93.8*
10 versus 3	291.5*	13 versus 3	121.7*
10 versus 2	392.0*	13 versus 2	222.2*
11 versus 12	-254.9*	9 versus 12	-446.6*
11 versus 10	-71.8*	9 versus 10	-263.5*
11 versus 6	6.4	9 versus 11	-191.6*
11 versus 5	87.4*	9 versus 6	-185.2*
11 versus 4	94.1*	9 versus 5	-104.2*
11 versus 13	97.8*	9 versus 4	-97.5*
11 versus 9	191.6*	9 versus 13	-93.8*
11 versus 3	219.6*	9 versus 3	27.9
11 versus 2	320.1*	9 versus 2	128.4*
6 versus 12	-261.3*	3 versus 12	-474.5*
6 versus 10	-78.2*	3 versus 10	-291.5*
6 versus 11	-6.4	3 versus 11	-219.6*
6 versus 5	81.0*	3 versus 6	-213.2*
6 versus 4	87.7*	3 versus 5	-132.2*
6 versus 13	91.4*	3 versus 4	-125.5*
6 versus 9	185.2*	3 versus 13	-121.7*
6 versus 3	213.2*	3 versus 9	-27.9
6 versus 2	313.7*	3 versus 2	100.5*
5 versus 12	-342.3*	2 versus 12	-575.0*
5 versus 10	-159.2*	2 versus 10	-392.0*
5 versus 11	-87.4*	2 versus 11	-320.1*
5 versus 6	-81.0*	2 versus 6	-313.7*
5 versus 4	6.7	2 versus 5	-232.7*
5 versus 13	10.4	2 versus 4	-226.0*
5 versus 9	104.2*	2 versus 13	-222.2*
5 versus 3	132.2*	2 versus 9	-128.4*
5 versus 2	232.7*	2 versus 3	-100.5*

Table 21. Scheffé results
(block 3—high beams).

Comparison between treatment numbers	Difference between means	Comparison between treatment numbers	Difference between means
14 versus 20	103.5	18 versus 14	-214.6*
14 versus 21	112.0	18 versus 20	-111.0
14 versus 23	119.8	18 versus 21	-102.6
14 versus 18	214.6*	18 versus 23	-94.7
14 versus 16	250.6*	18 versus 16	36.0
14 versus 24	395.0*	18 versus 24	180.4*
20 versus 14	-103.5	16 versus 14	-250.6*
20 versus 21	8.4	16 versus 20	-147.1*
20 versus 23	16.3	16 versus 21	-138.6*
20 versus 18	111.0	16 versus 23	-130.7
20 versus 16	147.1*	16 versus 18	-36.0
20 versus 24	291.5*	16 versus 24	144.4*
21 versus 14	-112.0	24 versus 14	-395.0*
21 versus 20	-8.4	24 versus 20	-291.5*
21 versus 23	7.8	24 versus 21	-283.0*
21 versus 18	102.6	24 versus 23	-275.2*
21 versus 16	138.6*	24 versus 18	-180.4*
21 versus 24	283.0*	24 versus 16	-144.4*
23 versus 14	-119.8		
23 versus 20	-16.3		
23 versus 21	-7.8		
23 versus 18	94.7		
23 versus 16	130.7		
23 versus 24	275.2*		

Table 22. Scheffé results
(block 4—high beams).

Comparison between treatment numbers	Difference between means
25 versus 19	82.8
25 versus 15	97.7*
25 versus 22	166.3*
25 versus 17	302.0*
19 versus 25	-82.8
19 versus 15	14.9
19 versus 22	83.5
19 versus 17	219.2*
15 versus 25	-97.7*
15 versus 19	-14.9
15 versus 22	68.6
15 versus 17	204.3*
22 versus 25	-166.3*
22 versus 19	-83.5
22 versus 15	-68.6
22 versus 17	135.7*
17 versus 25	-302.0*
17 versus 19	-219.2*
17 versus 15	-204.3*
17 versus 22	-135.7*

The interpretation of the (recognition distance) post-hoc analysis results is aided by visual inspection of the descriptive data tables presented earlier (tables 5 and 6), permitting directions of differences to be associated with those comparisons between treatment pairs that have been found to be statistically significant by the Scheffé procedure. In particular, the effectiveness of alternative treatments under low-beam viewing conditions, specifically for older test subjects, deserves further discussion as the most representative and the most safety-relevant among the conditions examined in this effort.

The first step in the interpretation of these data involved the winnowing of clearly ineffective treatments within each block from the set of candidates for eventual field testing. Treatments of this nature are identified by their shorter recognition distances and/or their statistically significant differences from other treatments within a block that exhibits the best (longest) recognition distances.

In block 1—treatments with neither an edgeline or any off-road elements—the low-beam data show that treatments 7 and 8 both resulted in significantly longer correct recognition distances than the baseline condition, treatment 1. However, baseline performance was extremely poor (and quite comparable) for both older and younger subjects, as appropriate to the dearth of delineation cues provided the driver under this test condition. Thus, a significant improvement relative to the baseline condition still resulted in a (mean) preview distance for correct recognition of the curve of less than 3 s at 88.5 km/h (55 mi/h) for older subjects for treatments 7 and 8, which were not significantly different from each other. It is, therefore, concluded that neither treatment 7 or treatment 8 should be selected for further consideration in this research.

In block 2—treatments including an edgeline but no off-road elements—the low-beam data indicate a cluster of less effective treatments: numbers 2, 3, 4, 5, and 9. These treatments all resulted in significantly shorter correct recognition distances than the best performing treatments in this group (numbers 6, 10, and 13). Treatments 11 and 12 were of intermediate effectiveness, performing significantly better than three and four members of the lowest cluster of treatments, respectively, and resulting in significantly poorer performance than only one of three treatments in the best cluster. This pattern of findings supports a decision to exclude treatments 2, 3, 4, 5, and 9 from consideration for further testing, but not to exclude either treatment 11 or 12, pending the additional comparisons described below.

In block 3—treatments including off-road elements but without an edgeline—one treatment, number 23, resulted in a correct recognition distance clearly and significantly better than all other treatments in this group. Inspection of the remaining treatments identifies two tiers in terms of treatment effectiveness. A cluster of more effective treatments includes treatments 18, 20, and 21, which distinguishes treatments 14, 16, and 24 as the least effective members of this block. While, aside from treatment 23, only treatment 18 was found to be significantly better than the three poorest performers in the block, an examination of older driver performance in isolation (see table 5) supports a decision to exclude treatments 14, 16, and 24 from further testing but to retain treatments 18, 20, 21, and 23 at this stage of analysis.

Finally, in block 4—treatments including both an edgeline and off-road elements—the results are clear-cut. One treatment, number 17, resulted in significantly shorter correct recognition distances than every other treatment in this grouping; also, its relative ineffectiveness was most pronounced for test subjects age 65 or older. This finding leads to the conclusion that this single treatment should be dropped from consideration for further testing, while the remaining treatments in this group should be retained.

This winnowing-out exercise cumulatively results in the elimination of 11 of the initial set of 25 (including baseline) treatments evaluated in the laboratory study. The remaining 13 treatments, plus the baseline, were considered as candidates for field testing, with additional discriminations among treatments dependent upon additional analysis of the (low-beam) data set.

Two additional tests of treatment performance, in terms of correct recognition distances from the PC, evaluated treatments in relation to the baseline condition but irrespective of the blocking scheme. It is important to note that the error term for this analysis approach reflects the variance in performance for all treatments considered together (rather than confining tests of differences to a specific block) within which subjects' responses for the younger or older group may have been more homogeneous than in another block. At issue was the level of agreement between treatments identified as significantly better performers using this analysis of nonblocked data.

The first of these analyses examined distances for correct target recognition under low-beam illumination for all subjects, while the second analysis examined the same response measure for 65-or-older subjects only. The "all-subjects" analysis provided continuity with the previously reported post-hoc tests, but without the blocking of treatments. The "older-subjects-only" analysis provided a clearer look at the performance of this group in isolation, reflecting the present research priority to accommodate the older driver. In the first case, a GLM analysis demonstrated significant effects of age group ($F = 9.96$; $df = 1$; $p < .003$) and delineation treatment ($F = 30.8$; $df = 24$; $p < .0001$), plus an interaction between these two variables ($F = 4.29$; $df = 24$; $p < .0001$). As before, the mean square value for subjects nested within group (overall) was used as the error term to evaluate the magnitude of the group effect. In the second case, the GLM analysis evaluated just the effect of delineation treatment, since only the older subjects' performances were examined. This analysis demonstrated a significant effect of treatments ($F = 10.1$; $df = 24$; $p <$ 0001).

Given the evidence of the significant effects of treatment, and of varying treatment effectiveness as a function of driver age (i.e., the age-group-by-treatment interaction), further Scheffé post-hoc tests were justified. Again, alpha was preset at .05 to define the critical value against which differences between means would be evaluated. The Scheffé outputs revealed the treatments that afforded subjects significantly greater recognition distances than the baseline condition (for both data sets described above). Results are displayed in the bar graph shown in figure 5.

With reference to this figure, the two gaps along the abscissa indicate the criterion levels for differences between each mean recognition distance for the various treatments, compared to the mean recognition distance for the baseline condition. The first gap indicates that all treatments except treatments 2, 3, 4, 5, 7, 8, 9, 11, and 24 resulted in significantly better performance than the baseline, taking all subjects' (correct) responses into account. The second gap indicates that only treatments 15, 18, 19, 22, 23, and 25, resulted in significantly better performance than the baseline when only the responses of the 65-or-older subjects were considered. This finding is directly attributable to the increased variance among older subjects' data. For descriptive purposes, the performance of all subjects and of the 65-or-older subjects only for every treatment included in the laboratory study is displayed in figure 5.

There is a straightforward relationship between the findings of these additional analyses and the prior analysis of blocked data. Both approaches found the same six treatments to be most effective. The same cluster of least effective treatments was also identified (i.e., numbers 2, 3, 4, 5, 7, 8, and 9). Treatment 24 had been winnowed out earlier, and in these analyses failed to reach either criterion indicating performance significantly better than baseline. Treatments 14, 16, and 17, which also were previously winnowed out as candidates for field testing, did result in performances exceeding the criterion for all subjects; however, among this group these three treatments were associated with the poorest performance among older drivers, and may thus be rejected as countermeasures likely to be of particular benefit to these highway users. Only in the case of treatment 11 did the additional analyses reveal a treatment that had not been definitely excluded earlier. However, treatment 11 failed to meet the less stringent (all subjects') criterion for performance significantly better than baseline. Based on this outcome, treatment 11 is not recommended for field testing.

Subjective Results

The remaining data set to be evaluated in the analysis of treatment conditions pertains to the subjective ratings of treatment effectiveness. Recall that the ratings were obtained using the magnitude-of-estimation technique, with subject judgments being based on a 100-point scale. Further, subjects were instructed to rate each treatment relative to the baseline delineation treatment (treatment 1). Tables 23 and 24 show the mean subjective ratings for each treatment, with the values based on all responses, for low-beam and high-beam conditions, respectively. Tables 25 and 26 show the mean ratings associated with correct responses only for both illumination conditions.

The subjective data judged most reliable and most relevant are those associated with correct responses under low-beam conditions (tables 25 and 26). This data set was subjected to additional review and analysis based on the ranking of the treatments and the correspondence between the subjective and objective data.

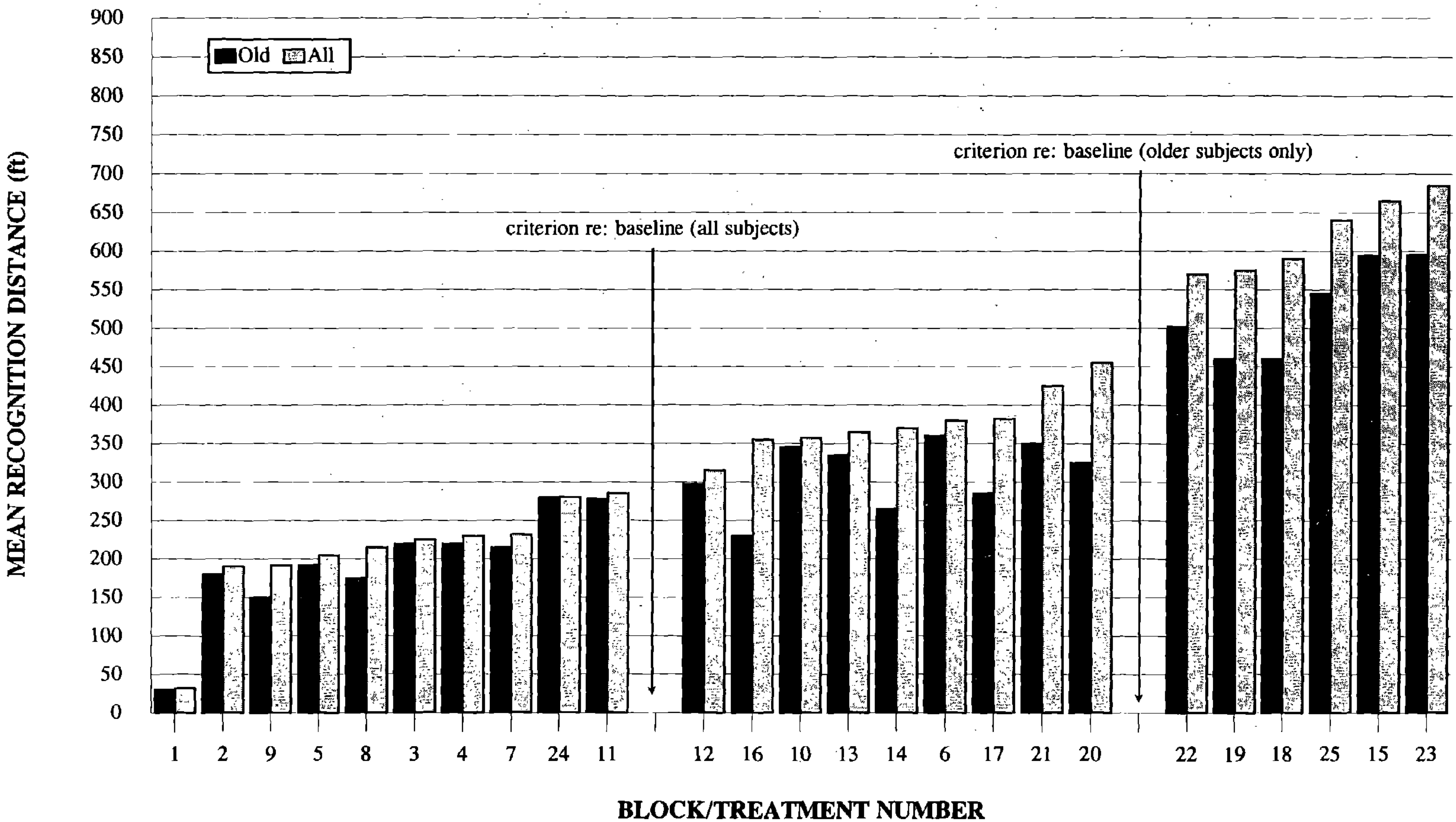

Figure 5. Mean recognition distance--old versus all subjects (with criteria for significance indicated).

Table 23. Mean and standard deviation values for subjective ratings (low-beam conditions—all responses).

Treatment Number

	1		2		3		4		5	
Age group	Mean	S D	Mean	S D	Mean	S D	Mean	S D	Mean	S D
Young/middle	10.9	8.9	17.4	11.4	17.5	10.3	20.4	14.3	29.2	16.3
All old	14.6	15.6	36.1	23.1	38.2	23.0	35.5	23.1	39.5	22.7

	6		7		8		9		10	
Age group	Mean	S D	Mean	S D	Mean	S D	Mean	S D	Mean	S D
Young/middle	27.9	14.1	29.7	20.1	16.3	12.7	21.1	10.2	25.8	15.3
All old	46.5	26.6	39.9	22.6	27.1	23.8	32.2	25.7	30.6	19.2

	11		12		13		14		15	
Age group	Mean	S D	Mean	S D	Mean	S D	Mean	S D	Mean	S D
Young/middle	23.3	13.8	33.6	13.7	31.2	17.2	44.7	15.7	39.6	17.7
All old	34.0	24.5	44.6	22.4	41.3	21.5	46.6	2538	40.8	24.2

	16		17		18		19		20	
Age group	Mean	S D	Mean	S D	Mean	S D	Mean	S D	Mean	S D
Young/middle	47.0	15.1	43.0	17.9	45.3	21.0	48.2	19.0	44.6	21.2
All old	47.9	25.2	44.9	25.8	43.1	23.5	39.4	18.2	43.3	22.8

	21		22		23		24		25	
Age group	Mean	S D	Mean	S D	Mean	S D	Mean	S D	Mean	S D
Young/middle	41.0	19.3	38.0	17.2	48.6	22.8	34.8	18.9	46.8	21.3
All old	52.0	27.3	41.8	25.9	44.7	25.6	36.6	23.1	46.2	24.3

Table 24. Mean and standard deviation values for subjective ratings (high-beam conditions—all responses).

Treatment Number

	1		2		3		4		5	
Age group	Mean	S D	Mean	S D	Mean	S D	Mean	S D	Mean	S D
Young/middle	6.1	7.8	11.3	11.6	11.3	10.3	20.6	11.0	22.9	11.8
All old	9.2	13.8	9.4	13.1	10.2	13.2	30.8	24.1	36.6	25.2

	6		7		8		9		10	
Age group	Mean	S D	Mean	S D	Mean	S D	Mean	S D	Mean	S D
Young/middle	22.8	12.3	23.5	13.3	20.5	30.7	19.9	11.5	19.4	14.2
All old	33.0	22.5	21.3	17.0	11.9	13.9	19.5	18.1	23.8	19.1

	11		12		13		14		15	
Age group	Mean	S D	Mean	S D	Mean	S D	Mean	S D	Mean	S D
Young/middle	21.3	15.3	26.8	13.1	26.9	18.2	43.2	17.4	41.0	18.1
All old	41.2	57.5	24.3	21.5	27.8	19.9	35.9	22.4	35.8	23.3

	16		17		18		19		20	
Age group	Mean	S D	Mean	S D	Mean	S D	Mean	S D	Mean	S D
Young/middle	41.8	18.0	39.8	17.9	48.8	23.5	43.9	20.6	46.0	24.9
All old	38.8	24.0	36.4	23.7	35.5	23.2	40.7	23.0	41.0	24.2

	21		22		23		24		25	
Age group	Mean	S D	Mean	S D	Mean	S D	Mean	S D	Mean	S D
Young/middle	42.6	22.5	43.8	20.9	50.1	20.5	40.7	20.1	45.5	23.5
All old	39.5	23.4	44.3	23.6	47.4	22.8	36.7	21.9	34.2	21.0

Table 25. Mean and standard deviation values for subjective ratings (low-beam conditions—correct responses only).

Treatment Number

	1		2		3		4		5	
Age group	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**
Young/middle	9.0	8.8	17.4	11.4	17.5	10.3	20.4	14.3	30.6	16.0
All old	12.0	12.7	35.8	22.6	36.8	22.1	35.5	23.1	41.5	22.8

	6		7		8		9		10	
Age group	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**
Young/middle	27.9	14.1	29.7	20.1	16.4	13.2	21.1	10.6	23.2	15.8
All old	45.7	24.9	39.9	22.6	23.1	18.7	31.0	25.5	33.5	20.5

	11		12		13		14		15	
Age group	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**
Young/middle	23.3	13.8	33.1	14.1	31.2	17.2	44.5	16.2	39.6	17.7
All old	34.8	25.3	45.9	21.6	40.6	21.4	47.5	26.3	40.5	21.9

	16		17		18		19		20	
Age group	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**
Young/middle	45.7	15.7	44.0	17.9	46.6	21.3	48.2	19.0	44.6	21.2
All old	47.8	26.6	44.7	26.4	37.5	20.0	39.1	19.1	40.7	22.3

	21		22		23		24		25	
Age group	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**
Young/middle	40.7	20.0	39.2	17.0	48.6	22.8	34.4	18.2	45.8	21.3
All old	52.0	27.3	39.6	25.3	43.1	24.6	37.1	21.4	35.4	24.2

Table 26. Mean and standard deviation values for subjective ratings (high-beam conditions—correct responses only).

Treatment Number

	1		2		3		4		5	
Age group	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**
Young/middle	4.5	3.0	12.8	11.6	9.7	4.8	20.6	11.0	22.4	12.1
All old	16.1	17.7	7.6	8.8	11.5	14.2	31.8	23.5	36.6	25.2

	6		7		8		9		10	
Age group	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**
Young/middle	22.8	12.3	23.5	13.3	21.9	13.5	21.2	10.8	19.0	13.6
All old	34.3	22.6	21.1	17.2	19.0	15.2	20.5	18.6	22.4	18.8

	11		12		13		14		15	
Age group	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**
Young/middle	21.3	15.3	26.8	13.1	26.9	18.2	43.2	17.4	41.0	18.1
All old	41.8	51.0	24.4	19.8	27.0	19.9	34.8	22.0	36.0	24.1

	16		17		18		19		20	
Age group	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**
Young/middle	41.8	18.0	39.8	17.9	48.8	23.5	43.9	20.2	46.0	24.9
All old	40.9	24.3	47.5	23.6	34.8	24.1	39.5	22.4	40.9	23.3

	21		22		23		24		25	
Age group	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**	**Mean**	**S D**
Young/middle	42.6	22.5	43.8	20.9	50.1	20.5	39.2	20.1	43.4	22.9
All old	39.0	23.4	45.0	23.2	48.3	22.6	37.8	22.6	32.5	21.4

Inspection of the older driver/low-beam subjective data relative to the corresponding objective data reveals several discrepancies. Treatments 10 and 25, which were recommended for field testing on the basis of recognition distance measures, were among the more lowly rated treatments. Conversely, while older subjects rated treatments 5, 7, 14, 16, and 17 among the top half in terms of subjective effectiveness, these treatments were excluded from the field testing recommendations on the basis of the recognition distance results. Of this group, treatments 5, 7, and 16, in particular, produced relatively shorter recognition distance for older drivers. The disparities between the objective and subjective test results bring up the question of the utility of the subjective data in choosing treatments.

To investigate the relationship between the subjective and objective data, the treatments were ranked from best to worst in terms of both the recognition distance measure (objective data) and the subject rating of each treatment (subjective data). Selected data from the low-beam data set are shown graphically in figures 6, 7, and 8. Figure 6 shows the comparison of older versus younger drivers with respect to the subjective ratings. The figure shows the rankings of the older drivers ordered from the treatment rated best (treatment 21) to that rated worst (treatment 1), along with the corresponding treatment rating by the younger drivers. The correspondence between the ranks of the two groups of drivers was assessed via the use of the Spearman Rank correlation (rho) and was found to be rho=.577, indicating a reasonable overall relationship between the two groups.

Figure 7 shows the comparative rankings between the subjective and objective rankings for the combined older drivers (age > 65) under low-beam conditions. Figure 8 shows the same data for the younger (driver group age 18 < 45). As can be seen from a visual inspection and comparison of figures 7 and 8, there is a much greater disparity between the subjective and objective results for the older drivers than for the younger group. These rankings were also subjected to an analysis via the Spearman Rank correlation. The rho values for older and younger drivers were .354 and .907, respectively.

The poor relationship between objective and subjective results for older drivers suggests that the subjective ratings of this group are not a good indicator of the performance that can be expected from pavement marking and delineation treatments. However, it is possible that the poor relationship may be a function of the rating procedure used. That is, it is known that older individuals exhibit some deficiencies in short-term memory. Coupling this with the fact that the subjective ratings required the subjects to recall the baseline treatment (treatment 1) as a point of comparison, it is possible that short-term memory deficits account for the resultant disparity between older and younger subjects. The issue of subjective ratings was further investigated during the field tests, since such ratings were obtained for each treatment using a similar procedure. However, given the possibility of older driver problems associated with short-term memory, the subjective data for the field tests used a modification of the procedure used for the laboratory study. Specifically, the subjects in the field trials had access to a photograph of the baseline treatment so that the rating of each treatment was not based totally on recall.

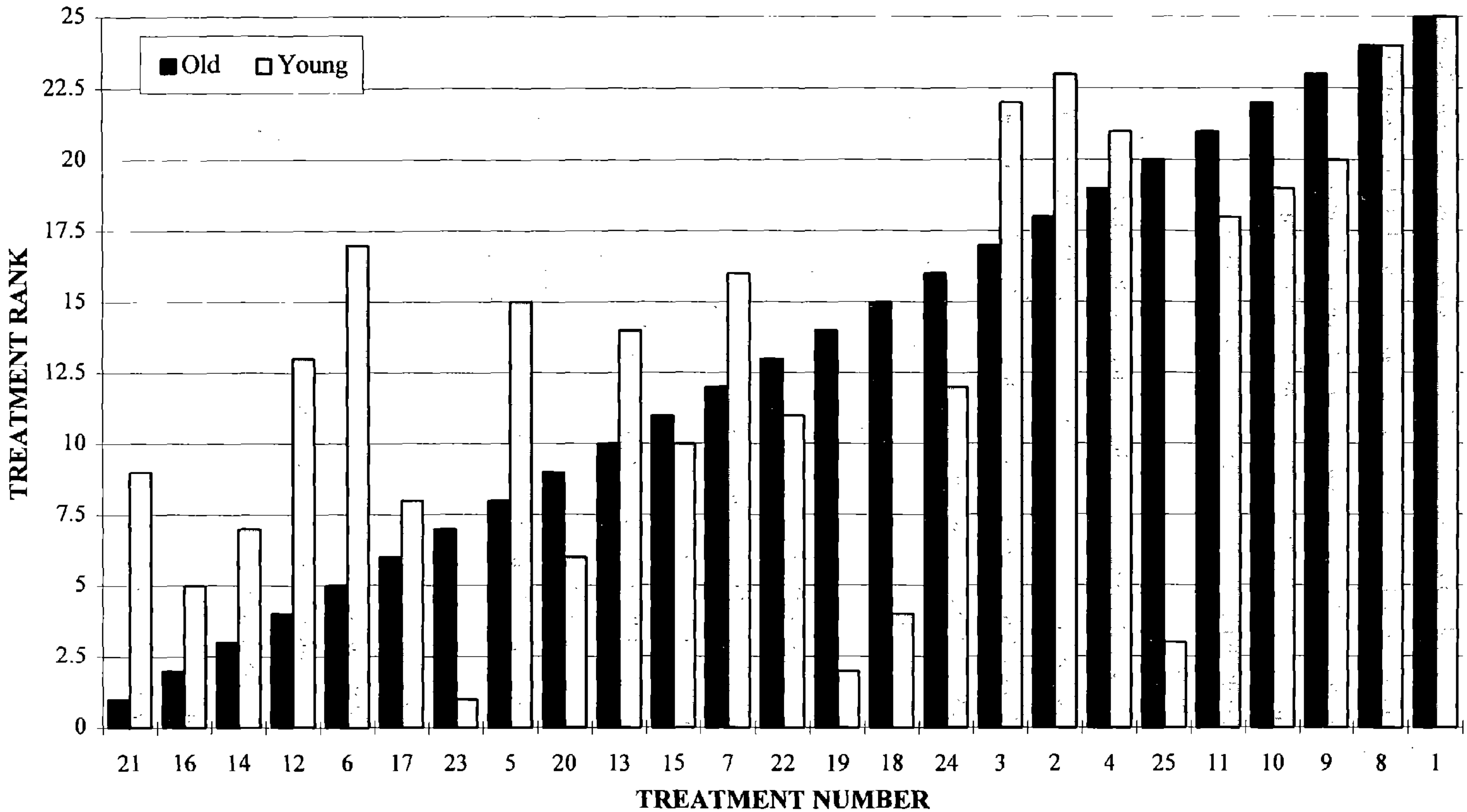

Figure 6. Comparison of subjective rank of treatments (older versus younger subjects).

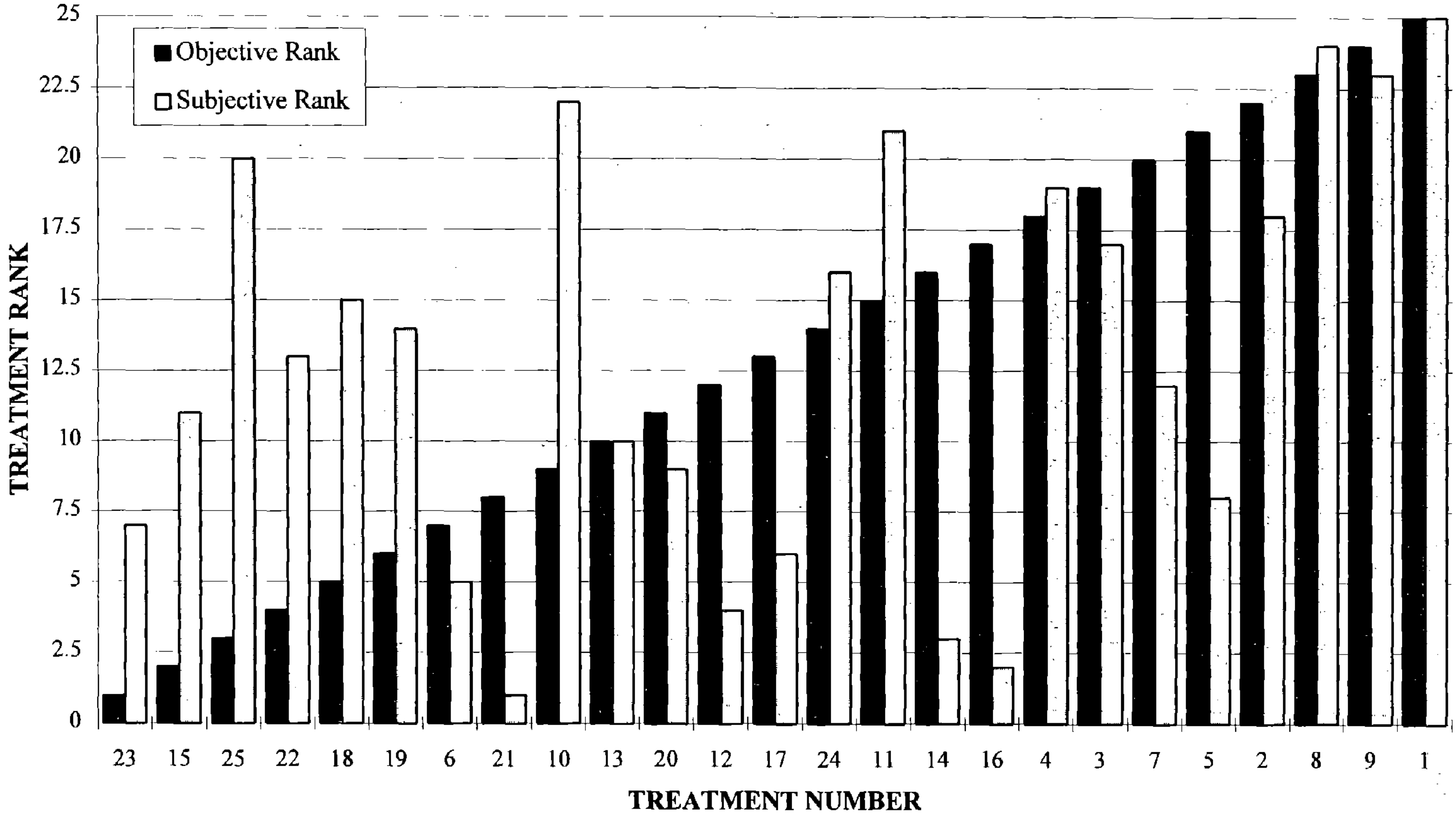

Figure 7. Comparison of objective versus subjective rank (older subjects).

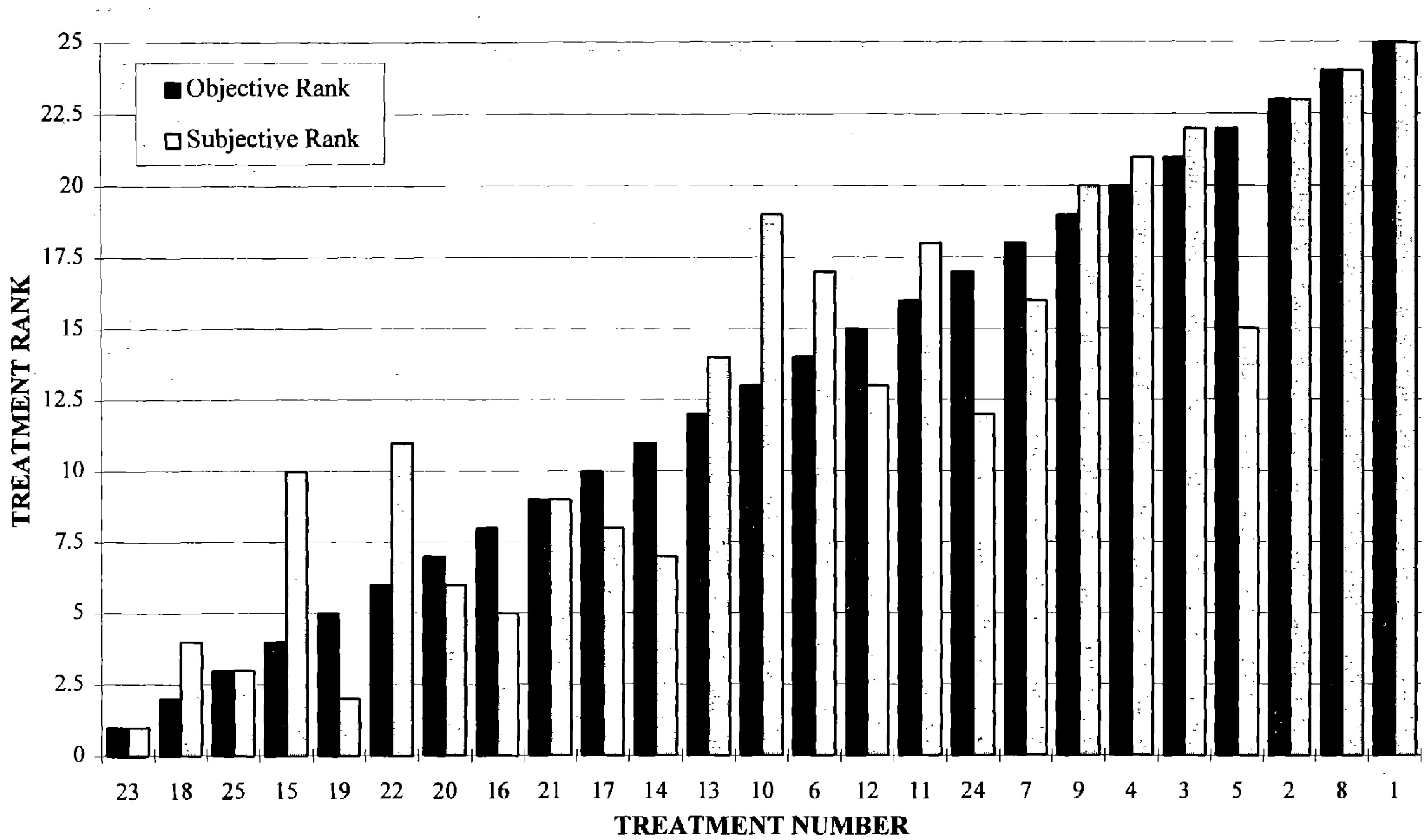

Figure 8. Comparison of objective versus subjective rank (young subjects).

Because of the poor relationship between subjective and objective results for older subjects, and because of questions as to why this occurred, the subjective data had little impact on the choice of treatments for inclusion in the field studies.

5. FIELD EVALUATIONS

INTRODUCTION AND OVERVIEW

Twelve pavement marking and delineation treatments were selected for field testing, primarily on the basis of the results of preliminary laboratory evaluations. With the exception of one treatment selected as a control, the treatments were expected to address deficiencies of older drivers.

The treatments were tested on a closed, oval test facility using test subjects. Two types of measures were used: recognition distance and visual occlusion time. The recognition distance measures were static tests done with pairs of subjects in a test vehicle. Visual occlusion trials were conducted with the subject driving the test vehicle. The test vehicle was instrumented and outfitted with an onboard computer to provide automatic data collection and avoid the need for manual data reduction.

To control the amount of time older test subjects were required to spend on the track for each session, a balanced incomplete-blocks design was used. This design allowed each subject to be exposed to eight treatments (six treatments plus the baseline treatment on a curve in each direction). The design permitted the analysis of effects for treatments, age, curve direction, and drivers within blocks, as well as interaction effects between treatments and age and between treatments and curve direction.

INDEPENDENT VARIABLES (TREATMENTS EVALUATED)

The independent variables in the study are the individual delineation and pavement marking treatments tested. The treatments selected for the field study were based primarily on the results of the simulation study and partly on engineering judgment. The treatments tested in the field are shown in table 27. Should the reader want to refer back to chapter 3 for fuller descriptions of the treatments, the numbers used for the field test and the corresponding numbers used for the simulator test are given in the table.

The reason that some treatments that did not do well in the simulator study are part of the treatment group tested in the field is relatively simple. Traffic engineers addressing problems that can be treated by enhanced delineation and marking treatments will be more likely to implement these types of countermeasures if they are perceived as being easily (i.e., inexpensively) applied. Accordingly, it stands to reason that some of the easier, less expensive treatments should be tested because they perform better than the baseline, albeit, not as well as some of the more complicated (and more expensive) treatments.

For these reasons, simulation treatments 8 and 14 are included because they represent the kind of quick-and-easy treatment that would appeal to an engineer who is looking for inexpensive treatments from an initial cost or life-cycle cost standpoint. To make room for treatments 8 and 14, treatments 13 and 22 were dropped from field testing. Treatment 13 is not included because it was felt that treatment 10 would adequately investigate the

Table 27. Treatments selected for field testing.

Simulator Treat. No.	Field Treat. No.	Treatment Description
1	1	101.6-mm (4-in) yellow centerline (baseline)
6	2	101.6-mm (4-in) yellow centerline and a 101.6-mm (4-in) (structured) white edgeline, brightness at level 3
8	3	101.6-mm (4-in) yellow centerline with yellow RPM and wide spacing
10	4	101.6-mm (4-in) yellow centerline with yellow RPM and wide spacing and white edgeline RPM and wide spacing
14	5	101.6-mm (4-in) yellow centerline and normally mounted chevrons with high intensity retroreflective sheeting and standard spacing
7	6	101.6-mm (4-in) yellow centerline, 101.6-mm (4-in) white edgeline, and normally mounted chevrons with high intensity sheeting and standard spacing
18	7	101.6-mm (4-in) yellow centerline, a standard flat post and standard spacing
19	8	101.6-mm (4-in) yellow centerline and a standard post delineator + edgeline
20	9	101.6-mm (4-in) yellow centerline and a fully retroreflectorized standard flat post and standard spacing
21	10	101.6-mm (4-in) yellow centerline and high intensity T-post delineators and standard spacing
23	11	101.6-mm (4-in) yellow centerline with yellow RPM and standard spacing and high intensity T-post delineators and standard spacing
25	12	101.6-mm (4-in) yellow centerline, a 101.6-mm (4-in) white edgeline, and engineering grade T-post delineators and standard spacing

effectiveness of widely spaced RPM's on the centerline and edgeline. Treatment 22 was not included because it was believed that treatment 21 isolates the effect of high-intensity T-post delineators, and the addition of an edgeline would be certain to increase the effectiveness of this type of treatment.

DEPENDENT VARIABLES

The two primary measures used in the treatment evaluations were recognition distance and visual occlusion. In addition to the objective measures, the subjects also rated each treatment relative to the perceived quality of the baseline treatment. The rating forms included a color photo of the baseline treatment to serve as a reference for each subsequent treatment rating.

Recognition Distance Trials

The purpose of the recognition distance trials was to determine which treatments provided the longest recognition distance performance with regard to the direction of a delineated/marked curve ahead. These trials, while conducted from a vehicle, were essentially static; that is, the judgments of the subjects were made when the experimenter stopped the vehicle at various distances from the curve. For the sake of efficiency, the trials were conducted with two subjects at a time. Independent observations were made by each subject and data were recorded every 30.5 m (100 ft) until both subjects correctly identified the direction of the curve twice in succession.

Visual Occlusion Trials

For the visual occlusion trials, a shield (similar to a large sun visor) was lowered in front of the driver's eyes at a predetermined distance from the delineated curve. The driver was instructed to raise the shield (via a button mounted on the steering wheel) whenever he or she felt uncomfortable as to the location of the curve ahead.

The assumption underlying the use of visual occlusion as a measure is that a subject who is more certain of the nature of the changes in the roadway ahead will drive for a longer period of time with the occlusion shield down. Thus, it is assumed that longer occlusion times are associated with better delineation/marking treatments.

The occlusion trials were conducted with the subject driving and the experimenter in the passenger seat. The vehicle used was equipped with a secondary brake pedal on the passenger/experimenter side. The trials were conducted at a speed of 48.3 km/h (30 mi/h), using the vehicle cruise control to maintain the same speed for all subjects on all trials.

Subjective Treatment Ratings

Following each trial in both the recognition distance and occlusion sessions, subjects were asked to rate the treatment that had just been encountered. Ratings were conducted in the manner described previously.

EXPERIMENTAL DESIGN AND ANALYSIS

The field experiment evaluated 11 treatments plus a control (baseline treatment 1). The subject pool included 33 older (age 65 or older) and 33 younger (age 18 to 45) drivers, with each subject being exposed to 8 treatments (6 treatments plus the control treatment deployed on a left and right curve). Within this design, each of the noncontrol treatments resulted in 18 data points for both the younger and older drivers. The balancing also took into consideration two directions of curvature used.

In assessing mean differences between treatments, since each subject receives only a subset of the possible treatments, it is important that each pair of treatments has the same number of individuals in common (i.e., that a balanced incomplete block [BIB] design be used). That is, treatments 2 and 3, for example, must have the same number of individuals in common as treatments 4 and 7.

The BIB design used consists of the 11 blocks listed in table 28. Each block was given to three older and three younger drivers. In addition, each driver was exposed to the control treatment on a left and a right curve. The alpha-numeric combinations within each block represent the treatment number (2, . . ., 12) and right or left curve (R, L), so that 10R represents treatment 10 on a right curve.

This design has the following properties: (1) each treatment appears in six blocks (e.g., treatment 4 appears in blocks A, D, E, G, H, and J); (2) each pair of treatments appears together in three blocks (e.g., 2 and 3 are together in blocks A, B, and C, and 6 and 10 are together in blocks D, I, and J); (3) each treatment has three right and three left curves; and (4) each of the three older and three younger drivers was exposed to each block, therefore, the design is balanced over younger and older drivers. Finally, to balance against possible order effects, the order of the treatments was randomized in each block. Note that it is properties 1 and 2 that define the BIB design.

The data from these experiments were analyzed using standard methods for BIB designs. This analysis included effects for treatments, age, curve direction, and drivers within blocks, as well as interaction effects between treatments and age and between treatments and curve direction. Where significant age and treatment interaction was observed, separate BIB analyses were performed on older and younger driver groups. These analyses were carried out using the SAS-GLM statistical analysis program.

The main difficulty with analysis of data in which the subjects do not receive every treatment is that the performance on a particular treatment may be affected by the subjects who receive that treatment. In order to get an estimator for the true mean for the treatment, it is necessary to adjust the sample mean for each treatment by a factor representing the estimated performance of the subjects receiving that treatment. Unfortunately, these adjusted estimators are not independent, which makes the analysis much more difficult. However, if the experiment is a BIB, then the methods of analysis are well known.[2]

Table 28. Treatment blocks by trial.

Block	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5		Trial 6		Trial 7		Trial 8	
	Treat No.	Curve Dir.	Treat No.	Curve Dir.	Treat No.	Curve Dir.	Treat No.	Curve Dir.	Treat No.	Curve Dir.	Treat No.	Curve Dir.	Treat No.	Curve Dir.	Treat No.	Curve Dir.
A	1	R	2	R	1	L	3	L	4	R	10	R	8	L	11	L
B	1	L	7	R	3	L	2	R	1	R	6	L	11	L	5	R
C	1	R	1	L	2	L	3	R	7	L	9	R	10	L	12	R
D	1	L	10	L	4	R	2	L	1	R	5	L	12	R	6	R
E	1	R	5	L	2	L	4	R	1	L	7	R	8	L	9	R
F	1	L	9	L	6	L	8	R	1	R	11	R	12	L	2	R
G	1	R	1	L	3	R	4	L	5	R	9	L	11	R	12	L
H	1	L	4	L	1	R	6	R	7	L	8	R	12	L	3	R
I	1	R	8	R	3	L	5	R	6	L	1	L	9	L	10	R
J	1	L	11	R	6	R	7	L	9	R	10	L	1	R	4	L
K	1	R	7	R	5	L	1	L	8	L	11	L	10	R	12	R

The post-hoc comparisons between treatments used the Ryan-Einot-Gabriel-Welsch (REGW) Multiple Range Test. This multiple-comparison procedure has a type I experimentwise error rate given by alpha = .05. However, it is more powerful than Tukey or Scheffé procedures. That is, the REGW procedure used is more liberal (relative to Tukey or Scheffé procedures) in assessing comparisons, but still controls the type I experimentwise error rate.

SUBJECT SAMPLE, ACQUISITION, AND SCREENING

Sample Characteristics

The sample size for the field studies was 66 subjects, with 33 in each of the age groups. The younger age group consisted of drivers from 18 to 45 years of age and was composed of 16 females and 17 males. The older age group consisted of drivers age 65 and over and was composed of 14 females and 19 males. Table 29 shows the average age of the overall age groups and the male and female subgroups.

Subject Acquisition

The procedure used for subject recruitment involved acquisition through church and civic organizations. Specifically, rather than making payments to individual subjects, a payment was made to the organizations for the total number of subject hours that members of the organization contributed to the study. This type of procedure has two advantages. First, because of the potential contribution to the organization, it is more likely that an official of the organization will aid in the recruitment process by presenting material about the study to the group and obtaining volunteer names, phone numbers, etc. This reduces the cost of identifying and scheduling subjects. Second, because the church or civic organization benefits from participation, individuals who may not otherwise volunteer for personal gain will volunteer to aid the organization. This is particularly true of people in the older age group. The procedure also mitigates the problem of self selection, which is more prevalent in older individuals.

Subjects were informed that it would be necessary to participate in two sessions, one for the detection distance trials and one for the occlusion trials. The motivation to attend multiple sessions was provided by making payment contingent upon completing the required number of sessions.

Subject Screening

The same visual screening procedures used for the preliminary laboratory studies were used for the field test subjects. The vision screening consisted of an evaluation of static acuity under low luminance (mesopic visibility: 5 cd/m^2) using Snellen charts, and an evaluation of contrast sensitivity using a Vistech wall chart. The averages for the groups for both measures are given in table 30.

Table 29. Average age of groups and subgroups.

Age Groupings	18-45 (Young)	>64 (Older)	Young Females	Young Males	Older Females	Older Males
Avg. Age	34.7	70.2	35.3	34.2	69.6	70.7

Table 30. Results of visual screening procedures for test subjects.

Visual Performance Measure	Driver Age Group	
	Younger (18-45)	Older (>64)
Snellen (Static) Acuity	20/20	20/25
Vistech Test Patch Correct Orientation Responses by Spatial Frequency		
1.5 cycles/degree	6.4	5.7
3.0 cycles/degree	6.6	5.7
6.0 cycles/degree	4.5	3.3
12.0 cycles/degree	2.2	1.1
18.0 cycles/degree	1.3	0.0

The WAIS tests used in the laboratory studies were not used in the field test screening procedures because they were not found to be useful in the laboratory screening.

TEST FACILITY

The study involved the testing of novel delineation/marking treatments and the use of the visual occlusion procedure. Therefore, the research was conducted on a closed facility where there would be no interaction with or interference from other traffic and where multiple treatments could be efficiently evaluated in single sessions.

The Pavement Durability Research Facility (subsequently referred to as the test track) was used for the research. The test track consists of a 1.61-km (1-mi) oval track designed to highway specifications. The oval is composed of a large curve on a -1.0 percent grade with a design speed of 72.4 km/h (45 mi/h) and a smaller radius curve on a +1.0 percent grade with a design speed of 56.3 km/h (35 mi/h). The tangents are on a +0.3 percent grade with a straight, unobstructed length of 365.8 m (1,200 ft). An additional area beyond the paved tangent provides a sight distance of 548.6 m (1,800 ft), if needed.

The area adjacent to the left side of the southern tangent consists of a paved vehicle dynamics area with a minimum 30.5-m (100-ft) width running the length of the tangent. The vehicle dynamics area was used to create and film the curves for the simulation study. This area provided the opportunity to create left and right curves at each end of the vehicle handling area. The use of both curve directions eliminated the effects of the existing cues. The total length available for the approach and curves is approximately 365.8 m (1,200 ft). This distance provides a curve "preview" distance well in excess of that recommended by most researchers. The narrowest portion of the vehicle handling area allowed a 152.4-m (500-ft) radius curve to be constructed. A drawing of the test facility is presented in figure 9.

TEST VEHICLE INSTRUMENTATION

The instrumentation package was a hardware-software system configured to collect both automatically and manually encoded data. It functioned as an on-line multiple-event recorder, collecting measures of driver responses and time/distance references tied to a common time base.

The package was built around a microcomputer. It included disk drives, CRT, and a keyboard. A hardware interface with analog and digital sensors automatically collected data on vehicle and/or driver performance. Power was supplied by an inverter wired to the vehicle alternator. The test vehicle was equipped with a distance measurement device from which speed could be derived from distance traveled and elapsed time. The data could be sampled at any specified interval and recorded continuously.

During automatic data collection, the instrumentation package used a program that sampled each of the inputs on a programmed sampling schedule and recorded the values along with the time the sample was taken. During this execution, demand entries could also

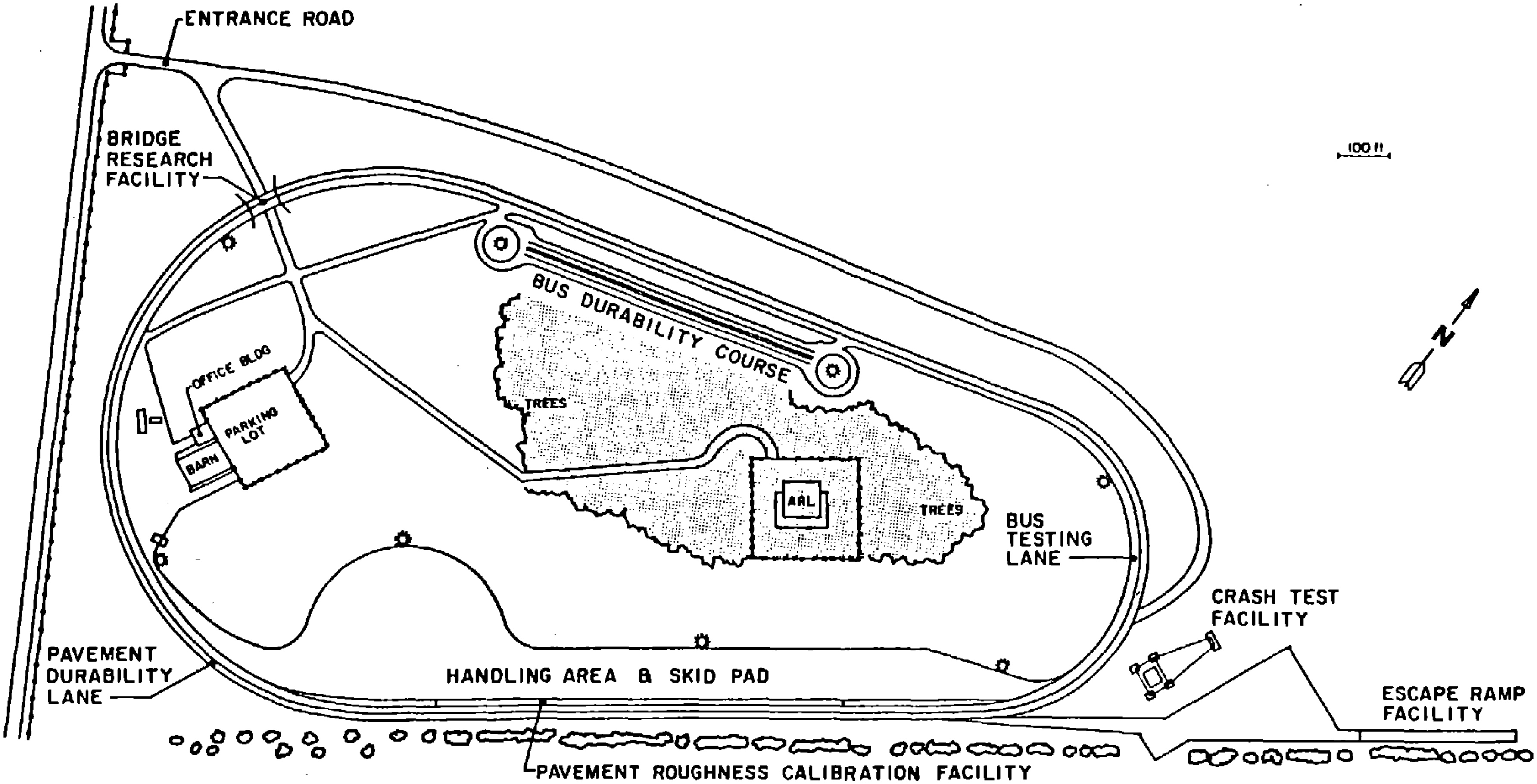

Figure 9. Transportation Research Facilities (test track).

be made. The software could be altered to allow collection and transfer of data from the sensors so that demand inputs made at the keyboard or via remote switch did not interrupt the processing. The keyboard was used for most demand entries, which could be made at any time. These entries could be menu-driven to provide the experimenter with cues when necessary. Other demand entries were via button boxes designed to accept subject responses.

The other element of the vehicle instrumentation was a device to provide visual occlusion during a trial. This was done by using a vision-occlusion device that consisted of two high-r/min DC motors linked by a common shaft with a lightweight visor attached to the shaft. The entire apparatus was attached to a rigid platform that was mounted to the ceiling of the test vehicle. The mounting hardware was flexible in design so that the position of the visor could be adjusted to meet the height requirements of the individual subject.

At the start of each trial, the motors held the visor up and out of the subject's field of view. At the appropriate time during the trial, the motors rotated the visor down (through 90 degrees or more, as required), thus occluding the subject's field of view. The visor was able to rotate from a fully open position to a fully occluded position in less than 1/30 of a second. The visor was activated by the experimenter at a predefined location. The visor was raised in response to a subject-controlled push-button switch mounted on the steering wheel of the vehicle. The signals associated with activation and deactivation of the occlusion shield were fed into the computer so that activation and deactivation times were recorded on disk to provide a measure of occlusion time.

The final element of the instrumentation was a secondary braking system. The secondary system could be operated by the experimenter if the subject driver deviated significantly from the appropriate path during the time that the occlusion device was down or if it was deemed necessary to stop the vehicle for safety reasons.

INSTALLATION OF DELINEATION AND MARKING TREATMENTS

One of the major considerations in the cost-efficient conduct of the treatment evaluations was to have a means of changing treatments rapidly so that test subjects could be exposed to the required number of treatments during a session of reasonable length. This was important not only from the standpoint of cost, but also from the standpoint of the experimental design. The greater the number of sessions required, the higher the probability that subjects would fail to complete all sessions. This is particularly true of older subjects in a nighttime driving situation. Thus, the study was designed so that only a single 2-hour (maximum) session was required for each type of measure.

To permit rapid deployment of treatments between successive trials, the location of each type of delineation/marking element was marked (in color code) on the pavement. Using these markings, appropriate spacing and orientation were maintained when the devices were deployed.

Roadside vertical delineation treatments such as posts and chevrons were mounted in base-weighted containers. Surface treatments such as RPM's had sufficient weight that they were simply placed on the marked roadway. Lane-line tape was mounted on flat black boards and were laid end to end for the appropriate length. All devices not being used on a trial were "stored" off the roadway, and workers were stationed out of sight of subjects during trials.

During the changeover, the experimenter stopped the vehicle at a location from which the subject could not see the deployment activity and had the subject fill out the rating form for the treatment just encountered. When the new treatment was in place, the deployment crew informed the experimenter via radio.

TEST PROCEDURES

All test subjects participated in both test procedures. All of the recognition distance data were obtained first. In no less than 1 month later, subjects were scheduled for the visual occlusion trials. The specific procedures for both types of trials are described in the following sections.

Recognition Distance Procedure

The trials began at a location 304.8 m (1000 ft) from the PC of the curve and progressed toward the curve in 30.5-m (100-ft) increments, with a stop and a subject judgment at each point. The progression toward the curve continued until subjects had the curve direction correct at two successive distances. The reason for static rather than dynamic data acquisition was based on concerns related to the increased decision-making times typically exhibited by older drivers. If older drivers are not forced to make a judgement at a given distance, decision uncertainty is likely to influence the recognition distances measured and confound the overall and age-related assessments of treatment visibility.

For purposes of efficiency, two subjects occupied the test vehicle at the same time for the recognition distance trials. Because younger drivers were expected to make earlier correct responses for the less visible treatments, every attempt was made to match subject pairs from the same age group. Each subject was equipped with a button-box response device with left, right, and "don't know" buttons, and each subject was required to respond at each distance. A small partition was placed between the subjects so that they could not obtain response cues from each other. As noted, responses were acquired from both subjects until two successive correct responses were elicited from each. The responses from each button box appeared on the laptop screen. The experimenter had a sheet specifying the treatment and the direction of curvature for each trial within the session. In this way, the experimenter knew when both subjects had made a correct response and could be sure that the appropriate treatment was deployed. Once both subjects had made two successively correct responses, the trial was terminated.

Visual Occlusion Procedure

As noted above, a subject's task was to drive with the shield lowered until he or she experienced discomfort associated with lack of information about the roadway ahead. A visual-occlusion shield (described previously in the "Test Vehicle Instrumentation" section) was activated by the experimenter at a location 128 m (420 ft) from the PC of the curve, and each subject raised the shield via a push button on the steering wheel. The signals generated by the buttons associated with lowering and raising the occlusion shield were recorded on the disk in the onboard computer to provide the means to associate the vehicle location, speed, and time data with each occlusion trial.

Prior to initiating the test trials, a familiarization/training session was conducted. First, the operation of the occlusion device was demonstrated while the car was stationary. Following this demonstration, each subject was instructed to drive a circuit at the test facility. This served to familiarize the subjects with the vehicle characteristics, the operation of all controls, and the nature of the test track. Toward the end of the circuit, the activation of the occlusion device was again demonstrated, first on a tangent section and then on a curve approach. The subjects were warned about the activation of the shield during this part of the session. As a continuation of the familiarization session, the subjects were asked to maintain the 48.3 km/h (30 mi/h) speed that was used for the testing, but the cruise control was used. Following this, another circuit was driven on the track. At this time subjects used the cruise control and the shield was dropped without warning.

Following this familiarization procedure, each subject was queried as to whether or not they were comfortable with the procedure. If not, a subject was permitted to drive another circuit around the track and the occlusion procedure was demonstrated again.

For each trial, the vehicle was started at a point on the track where the 48.3 km/h (30 mi/h) speed could be easily reached and the cruise control was set at a distance of approximately 304.8 m (1000 ft) from the curve. During the trials, the experimenter observed the speedometer and, if necessary, verbally instructed each subject to activate the speed control once the criterion speed was reached. The subjects' instructions and training are fully described in appendix B.

Subjective Data Acquisition Procedure

For the subjective ratings, each study participant was asked to assign a number from 1 to 100 to denote the effectiveness of the markings and delineators in conveying downstream curve directional information. After the first trial (always the treatment 1 baseline condition), subjects were told that the treatment represented the lowest level of curve direction information. Subjects were then instructed to rate all other treatments in relation to the baseline. The amount of time between the completion of a subject's curve recognition response and the subjective rating of treatment effectiveness was consistently less than 45 s. As noted before, a color photograph of the baseline treatment was provided on the rating forms to serve as a rating reference.

6. FIELD STUDY RESULTS

The study results are divided into major sections representing the recognition distance results and visual occlusion results. Each of these sections is subdivided into presentation of the objective and subjective data. Another section presents comparisons of the two measures with respect to treatment rankings and the correlation between the two measures. Within each section, the overall results are described and comparisons are made between the older and younger driver groups.

To avoid requiring the reader to return to the front of the report for identification of treatment characteristics, a treatment description table (table 31) is shown on the next page.

OBJECTIVE RECOGNITION DISTANCE RESULTS—GENERAL

Because of the wide range of treatments evaluated (i.e., ranging from the baseline treatment [a single yellow line] to very bright and multiple element treatments), all treatment effects are, as expected, highly statistically significant. The critical issues are the significance of the differences between various treatments and the differences between the two age groups.

With regard to the combined age groups, the analysis of variance (ANOVA), table 32, shows that all factors and interactions were significant at the $p=.05$ level or beyond. The significance of the curve direction factor and the significant interaction of curve direction with treatment indicates that some treatments were better on left curves and some were better on right curves. The treatment-age interaction is not surprising because one would expect older drivers to exhibit shorter recognition distances on treatments that were less bright or smaller.

Table 33 shows the recognition distances observed and the standard deviations for each treatment. These data represent the mean performance of the entire sample and the data from the left and right curves combined. As shown, the range of recognition distances is wide, from 21.6 m (71 ft) for the baseline treatment to 279.5 m (917 ft) for treatment 12. The same data are shown graphically in figure 10. However, the graphic shows the treatments ordered by increasing recognition distance. The horizontal lines across the bars in figure 10 represent the results of the Ryan-Einot-Gabriel-Welsch multiple range test used for the post hoc analysis. The horizontal bars across groups of treatments indicate that the differences between the treatments were not statistically significant. For example, the six treatments producing the longest recognition distances (treatments 5, 11, 6, 9, 10, and 12) produced, from a statistical standpoint, the same performance. Based on a comparison of the recognition distance values, a difference of 26.2 m (86 ft) between treatments is required to produce a significant difference with the sample used.

Table 31. Treatments tested in the field.

Treament Number	Centerline Treatment	Spacing	Edgeline Treatment	Spacing	Off-road Edge Treatment	Spacing
1	4-in Yellow Line	NA	None	NA	None	NA
2	4-in Yellow Line	NA	4-in Structured Line	NA	None	NA
3	4-in Yellow Line + Yellow RPM's	Wide	None	NA	None	NA
4	4-in Yellow Line + Yellow RPM's	Wide	White RPM's	Wide	None	NA
5	4-in Yellow Line	NA	None	NA	Normal Mount Chevrons	Standard
6	4-in Yellow Line	NA	4-in White	NA	Normal Mount Chevrons	Standard
7	4-in Yellow Line	NA	None	NA	Std. Flat Posts (Hi-Intensity)	Standard
8	4-in Yellow Line	NA	4-in White	NA	Std. Flat Posts (Hi-Intensity)	Standard
9	4-in Yellow Line	NA	None	NA	Full Reflet. Posts (Hi-Intensity)	Standard
10	4-in Yellow Line	NA	None	NA	T- Posts (Hi-Intensity)	Standard
11	4-in Yellow Line + Yellow RPM's	Standard	None	NA	T- Posts (Hi-Intensity)	Standard
12	4-in Yellow Line	NA	4-in White	NA	T- Posts (Engineering)	Standard

1 in = 2.54 cm

Table 32. ANOVA—recognition distance
(combined age groups and curve direction).

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
Treatment (TRT)	11	6567.56	597.05	213.58	0.0001
Age Group (AGE)	1	93.34	93.34	20.35	0.0001
Subjects	64	305.20	4.77	1.71	0.00
Curve Dir. (CURVE)	1	10.17	10.17	3.64	0.0571
TRT* CURVE	11	103.84	9.44	3.38	0.0002
TRT*AGE	11	79.93	7.27	2.60	0.0033

Table 33. Recognition distance means and standard deviations
(combined age groups and combined curves).

	Treatment Number											
	1	2	3	4	5	6	7	8	9	10	11	12
Mean	71	211	192	161	831	872	592	742	875	897	864	917
SD	107	67	154	96	262	195	295	272	221	196	206	111

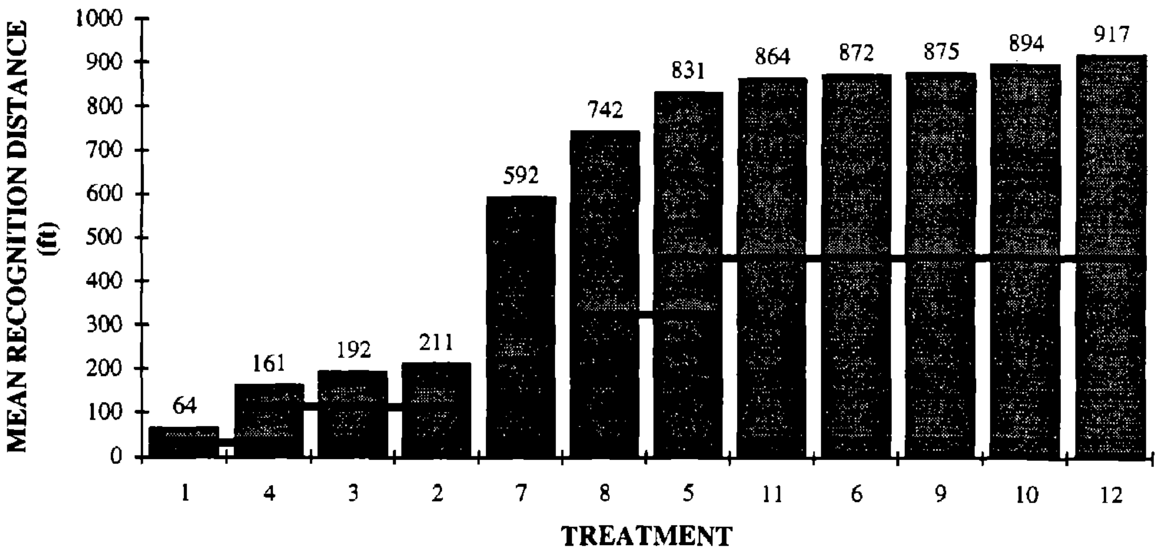

Figure 10. Mean recognition distance (combined age groups and curves).

OBJECTIVE RECOGNITION DISTANCE RESULTS—CURVE DIRECTION

The ANOVA's for each curve direction are given in tables 34 and 35. As shown, treatment, age, and the treatment/age interaction are statistically significant for the right curve. For the left curve, the same two main effects are significant, but the treatment/age interaction, in this case, is not.

The recognition distances and standard deviations for each curve direction are shown in tables 36 and 37. Figure 11 provides a graphic comparison of the performance on right versus left curves for each treatment. A comparison of the recognition distances for the different curve directions reveals that there are only three treatments that result in large disparities. These are treatments 7, 8, and 9. Treatments 7 and 8 produced longer recognition distances for the left curve, with the comparative differences being 82.9 and 52.4 m (272 and 172 ft), respectively. The difference for treatment 9 was 45.7 m (150 ft), with the right curve producing the better performance. The differences between left and right curves for all other treatments ranged from 3.4 to 20.4 m (11 to 67 ft.) Thus, it can be assumed that treatments 7, 8, and 9 account for the significant difference in curve direction in the overall ANOVA.

A review of these three treatments provides little insight into the relative qualities of the treatments with regard to right versus left curves. The only difference between treatments 7 and 8 is that treatment 8 included an edgeline and treatment 7 did not. The addition of the edgeline could certainly account for the longer recognition distance on left curves, but the differences in curve direction cannot be explained with regard to visual quality of the treatments. Treatment 9 included a fully reflective flat post, but no edgeline. While it produced more than adequate recognition for both curve directions, the reasons why it would perform better on right curves cannot be explained. When the recognition distance data are converted to rankings, treatment 9 is the best treatment on right curves, but ranks seventh for left curves.

OBJECTIVE RECOGNITION DISTANCE RESULTS—AGE GROUP COMPARISONS

The analysis of variance of the younger subject data yielded statistically significant effects ($p = > .05$) for each of the main factors and for the treatment/curve interaction (see ANOVA table 38). The analysis of the data from the older group differed only in that the curve direction was not significant (see table 39).

Tables 40 and 41 show the mean and standard deviations for the younger and older groups, respectively. Table 42 shows a direct comparison of the two age groups. As can be seen from a comparison of the recognition distances of the two groups, the younger group performs better on all but treatment 1. The differences range from a low of 3.4 m (11 ft) for treatment 2, to a maximum of 82.9 m (272 ft) for treatment 8.

Table 34. ANOVA—recognition distance
(combined age group—right curves).

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
Treatment (TRT)	11	3219.88	292.72	106.46	0.0001
Age Group (AGE)	1	44.31	44.31	12.90	0.0006
Subjects	64	223.25	3.49	1.27	0.1145
TRT*AGE	11	106.46	9.68	3.52	0.0002

Table 35. ANOVA—recognition distance
(combined age groups—left curves).

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
Treatment (TRT)	11	3378.21	307.11	117.20	0.0001
Age Group (AGE)	1	49.45	49.45	13.90	0.0004
Subjects	64	232.44	3.63	1.39	0.0498
TRT*AGE	11	31.09	2.83	1.08	0.3811

Table 36. Recognition distance means and standard deviations
(combined age groups—right curves).

	Treatment Number											
	1	2	3	4	5	6	7	8	9	10	11	12
Mean	59	194	217	156	850	839	456	656	950	906	833	922
SD	152	54	195	62	285	248	225	303	92	170	220	100

Table 37. Recognition distance means and standard deviations
(combined age groups—left curves).

	Treatment Number											
	1	2	3	4	5	6	7	8	9	10	11	12
Mean	70	228	167	167	811	906	728	828	800	889	894	911
SD	99	75	97	124	242	121	299	211	283	225	192	123

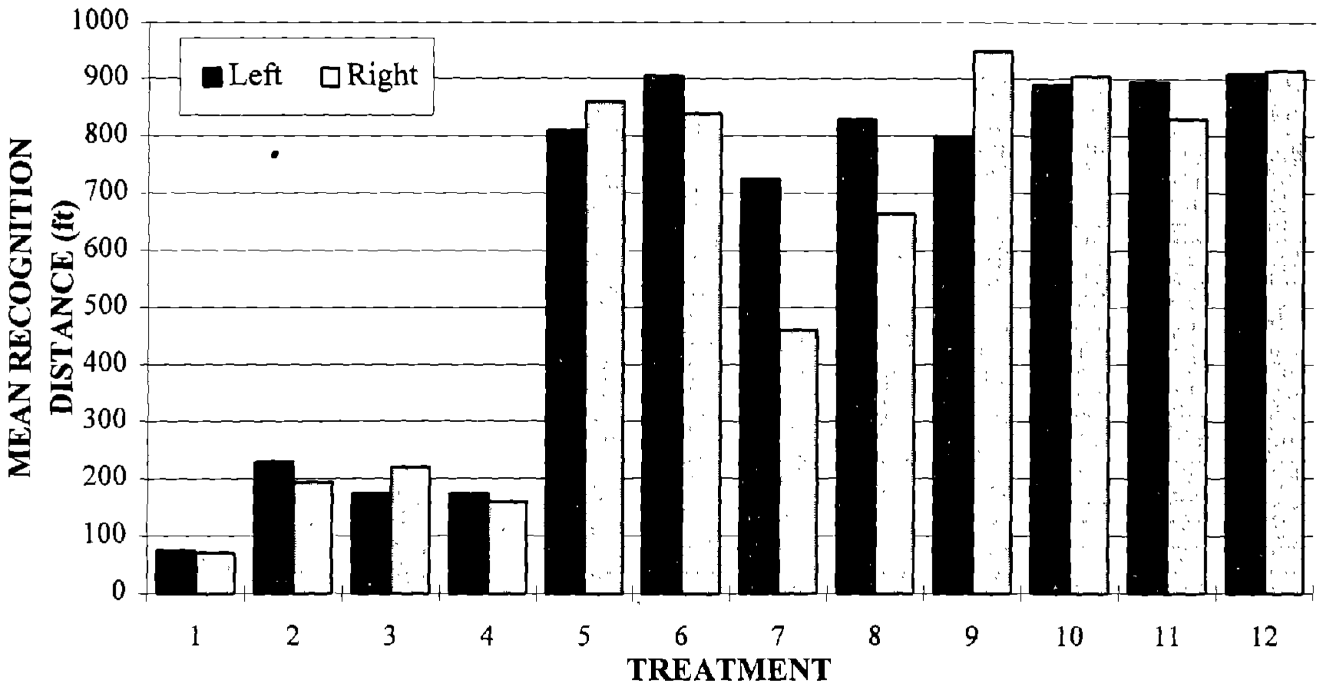

Figure 11. Recognition distance-left versus right curves (combined age groups).

Table 38. ANOVA—recognition distance (younger group).

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
Treatment (TRT)	11	3902.97	354.82	233.63	0.0001
Subjects	32	78.29	2.45	1.61	0.0262
Curve Dir. (CURVE)	1	5.97	5.97	3.93	0.0486
TRT*CURVE	11	57.26	5.21	3.43	0.0002

Table 39. ANOVA—recognition distance (older group).

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
Treatment (TRT)	11	2741.69	249.24	63.13	0.0001
Subjects	32	186.73	5.84	1.48	0.0564
Curve Dir. (CURVE)	1	4.33	4.33	1.10	0.2960
TRT*CURVE	11	106.35	9.67	2.45	0.0068

Table 40. Recognition distance means and standard deviations (combined curves—younger group).

	Treatment Number											
	1	2	3	4	5	6	7	8	9	10	11	12
Mean	52	217	206	183	917	928	622	878	933	933	922	967
SD	67	86	130	120	129	123	286	186	103	191	159	59

Table 41. Recognition distance means and standard deviations
(combined curves—older group).

Treatment Number												
	1	2	3	4	5	6	7	8	9	10	11	12
Mean	77	206	178	139	744	817	561	606	817	856	806	867
SD	113	42	177	61	329	238	309	280	287	218	234	128

Table 42. Recognition distance by treatment
(older versus younger—combined curves).

Treatment Number												
	1	2	3	4	5	6	7	8	9	10	11	12
Older	77	206	178	139	744	817	561	606	817	856	806	867
Younger	52	217	206	183	917	928	622	878	933	933	922	967

Figure 12 shows the recognition distance differences in age groups for combined curves. Note that in this figure the treatments are presented in ranked order in accordance with the performance of older drivers. In these comparisons there is, as expected, a consistent pattern of younger subjects exhibiting better performance, i.e., longer recognition distances. Recall that when the right and left curve data are combined, the difference between age groups is highly statistically significant (see table 32). However, as shown in figures 13 and 14, for right and left curves separately, similar consistency of the younger group does not exist. However, as shown in tables 34 and 35, the age differences are statistically significant. From a practical standpoint it may matter little because the operational community would most likely be resistant to treating the curve directions differently.

SUBJECTIVE RECOGNITION DISTANCE RESULTS

This section reports on the ratings subjects assigned to the various treatments after each trial. Recall that on the first trial each individual was exposed to treatment 1 (baseline). This initial exposure, along with a color photograph of the baseline treatment on the rating sheets, served as the basis for judging the other treatments. The subjects were asked to judge the treatments on a 100-point scale. However, many individuals failed to use the entire scale; a number of subjects never assigned a rating over 60. This practice was more prevalent in the older group.

The ANOVA of the subjective data produced highly significant effects for treatment and subject factors (see table 43). The treatment/age-group interaction was also highly significant ($p= < .05$). However, the age-group factor was not significant. Thus, while across the entire range of treatments there was no age effect, certain treatments produced substantial differences in the ratings.

Table 43. ANOVA—subjective data, recognition distance trials.

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
Treatment (TRT)	11	174818.90	15892.63	55.13	0.0001
Age Group (AGE)	1	3368. 14	3368.14	1.97	0.1663
Subjects	64	109918.80	1717.48	5.96	0.0001
TRT*AGE	11	17997.20	1636.11	5.68	0.0001

From a practical standpoint, it would seem that treatments that performed the best for older drivers without producing any problems for younger drivers should, on the basis of the objective recognition distance results, be the primary candidates for implementation recommendations.

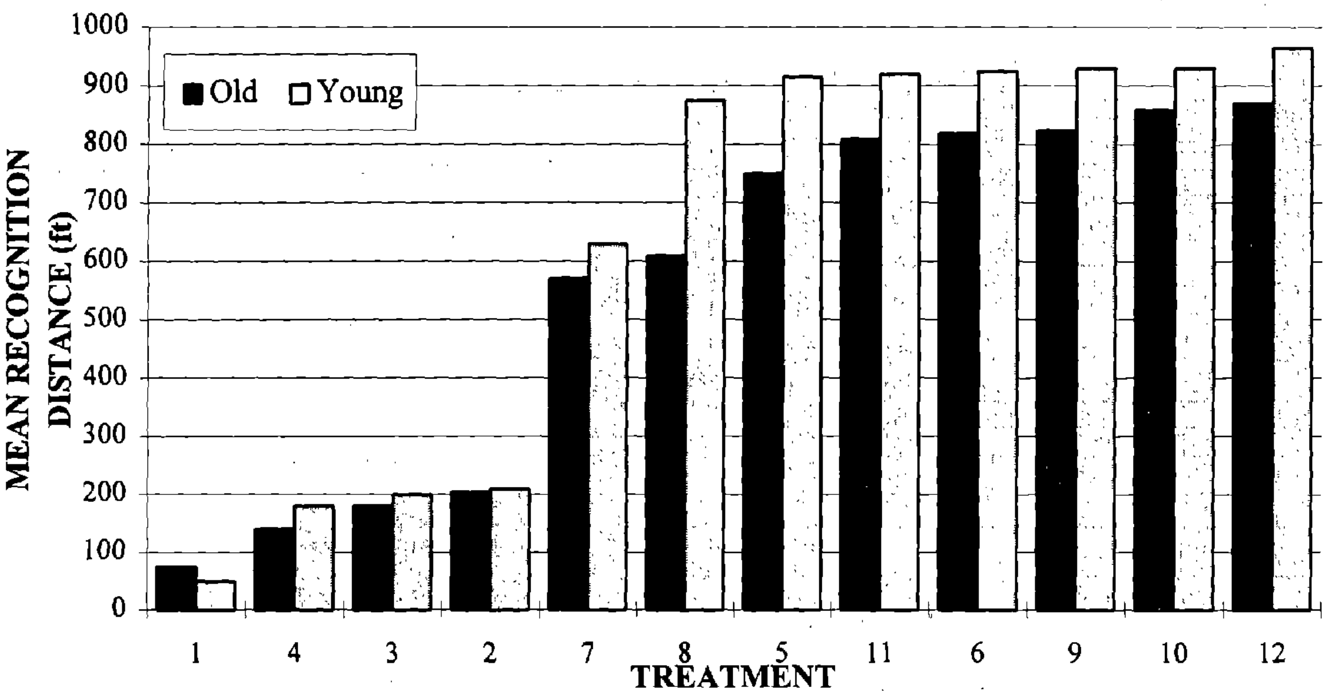

Figure 12. Recognition distance-old versus young groups (combined curves).

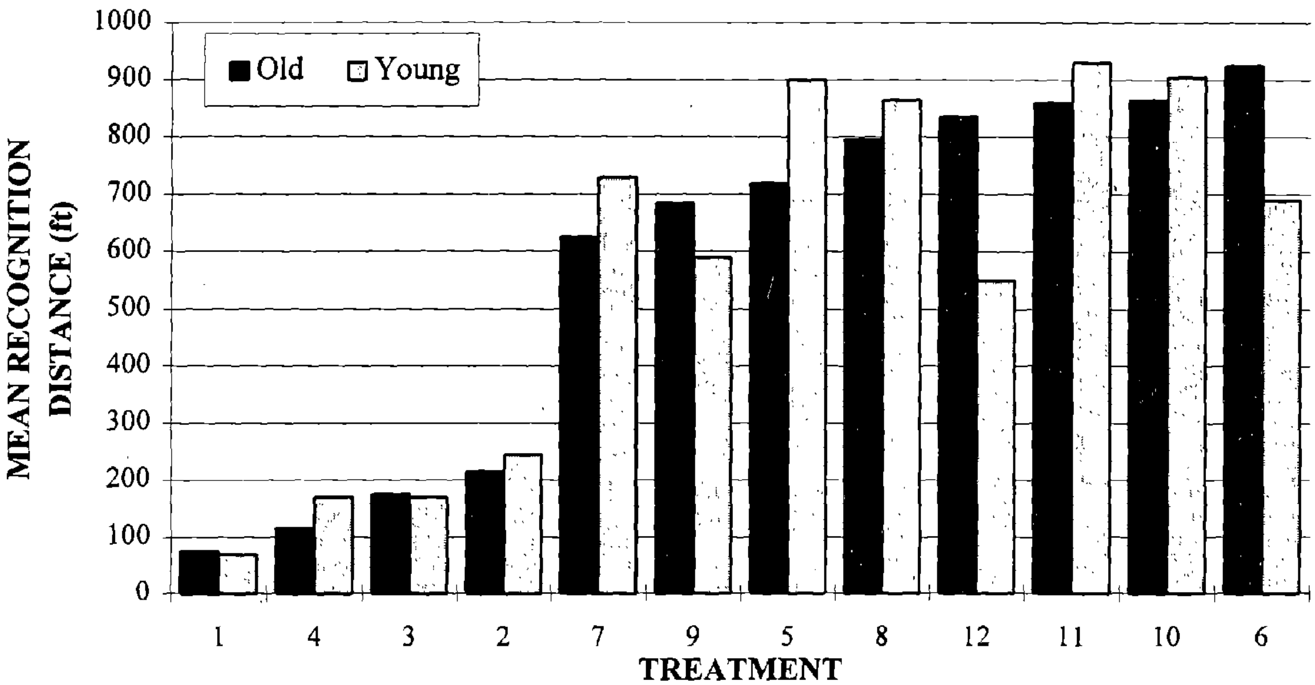

Figure 13. Recognition distance-old versus young groups (left curves only).

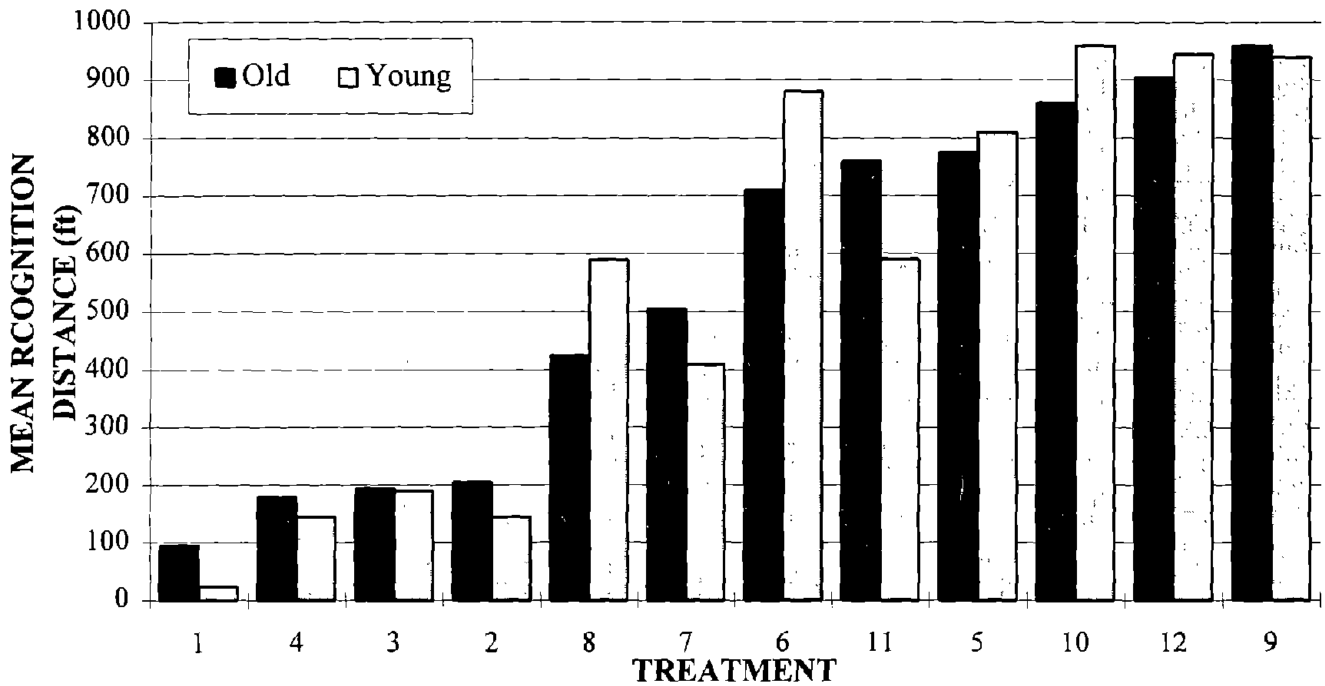

Figure 14. Recognition distance-old versus young groups (right curves only).

The mean ratings across the entire sample are shown in figure 15. The treatments are arranged in ascending order across the treatment axis. As can be seen, the differences between the mean ratings over the seven most highly rated treatments are small. The Ryan-Einot-Gabriel-Welsch post-hoc test showed that the top seven treatments (5, 6, 8, 9, 10, 11, and 12) were not significantly different from one another. The horizontal bars indicate the groupings that resulted from the post-hoc analysis.

Figure 16 shows the mean rating differences between the two age groups. The data are plotted in accordance with the ascending ratings for the older group. As with the overall ratings, the differences between the more highly rated treatments are small. The Ryan-Einot-Gabriel-Welsch post-hoc test showed that the eight treatments most highly rated by the older group (treatments 5, 6, 7, 8, 9, 10, 11, and 12) are not significantly different from one another. Similarly, the seven treatments rated most highly by the younger group (treatments 5, 6, 8, 9, 10, 11, and 12) do not differ significantly.

As reflected in the overall data plot (figure 15) the comparison of the two groups shows that there are a number of treatments that are rated highly by both (treatments 5, 6, 8, 9, 10, 11, and 12). According to the post-hoc analysis, these "preferred" treatments are not significantly different from one another. Thus, it would appear that the subjective data will be of little help in making recommendations.

Both of the data sets for the recognition trials (objective and subjective) have been ranked lowest to highest. Figure 17 shows the objective ranks (recognition distance means) compared to the subjective ranks (treatment rating means). The ranks are plotted so that the objective data are arranged in descending order. As can be seen, most of the disparities between the two data sets occur among the more highly ranked treatments. That is, the objective and subjective measures are in reasonable agreement for treatments that produced the lowest recognition mean, but not for treatments that produced the highest recognition mean.

RECOGNITION DISTANCE RESULTS—SUMMARY

The recognition distance values obtained from the total sample (combined age groups and curve direction) ranged from a low of 19.5 m (64 ft) for the baseline treatment (treatment 1) to a high of 279.5 m (917 ft) for the best treatment (treatment 12). However, there were six treatments that produced relatively long recognition distances and it was found that these were not significantly different from one another. Among the best six treatments (treatments 5, 11, 6, 9, 10, and 12), the recognition distance values obtained ranged from 253.3 m (831 ft) for treatment 5 to 279.5 m (917 ft) for treatment 12.

The analysis of curve direction effects produced statistically significant differences for treatment and age. In this analysis, treatments 7 and 8 resulted in longer recognition distances for left curves, whereas treatment 9 produced the longest distance for right curves.

The ANOVA for the younger subject subgroup produced significant effects for all main effects and for the treatment turn interaction. The analysis for the older subgroup was the

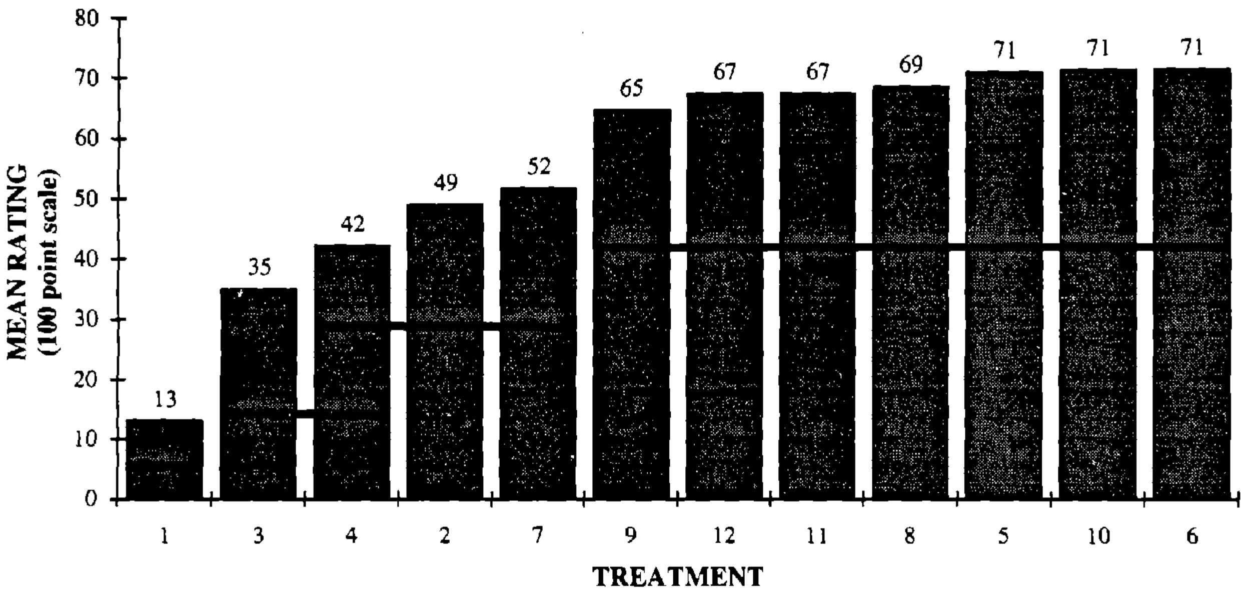

Figure 15. Recognition distance trials—treatment ratings (combined age groups).

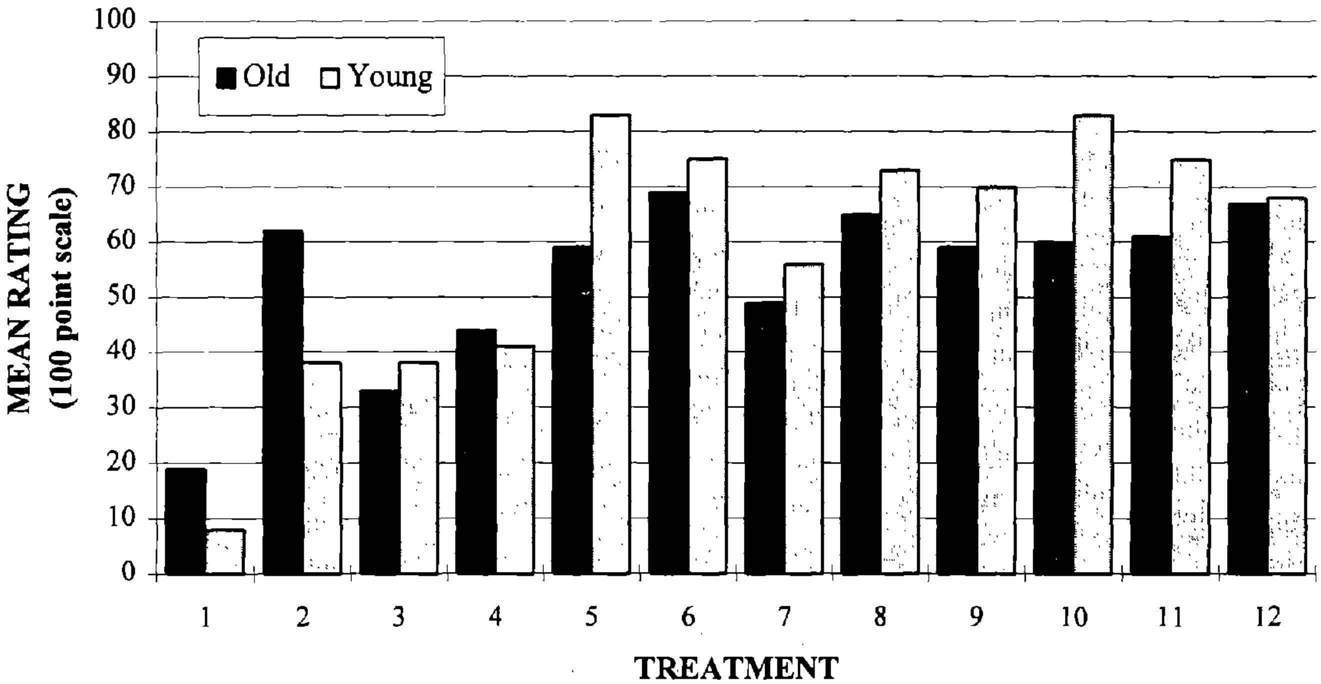

Figure 16. Recognition distance trials-treatment ratings (old versus young).

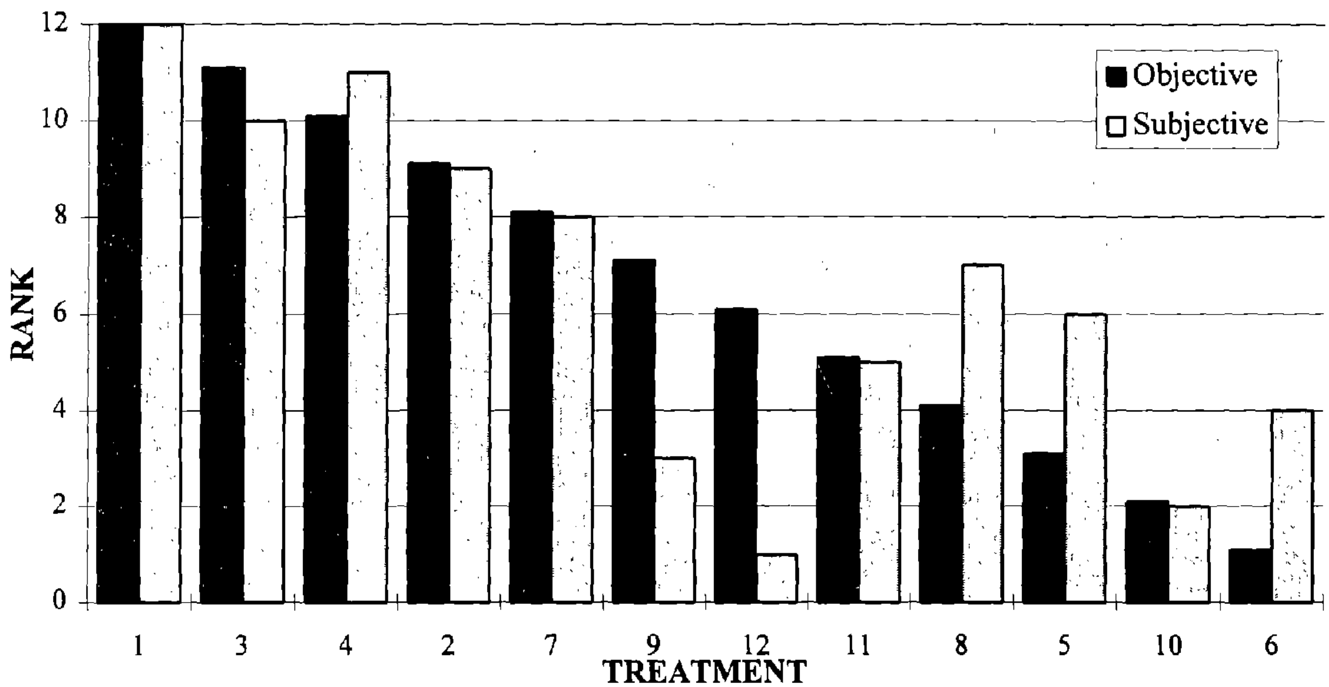

Figure 17. Recognition distance trials-treatment ratings (objective versus subjective data).

same with the exception of the absence of a significant curve direction effect. With the exception of treatment 1, the younger group performed better (i.e., produced longer recognition distances for all treatments.

With regard to the subjective (ratings) data for the recognition distance trials, the treatment effect was highly significant, but age group was not. The post-hoc analysis of ranks calculated from the combined age and curve data showed that the seven most highly rated treatments (treatments 5, 6, 8, 9, 10, 11, and 12) were not significantly different from one another.

VISUAL OCCLUSION—OBJECTIVE RESULTS

As described previously, the visual occlusion data are reported in terms of the interval between the time when the experimenter lowered the occlusion shield to the time the subject raised the shield. Before presenting the results, one particular aspect of some subjects' behavior should be mentioned; that is, some subjects' tendency to compete or engage in what they may have considered risk-taking behavior. In many cases, a subject told the experimenter that the shield could be kept down longer on the next trial. Such comments were made in spite of the fact that the subject did not know which treatment would be deployed for the next trial. For this reason it is felt that the measure of time may be confounded by personality variables. Also, each subject knew that there was a secondary (experimenter activated) brake in the car and that there would be no other traffic to contend with because of the closed test track. Therefore, the occlusion measure is likely to be confounded by the situations described above and is not considered to be as good a measure of the visual quality of the delineation/marking treatments as is the recognition distance measure.

As shown in table 44, only the treatment and subject factors produced statistical significance. Unlike the performance data associated with recognition distance, neither age, curve direction, or any interactions achieved an acceptable ($p = < .05$) level of significance. The ANOVA's for all of the other data subsets (younger, older, left curve, and right curve) produced the same pattern of results as those shown in table 44, and, therefore, are not presented.

For purposes of visual inspection, the mean visual occlusion times and standard deviations are given in table 45 for younger and older subject groups and for the entire subject sample. As a review of table 45 reveals, the differences between the minimum and maximum mean occlusion times are small; differences of 1.9 s, 1.2 s, and 1.4 s for the older, younger, and overall groups, respectively. At the 48.3 km/h (30 mi/h) speed used for the test trials, these times translate to differences in distances traveled of 20.1 m, 16.2 m, and 18.9 m (66 ft, 53 ft, and 62 ft) for the older, younger, and overall groups, respectively.

Figure 18 shows the overall mean occlusion times ordered from lowest to highest. The dark horizontal lines show the results of the post-hoc tests for significant differences between treatments. Treatments crossed by the horizontal lines are not significantly different. As

Table 44. ANOVA—visual occlusion
(combined age groups and curve direction).

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
Treatment (TRT)	11	92.66	8.42	7.77	0.0001
Age Group (AGE)	1	10.73	10.73	0.43	0.5146
Subjects	64	1756.55	27.44	25.42	0.0001
Curve Dir. (CURVE)	1	1.39	1.39	1.28	0.2577
TRT*CURVE	11	18.81	1.71	1.58	0.1006
TRT*AGE	11	10.51	0.96	0.89	0.5555

Table 45. Mean occlusion time (in seconds).

Age Group	Stat. Meas.	Treatment Number											
		1	2	3	4	5	6	7	8	9	10	11	12
Old	Mean	2.4	3.1	2.6	4.3	4.1	3.0	3.2	3.8	2.7	3.9	3.3	3.9
	SD	1.9	2.4	1.6	3.0	2.6	2.7	2.5	2.5	2.3	3.0	2.0	2.8
Young	Mean	2.4	2.8	3.4	3.1	3.6	3.0	2.9	2.8	3.0	3.5	2.9	3.3
	SD	1.4	1.4	1.5	1.4	2.1	1.7	1.9	1.8	1.8	2.6	2.0	2.7
All	Mean	2.4	2.9	3.0	3.7	3.8	3.0	3.1	3.3	2.8	3.7	3.1	3.6
	SD	1.6	2.0	1.6	2.4	2.4	2.2	2.2	2.2	2.1	2.8	2.0	2.7

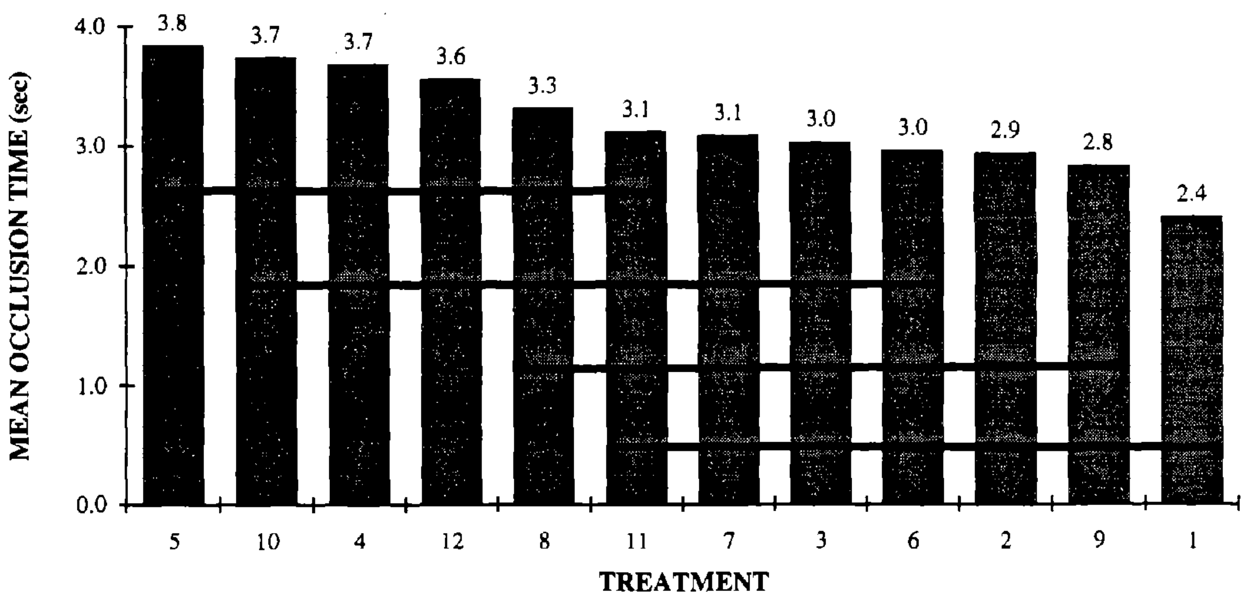

Figure 18. Occlusion time (combined age groups and curves).

shown, the six treatments with the longest occlusion times are not significantly different from one another. The large degree of overlap between groups of treatments that are not significantly different from one another makes this data set difficult to interpret.

Figure 19 shows the mean occlusion time differences between the younger and older groups. With regard to the comparisons, it can be seen that longer occlusion times for the older group occurred only for treatments 3 and 9. Treatments 1 and 6 produced equal times for each group. The eight remaining treatments resulted in longer occlusion times for the younger group.

Figure 20 shows the mean occlusion time for left and right curves for the combined age groups. In this case, half of the treatments produced longer occlusion times for left curves (treatments 4, 6, 7, 9, 10, and 12), while the other half produced longer occlusion times for left curves (treatments 1, 2, 3, 5, 8, and 11). When considered in conjunction with the overall ranking of mean occlusion time (figure 18), there is no evidence that curve direction is related to the overall picture. This, of course, is evidenced in the lack of significance in curve direction effects in the analysis of variance of these data sets.

On the basis of these data, along with concerns about the influence of personality variables on performance, it is assumed that the occlusion time measure, as implemented in the study, gives us little basis for choosing the most adequate treatments for older drivers.

VISUAL OCCLUSION—SUBJECTIVE RESULTS

The ANOVA for the occlusion trial ratings (see table 46) is similar to that for the objective (occlusion time) data. That is, only the treatment and subject factors produced statistically significant results. Like the performance data associated with occlusion, neither age, curve direction, or any interactions achieved an acceptable ($p=.05$) level of significance. However, the analyses for some of the data subsets produced some significant F-ratios.

The ANOVA of the rating (subjective) data for the older age group (combined curve data) produced a significant effect ($p=.030$) for the curve direction factor (see table 47). Also, the analysis of subjective right curve data for the combined age groups produced a significant effect ($p=.0006$) for the age group factor (see table 48). Both of these subsets also showed treatment and subjects to be significant. The mean occlusion trial ratings of each treatment for the separate and combined age groups are presented in table 49.

Figure 21 presents the overall occlusion trial ratings, with the horizontal line across bars representing the post-hoc (Ryan-Einot-Gabriel-Welsch) analysis for significant differences between treatments. Recall, the treatment bars spanned by the horizontal lines were shown not to differ significantly from one another. The occlusion trial rating data showing the differences between the age groups is presented in figure 22.

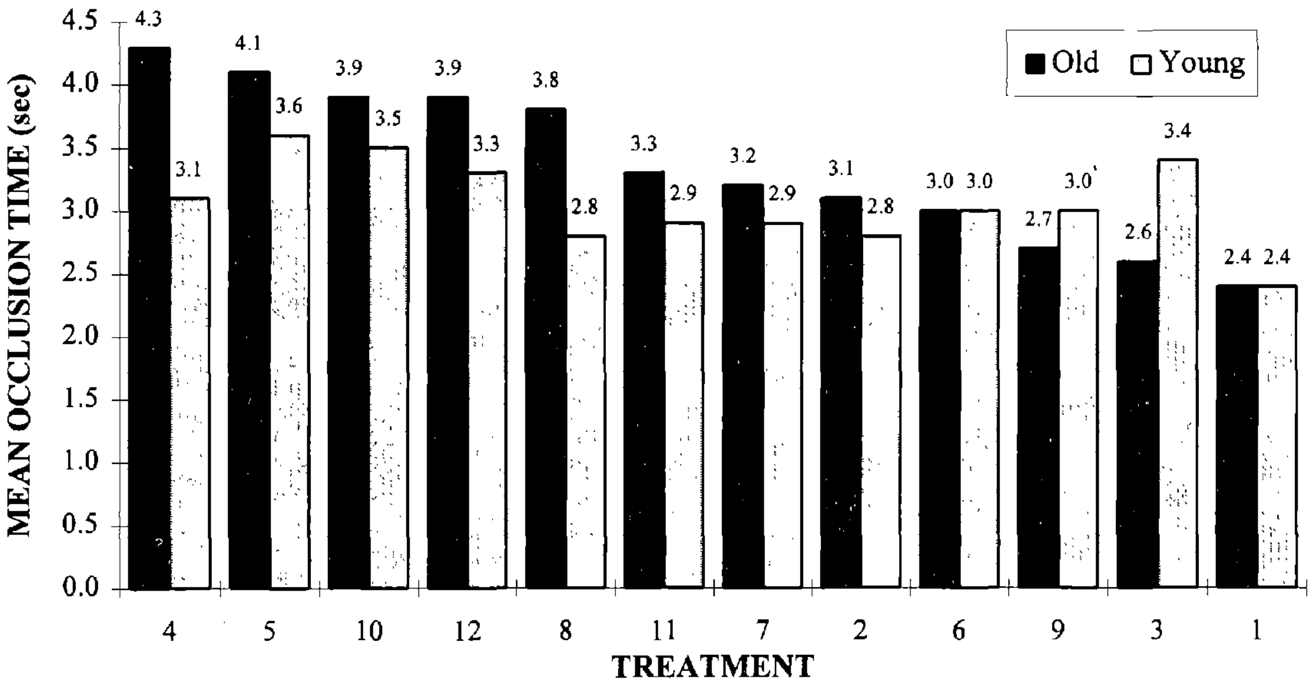

Figure19. Occlusion time (old versus young).

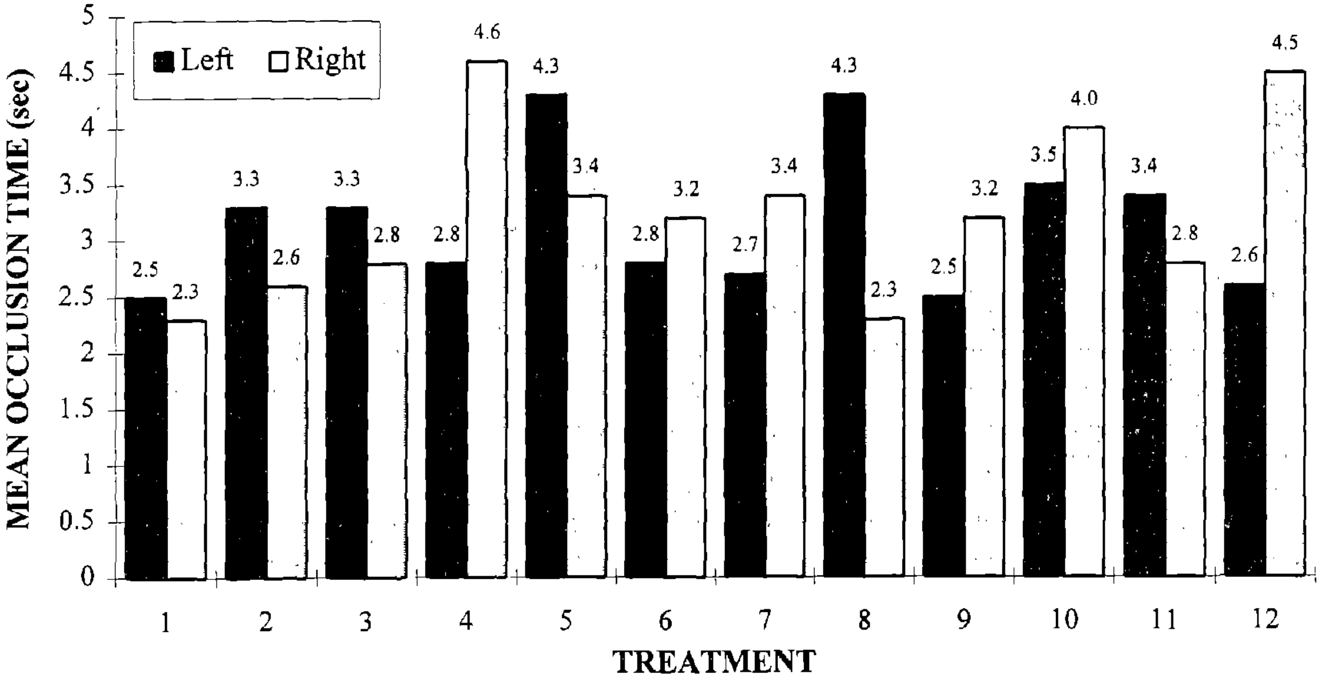

Figure 20. Occlusion time-left versus right curves (combined age groups).

Table 46. ANOVA—visual occlusion ratings
(combined age groups and curve direction).

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
Treatment (TRT)	11	193918.25	17628.93	78.63	0.0001
Age Group (AGE)	1	1789.84	1789.84	1.33	0.2528
Subjects	58	78918.64	1360.67	6.07	0.0001
Curve Dir. (CURVE)	1	443.57	443.57	1.98	0.1605
TRT*CURVE	11	2317.43	210.68	0.94	0.5023
TRT*AGE	11	3119.62	283.60	1.27	0.2437

Table 47. ANOVA—Visual occlusion ratings
(older age group and combined curves).

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
Treatment (TRT)	11	70530.32	6411.85	26.70	0.0001
Subjects	26	48869.48	1879.60	7.83	0.0001
Curve Dir. (CURVE)	1	1159.34	1159.34	4.83	0.0297
TRT*CURVE	11	1414.53	128.59	0.54	0.8762

Table 48. ANOVA—visual occlusion ratings
(right curve—combined age groups).

Source	DF	Type III SS	Mean Sq.	F Value	Pr > F
Treatment (TRT)	11	79349.18	7213.56	30.88	0.0001
Age Group (AGE)	1	2872.04	2872.04	12.30	0.0006
Subjects	57	39832.39	698.81	2.99	0.0001
TRT*AGE	11	1851.92	168.36	0.72	0.7168

Table 49. Subjective ratings
(younger, older, and combined groups).

Group	Treatment Number											
	1	2	3	4	5	6	7	8	9	10	11	12
Young. Rating	11	34	44	51	78	75	64	74	79	77	82	79
Old Rating	12	40	41	59	77	70	61	66	62	64	71	70
All Rating	12	37	62	54	77	72	63	71	72	71	75	75

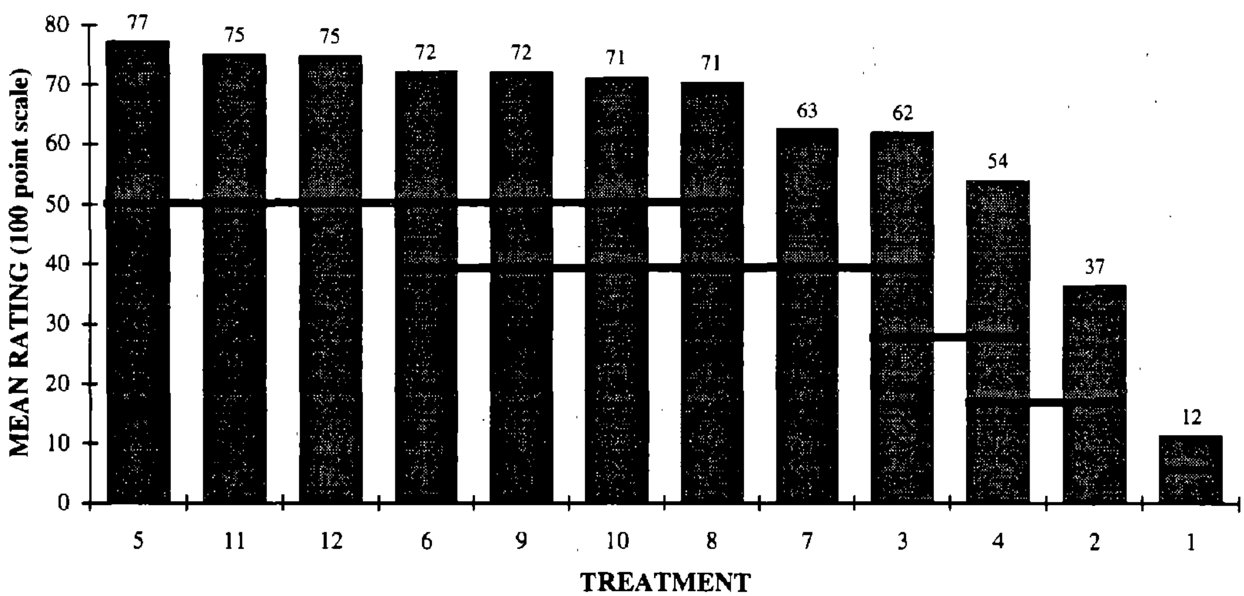

Figure 21. Occlusion trial ratings (combined age groups and curves).

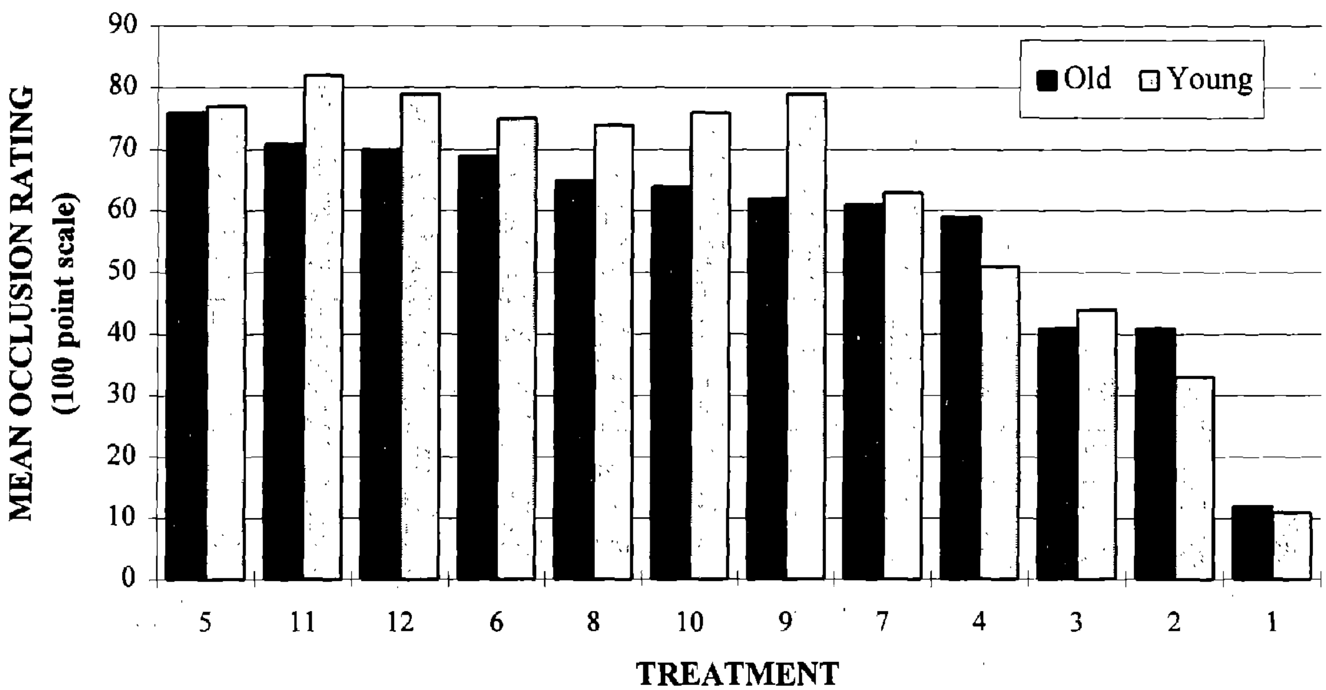

Figure 22. Occlusion trial ratings (old versus young).

With regard to the overall rating data (figure 21), it provides little information that will aid in the recommendation of treatments. There was not a statistically significant age group effect in the overall analysis of variance, and the post-hoc analysis showed that there were no significant differences between the seven most highly rated treatments. The relative absence of age effects can be seen in figure 22.

OCCLUSION RESULTS—SUMMARY

The overall analysis of occlusion time (age groups and curve direction combined) showed that treatment and subjects were the only statistically significant main effects. Neither age, curve direction, or any of the interactions reached an acceptable ($p = > 05$) level of significance. The differences between the longest and shortest occlusion times were relatively small, with differences of 1.9 s and 1.2 s for the older and younger groups, respectively. The maximum difference between the shortest occlusion time (treatment 1) and the longest time (treatment 5) was 1.4 s. Further, as with the recognition distance data, there were no statistically significant differences between the six treatments with the longest occlusion time. Also, there was a great deal more overlap between treatments throughout the overall occlusion time data set.

The analysis of the subjective data set (treatment ratings) resulted in no significant differences in age or curve direction; nor were there any significant interactions between the main effects. Finally, there were no significant differences between the seven most highly rated treatments.

COMPARISON OF THE DEPENDENT MEASURES

As shown in figure 23, the comparisons of ranks of the subjective (rating) data and the objective occlusion time data exhibit a number of disparities. For example, as figure 23 shows, treatments 4 and 10 resulted in relatively good performance (longer occlusion times) but were not very highly rated. Alternatively, treatments 6 and 9 ranked fairly low on performance but were rated relatively high.

As is clear in table 50, the two sets of objective data (recognition distance versus occlusion time) also exhibited very low correlations in terms of their relative rankings. As shown, the highest correlation coefficient was .248 for treatment 8. Perhaps this could be accounted because it would be the most frequent treatment to which our sample of Pennsylvania subjects would be exposed. As noted in the discussion of the visual occlusion procedure, the staff feels that the procedure, as implemented, involved personality attributes (e.g., competitiveness and risk taking) that may have confound the measure. Because the recognition distance measure is more pure, in that it primarily involves vision, it is felt to be the best indicator of delineation/marking quality. While not tested via the use of lateral position/lane tracking equipment, it is possible that recognition distance is the better measure for long preview and that occlusion may be a better measure for "moment-to-moment" information such as tracking.

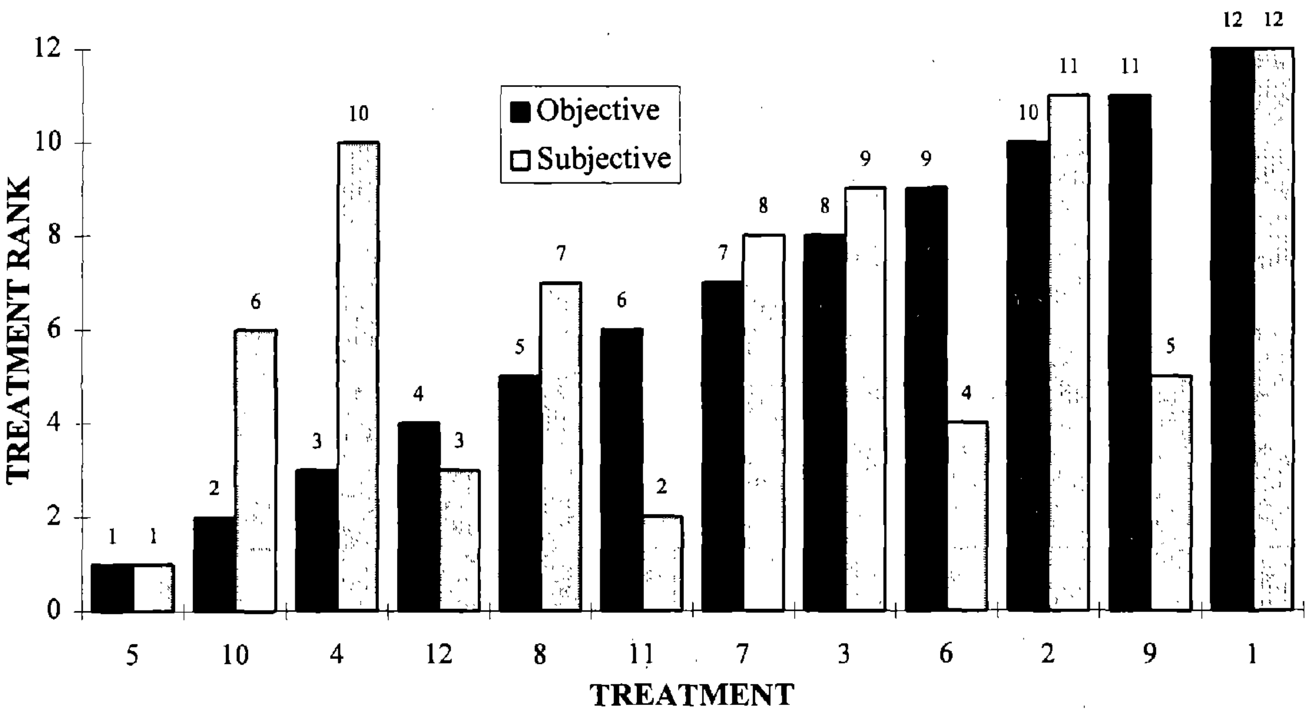

Figure 23. Comparison of ranks of objective versus subjective occlusion data.

Table 50. Correlations between recognition distance and occlusion (performance data).

Treatment	Correlation Coefficient
1	- 0.015
2	+ 0.204
3	+ 0.028
4	+ 0.243
5	+ 0.078
6	+ 0.159
7	- 0.108
8	+ 0.249
9	+ 0.177
10	+ 0.120
11	- 0.074
12	+ 0.062

CONCLUSIONS AND RECOMMENDATIONS BASED ON PERFORMANCE DATA

To aid the reader in maintaining an overall view of the performance and ranking of treatments as they pertain to the conclusions and recommendations, table 51 was constructed for reference. The table summarizes the measure and rank for both of the dependent variables for each delineation/marking treatment.

For both objective and subjective data sets, there are at least five of the highest ranked treatments in each set that are not significantly different from one another regardless of the measure. Treatments 5, 10, 11, and 12 appear in all four data sets (i.e., objective and subjective sets for both measurement procedures). From the standpoint of the field test, they are considered the most likely candidates for recommendation.

One method for choosing candidate treatments is to identify the treatments that were most effective for older drivers without being detrimental to younger drivers. Of the four candidate treatments listed above, treatment 12 produced the longest recognition distance (and smallest standard deviation) for older subjects. For younger subjects this treatment also produced the longest recognition distance. Treatment 12 also ranked second in the recognition trial ratings of older subjects. While the treatment was ranked seventh by the younger group, it still appeared within the top set of treatments that were not significantly different from one another. With regard to mean occlusion time, treatment 12 ranked fourth in the overall data set and for both age groups. For the occlusion rating data, both age groups produced a mean rank of third.

Treatment 10 produced the second highest overall recognition distance and visual occlusion time. It also produced the second highest overall rating for the recognition distance trials and the sixth highest for the occlusion trials. Additionally, it produced the second longest recognition distance for the older subject group and the third longest for the younger group. The mean rating for the occlusion trials resulted in ranks of sixth and fifth for the older and younger groups, respectively. However, there was no significant difference from the higher-ranked treatments.

Treatment 11 produced the fifth longest recognition distance and the sixth longest occlusion time. For the rating data, the treatment was ranked sixth for the recognition distance trials and second for the occlusion trials. Both the younger and older groups produced mean recognition distances that ranked fifth. The mean rating for the occlusion trials resulted in a rank of second for the older group and first for the younger group.

Treatment 5 produced the sixth longest recognition distance, and was the lowest of the group of treatments that were not significantly different from one another. However, it produced the highest occlusion time of any treatment and also the highest rating for those trials. For the recognition distance trials, the mean overall rating ranked third. With regard to age group, the older group mean rating for the recognition trials produced a rank of eighth; the lowest of the top group of treatments that were not significantly different from one another.

Table 51. Summary of results by treatment.

								Treatments and Characteristics			
Occlusion (rating)	Rank	Recognition Distance (rating)	Rank	Occlusion (seconds)	Rank	Recognition Distance (feet)	Rank	Treatment	Centerline Elements	Edgeline Elements	Off-Road Elements
59	9	13	12	2.4	12	64	12	1	Yellow Stripe	None	None
37	12	49	9	2.9	10	211	9	2	Yellow Stripe	White Stripe (structured)	None
43	11	35	11	3.0	9	192	10	3	Yellow + RPM (wide spacing)	None	None
53	10	42	10	3.7	3	161	11	4	Yellow + RPM (wide spacing)	White RPM (wide spacing)	None
77	1	71	3	3.8	1	831	6	5	Yellow Stripe	None	Chevrons
72	4	71	1	3.0	8	872	4	6	Yellow Stripe	White Stripe (normal)	Chevrons
63	8	52	8	3.1	7	592	8	7	Yellow Stripe	None	Standard Posts
70	7	69	4	3.3	5	742	7	8	Yellow Stripe	White Stripe (normal)	Standard Posts
72	5	65	7	2.8	11	875	3	9	Yellow Stripe	None	Fully reflectorized posts
71	6	71	2	3.7	2	894	2	10	Yellow Stripe	None	T-Posts (high intensity)
77	2	67	5	3.1	6	864	5	11	Yellow + RPM (std. spacing)	None	T-Posts (high intensity)
75	3	67	6	3.6	4	917	1	12	Yellow Stripe	White Stripe (normal)	T-Posts (Engineering)

Note: Shaded cells in the rank columns indicate treatments that were not significantly different from one another.

Based on the consistency criterion and the performance of older versus younger drivers (and keeping in mind the number of treatments that were statistically similar), it is judged that treatments 12 and 10 provide the best overall performance. However, each of the four treatments (5, 10, 11, and 12) can be expected to improve performance for older drivers and to have no detrimental effect on younger drivers.

7. COST/BENEFIT ANALYSIS

COST/BENEFIT METHODOLOGY

The purpose of this study was to investigate the effects of enhanced delineation and pavement markings on driver behavior, particularly older drivers. The investigation was also to include an analysis of the costs and benefits of the enhanced treatments. This chapter examines the economic feasibility of the tested treatments, including costs associated with implementing and maintaining the treatments. The purpose of this evaluation is to provide the practicing traffic engineer with an assessment of benefits and costs for the treatments investigated and an associated ranking of treatment costs to assist in determining the feasibility of each treatment.

A comparison of benefits and costs was conducted to provide a basis for evaluating the treatment alternatives. Studies of highway safety products generally quantify benefits as a change in a related measure of effectiveness. Typical MOE's for the installation of highway safety devices include reductions in accidents, reductions in accident severity, improvements in driver behavior such as reduced speed variance, and improvements in driver visibility. However, an analysis of accidents and accident severity requires an extensive time period to establish and observe changes in collision and severity trends. Although accident records are a preferred MOE for the evaluation of safety products, such data were not available for this analysis. Two driver performance measures were used in the controlled field study to determine the effectiveness of the treatments: (1) curve recognition distance and (2) visual occlusion time. Of the two measures, the curve recognition distance provided the more reliable results and, therefore, was chosen as the primary measure of benefit or effectiveness for this analysis.

The costs associated with implementing a safety product can be derived from acquisition, installation, and maintenance of the product. Such costs can include an indirect expense associated with utilizing a maintenance vehicle, an indirect delay cost incurred by drivers during installation, a direct material cost, and a direct labor charge. The evaluation included in this report limited costs to installation costs incurred for purchasing or fabricating a safety treatment plus the direct labor cost for installing the device in the field. Associated maintenance and replacement costs were also considered in the evaluation.

The economic model used in this study had to address the problem of unequal service lives for safety treatments. Depending upon factors such as traffic volume and environmental conditions, pavement markings become ineffective in less than a year while delineation posts and signs (chevrons) can last for 10 years or more. This obstacle was overcome by limiting the study period to the longest service life observed among all products and then calculating a present worth value based on installation, material, and maintenance costs. The present worth value is an amount at the present time, $(t)=0$, that is equivalent to an investment's cash flow, F_j, for a particular interest rate, i. Thus, the present worth of an investment proposal j at interest rate i with a life of n years can be expressed as:

$$PresentWorthValue = \sum_{t=0}^{n} F_{jt} (1+i)^{-t} \qquad (1)$$
$$Where \quad (-1 < i < \infty)$$

Present worth values of treatments were combined to provide a total present worth value for combinations of treatments. Present worth calculations used a 4-percent discount rate, as recommended in previous economic studies of highway signing and markings.[49] Products with service lives shorter than the study period were replaced with the same product (using the same initial installation cost) until a duration equal or in excess of the study period was reached. A zero-dollar salvage value was attributed to the portion of the service life past the study period.

TREATMENT COST AND SERVICE LIFE

A variety of sources was utilized to collect costs and service-life estimates of the treatments tested. Telephone conversations with State agencies, field supervisors, product manufacturers, and highway contractors provided installation costs, service-life estimates, and maintenance policies. In many instances, costs associated with installation and maintenance of individual treatments were not readily available. In addition, service lives for RPM's, chevron signing, and delineation posts were difficult to assess due to variations in maintenance and replacement policies. In instances where exact figures were not available, an estimate was provided. As is evident in the following discussion, most of the products were given a range of values for installation costs and service life. Quantity estimates for each treatment are based on a 91.4-m (300-ft) curve length with 61-m (200-ft) transition lengths.

Painted Centerline and Edgeline Markings

Centerline pavement markings are ordinarily used to separate traffic in opposing directions, and edgeline markings are used to mark the edge of paved surfaces. Existing binders for these markings include fast-drying, high-solvent paint; latex paint; thermoplastic; epoxy; and polyester. The two most common binders are high-solvent paint and thermoplastic adhesion. A literature review revealed useful cost estimates from a *Public Roads* article titled "Benefit-Cost Analysis of Lane Marking."[49] The article suggests that installation costs for fast-drying, high-solvent paint commonly used in highway striping is between $0.035 and $0.07 per linear foot (inflated to December 1990 dollars using Consumer Price Index). Comments from various transportation agencies on installation costs correlated with those expressed in the article, although it was expressed that centerline paint is slightly more expensive than edgeline paint. The report also suggested that line markings can exhibit a useful service life between 6 months and 7 years, depending upon Average Daily Traffic (ADT) and environmental conditions. Further conversations with transportation personnel suggested that a realistic estimate of service life for painted centerline and edgeline markings is two years; the study reflects this longevity estimate. The number of linear feet of both markings assumes a continuous double-line center stripe with a continuous edgeline stripe throughout the curve and a 61-m (200-ft) transition section before and after the curve.

Structured Edgeline Tape

There is a variety of structured edgeline striping manufactured for highway use. The term "structured" refers to a raised pattern that is molded into the edgeline tape. The material tested in this study is manufactured by 3M. A 3M representative provided an approximate material cost of $1.25 per linear ft with an installation cost ranging from $0.25 to $0.50 per linear ft, depending upon local economics (i.e., total installed cost ranged from $1.50 to $1.75 per ft). Durability of the tape is guaranteed by the manufacturer for a 4-year period with certain restrictions. A highway contractor, who performs road work in four south-eastern States, provided similar cost estimates for materials and installation. The Virginia Department of Transportation has applied the tape in several locations and remarked that it may last up to 6 years. However, detailed information on installation costs and service life was difficult to assemble because it was generally found that States rely heavily on thermoplastics for striping needs and utilize structured and roll-in-place striping mainly for short-term projects. For structured edgeline material, an estimated service life of 4 years was used because it is the guaranteed service life. For the economic evaluation, identical quantities of edgeline material and painted edgeline material were used.

Flexible Delineation Posts

Flexible delineation posts are longitudinal stakes that employ a minimum 76.2-mm (3-in) reflective element (usually reflective sheeting). These posts are typically placed in a series along the shoulder of a road to indicate the roadway alignment. For this study, four types of flexible delineation posts were evaluated: (1) a standard post with 101.6-mm (4-in) by 457.2-mm (18-in) of engineering grade retroreflective sheeting, (2) a fully-reflective post with 101.6-mm (4-in) by 1219.2-mm (48-in) of high-intensity retroreflective sheeting, (3) a standard T-Post consisting of a 101.6-mm (4-in) by 457.2-mm (18-in) horizontal section and a 25.4-mm (1-in) by 762-mm (30-in) vertical section of engineering grade sheeting, and (4) a high-intensity T-Post consisting of a 101.6-mm (4-in) by 457.2-mm (18-in) horizontal section and a 25.4-mm (1-in) by 762-mm (30-in) vertical section of high-intensity retroreflective sheeting. After speaking with several manufacturers and State officials it was discovered that delineation posts are typically available in 76.2-mm (3-in) widths with 25.3-mm and 76.2-mm (1-in and 3-in) length increments. Therefore, current costs did not reflect the sheeting sizes used in this study. The most common size for reflective sheeting was a 76.2-mm (3-in) by 304.8-mm (12-in) element. In addition, total material costs for delineation posts fluctuated due to the material composition of the post as well as the reflective element costs. Hence, it was reasoned that an estimate for the cost of the posts used in this study could be produced from a base cost for a typical delineation post plus an additional cost for reflective material.

Several State officials provided standard post material costs ranging from $7 to $16 per post, with installed costs averaging between $20 to $30 a post. A base-installed cost of $25 was used for a standard delineation post. Additional costs for the type and quantity of reflective sheeting were applied to the base-installed cost for a standard post to determine the installed cost of a T-post and a fully reflective post with high-intensity sheeting. Retroreflective high-intensity sheeting is approximately $3.75 per ft^2, and engineering grade sheeting is about \$0.80 to \$0.85 per ft^2. A typical T-post uses about 0.71 ft^2 of material, and a fully reflective post requires 1.33 ft^2 of material. Thus, installed costs for the posts were calculated as shown in table 52.

Service life for these products also varied considerably. Factors such as material composition, environmental conditions, and exposure to vehicular impact influence delineation longevity. As an estimate, highway delineation posts were found to last between 7 and 10 years, with replacement costs equal to original installation costs. A 5-year service life was determined for delineation posts with engineering grade sheeting, and a 10-year service life was determined for posts with high-intensity retroreflective sheeting. Quantity estimates for the economic evaluation are based on 15.2-m (50-ft) spacing throughout the curve length and 61-m (200-ft) curve transition lengths.

Table 52. Delineation post cost estimates.

Description	Price Range
Standard post with 101.6 mm (4 in) by 457.2 mm (18 in) of engineering grade retroreflective sheeting.	\$20.00 to \$30.00
Fully-reflective post with 101.6 mm (4 in) by 1219.2 mm (48 in) of high-intensity retroreflective sheeting.	\$25.00 to \$35.00
Standard T-Post consisting of a 101.6-mm (4-in) by 457.2-mm (18-in) horizontal section and a 25.4-mm (1-in) by 762-mm (30-in) vertical section of engineering grade sheeting.	\$20.56 to \$30.56
High-intensity T-Post consisting of a 101.6-mm (4-in) by 457.2-mm (18-in) horizontal section and a 25.4-mm (1-in) by 762-mm (30-in) vertical section of high-intensity retroreflective sheeting.	\$22.66 to \$32.66

Raised Pavement Markers (RPM)

The MUTCD states that raised pavement markers can be used as a positioning guide with other longitudinal markings and as a supplement with other markings for channelizing islands or approaches to obstructions.[50] These markers are typically a molded plastic dome or button with an embedded retroreflective element.

The only in-service/brightness data uncovered came from two sources. The Joint Technical Report of CIE/PIARC-CIE 73 provides visibility distance data for three types of RPM's exposed to traffic for 2 years.[39] Also, Blaauw and Padmos provide data on the visibility distance of RPM's after 22 months of service.[40] However, this information was not used in the cost-benefit calculations.

Material and installation cost estimates were provided by Maryland, Virginia, and Pennsylvania department of transportation (DOT) officials. Material costs for raised pavement markers fluctuated from State to State due to the numerous shapes, types, and quantities of RPM's that are available.

The field study used normal RPM's that were degraded to provide the reflectivity of a snow-plowable RPM. Therefore, the cost-benefit evaluation used a material and installation cost associated with a snow-plowable RPM. Snow-plowable RPM's typically consist of a metal casing and a plastic retroreflective lens. The whole unit is typically installed flush with the surface of the pavement to relieve the marker of contact with snow-plow blades. Discussions with transportation personnel indicated that installation costs for snow-plowable markers range from $25 to $35 for each marker. However, the service life of the marker is limited by the durability of the retroreflective lens. Actual service life for the RPM's was difficult to determine because the metal casings last longer than the retroreflective lenses inside the marker. Longevity for the metal casings could not be determined, but it was established that the plastic lenses usually require replacement after 3 years. The plastic lenses represent an installed cost of about $8 each for materials and installation at approximately 3-year intervals. Quantity estimates for the economic evaluation are based on 12.2-m (40-ft) spacing throughout the length of the curve and 61-m (200-ft) transition lengths in both directions of travel.

Chevron Signs

Installation costs for chevron signing is based on a 457.2-mm (18-in) by 609.6-mm (24-in) sign with high-intensity sheeting. Telephone conversations with transportation officials in Maryland, Florida, and Georgia provided an approximate installation cost of $96 for each chevron sign. The expected service life of a chevron sign with high-intensity sheeting is about 10 to 15 years. This was corroborated in a recent Pennsylvania DOT study that evaluated the high-intensity sheeting used on "No Passing Zone" pennants. The study revealed that ". . . 14- and 15-year-old sheeting had an average brightness level 23 percent brighter than the minimum specification brightness for new high-intensity sheeting."[51] However, service lives for chevron signs are influenced by maintenance and replacement policies of the State or local DOT. To provide a conservative assessment of the service life of a chevron sign, the investigators used a service life of 10 years with no associated maintenance or salvage value. The MUTCD does not provide a fixed standard for placement and spacing of chevron signing. The number of signs necessary to delineate a 91.4-m (300-ft) curve was also difficult to assess. The MUTCD states in section 2C-6, "Warning Signs," that chevron sign spacing should be such ". . . that the motorists always have two in view, until the change in alignment eliminates the need for the signs."[50] This guideline suggests that the placement and spacing of chevron signs is unique to each site. Pennsylvania DOT indicated that the number of chevrons required on a curve is determined by a local sign supervisor who visually inspects each site for placement. Typically, other methods of warning drivers about geometric changes are employed when more than five or six chevron signs are needed. The economic evaluation used five signs for each side of the roadway for cost assessment purposes.

Cost Summary

Table 53 provides a summary description of each item used in the study and an accompanying range for installation costs and service life. Centerline and edgeline striping installation costs are provided per a linear ft of striping, and all other treatment costs are provided per item. The raised pavement markers are the only treatment with an associated maintenance cost. The estimated cost of $280 every 3 years reflects the replacement cost of the reflective lenses in the markers.

Table 53. Treatment installation costs and service lives.

Description	Materials/ Installation Cost	Service Life
101.6-mm (4-in) Yellow Painted Centerline	$0.035-$0.040 plf	2 years
101.6-mm (4-in) White Painted Edgeline	$0.035-$0.040 plf	2 years
101.6-mm (4-in) Structured White Edgeline	$1.50-$1.75 plf	4 years
Yellow Raised Pavement Markers (Snow-Plowable)	$25.00-$35.00 ea.	3 years reflective lens
White Raised Pavement Markers (Snow-Plowable)	$25.00-$35.00 ea.	3 years reflective lens
Normally Mounted Chevrons with High-Intensity Sheeting	$96.00 ea.	10 years
Standard Flat Delineation Post with High-Intensity Sheeting	$20.00-$30.00 ea.	5 years
Fully Retroreflective Delineation Post with High-Intensity Sheeting	$25.00-$35.00 ea.	7 years
Delineation T-Post with High-Intensity Sheeting	$22.66-$32.66 ea.	7 years
Delineation T-Post with Engineering grade Sheeting	$20.56-$30.56 ea.	5 years

Data Analysis

The desired approach for calculation of cost/benefit ratios was to develop indices of cost (present worth value) per foot of recognition distance yielding an individual measure representing treatment cost/benefit values for comparison purposes. However, as reported earlier, the statistical analysis of the recognition distance data indicated that there were several treatment groups that did not exhibit significantly different mean recognition distances. This indicates that although there were differences in the mean values of recognition distance, these means were not significantly different because of the wide variances. Therefore, it was decided to merely rank those treatments within a statistical group by order of their present worth costs.

Table 54 shows the mean recognition distance (for the combined age groups) and the low, high, and median value of the present worth in dollars for each of the treatments. The treatments, as shown, are ranked by their recognition distance, from highest to lowest. The statistical group letter indicates that the treatments sharing a common letter do not have significantly different recognition distances (treatments 5 and 4 are shown in two groups for reasons explained later). In table 54 there is a division between treatments of statistical groups A, B, and C and groups D and E. These letter groupings are the nongraphic equivalent of the horizontal lines across the bars used in several of the bar graphs in chapter 5. The lower-group treatments have recognition distances significantly lower than the upper-group treatments. As was discussed earlier in this report, the distinction between these two aggregate groups is that the lower groups were pavement marking treatments, i.e. paint lines, raised pavement markers, and structured lines. The upper groups had at least a vertical treatment in the form of either chevron signs or one of the different flexible delineation posts. A quick review of table 51 reveals that all of the treatments with a sign or post element provided a much greater recognition distance in comparison to pavement marking treatments. When evaluating the benefit of an improvement in recognition distance, it is necessary to relate the improvement to a standard design criterion such as stopping sight distance, passing sight distance, or decision sight distance. Such a correlation allows for a practical assessment of the treatment and provides a design standard upon which an "enhanced" treatment can be defined. It was surmised that an estimate for an "enhanced" treatment should provide a driver greater recognition distance than the minimum stopping sight distance for a curve on a rural highway. This design criteria was selected because it allows for a conservative and reasonable comparison, since drivers on rural highways will probably only have to negotiate a slight speed reduction and/or change in vehicle path.

In particular, it was surmised that driver recognition distance to a curve should be in excess of the minimum required stopping sight distance for a 55 mi/h design speed. The American Association of State Highway and Transportation Officials (AASHTO) "Green Book" suggests that for a 55 mi/h design speed the stopping sight distance to a horizontal curve should be between 137.2 m to 167.6 m (450 ft to 550 ft).[52] Since the "Green Book" provides values as minimums, the acceptable minimum distance was set at 182.9 m (600 ft) of recognition distance. Therefore, any "enhanced treatment" should provide at least 182.9 m (600 ft) of recognition distance to provide adequate time for drivers to respond to impending path tracking and speed changes.

Table 54. Present worth values and benefit/cost ratios.

Treatment	Statistical Group	Overall Mean Recognition Distance(Ft)	Present Worth in Dollars		
			Low Value	Median Value	High Value
12	A	917	1935	2493	3050
10	A	897	964	1228	1491
9	A	875	1030	1294	1557
6	A	872	1619	1867	2114
11	A	864	2907	3346	3784
5	A	831	1290	1414	1537
8	B	742	1900	2458	3016
7	C	592	1571	2005	2439
2	D	211	4985	5497	6008
3	D	192	2272	2571	2870
4	D	161	4215	4689	5162
1	E	64	330	454	577

As previously shown in table 53, installation costs varied considerably for many of the safety treatments. The present worth calculations reflect this disparity with a "low" and a "high" present worth value for each alternative. The median present worth value is simply an arithmetic average of the "low" and "high" present worth values.

COST/BENEFIT CONCLUSIONS

There are a number of considerations that should be addressed when conducting cost/benefit analysis. In any economic analysis, variances in regional economies will influence comparison results. This investigation relied on data from several regions, attempting to encompass variances in economies by using cost and service-life ranges. However, caution is advised when assuming that the ranges reported reflect local economies. Such local variances are difficult to assess. Labor rates and product materials are not uniform across all States, which creates variances in determining cost estimates. Therefore, the cost ranges supplied should not be implied as absolute values.

Variances in product service lives can also create inconsistencies in comparisons. For instance, the longevity of reflective sheeting for signing in southern States can be expected to be less than in northern States, due to the increased exposure to damaging ultraviolet sunlight. In contrast, painted lines in northern States may have a lower service life than in southern States because of snow-plow damage. Thus, environmental differences will influence a treatment's service life. Additionally, the service life of a product can be influenced by its exposure to harmful events—centerline striping in high-traffic areas will not retain reflectivity as long as the same striping in low-traffic areas, and chevron signing on sharp curves has a greater risk of vehicle collisions than chevron signing on gentle curves. Although these factors are accounted for in estimates of product service lives, it should be recognized that benefits and costs can be site specific.

Eight treatments (treatment numbers 5 through 12) produced recognition distances equal to or greater than the 182.9-m (600-ft) stopping sight distance criteria and could, therefore, be considered enhanced treatments. Of these treatments, alternatives 9 and 10 provided the lowest cost estimates for a 10-year study period. Treatment 9 provided 266.7-m (875-ft) of recognition distance using high-intensity, fully retroreflective, flexible flat posts and centerline striping. Alternatively, treatment 10 provided 274.3-m (900-ft) of recognition distance using high-intensity, retroreflective, flexible T-Posts and centerline striping. However, statistical results suggest that there is no significant difference in recognition distances for the two treatments or between any treatment in statistical group A. Therefore, statistical results suggest that any treatment in statistical group A will provide an equivalent measure of recognition sight distance. Because group A encompasses six of the eight enhanced treatments, it does not appear beneficial to rank the enhanced treatments by measures of recognition distance. Another alternative is to rank the eight treatments by a measure of their perspective present worth values. In table 55, the eight treatments have been ranked using a normalized cost ratio. The normalized cost ratio is calculated as a ratio of the lowest cost (using median present worth values) to the cost for the comparison treatment. Therefore, table 54 reflects cost ratios in relation to the cost of treatment 10, the lowest cost item of the "enhanced" treatments. Thus, treatments 8 and 12 are approximately twice as expensive as treatment 10, and treatment 11 is almost three times more costly.

However, ranking the treatments by a ratio of their corresponding median present worth values also does not provide an adequate measure for comparison because six of the eight "enhanced" treatments used flexible delineation posts, elements which produced the greatest variances in installation costs and service lives. Such variations suggest that ranking the enhanced treatments by a measure of cost would not provide an impartial assessment of the treatments. Therefore, it is suggested that the practicing engineer consider local economics and site characteristics to determine the most beneficial enhanced treatment.

In conclusion, several treatments have been identified that provide enhanced driver recognition distance to a curve. These treatments all utilize a vertical element to provide increased recognition distance. Determination of the most cost-effective alternative from those presented in table 55 will depend on consideration of maintenance policies and local economics. Therefore, it is surmised that identifying the most cost effective of these treatments will depend upon these factors and the influential characteristics of the site on which they will be considered for use.

Table 55. Normalized cost values for enhanced treatments.

Enhanced Treatment #	Treatment Description	Median Present-Worth Value (Dollars)	Normalized Cost Ratio
10	yellow centerline with high intensity T-posts	1228	1.00
9	yellow centerline with fully reflectorized posts	1294	1.05
5	yellow centerline with chevrons	1414	1.15
6	yellow centerline, white edgeline and chevrons	1867	1.52
7	yellow centerline and standard posts	2005	1.63
8	yellow centerline, white edgeline and standard posts	2458	2.00
12	yellow centerline, white edgeline and engineering grade T-posts	2493	2.03
11	yellow centerline, centerline RPM's and high intensity T-posts	3346	2.72

8. CONCLUSIONS AND RECOMMENDATIONS

The fact that a wide variety and a large percentage of the treatments tested failed to show statistically significant performance differences makes recommendations difficult. As mentioned previously, there are eight treatments that, from the standpoint of curve recognition distance, exceed the "Green Book" stopping sight distance criteria, i.e., they provide the driver with enough distance to stop and, therefore, enough distance to make appropriate changes in speed and path. The recommendations are made primarily on the basis of differences in recognition distance values, even though many of the differences are nonsignificant from a statistical standpoint. For reasons explained previously, the occlusion time results were considered of lesser importance than the recognition distance measure.

From the standpoint of the field results, the criteria of consistency (as described in table 51) were applied. That is, the treatments that produced good performances across all objective and subjective measures and did well for the older driver group were considered prime candidates for recommended use to improve the safety of older drivers. Use of these multiple criteria led to the choice of treatments 5, 10, 11, and 12.

Based on the consistency criterion and the performance of older versus younger drivers, and keeping in mind the number of treatments that were statistically similar, it was determined that treatments 12 and 10 provide the best overall performance. However, each of the four treatments (5, 10, 11, and 12) can be expected to improve performance for the older driver without inducing detrimental effects on the younger driver.

In applying the cost-benefit criteria, and focusing on the recognition distance measure, it was found that treatment 10 provided the lowest cost estimates for a 10-year period. It was also pointed out that because six of the eight treatments were not statistically different with regard to the recognition measure, it does not appear beneficial to rank the enhanced treatments simply by measures of recognition distance. An alternative is to rank the eight treatments on the basis of their perspective present worth values. The eight treatments exceeding the "Green Book" stopping sight distance value of 182.9 m (600 ft) were ranked using a normalized cost ratio. The normalized cost ratio is calculated as a ratio of the lowest cost (using median present worth values) to the cost for the comparison treatment. In this case, cost ratios were calculated in relation to the cost of treatment 10, the lowest cost item of the enhanced treatments. Thus, of the four treatments considered purely on the basis of the field results, treatment 12 was calculated as being approximately twice as expensive as treatment 10. Treatment 5 was just slightly higher in cost than treatment 10, and treatment 11 was three times more expensive than treatment 10. Thus, considering both performance and cost benefits, treatments 5 and 10 would be the recommended choices.

There are, however, some flaws in these choices. Delineation and marking treatments are designed to provide a preview of roadway features ahead and give the driver information about the lateral position of the vehicle on the roadway. However, neither of the treatments recommended above includes an edgeline. Thus, the lateral position information is not provided to the driver. While expensive, treatment 12, which includes an edgeline, produced the highest overall recognition distance values for both age groups. This leaves us with the conclusion that it may cost more to most adequately meet the needs of the older driver. However with the requirement to meet all of the guidance needs of the older driver, i.e., both long preview and moment-to-moment tracking, treatment 12 is the logical recommendation.

In addition to identifying delineation and marking treatments that could aid the older driver, another finding emerged from the study. A review of the treatments judged best from the standpoint of their ranking on the four measures indicates that all included an off-road device that is characterized by greater size than most current delineation devices. Treatments 10, 11, and 12 included post delineators that were fully reflectorized, i.e, retroreflective material extending from the top of the post to the ground, and treatment 5 included chevrons. All of these devices provided more reflective area and performed better than the standard posts most frequently used.

APPENDIX A: METHOD OF CHOOSING AND DESCRIPTION OF TREATMENTS SELECTED FOR EVALUATION

METHOD OF CHOOSING TREATMENTS

The identification of delineation and marking enhancements to improve older driver performance was completed in two steps. In the first step, each of the study team members was sent a technical memorandum summarizing the information that was gathered as part of the background material review. The memorandum contained information about older driver deficiencies and the performance characteristics of different types of pavement markings and delineation devices. Appended to the memorandum was a set of specification and ranking forms. The study team members were sent two copies of the forms; one on which they could actually work (i.e., erase, cross-out, draw arrows, etc.), and the other on which they could fill in their suggestions and return to the research team. The evaluators were asked to specify different marking and delineation treatments that would be most likely to benefit older drivers. They were cautioned that their suggested enhancements must target the older driver population. It was also pointed out that any suggested enhancements must be presently feasible. The completed forms were returned to the research team.

The next step involved a brainstorming session among the principal study team members. The objective of the session was to discuss the enhancements that had been suggested by the team members on their specification and ranking forms and to decide what treatments should actually be tested in the simulator study.

Before any group discussions began during the meeting, each of the participants had an opportunity to review the specification and ranking forms of all of the other participants. After the review of the individual specification and ranking forms was complete, a general discussion of issues related to the topic of developing enhanced pavement markings and delineation for older drivers was held. After this general discussion was completed, each component (e.g., size, luminance, contrast, etc.) of the specification for a particular treatment type (surface treatments, e.g., pavement markings; raised surface treatments, e.g., raised pavement markers; and off-road treatments, e.g., chevrons, post-mounted delineators) was considered as to how it affected the older driver and how it could be changed given current product characteristics.

Initially, it was decided that the two general highway features about which drivers need supplemental information in the form of pavement markings and delineation devices are: continuous features such as curves and discrete features such as bifurcations, curving bays, or lane drops. For all of these features, there are certain types of information that a driver needs. Drivers need a preview of the roadway features that are ahead so that surprises about changes in roadway alignment are minimized, and they also need information about their lateral position on the roadway so they can steer their vehicles. Given the universe of treatments that could be tested for this study, it was determined that the treatments that were to be selected should adequately represent devices that provide one, the other, or both types of information to the driver.

The type of information provided to the driver was also considered. Generally, most of the information that a motorist receives is visual. However, there are traffic control devices that provide auditory and vibrotactile information as well (e.g., rumble strips, raised pavement markers, or structured pavement markings). These types of devices are excellent at heightening the attention level of the motorist. The benefit of redundant systems is well known, and providing sensory signals, other than visual cues, should have beneficial effects for older drivers. However, it was decided that given the test protocols that were used for the simulator and field testing, it was not likely that many of the subjects would be exposed to auditory or vibrotactile information (i.e., given the alerted state of being involved in an experiment about nighttime driving, few subjects would actually leave the traveled way). It was also determined that most run-off-the-road accidents, where inattention is the principal cause, occur on tangent sections. Therefore, it was decided that while the auditory or vibrotactile feedback characteristics of certain treatments would not be ignored, these characteristics would not be primary reasons for selecting a particular treatment.

Once the group decided to focus on treatments that principally provide visual information, the characteristics of a visually oriented traffic control device that could be varied in response to the needs of older drivers were identified in general terms. The terms bigger, brighter, and more frequent were used to describe the areas where device specifications could be varied to improve the performance of older drivers. The term bigger means changing a physical dimension of a TCD or moving a standard-size device closer to the driver (e.g., changing the lateral offset for an off-road device). The term brighter covers the parameters of luminance and contrast. Much of the literature talks about the reduced contrast threshold level for the older driver in detecting roadside objects. Contrast sensitivity is usually discussed in terms of a contrast ratio, which is a function of the luminance of the target and the luminance of the background area behind the target. Generally, it was thought that the background luminance for surface treatments (i.e., pavement markings, RPM's, etc.) cannot be varied a great deal on black pavements (asphaltic concrete), however, on white pavements (portland cement concrete) the background contrast can be altered quite a bit (e.g., placing black stripes adjacent to a surface treatment). Given the limitations of the field test facility, it would not be possible to use this type of treatment. The panel realized that contrast is a crucial variable with respect to older drivers. However, through the use of analytical procedures identified in CIE 73, it is possible to determine the contrast of any treatment tested on any surface. Therefore, since background luminance is so hard to vary, the variable of interest becomes the luminance of the target. Although the luminance of the target should be the parameter that is changed, the luminance of several of the treatment types is relatively hard to measure. Therefore, it was decided to use the target brightness as a surrogate for luminance.

The frequency of exposure to a treatment is a function of the treatment type. For pavement markings, when a solid line is used the exposure of this device to the driver is continuous. For other types of treatments, such as RPM's, the exposure is a function of longitudinal spacing. While spacing may be a crucial variable, it would not be possible to vary this element across treatments without causing the number of test treatments to exceed the time and cost constraints of this study. Given the information found in the review of the background material, the panel felt that they would rather vary other specification elements that might have a greater influence on the performance of the older driver.

The frequency can also mean the redundancy of the system. The information can be presented as a single longitudinal line of retroreflected light that is on or off of the road (e.g., an edgeline). The driver uses this one line as an anchor point and tries to drive his vehicle parallel to and at a comfortable offset from the line. Information can be presented as two lines of retroreflected light on or off of the road. With this type of system, the driver tries to place his vehicle between the two lines to track the proper path. The addition of a third line creates a truly redundant system. The centerline and edgeline create a fixed path for the driver to traverse, and the off-road line adds the redundant information.

It was decided that some baseline conditions needed to be established to provide a starting point for developing test scenarios. The enhanced treatments are supposed to aid older drivers on two types of facilities: two-lane rural roads and four-lane rural freeways. It was decided that a minimum treatment on a two-lane rural road would generally consist of a single 101.6-mm (4-in) yellow centerline with no edgeline marking. The minimum treatment on a rural freeway would generally consist of a 101.6-mm (4-in) yellow centerline and a 101.6-mm (4-in) white edgeline. It was also decided that all pavement marking and delineation devices are more visible when a vehicle is using its high-beam headlights. However, since the worst case situation is when vehicles are using their low-beam headlights, and since a good part of the driving on rural facilities, especially by older drivers, is done using low-beam headlights, it was decided to test all baseline and enhanced treatments using low-beam headlights.

INDIVIDUAL TREATMENT ELEMENTS

Pavement Marking Treatments

Materials

The different pavement marking treatments that were suggested by the research team included paints, epoxies, preformed tapes, polyester tapes, and thermoplastic tapes. While all of the these different materials have different brightness characteristics, it was decided that it would be best to test relative levels of brightness (e.g., low, medium, or high). Because all of these materials could fall into one of these categories relative to each other, and because the principal performance characteristic of marking materials is wear, it was decided to leave consideration of materials to the cost-effectiveness analysis that is to be performed later in the project.

Size

There were only two different size parameters that can be varied for continuous markings thickness and width. Thickness primarily controls material brightness under wet weather conditions. It was decided that since dealing with wet weather was not a principal concern of this research (and since other projects are looking into this area), thickness would be considered as part of the cost-effectiveness analysis. There were only three stripe widths suggested by the panel on the completed specification and ranking forms: 101.6 mm, 152.4 mm, and 203.2 mm (4 in, 6 in, and 8 in). It was decided that 101.6-mm (4-in) wide stripes would have to be part of the experiments. At some standard inservice brightness levels, 101.6-mm (4-in) wide stripes were used as a benchmark condition by which the enhanced treatments could be measured. The 101.6-mm (4-in) width was also used a an anchor point around which other parameters were varied (e.g., brighter 101.6-mm [4-in] lines). However, it was not clear if there would be a measurable difference in performance between 101.6-mm (4-in) stripes and 152.4-mm (6-in) stripes, and 152.4-mm (6-in) stripes and 203.2-mm (8-in) stripes. It was also pointed out that painted pavement markings are usually repainted because their daytime visibility performance has degraded. However, their nighttime performance is usually still adequate. This leads to an operational scenario where 203.2-mm (8-in) wide stripes could be used and where only alternating 101.6-mm (4-in) widths of the line would need to be painted when the daytime performance deteriorates. This would give a 101.6-mm (4-in) stripe that is visible in the daytime, and a 203.2-mm (8-in) stripe that is visible at night. Since not all possible conditions could be tested, it was decided to test only the 203.2-mm (8-in) stripes as an enhanced width treatment in the study.

Brightness

All of the panel members were aware of the problems that older drivers have in detecting low contrast targets. However, given the fixed background luminance of the roadways, both dark and light colored, and the brightness values of existing materials, it was decided to test a range of stripe brightnesses to determine the brightness at which the older driver benefits from the increased contrast ratios provided by the brighter lines.

Once the size and brightness elements were discussed, the panel felt confident that a discussion of specific treatments could begin for the pavement marking treatments.

APPENDIX B: SUBJECT INSTRUCTIONS FOR RECOGNITION DISTANCE AND OCCLUSION TRIALS

TEST SUBJECT INSTRUCTIONS—RECOGNITION DISTANCE TRIALS

I am going to read the instructions for the experiment so that all volunteers have exactly the same information before the experimental trials begin.

As explained to you in previous communications, the purpose of this research program is to find out whether we can improve roadway guidance treatments, particularly for older drivers. In case you are not familiar with the term, roadway guidance treatments are the bright buttons or posts you see on the side of the road, the bright markers sometimes put on the surface of the road, and the paint lines in the center and on the edge of the road. We know that many drivers over age 65 don't see as well at night as younger drivers and we are trying to find guidance treatments that will improve safety and make older drivers more comfortable during night driving. If we are successful, older drivers are more likely to want to drive at night and, therefore, their overall mobility will be improved.

For the experiment tonight we are interested in which roadway guidance treatments allow you to see curves from a greater distance so that, if you were approaching the curves, you would be ready to take appropriate actions, such as reducing speed.

When we arrive at our starting point on the test track we want you to look down the yellow centerline and determine whether the curve ahead goes to the left, the right, or whether you cannot yet tell the direction of the curve.

[Experimenter shows both volunteers the response boxes]

Hold the boxes sideways, like this. The left button is labeled "L" (LEFT), the middle "?" (DON'T KNOW), and the right is labeled "R" (RIGHT). You will press one of the three buttons to indicate the direction of any curve ahead. If you can't yet determine the direction at any stopping point, you will press the button labeled with the "?." This procedure will be repeated each time I stop the car on the approach to the curve. After each stop, please don't push any of the buttons until I ask you to do so. Don't be concerned about the sounds you hear coming from the computer. They simply indicate that the data collection program is operating properly.

Our starting point for each of the eight treatments you will be judging may be too far away for you to be able to identify the direction of any curve ahead. Therefore your first few responses may be "?" (DON'T KNOW). Since we are trying to determine the roadway guidance treatment you can see the best, we do not want you to guess. This is not a test of you, but a test of which treatment provides the best information about the road ahead. If a particular guidance treatment does not definitely tell you that the road ahead will curve in a particular direction, your response should be "DON'T KNOW."

After the second trial is completed, we will also ask you to rate each treatment on a simple form. Before we do the first trial, do you have any questions?

[After first trial give SS's clipboard, light, and rating form]

The photo on the rating form is the guidance treatment you saw on the trial we just completed. While the photo shows a left curve, the actual trial may have been a right or a left curve. The photo is simply a reference we want you to use to make the ratings. It represents the lowest level of guidance information you will be asked to judge and would be rated rather low. We want you to assign a number from 1 to 100 to each guidance treatment you see tonight. The number you assign will be your judgment of the effectiveness of each treatment in providing information as to the direction of any curve. Please judge all of the treatments in relation to the lowest level treatment; the one used for trial 1 and shown on the photo. Do you have any questions about the rating?

Please do not talk to one another during the trials or discuss the treatments while you are completing the rating form. While we are waiting between trials, I may also be asking you some questions about how often you drive at night, what kinds of driving situations you avoid, etc. We will record your impressions on tape at that time since it would take too much time to write them down. This information will simply be used to supplement the other data.

TEST SUBJECT INSTRUCTIONS—VISUAL OCCLUSION TRIALS

I am going to read the instructions for the experiment so that all volunteers have exactly the same information before we begin.

The purpose of the trials we are going to do tonight is the same as the trials you did before. We want to determine the best roadway guidance treatment for night driving. Tonight's experiment is just a different way to determine which treatment is best. You may recall that the roadway guidance treatments we are testing involve yellow and white stripes and reflective markers on the road, and upright reflective markers just to the side of the road. You will see the same treatments tonight that you saw during your first session.

What you see mounted at the top of the windshield is a visual shield that will come down over the windshield to prevent you from seeing down the road. It works like this.

[Experimenter activates occlusion device]

The roadway guidance treatments will be set up in the wide area of blacktop that we used in the first session. At some point, as you approach them, the shield will automatically come down as it just did. The purpose of each trial is to see how long you are willing to drive with the shield down; that is, without being able to see down the road. This button that you will be holding will raise the shield when you push the button and release it. The shield goes up on the release of the button. Push and release the button now so that you can see how the shield works. Remember that the release of the button is what raises the shield.

Now I'll lower the shield again and you push and release the button to raise it. We'll do this several times so that you can see how long it takes for the shield to go up.

[Show volunteer how to hold switch and explain reset procedure]

Before I demonstrate the shield operation again I am going to lower it and I would like you to adjust the height of the seat so that you cannot see under the shield when you are sitting in your normal driving position. The control for raising and lowering the seat is at the side of your seat.

[Show volunteer where to hold steering wheel]

In other experiments using this procedure it has been found that better roadway information, such as improved guidance treatments, results in drivers going for longer periods of time with the shield down. This means that they are comfortable with the information they have gathered from the road (before the shield drops) and are more certain about what is ahead; for instance, a curve. It seems that the higher the quality of the roadway information, the longer a driver is willing to proceed without being able to see down the road.

The car has a second brake pedal that I can operate in case you get off course during the time the shield is down. This is a feature to avoid any safety problems. If I think it is necessary to slow or stop the vehicle with the secondary brake I will tell you that I am going to do so.

We will also use the car's cruise control during the trials. I will ask you to set it on the approach to the roadway guidance treatment on each trial. When I tell you to set the cruise control, you simply push this button and remove your foot from the gas pedal. The cruise control will go off when you tap the brake pedal.

[Show volunteer cruise control button]

Now, fasten your seat belt and we will begin driving slowly around the track so that you become familiar with the brake and gas pedals and the cruise control button. I will not lower the shield now.

[Direct volunteer from parking lot to oval]

[Caution volunteer about buses and one-lane bridge]

[When on straightaway, have volunteer activate cruise control]

[Remind volunteer where to hold steering wheel and how to hold switch]

[Have volunteer stop at reflective marker]

This will be the location where we start each trial during tonight's session. We will now do two practice trials.

You will proceed around the curve ahead, after which you will see the beginning of the yellow line we followed in the first session. The beginning of the line will be identified with some yellow reflective marker on the pavement. You will continue driving to the right of the yellow line as if it were the centerline on a two-lane roadway. I will be monitoring your speed. I will tell you as you near 30 mi/h, and when you reach the correct speed I will tell you to push the cruise control button and remove your foot from the gas pedal. You should watch the road ahead and not the speedometer. I will tell you when you have reached the right speed and should press the cruise control button.

At some point after you set the cruise control, I am going to verbally warn you that the shield is going to come down. When the shield drops I want you to press and release your button to raise the shield. We'll do this a few times while you are moving so that you can get used to the whole procedure. In each case, raise the shield soon after I lower it. Do not try to leave it down yet. Before we begin collecting data, we'll give you another practice trial that will be just like the real trials.

Experimenter "talks" volunteer around curve as below:

[Identify the beginning of the yellow line]

[Notify volunteer as speed approaches 30 mi/h]

[Tell volunteer to push cruise control button and remove foot from gas pedal]

[Warn volunteer that shield will drop and activate shield]

[Complete a few shield cycles on the approach to the curve and beyond]

[Direct subject to tap brake pedal to deactivate cruise control]

[Return to the oval and the starting point]

Do you have any questions before we begin the final practice trial?

This time, we will do a practice trial that is just like a real trial. I won't tell you that I am going to lower the shield. I will just do it sometime after I tell you to push the cruise control button. When you are uncomfortable with the shield down, press and release your button and the shield will go up. If you leave the shield down longer than necessary, I may ask you to raise it. Otherwise, raise it yourself whenever you feel you must see the road ahead. During this final practice trial and all real trials, please stay in the normal driving position and do not look under or around the shield when it is down. As soon as you raise the shield, you should tap the brake pedal to release the cruise control. At that point the trial is completed and you should return to the oval and proceed to the starting point for the next trial.

[Talk volunteer through practice trial and radio crew to setup first treatment]

Do you have any questions before we begin the trials? As in the session completed before, we also want you to rate each guidance treatment. You will get a rating sheet to fill out after you have completed each trial.

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