Age Differences in a Visual Information Processing Capability Underlying Traffic Control Device Usage

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Three laboratory studies addressing the magnitude of age-related differences in visual performance and their effect on delineation recognition and sign word-message legibility were conducted by using a repeated-measures experimental design. A method of limits procedure using a Landolt-C detection task defined contrast sensitivity decrements among drivers aged 65 to 80 relative to drivers aged 18 to 49; the average threshold elevation factor for all older drivers tested was in the 2 to 2.5 range, and was as high as 20 for the poorest performers in the older driver test sample. Also, a self-selected sample of older drivers with unrepresentatively good visual performance capabilities was indicated through comparison of multiple older driver groups in this research. Significant age effects were observed in quantifying the required brightness (contrast) of pavement striping to discriminate a left- from a right-bearing curve at varying distances downstream on a two-lane roadway, as well as the required character size to read single words and complete (novel) messages on regulatory, warning, and guide sign stimuli. Correlations between measured contrast sensitivity for test subjects and their performance on the two subsequent tasks were calculated; maximum variance-accounted-for by this visual performance index in the delineation recognition task was under 11 percent and reached 27 percent for the legibility task. It was concluded that cognitive factors play a significant role in driving tasks previously hypothesized to rely principally on sensory capabilities, with implications for the design of traffic control element countermeasures to accommodate the older driver population.

The percentage of older drivers on America's highways will inevitably grow in the decades ahead, reflecting a sustained trend toward the aging of the population as a whole (*1*,*2*). This trend is further accentuated by indications that the proportion of licensed drivers aged 65 and older is increasing faster than the 65+ population itself (*3*). It is therefore prudent to anticipate ways in which the present system of traffic control devices (TCDs) may fail to accommodate the special needs of this group of motorists. If the most significant deficiencies with signs, markings, and other traffic control elements as now experienced by older drivers can be pinpointed, timely design changes that can improve future levels of safety and operational efficiency on the nation's roads will be permitted. A necessary first step in any redesign effort is to obtain relevant measures of age-related differences for the full range of sensory-perceptual, cognitive, and psychomotor (movement-to-control) functions that underlie safe and effective usage of TCDs. This report presents findings that address one important aspect of driver information processing: visual performance.

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RESEARCH METHODOLOGY

Specifically, a Landolt-C visual contrast sensitivity measure was initially performed by young–middle-aged and older drivers, followed by studies assessing the relative capabilities of these groups with respect to (a) the required contrast for pavement delineation (striping) at which downstream heading on a curved roadway can be discriminated without error, both with and without the presence of veiling luminance (glare) and (b) the required letter size (subtended visual angle) at which novel word combinations and complete messages can be read on regulatory, warning, and guide signs of varying luminance, both with and without the presence of glare.

The selection of the test sample received special attention in this research, given strong evidence from literature reviews (*4*) that this area of study is characterized by exaggerated variability among older subjects, suggesting that performance-oriented comparisons of both paid participants and volunteers often may be biased in the direction of an unrepresentatively capable segment of the overall older driver distribution. Consequently, the research design for the contrast sensitivity measure provided for 30 drivers in the age range 18 to 49 and 60 drivers in the age range 65 to 80. The 30 young–middle-aged drivers and half (30) of the older drivers were solicited as paid participants through newspaper ads and in-person presentations to local American Association of Retired Persons (AARP) chapters. These groups were designated as the "regular" test samples (Groups 1 and 2). Next, the additional "cross-validation" sample of the remaining 30 drivers aged 65 to 80 was selected (Group 3). This third group was obtained through visits to Pennsylvania photo license centers, where license renewal date-birth date (day of year) determines who among the driving public walks through the door on any given day. Although still not affording a completely random selection of research participants, the latter approach arguably produced a more representative sampling of older drivers.

It is critical to note that all reported differences between test (age) groups for the later, roadway heading discrimination and sign word-message legibility studies are restricted to comparisons involving the "regular" Group 1 and 2 test samples. The cross-validation sample, identified as Group 3 in the contrast sensitivity task, did *not* serve as test participants in the subsequent studies. Thus, to the extent that Group 2 versus Group 3 differences were demonstrated for the visual performance measure, it must be assumed that all age-related differences shown by the subsequent studies will be considerably exaggerated when generalizing to the wider range of capabilities observed in the entire older driving population.

Visual Contrast Sensitivity Task

Visual contrast sensitivity undeniably contributes to the detection and recognition of many traffic control devices, with painted roadway delineation being perhaps the most crucial, and has been shown to decline significantly with advancing age. The work of Blackwell, in particular, has indicated that a 60-year-old driver may be expected to require roughly 2.5 times the contrast as a 23-year-old driver to realize the same level of target visibility (*5*). Both the brightness (luminance) of a detection-recognition target and that of its background, or surrounding roadway environment, play a role in determining contrast level; since everyone's sensitivity to contrast falls off to some extent as background luminance is reduced, high contrast is required by all drivers to see signs, roadway striping, etc., when lighting levels are low. But, the age effect noted above suggests that disproportionate increases in target (TCD element) brightness may be necessary to accommodate the elderly under nighttime driving conditions. The present contrast sensitivity task was designed to describe differences within and across age groups in this test sample on this key index of visual performance.

The methodology used in this initial laboratory task used a Landolt-C as a target stimulus—actually a ring with a gap in it—in which the subject's task was to detect the orientation of the gap. On a given presentation of the test stimulus, the gap was randomly oriented in one of eight positions corresponding to the four cardinal compass directions, plus each intermediate position. The subject was seated 20 ft from the target; at that viewing distance, the overall target diameter described a visual angle of 20 minutes and the target gap and stroke width both were 4 minutes. Dark-adapted subjects viewed the target presentations at three background luminance levels (5° surround): 0.1, 1.7, and 100 cd/m^2, respectively. The target was presented for 0.2 second on a given test trial, and both ascending and descending target contrast trials were used in a method of limits to define each person's detection threshold at each background luminance level. Target contrast was varied by changing target brightness from trial to trial, with brightness controlled through the use of Kodak Wratten neutral density (0.1 log steps) gel filters.

Roadway Heading Discrimination Study

The roadway heading discrimination experiment investigated the differences in target (delineation) contrast required to discriminate a right-bearing from a left-bearing roadway under varying distance-to-curve and glare conditions for young–middle-aged versus older driver test groups. On all trials, subjects were told to wait to respond "right" or "left" for a given roadway stimulus until they had sufficient information to actually steer their vehicle in that direction, if viewing the same scene while driving. Four roadway scenes were used as test stimuli, including right- and left-bearing 7° horizontal curves beginning at apparent (scaled) distances of 100 and 200 ft (30.5 and 61 m, respectively) downstream. A tangent section of roadway was always shown in the scene's foreground. Each of the four roadway scenes presented in this study consisted of two slides; a background slide containing the sky, roadway surround, and pavement surface, and a second, over-projected slide containing the target delineation (pavement markings). The over-projection technique allowed for independent manipulation of pavement marking brightness.

Delineation brightness attenuation was accomplished by using 3-in. (7.6-cm)-square neutral density filters mounted side-by-side on horizontally rolling glass frames interposed between projector and screen. The frames permitted a combination of 40 attenuation levels ranging from no attenuation to 3.9 units of attenuation in 0.1 log units. All test stimuli were photometered by using a Spectra Pritchard 1980A.

The brightness of every over-projected, scaled-perspective roadway scene was further corrected to display a distribution of target and background luminances consistent with the isoluminance contours produced by No. 4656 (halogen) low-beam headlight illumination. The correction was accomplished by projecting each (background *and* target) image through a "headlight mask," a mosaic of 0.5 in. (1.3-cm) squares of neutral density filter material sandwiched between two glass plates to achieve the desired isoluminance contours. Figure 1 illustrates the experimental apparatus for this study.

Upon arrival to the laboratory, each participant was seated in a chair positioned 5.6 ft (1.7 m) from a slide projection screen, providing an eye height of 3.5 ft (1.06 m). The chair was positioned to preserve the perspective of a two-lane roadway (each lane being 12 ft wide) with the first segment of a dashed white center line perceived to begin 10 ft (3.04 m) from the subject's eye. Each participant was dark-adapted for at least 10 minutes while receiving instructions. As noted earlier, participants were told to respond left or right *only* when they were as sure about the roadway heading as they would need to be to steer their car in that direction if they saw the same scene through their windshield while driving at night

Delineation stimulus presentation was blocked at two levels of disability glare: no glare and glare that averaged 0.92 lx (SD, 0.11) across trials (i.e., some variability resulting from fluctuations in line voltage and bulb wear were observed). A 12-volt bulb affixed to the projection screen served as the glare source; the bulb was positioned 6 in. (15.2 cm) laterally from the point of road curvature in the scene, or approximately 6° off of the driver's forward line of sight. The 0.92-lx glare level is consistent with the intensity of an oncoming vehicle's low-beam halogen headlights seen from a distance of 100 ft, assuming 12-ft (3.66-m)-wide lanes on a two-lane roadway. Illuminance (glare source) measurements were recorded for each subject by using a Minolta model T-1 illuminance meter held at the subject's eye position during data collection.

All trials at the no-glare level were completed before the presentation of any glare trials to prevent transient adaptive effects from a glare trial from interfering with performance on a subsequent no-glare trial. Also, the different simulated

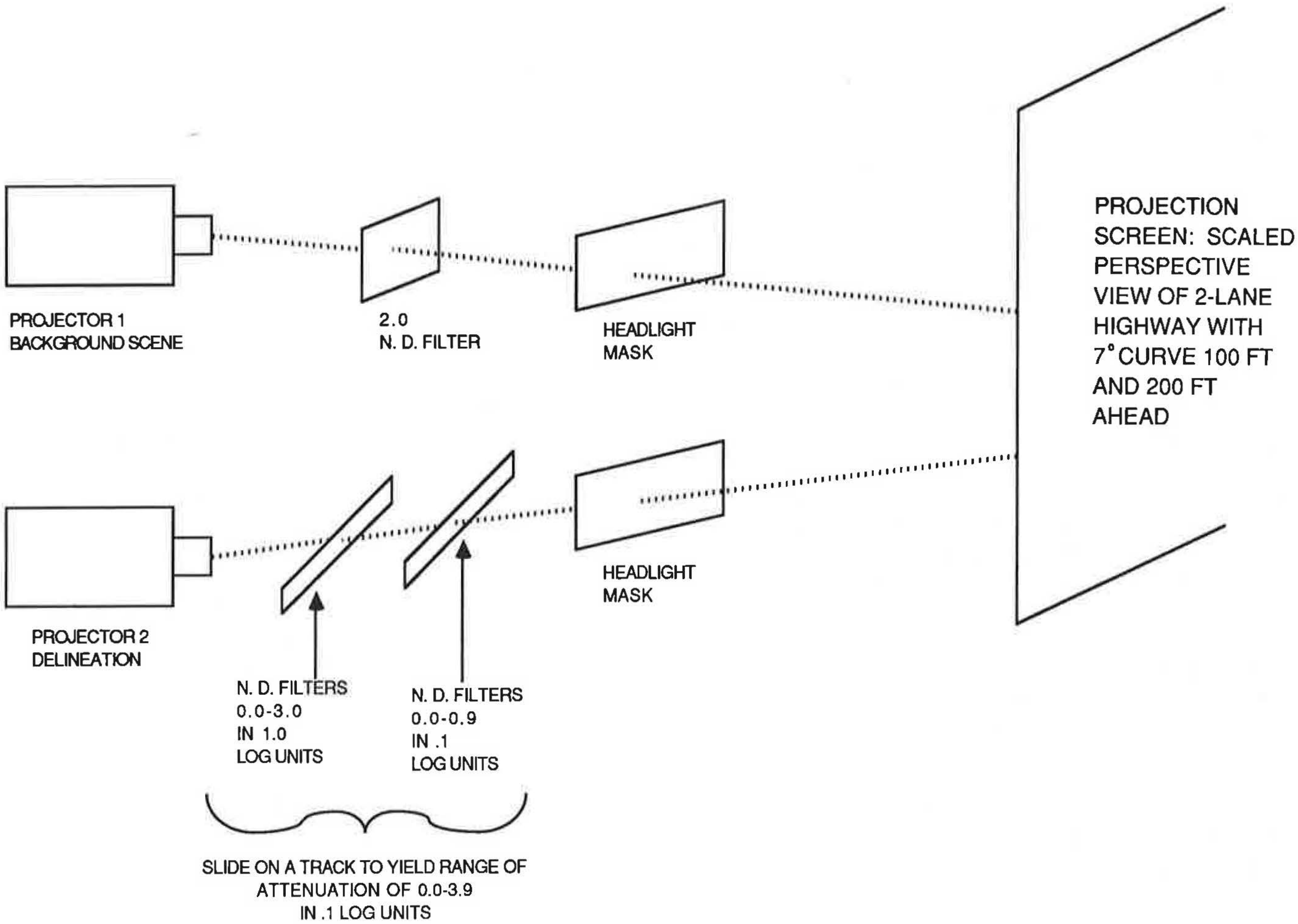

FIGURE 1 Arrangement of experimental apparatus.

observer-target separation distances for both left- and right-bearing curves were presented in random order. The duration of each slide presentation was 0.5 second; a trial consisted of a series of 0.5-second presentations of a given test stimulus in which each successive exposure used the neutral density filters to depict the delineation in either marginally higher or marginally lower contrast to the background roadway scene. The intertrial interval was 5 seconds.

Both ascending and descending brightness trials were presented in the method of limits to define each subject's heading determination threshold at each target separation distance. On ascending brightness trials, subjects were required to respond correctly three consecutive times before the next trial was presented. Descending brightness trials ended when a subject responded that he or she was uncertain of the roadway heading. Subjects were given at least two practice trials to make certain that they understood the test protocol. Subjects completed three replications of ascending brightness and three replications of descending brightness trials for each stimulus slide for each level of glare, for a total of 48 trials.

Sign Word-Message Legibility Study

After completing the delineation study, subjects were given a 10-minute break. They were then brought back into the laboratory, where they were seated in a chair positioned 20 ft (6.09 m) from the projection screen and were again dark-adapted while receiving instructions. The experimenter explained the task of trying to read a sign message at a glance, for (guide) signs with white lettering on a green background, (warning) signs with black lettering on a yellow background, and (regulatory) signs with black lettering on a white background. Subjects were advised that each sign would contain a four-word message constructed from common words combined into novel phrases, for example, NARROW BUSES MUST YIELD (regulatory), NEXT ROUGH DETOUR HILL (warning), and STATE BORDER ACCESS ROAD (guide).

The first sign projected on the screen was too small to read for all subjects, with sign size (and therefore letter size) increasing with each successive presentation. A tone was heard before each stimulus presentation, as a "ready" signal. Subjects were asked to respond verbally when they could first detect any individual words, and also when they could read the entire message.

Since the viewing distance was held constant at 20 ft, letter size was manipulated by varying the visual angle subtended by the letter at the subjects' eyes. Letter size ranged from the Snellen equivalent of 20/12.5 (visual angle = 0.625 minute) to 20/125 (visual angle = 6.25 minutes), in increments of ½-line Snellen acuity differences. (NOTE: Snellen letters are five times their stroke width in height; a stroke width that subtends 1 minute of visual angle at a viewing distance of 20 ft defines normal acuity of 20/20.)

Franklin Gothic lettering used for the upper case regulatory and warning sign letters and Helvetica Bold lettering used for the lower case letters on the guide sign stimuli closely resembled the Series D font used on traffic signs. The lettering was placed on clear acetate following the spacing guidelines specified in the Standard Highway Signs manual. The messages were then overlaid on 3M engineering grade sheeting of the desired color and photographed. Variation in letter size for the test stimuli was achieved by progressively zooming in while photographing a projected image of each sign.

Each stimulus was presented for a 0.5-second duration, with a trial consisting of a series of 0.5-second presentations of successive letter size increments for a particular test stimulus in which a legibility response was required for each presentation. The experimenter recorded the letter size at which the subject could first correctly detect any word, and the letter size at which the entire message could be read. A trial ended when the subject could correctly read the message or when the letter size corresponding to 20/125 was presented without a correct legibility response, whichever occurred first.

The mean message length across all signs was 19.94 letters, and ranged from 18 to 22 letters per message. Messages were constructed from four-, five-, and six-letter words. It was important to hold message length constant to avoid confounding message length with message legibility. In all, 54 four-word combinations were devised for this study, divided into three sets of 18 each regulatory, warning, and guide sign stimuli. Overall, the test conditions for this study permitted three novel message replications for every combination of sign type and luminance level and glare condition.

Stimulus presentation was blocked at two levels of glare: no glare, and glare that averaged 1.26 lx (SD = 0.33) across trials. As in the earlier study, some variability across trials resulted from fluctuations in line voltage and bulb wear. A 12-volt bulb again served as the glare source but located in this study approximately 6° off the subject's forward line of sight on a stand near the subject's seating position. Illuminance (glare source) measurements were recorded for each subject by using a Minolta model T-1 illuminance meter held at the subject's eye position during data collection. All no-glare trials were presented before presentation of any glare trials to prevent transient adaptive effects from a glare trial from influencing performance on a subsequent no-glare trial.

Stimulus luminance was also varied in this study, to simulate the effect of viewing real-world signs set back at increasing distances from the roadway edge (and therefore at lower luminances). Three luminance levels were employed for each of the three sign categories of interest. Specific luminance values in candelas per square meter (cd/m^2) for regulatory sign stimuli at levels L_1, L_2, and L_3 were 0.126, 0.080, and 0.050 for targets (letters) and 3.44, 2.17, and 1.37 for the corresponding background (sign panels). For warning sign stimuli, actual target luminance values tested were 0.099, 0.063, and 0.031, with corresponding background values of 2.14, 1.35, and 0.677. For guide sign stimuli, L_1, L_2, and L_3 for the letters equaled 1.10, 0.754, and 0.475, with values of 0.089, 0.060, and 0.038 for the corresponding sign panels. As before, all luminance measures were obtained by using a Spectra Pritchard 1980A photometer.

Contrast values remained constant within each sign category, as both target and background elements were attenuated by using common neutral density filter factors for luminance conditions L_2 and L_3, respectively, relative to the highest (L_1) luminance condition. Calculated contrast values $[(L_t - L_b)/L_b]$ for the regulatory, warning, and guide sign stimuli were −0.96, −0.95, and 11.5, respectively.

RESULTS AND CONCLUSIONS

Participants actually completing data collection requirements for the contrast sensitivity task included 14 males and 16 females in the young–middle-aged test group (Group 1), with an overall age range of 19 to 49 and a median age of 35; 16 males and 15 females in the "regular" older sample (Group 2), with an overall age range of 65 to 80 and a median age of 69; and 10 males and 9 females in the "cross-validation" older sample (Group 3), with an overall age range of 65 to 77 and a median age of 69. Only Group 3 experienced any attrition, with six individuals dropping out due to fatigue or lack of interest, and five others excused because of equipment malfunction in the laboratory.

For the roadway heading discrimination study, the participants from the young–middle-aged test sample completing data collection requirements included 14 males and 15 females with an overall age range of 19 to 49 and a median age of 35.5; and 15 males and 15 females from the regular older driver sample, with an overall age range of 65 to 80 and a median age of 69. Finally, participants from the young–middle-aged test sample completing data collection requirements for the sign word-message legibility study included 12 males and 16 females with an overall age range of 19 to 49 and a median age of 35; and 15 males and 15 females from the regular older driver sample, with an overall age range of 65 to 80 and a median age of 69.5.

Visual Contrast Sensitivity Test

The contrast sensitivity data were blocked for analysis at each of the three included background luminance (L_b) levels for comparison of the detection thresholds of the driver groups tested in this research. Within each L_b level, each subject's threshold was determined by translating the neutral density setting at which five out of eight correct responses were obtained (to compensate for guessing) to a target luminance value, then substituting into the expression $(L_t - L_b)/L_b$ to result in a contrast value (C).

Mean and median contrast values at threshold, plus standard deviations, are presented in Table 1 for the younger and older regular samples and the older cross-validation sample tested in this research, designated as study Groups 1, 2, and 3, respectively, in this report. As shown in this table, the mean and standard deviation threshold contrast values suggest dramatic differences between groups under the lowest lighting condition; under progressively higher background luminance levels, the pattern of differences remains constant, but the percent change from one group to another becomes less pronounced. The shift in median performance levels across lighting conditions is much more stable, reflecting the presence of extreme data points distributed among Group 2 and, especially, Group 3.

A series of six t-tests were planned to evaluate the obtained differences between Groups 1 and 2 and between Groups 2

TABLE 1 CONTRAST SENSITIVITY (4′ LANDOLT-C TARGET) THRESHOLDS FOR INCLUDED STUDY GROUPS

	Threshold Contrast (C)								
	@L_{b1} (0.1 cd/m²)			@L_{b2} (1.7 cd/m²)			@L_{b3} (100 cd/m²)		
	$\bar{X}$	med.	σ	$\bar{X}$	med.	σ	$\bar{X}$	med.	σ
Group 1 (n=30)	1.05	0.85	0.70	0.21	0.17	0.12	0.11	0.08	0.09
Group 2 (n=31)	4.35	1.83	9.40	0.45	0.35	0.28	0.15	0.14	0.11
Group 3 (n=22)	20.91	2.48	69.28	2.52	0.45	4.82	0.30	0.17	0.34

NOTE: To convert cd/m² to fL, multiply by 0.292

TABLE 2 MEAN AND STANDARD DEVIATION CONTRAST REQUIREMENTS FOR DELINEATION RECOGNITION/ROADWAY HEADING DISCRIMINATION BY TEST (AGE) GROUP, DISTANCE TO CURVE, AND GLARE CONDITION

Test (age) group	Distance to curve							
	100 ft				200 ft			
	No glare		Glare		No glare		Glare	
	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ
young/middle-aged	1.20	.36	2.42	1.69	1.23	.29	2.35	1.16
elderly	1.27	.54	2.88	2.06	1.32	.51	3.25	3.05

and 3 at each background luminance level. After preliminary F_{max} tests led to rejection of a hypothesis of homogeneity of variance for the comparisons of Group 1 and Group 2 at L_{b1}, and Group 2 and Group 3 also at L_{b1}, a log transformation was applied to these data before conducting the *t*-tests.

The outcomes of the *t*-tests indicated statistically significant or marginally significant differences for five out of six comparisons; only the comparison between the performance of Groups 1 and 2 at L_{b3}, the brightest background condition, did not approach statistical significance. For the Group 1-Group 2 comparisons at L_{b1} and L_{b2}, respectively, $t = 5.40$ ($P < .001$) and $t = 4.24$ ($P < .001$), for degrees of freedom (d.f.) = 59. For the Group 2-Group 3 comparisons at L_{b1}, L_{b2}, and L_{b3}, respectively, $t = 1.60$ ($P < .06$), $t = 2.39$ ($P < .02$), and $t = 2.35$ ($P < .02$), for d.f. = 51.

These findings lead to at least two important conclusions. First, the spread between the visual capabilities of young–middle-aged drivers (Group 1) and a self-selected sample of older motorists (Group 2) is consistent with the substantial differences contained within a standard reference summarizing results of Blackwell and others (*5*). More seriously, there is evidence of a pronounced selection bias in these data, such that a large proportion of active, older drivers may in fact suffer far greater visual performance deficits than are typically detected in psychophysical studies of this nature.

Roadway Heading Discrimination Study

Results of the roadway heading discrimination study are described by the more detailed data summary presented in Table 2, which contrasts the mean and standard deviation performance of older versus young–middle-aged drivers according to glare condition and distance-to-curve condition in this study. It is apparent from reviewing the data in this table that, although the introduction of glare affected both test (age) groups, the effect of the range of reduced target (task detail) size associated with increasing distance-to-curve in this study was limited to a performance decrement among the older driver group only. Further, when the data are collapsed across glare and distance conditions to calculate an overall effect of test (age) group, the older test sample required a level of contrast 20 percent greater than that for the young–middle-aged group to achieve the discrimination task in this study.

Statistical tests conducted on the data in this study included a three-way analysis of variance (ANOVA) to examine the main effects and possible interactions of the variables test (age) group, glare (present versus Table 2 absent), and distance-to-curve. The direction of curvature was not included as a variable in data analysis, having been introduced as a stimulus condition to define the discrimination task (right versus left), with the order of right versus left presentations randomized across all trials in the study.

The findings of the ANOVA included the hypothesized main effect of test (age) group (F = 6.77; d.f. = 1, 440; P < .01); an even stronger effect of glare (F = 103.7; d.f. = 1, 440; P < .001); and, a significant test (age) group-by-glare interaction (F = 4.18; d.f. = 1, 440; P < .04). A Scheffe post-hoc test indicated that both variables made a significant (P < .05) contribution to this interaction, even though the magnitude of the main effect associated with glare condition was considerably larger than that associated with the test (age) group.

An additional, one-way ANOVA was conducted to test for a main effect of gender on performance in this study. Although an exaggerated decrement in performance was noted for older females versus older males, just the opposite finding was observed among the young–middle-aged test group. Overall, the differences attributable to this factor were shown to be not statistically significant.

Further analysis of these data consisted of Pearson product-moment correlations between the contrast at threshold for the present discrimination task, versus the tested contrast sensitivity for each subject as measured earlier. Of course, for the present set of correlations, only the contrast sensitivity measures for those subjects actually completing this study could be used.

The results of this analysis are presented in Table 3. Interestingly, the strongest correlation—and greatest amount of variance accounted for in this study—is demonstrated for subjects' tested contrast sensitivity at a background luminance of 1.7 cd/m². This finding is consistent with the mesopic conditions that frequently characterize nighttime driving. More surprising, none of the correlations are high in an absolute sense; thus, an important conclusion implied by these results is that nonsensory factors play a prominent role in driver discriminations of downstream roadway heading, given the visual cues available to test subjects in this study.

TABLE 3 PEARSON PRODUCT-MOMENT CORRELATIONS BETWEEN MEASURED CONTRAST SENSITIVITY AT VARYING BACKGROUND LUMINANCES AND MEAN CONTRAST REQUIREMENTS FOR DELINEATION RECOGNITION/ROADWAY HEADING DISCRIMINATION (GLARE ABSENT) WITH CALCULATED r^2

Background (adaptation) luminance	Correlation, r	Variance-accounted-for, r^2
L_b = 0.1 cd/m²	.099	1.0%
L_b = 1.7 cd/m²	.328	10.8%
L_b = 100 cd/m²	.261	6.8%

Sign Word-Message Legibility Study

Results of the sign word-message legibility study are presented beginning with summary descriptive statistics documenting the overall effect of test (age) group on the two performance measures of interest in this study, as shown in Table 4. For the reader's convenience, the dependent measure is reported both in terms of minutes of visual angle of character stroke width, as well as in terms of an equivalent Snellen fraction denominator. Apparent trends in this summary of data include a consistently superior performance for young–middle-aged and older test groups alike on the negative versus positive contrast stimuli; also, for both groups, the letter size required for complete message legibility was consistently larger than that required to discern individual words on a sign. In comparisons between groups, however, the older driver sample without exception demonstrated a need for larger mean letter sizes, plus elevated standard deviations, relative to the younger test sample.

When performance in this study is broken down by one additional level to examine separately the conditions of glare versus no-glare, there is no evidence of any clear effect. The responses of the young–middle-aged group actually showed a marginal improvement when glare was present, although

TABLE 4 MEAN AND STANDARD DEVIATION CHARACTER SIZE EXPRESSED IN MINUTES OF VISUAL ANGLE (WITH SNELLEN FRACTION DENOMINATOR EQUIVALENT) REQUIRED FOR REGULATORY, WARNING, AND GUIDE SIGN WORD AND MESSAGE LEGIBILITY AS A FUNCTION OF TEST (AGE) GROUP ONLY

Test (age) group	Sign Type	Character size (Snellen denominator)			
		Word		Message	
		$\bar{X}$	σ	$\bar{X}$	σ
young/middle-aged	regulatory	1.33 (26.6)	.45 (9.0)	1.92 (38.4)	.57 (11.4)
	warning	1.29 (25.8)	.46 (9.2)	1.92 (38.4)	.63 (12.6)
	guide	1.79 (35.8)	.57 (11.4)	2.68 (53.6)	.86 (17.2)
elderly	regulatory	1.82 (36.4)	.53 (10.6)	2.57 (51.4)	.75 (15.0)
	warning	1.84 (36.8)	.59 (11.8)	2.71 (54.2)	.89 (17.8)
	guide	2.52 (50.4)	.82 (16.4)	3.78 (75.6)	1.31 (26.2)

TABLE 5 MEAN AND STANDARD DEVIATION CHARACTER SIZE EXPRESSED IN MINUTES OF VISUAL ANGLE (WITH SNELLEN FRACTION DENOMINATOR EQUIVALENT) REQUIRED FOR REGULATORY, WARNING, AND GUIDE SIGN WORD AND MESSAGE LEGIBILITY AS A FUNCTION OF TEST (AGE) GROUP AND STIMULUS LUMINANCE LEVEL (NO-GLARE TRIALS ONLY)

a. word legibility

test (age) group	sign type	Character size (Snellen denominator)					
		L_1		L_2		L_3	
		$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
young/middle-aged	regulatory	1.36 (27.2)	.33 (6.6)	1.35 (27.0)	.37 (7.4)	1.34 (26.8)	.50 (10.0)
	warning	1.26 (25.2)	.42 (8.4)	1.35 (27.0)	.53 (10.6)	1.32 (26.4)	.46 (9.2)
	guide	1.86 (37.2)	.51 (10.2)	1.92 (38.4)	.61 (12.2)	1.81 (36.2)	.60 (12.0)
elderly	regulatory	1.75 (35.0)	.42 (8.4)	1.77 (35.4)	.49 (9.8)	1.83 (36.6)	.57 (11.4)
	warning	1.72 (34.4)	.42 (8.4)	1.79 (35.8)	.54 (10.8)	1.84 (36.8)	.55 (11.0)
	guide	2.31 (46.2)	.66 (13.2)	2.60 (52.0)	.73 (14.6)	2.58 (51.6)	.81 (16.2)

b. message legibility

test (age) group	sign type	Character size (Snellen denominator)					
		L_1		L_2		L_3	
		$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
young/middle-aged	regulatory	1.98 (39.6)	.46 (9.2)	1.98 (39.6)	.53 (10.6)	1.93 (38.6)	.65 (13.0)
	warning	1.95 (39.0)	.57 (11.4)	1.96 (39.2)	.74 (14.8)	1.96 (39.2)	.58 (11.6)
	guide	2.87 (57.4)	.81 (16.2)	2.78 (55.6)	.87 (17.4)	2.72 (54.4)	.93 (18.6)
elderly	regulatory	2.48 (49.6)	.56 (11.2)	2.50 (50.0)	.69 (13.8)	2.58 (51.6)	.84 (16.8)
	warning	2.59 (51.8)	.70 (14.0)	2.57 (51.4)	.78 (15.6)	2.73 (54.6)	.86 (17.2)
	guide	3.77 (75.4)	1.06 (21.2)	3.89 (77.8)	1.23 (24.6)	3.94 (78.8)	1.25 (25.0)

the older group generally demonstrated the expected performance decrement for the comparisons of glare versus no-glare. In all cases, however, the apparent differences attributable to glare were very slight, described by at most a 10 percent shift in required target size for word and message legibility between glare and no-glare conditions.

This finding is in sharp contrast to the highly significant effect of this factor in the roadway heading discrimination study. A likely explanation for this outcome follows from the placement of the glare source in the respective studies. In the previous study the glare source was attached to the projection screen and thus remained in a constant, fixed position with respect to the (projected) test stimuli; in this study, the glare source was attached to a stand and positioned only a few feet in front of the subject at the desired angle of eccentricity. With the latter arrangement, a very slight leaning of the subject's head to one side at stimulus onset—a gesture that would have been difficult to observe from the experimenter's station in this study—could have substantially attenuated the veiling luminance experienced by the subject.

Finally, Table 5 presents a further breakdown of performance (for no-glare trials only) according to stimulus luminance level (L_1, L_2, and L_3 as defined earlier). Patterns in these data may be described that again indicate the need for larger letter sizes, accompanied by larger standard deviations, for the older versus the younger test (age) group, across both glare conditions. Within the test group, however, the older subjects typically demonstrated their best performance (i.e., smallest visual angles of stimuli required for legibility) under the highest luminance condition (L_1), whereas the younger subjects performed at levels that were roughly constant across luminance conditions or were superior at L_2 or L_3, as opposed to L_1. For both groups, it remains apparent that the positive contrast (guide) signs were consistently the most difficult to read across all luminance conditions.

Statistical tests conducted on these data included, first, a set of two-way ANOVA blocked according to sign type and glare condition, which separately examined word and message legibility performance differences as a function of test (age) group, stimulus luminance level, and the group-by-luminance level interaction. In general, only differences between test (age) groups were shown to be statistically significant; a main effect of stimulus luminance level was demonstrated only for guide signs.

Specifically, for regulatory signs, the main effect of test (age) group was significant at $P < .001$ for word legibility under both glare and no-glare conditions ($F = 45.9$; d.f. = 1, 168 and $F = 39.0$; d.f. = 1, 168, respectively); with message legibility as the dependent measure, main effects were similarly demonstrated at $P < .001$ ($F = 47.6$; d.f. = 1, 168 with glare present and $F = 33.7$; d.f. = 1, 168 with glare absent). No main effects of luminance level or interactions of test (age) group with stimulus luminance were shown for regulatory signs in this study, for either word or message legibility, under either glare or no-glare conditions.

An identical pattern of results was demonstrated for warning signs. The main effect of test (age) group was significant at $P < .001$ for the word legibility measure with glare present ($F = 54.6$; d.f. = 1, 167) and with glare absent ($F = 39.6$; d.f. = 1, 169), and also at $P < .001$ for the message legibility measure with glare present ($F = 49.0$; d.f. = 1, 167) and with glare absent ($F = 39.0$; d.f. = 1, 169). Again, no main effects of stimulus luminance level or interactions between test (age) group and stimulus luminance were shown for either word or message legibility either with or without glare.

For guide signs, the expected main effect of test (age) group was significant at $P < .001$ for the word legibility measure with glare present ($F = 54.7$; d.f. = 1, 168) and with glare absent ($F = 39.0$; d.f. = 1, 168), and also at $P < .001$ for the message legibility measure with glare present ($F = 41.1$; d.f. = 1, 168) and with glare absent ($F = 46.0$; d.f. = 1, 168). As noted above, main effects of stimulus luminance level were also demonstrated for this sign type, though only with glare present and more significantly for the message than for the single-word legibility measure. With the complete message response requirement, the effect of stimulus luminance level was significant at $P < .01$ under the glare condition ($F = 4.2$; d.f. = 2, 168) but did not approach significance when glare was absent. When the response requirement was to read a single word as opposed to the entire message on a guide sign, the significance of the effect of stimulus luminance was marginal with glare present ($F = 2.7$; d.f. = 2, 168; $P < .07$) and again negligible under the no-glare condition. No significant interactions of test (age) group and stimulus level were noted for either the word or message legibility measures under either glare or no-glare conditions.

An additional one-way ANOVA was conducted to test for main effects of subjects' gender on the word and message legibility measures for each sign type. For regulatory signs, the effect of sex did not approach significance for either word legibility or message legibility performance measures. Likewise, the warning sign data showed no significant differences due to the gender of subjects, for either word legibility or message legibility. The performance differences between males and females with respect only to word legibility on guide signs, although not significant, did approach the conventional 0.05 cutoff ($F = 3.35$; d.f. = 1, 344; $P < .07$); in terms of the absolute magnitude of differences between sexes on this single response measure, females averaged 6.7 percent better than males across all test conditions. When performance on the message—as opposed to word—legibility measure for guide signs was analyzed, the effect of gender was diminished and did not approach statistical significance.

As in the roadway heading discrimination study, Pearson product-moment correlations were calculated between subjects' measured contrast sensitivity, at three background (adaptation) luminance levels, and their performance on the dependent measures in this study. Table 6 displays the results of this analysis by sign type and stimulus luminance level. As shown in this table, the measured contrast sensitivity of subjects at the lower (0.1 and 1.7 cd/m^2) background luminances were correlated most strongly with performance on both the word and message legibility measures, across all three stimulus (sign) luminance levels tested in the laboratory. This is not surprising, since the range of sign luminances presented to subjects fell roughly between 0.03 and 3.0 cd/m^2.

Again, the magnitudes of the variance-accounted-for figures in the correlational analysis are most interesting. Accounting for 25 percent and more of the variance in a realistic driving performance measure on the basis of a single psychophysical indicator is potentially a useful finding. The increased magnitudes of the obtained r^2 values in this study relative to the previous effort also deserve mention; arguably, the sensory (visual screening) data are a stronger predictor of task performance when the subject is performing a feature-matching response such as letter-word legibility than when performing the more ambiguous delineation recognition task.

GENERAL DISCUSSION

This report suggests a special concern regarding one indication of the decline in visual performance capability among aged adults. A critical first step in a driver's processing of the information provided by TCDs is access to the full range of sensory inputs afforded by a normal, healthy visual system. Because of increased light absorption and scattering in the crystalline lens (*6*), however, the eyes of older drivers require a markedly higher level of contrast for objects in the roadway environment to perform as safely and effectively as younger drivers. Specifically, the present findings suggest that at night roughly 2 to 2.5 times more contrast is needed by the median or 50th percentile older driver, whereas individuals representative of the lowest quartile of visual performance among this age group—including persons who do report driving at night, at least occasionally—may require 10 to 20 times more contrast than an average younger driver.

This diminished visual capability was hypothesized to have the strongest impact on the use of various pavement markings and on sign legibility in this research. In fact, older drivers participating in focus groups earlier in this project (*7*) complained vigorously about missing or faded edgelines, about undelineated lanes at the "aim points" when completing left turns at intersections, and, to a lesser extent, about difficulty in reading road signs. Also, these motorists reported associated problems including hesitation and erratic driving

TABLE 6 PEARSON PRODUCT-MOMENT CORRELATIONS (r) BETWEEN MEASURED CONTRAST SENSITIVITY AT VARYING BACKGROUND LUMINANCES AND MEAN CHARACTER SIZE REQUIREMENT FOR WORD AND MESSAGE LEGIBILITY (GLARE ABSENT) WITH CALCULATED r^2 (VARIANCE-ACCOUNTED-FOR)

Background (adaptation) luminance	Legibility performance measure	Sign type	Stimulus luminance level L_1 r	L_1 r^2	L_2 r	L_2 r^2	L_3 r	L_3 r^2
$L_b = 0.1\ cd/m^2$	word	regulatory	.482	23.2%	.446	19.9%	.454	20.6%
		warning	.346	12.0%	.386	14.9%	.483	23.3%
		guide	.517	26.7%	.404	16.3%	.422	17.8%
	message	regulatory	.493	24.3%	.471	22.2%	.438	19.2%
		warning	.466	21.7%	.394	15.5%	.469	22.0%
		guide	.508	25.8%	.442	19.5%	.404	16.3%
$L_b = 1.7\ cd/m^2$	word	regulatory	.528	27.9%	.446	19.9%	.459	21.1%
		warning	.473	22.4%	.424	18.0%	.473	22.4%
		guide	.490	24.0%	.465	21.6%	.460	21.2%
	message	regulatory	.483	23.3%	.513	26.3%	.476	22.7%
		warning	.500	25.0%	.418	17.5%	.489	23.9%
		guide	.492	24.2%	.520	27.0%	.424	18.0%
$L_b = 100\ cd/m^2$	word	regulatory	.220	4.8%	.126	1.6%	.150	2.3%
		warning	.212	4.5%	.213	4.5%	.215	4.6%
		guide	.238	5.7%	.195	3.8%	.169	2.9%
	message	regulatory	.288	8.3%	.258	6.7%	.232	5.4%
		warning	.253	6.4%	.265	7.0%	.245	6.0%
		guide	.298	8.9%	.273	7.5%	.183	3.3%

behaviors as they seek the additional information needed to accomplish intended vehicle maneuvers.

Despite the magnitude of differences observed in the contrast sensitivity measure, however, a relatively small percentage of variance was accounted for in drivers' responses, particularly on the delineation recognition task. Possible explanations suggested by the technical literature (*4*) include hypothesized deficits in selective attention or pattern recognition-integration or, more generally, a fundamental difference in strategy where older drivers required greater certainty before responding. In any event, the apparent contribution of cognitive factors to the present results suggest that design guidelines for retroreflective traffic control elements should take note of driver performance variables over and above those "purely sensory" deficits long recognized to accompany advancing age.

Probably the single most important outcome to emphasize in this discussion is the tremendous increase in variability of performance among older drivers. This aspect of behavior poses the greatest challenge to TCD redesign efforts to accommodate older drivers, given a population in which the most capable individuals can meet and often exceed performance expectations for any age group. Also, the magnitudes of variability observed among the two groups of older drivers participating in this research indicate a substantial self-selection bias, in which unrealistically high estimates of the older driver population's capabilities were produced by those individuals recruited through responses to newspaper advertisements and solicitations at AARP chapters. Clearly, it is essential to exercise special care in sampling the older driver population when deriving estimates of performance capabilities. As work continues to investigate the relationship between age and traffic control device use, researchers and policymakers must aggressively challenge the credibility of findings generated by volunteer or otherwise unrepresentative test samples of older drivers.

As a final note, the role of complementary efforts at the state level to develop assessment and qualifications programs to identify diminished capability drivers deserves mention. Such screening not only has the potential to moderate the demand for changes in the current system of TCDs; if equitably administered it more properly focuses attention on a driver's abilities instead of on his or her age per se.

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