Intersection Negotiation Problems of Older Drivers

VOLUME I: TECHNICAL REPORT

NOTICE

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16. Abstract

This project included a background literature synthesis and observational field study. The research goals were to document driving problems and errors at intersections, for older drivers using their own cars to travel familiar and unfamiliar routes, and to measure how well they could be predicted by prior tests given in an office setting. Volume I presents the field study methodology and results; Volume II presents the background synthesis.

Field observations of intersection negotiation were conducted using 82 subjects, age 61 and older, referred to the California Department of Motor Vehicles for special testing. The subjects first completed a functional test battery measuring vision, attention capabilities, and head/neck flexibility. They then underwent on-road testing administered by DMV examiners. Subjects were administered the test on both an unfamiliar and familiar route, unless the testing was prematurely terminated for safety reasons. During the on-road tests, a miniature, multiple-camera apparatus in the driver's own vehicle recorded visual search behaviors, brake and accelerator use, and traffic events in the forward scene. Analysis of the videotaped data revealed a high incidence of visual search errors. Many common behaviors were included (such as failure to look to the sides when traveling through an intersection on a green light) that were technical errors, but which rarely require an emergency response. The highest error rate for an actual maneuver, as captured by the cameras, was making a lane change with an unsafe gap. This problem was exaggerated on the low familiarity test route, where drivers had no expectation of where the next turn would occur. Analysis of errors recorded by the DMV examiners followed the same general pattern as the video-based error classification, where scanning errors predominated across both familiar and unfamiliar test routes, and maneuver errors occurred less frequently. Those driving errors observed most often by the examiners included failure to stop completely at a stop sign, stopping over a stop bar, improper turning path, and stopping for no reason. Regression analyses examined the relationships between functional test results and weighted examiners' error scores. Speed of response on visual discrimination tasks was the best predictor, but no single measure accounted for more than 18% of variance on the criterion.

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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.

Symbol	When You Know	Multiply By	To Find	Symbol
		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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The authors wish to acknowledge the crucial assistance of the California Department of Motor Vehicles in the performance of this study. Most critical were the contributions of Dr. Mary K. Janke, who was responsible for development of the drive test protocols and who coordinated analysis of an important subset of data included herein; and Ms. Sandra Winter Hersch, a graduate assistant employed by Dr. Janke, who administered the functional test battery. Continuing support from Mr. Raymond C. Peck and Ms. Carole Bedwell throughout the duration of this project are also gratefully acknowledged.

EXECUTIVE SUMMARY

The goals in this research were to obtain valid field measures of older drivers' difficulties when negotiating intersections, and to determine if their visual, mental, or physical abilities measured in an office could predict their performance behind the wheel. This work was spurred by statistics showing intersections to be the singular site type where older drivers are most significantly overrepresented in motor vehicle crashes.

Field observations of intersection negotiation were conducted using 82 subjects referred to the California Department of Motor Vehicles (DMV) for special testing. Preceding the field study, a literature review produced a synthesis of age and intersection driving difficulties, which is available as a companion volume to this report. This review guided development of a functional test battery, termed *MultiCAD*. A task analysis of intersection approach and negotiation requirements for safe vehicle control actions was also completed.

Of the 82 subjects, 26 were labeled as cognitively impaired by the referral source, and 56 entered the study labeled as cognitively unimpaired. The average age of all subjects was 77. Each subject completed a battery of functional measures to test vision, attention, and selected perceptual skills. Specifically, the functional abilities of the study sample measured by the test battery (*MultiCAD*) included static and dynamic visual acuity; static and dynamic visual contrast sensitivity; sensitivity to relative motion of other vehicles slowing or stopped in the road ahead; divided attention (in a brake reaction situation); detection of pedestrian and vehicle targets in the visual periphery, while attending to a central (foveal) task; and head/neck flexibility (degrees of rotation to both sides).

Following completion of the functional test battery, the subjects performed test drives over a common "standard" route of relatively low familiarity. Unless terminated for safety reasons, the subject then completed a test drive over a high familiarity route in his/her home area. On both routes, the subjects used their own vehicles, and were accompanied by a DMV examiner. The examiner could terminate a test drive at any time for safety reasons.

Driving errors were recorded both by in-vehicle cameras installed on the subject's vehicle by the project team, and by the DMV examiner using a score sheet. Key findings are summarized below.

The video-based classification, which expresses how often an error occurred *in relation to the total number of opportunities to commit the error*, showed that scanning errors were extremely common. Drivers failed to observe behind their vehicles before slowing down during the approach to an intersection 87 percent of the time on unfamiliar routes and 96 percent of the time on familiar routes. They also failed to scan to the sides after entering the intersection 75 percent of the time, on both route types. One type of maneuvering error, "infringing on others' right-of-way when changing lanes," was also notable, occurring at a 90 percent rate on unfamiliar routes and a 57 percent rate on familiar routes. This error was operationally defined as initiating a lane change with less than 2 seconds of headway.

Further analysis showed mean (videotaped) error rates to vary as a function of the type of traffic control (signal, stop sign, yield, or no control), the familiarity of the course, and the type of movement (straight through, left turn, right turn). Route familiarity had little to no effect on error rates exhibited at signalized intersections. However, for right turns in yield and uncontrolled intersections, error rates were noticeably higher on the unfamiliar course. This may have resulted from drivers "knowing what to look for" as a result of experience in familiar areas.

The error classification produced from the DMV examiners' score sheets followed the same general pattern as the video-based error classification, where scanning errors predominated across both familiar and unfamiliar test routes, and maneuver errors occurred less frequently. The more common maneuver problems included "failure to come to a complete stop at a stop sign," which was noted on 53 percent of the test drives over unfamiliar routes and 57 percent of the test drives over familiar routes. "Stopping for no reason" was noted on 39 percent and "turning too wide or too short" on 46 percent of test drives over unfamiliar routes; both were noted on 26 percent of test drives on familiar routes. Other potentially serious safety problems noted on at least 20 percent of test drives (on unfamiliar routes) by the examiners included "stopped over limit lines (stop bars)," "consistently drives too slowly," and "unsafe left turn gap acceptance." These errors were less common on the familiar routes; presumably this reflected differences in drivers' expectancies for the demands encountered along each route type. Errors that were *more* frequent on the familiar routes, being noted on at least 20 percent of test drives, included "infringes on others' right-of-way when changing lanes" and "near miss (pedestrian or car) other than during gap acceptance." It is important to note that errors recorded on examiners' score sheets were *not* exposure-based. Whether an error was committed once or many times by a driver, it was recorded *only as a single occurrence, and the number of opportunities to commit the error are not reflected in these data.*

To determine the efficacy of the *MultiCAD* tests in predicting on-road driving performance, correlational analyses were performed to determine the strength of the relationship between each functional status test in the *MultiCAD* battery and an error score derived from the DMV examiner's score sheet. The error score was weighted to reflect the seriousness of the committed errors. Results of the analyses showed that the weighted error score was significantly predicted by (1) the speed of (correct) responses on certain measures of visual acuity and contrast sensitivity, and (2) response accuracy (error rate) on brake reactions to pedestrian and vehicle movements constituting safety threats that were presented in a driving video.

This report discusses implications of the present research findings for licensing assessment strategies and policies. Older drivers, like *all* drivers, seem to engage in many intersection negotiation behaviors that could be classified as driving errors, but which have little apparent bearing on safety. Therefore, research into the types of predictor-criterion relationships at issue here should focus specifically and exclusively on those errors which best predict crashes, consistent with the practices of licensing examiners. Reports of significant relationships with performance measures that do *not* discriminate crashes only cloud the issue.

The present findings suggest that improvements in the safety of intersection negotiation by older drivers can be brought about through changes in engineering practice, such as increased use of signals. However, since this practice is likely to be cost-prohibitive at all but the highest crash sites, a suggested benefit of restricting certain, high-risk older drivers to travel on familiar routes should be evaluated, in controlled studies wherever permissible.

The difficulty remains in identifying who the high-risk older drivers are. Test reliability problems plague many procedures for measuring driving-related impairments. Poor results on component measures of driving ability may mask overall competence for the driving task, at least under a given set of conditions, by older persons who apply a variety of compensatory strategies. Finally, practical limitations in the time, expense, and/or complexity of any assessment procedures considered for large-scale implementation among the older population suggest that the greatest contribution to improved safety may result from measures designed to identify only the most clear and profound levels of diminished functional capability.

PROJECT BACKGROUND, OBJECTIVES, AND SCOPE

The single most pronounced area of difficulty for older drivers, as documented extensively in recent crash analyses, is the approach to and negotiation of intersections; concurrent work has linked such difficulties to a number of diminished functional capabilities known to decline with normative aging. This body of work is exhaustively reviewed in *Volume II* of this report, and an overview is presented several pages below. Based on our review, gaps in knowledge were identified, and priorities for continuing research in this area were defined. Accordingly, the overall goal of the present project was, first, to objectively derive a comprehensive classification of the types of specific driving errors evidenced at intersections by elderly motorists suffering functional decline; and, second, to advance understanding of the relationships between alternative measures of functional capability and an accepted index of crash risk.

Historically, attempts to directly relate measures of functional capability to motor vehicle crashes, as modeled in Figure 1, have shown associations that are modest at best, typically accounting for well under ten percent of the variability in the criterion measure (crash rates). This includes both sensory (visual) performance measures such as acuity and contrast sensitivity, plus measures of perceptual and cognitive skills including immediate memory span, complex reaction time, discrimination of embedded figures, and an array of additional functional capabilities, using various testing techniques.

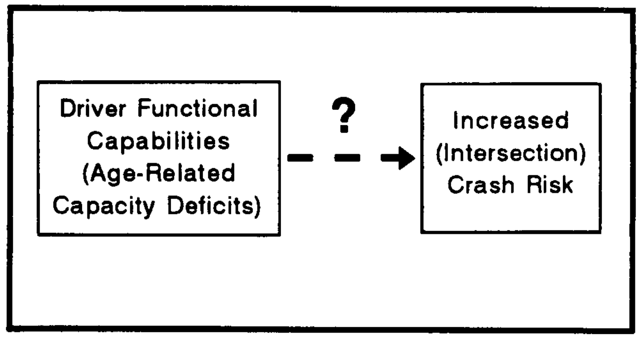

Figure 1. Hypothesized relationship between functional capability and motor vehicle crashes.

The reasons for this failure are many, as reported by Peck (1993) and others. Most importantly: since crashes are rare, most drivers remain crash-free for many years, thus restricting the range for this variable in any analysis; and, crashes are not a direct and inevitable result of unsafe driving behaviors, but are the consequences of interactions between a driver's behavior, situational factors, and the actions of other motorists.

The most successful of the efforts simplistically modeled in Figure 1 has examined the relationship between involvement in selected intersection crash types and measures of attentional and pre-attentional behavior, most notably research addressing the functional or "useful" field of view (UFOV). This body of work has predominantly considered crashes *retrospectively*, however, and with samples who have been selected specifically on the basis of prior crash involvement. Under these methodological constraints, the crash variance accounted for has been reported to exceed 25 percent (cf. Ball, Owsley, Sloane, Roenker, and Bruni, 1993). In contrast, another related study by the California Department of Motor Vehicles (CA DMV) using 3,669 randomly-selected license renewal applicants showed correlations between UFOV measures and crashes for drivers age 70 and older that were statistically significant, after adjusting for gender, age, and driving exposure, but the percentage of crash variance accounted for fell to just over 4 percent (Hennessy, 1995).

The importance of this work, regardless of specific outcomes, is that few now accept sensory (visual) ability alone as necessary and sufficient for safe driving. Instead, a broader focus incorporating attentional stages of information processing has gained acceptance among researchers and practitioners alike, and appears to hold promise for both screening and diagnostic tests to identify high-risk drivers.

A further evolution of thinking in this area of research has been to broaden criterion measures to focus upon *driving competency*, apart from the outright occurrence of a crash. This construct-valid approach offers several distinct advantages. First, measures of competency may be developed which are directly observable. Second, the instances of *in*competency, manifested as driving errors in a particular performance context with describable physical attributes, level of task demand, degree of familiarity/expectancy for the vehicle operator, etc., occur with a much higher frequency than crashes do. Gebers (1990), in applying a theoretical (Newbold-Cobb) model to 3-year crash rates for the California driving population, calculated that the maximum correlation that could be obtained between an *infallible* test battery or predictor variable and crash rates was 0.33; this reflects the restriction of range and variability in crash occurrence that were noted above. Using directly observable measures of driver performance deemed to be acceptable surrogates for crash risk (i.e., significantly correlated with crashes), this limiting factor in testing hypothesized consequences on safety of drivers' diminished functional capability is removed.

The next logical step is to determine how (age-related) diminished functional capabilities may predict driving errors, particularly *critical errors* that a strong consensus among traffic safety experts would characterize as direct antecedents of crashes. A recent study which has followed this paradigm has been reported by Janke and Hersch (1997). As modeled in Figure 2, clear associations between one or more measures of functional ability and driving competency could provide the strongest argument to date that this approach to prediction of crash risk will ultimately be fruitful. At the same time, the identified functional measures would assume priority as candidates for subsequent research studies and pilot programs by licensing agencies.

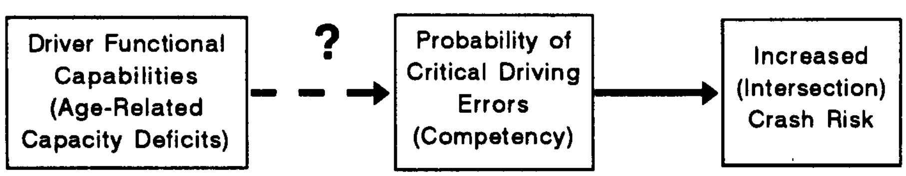

Figure 2. Elaboration of model showing hypothesized relationship between functional capability and crash risk.

What remains to be accounted for in the simple models diagrammed thus far is the contribution of "situational factors," as underscored earlier. These factors control when a specific driving behavior—even including some blatantly extreme examples such as crossing the highway centerline—results in a crash instead of a near-miss, or a non-event entirely (e.g., when driving on a road completely free of other traffic, or raised objects). Situational factors thereby mediate the relationship between functional status and the occurrence and criticality of driving errors. Key among these, based upon reviews conducted by members of this research team (Staplin, Lococo, and Sim, 1990, 1993; Staplin, Harkey, Lococo, and Tarawneh, 1997; Staplin, Ball, Park, Decina, Lococo, Gish, and Kotwal, 1997; Staplin, Lococo, McKnight, McKnight, and Odenheimer, *in press*), are assumed to be (1) the driving task demands, particularly those requiring "effortful" (serial) information processing, and (2) the driver's expectancies—reflecting familiarity or prior knowledge accessible in memory—relating to potential hazard sources encountered and vehicle control actions required along the to-be-traveled route. The relationships hypothesized to be mediated by these variables are modeled in Figure 3.

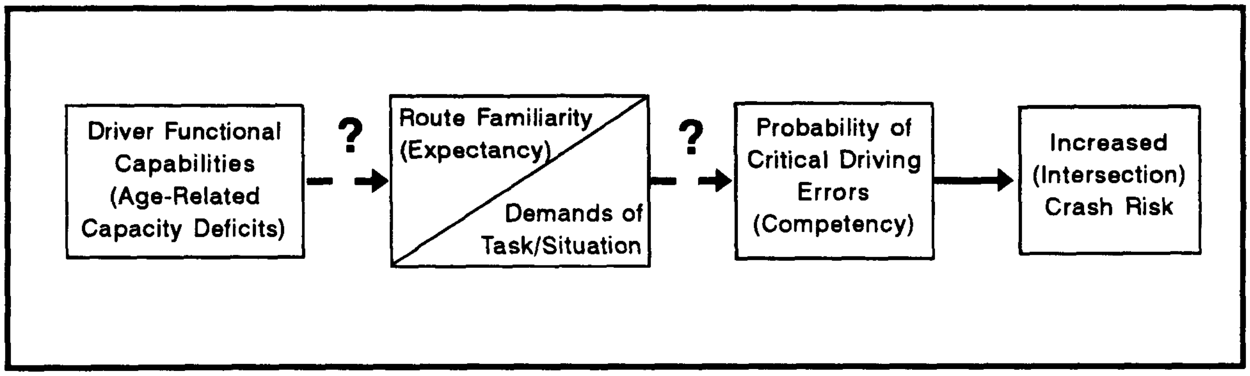

Figure 3. Hypothesized mediating variables governing criticality of driving errors, with resulting effect on crash risk, in relation to declining functional capacity.

Together, the variables identified in Figure 3 provided the theoretical framework for this study, and led to a definition of its scope. While the focus on intersection *negotiation* dictated a field study, the primary objective to develop a classification of driving difficulties suggested the need for an objective means of marking the occurrence of driving errors to complement the traditional approach of examiners' scoring of performance during an on-road test drive. A differentiation of task demands and route familiarity, at least on an ordinal basis, was also desired to explore the influence of these hypothesized mediating factors. In addition, a sample selection strategy which guaranteed that varying aspects of functional decline, including significant degrees of impairment, was crucial to this study. Finally, in this research it was essential to thoroughly document the functional status of all study participants, drawing upon as many reliable alternative measures and assessment techniques as could practically be implemented.

To address these requirements, a study was conducted in cooperation with the CA DMV, using a sample of drivers over the age of 60 who had been referred to the Department for reexamination. A within-subjects research design was applied, calling for two test drives by each subject: one drive on a standard route presumed to be of relatively lower familiarity, common to all study participants; and a second drive over a route of relatively higher familiarity that was unique to each individual, in the immediate area of the person's residence. Field measures of driving competency were obtained, using a modified driver performance evaluation protocol with demonstrated interrater reliability, scored by examiners who were specially-trained in its use and in the testing of older, frail individuals. Complementary, observational data were obtained during test drives through miniature on-board videocameras recording the view of traffic through the windshield, the rear window view, and a view of the driver's head and eyes. These were reduced to yield descriptive logs of driving errors during later analyses. Before completing the first test drive, each subject completed a battery of vision measures and other tests of attentional and perceptual skills developed for this research project.

In the following sections of this document, a brief overview of older driver functional deficits and problems in the use of intersections is presented, the study methodology is described, and data analysis procedures and results are reported, closing with a discussion of the study's findings.

OVERVIEW OF AGE DIFFERENCES AFFECTING SAFE DRIVING AT INTERSECTIONS

One of the principal concerns surrounding older road users is the ability of these persons to safely maneuver through intersections. Hauer (1988) reported that 37 percent of the fatalities and 60 percent of the injuries experienced by older drivers, occur at intersections. For drivers age 80 and older, more than half of fatal crash involvements occur at intersections, compared to 25 percent or less for drivers up to age 45 (Insurance Institute for Highway Safety, 1988). These data reinforce a long-standing recognition that driving situations involving complex speed-distance judgments under time constraints—the typical scenario for intersection operations—are more problematic for older drivers than for their younger counterparts (Waller, House, and Stewart, 1977).

AGE-RELATED FUNCTIONAL DEFICITS

An examination of the characteristics of older road users that affect intersection use reveals that this population differs from their younger counterparts in a number of important ways. This group may experience greater difficulties at intersections as the result of diminished capabilities, which limit both *response initiation* and *movement execution*.

The safety and mobility of older road users at intersections are overwhelmingly vision-dependent. Static, geometric features and traffic control devices (TCDs), plus a wide array of dynamic targets, are relevant to drivers and pedestrians at intersections; these must be detected and recognized in a timely fashion to allow for the subsequent cognitive processing preceding response selection and action. Deficits in vision and vision-dependent processes that probably have the greatest impact on older road users at intersections include diminished capabilities in spatial vision, the functional or "useful" field of view (UFOV), and depth and motion perception.

Spatial visual functions, including acuity and contrast sensitivity, are probably the most important functions for detection/recognition of downstream features at intersections. Tests of visual acuity—measuring response to high spatial frequency stimuli at contrast levels far above threshold—show a slow decline, beginning during the forties, which accelerates markedly during the sixties (Richards, 1972). Shinar and Schieber (1991) have argued that *dynamic* visual acuity—the ability to resolve targets by a moving driver, or moving targets by a standing pedestrian—should correlate more strongly with crash involvement, especially among older individuals. Though the loss of sensory response is greatest for high-frequency (more than 24 cycles/deg) information, older road users' sensitivity to visual contrast at lower and middle-range spatial frequencies (i.e., for 6-, 12-, and 18-cycle/deg targets) also declines steadily with increasing age over 40 (Owsley, Sekuler, and Siemsen, 1983).

Next, the UFOV measure addresses the detection, localization, and identification of targets against complex visual backgrounds, i.e., the earliest stage of visual attention used to quickly capture and direct attention to the most salient events in a driving scene. Most importantly, tests assessing the useful field of view appear to be better predictors of problems in driving than are standard visual field tests. In one study, drivers with restrictions in

UFOV had 15 times more intersection crashes than those with normal visual attention (Owsley, Ball, Sloane, Roenker, and Bruni, 1991).

Finally, age differences in the use of visual cues for depth and motion perception deserve emphasis. Researchers have found that the angle of stereopsis (seconds of arc) required for a group of older drivers age 75+ to discriminate depth using a commercial vision tester was roughly twice as large as that needed for an 18- to 55-year-old group to achieve the same level of performance (Staplin, Lococo, and Sim, 1993). Also, it has been shown that older persons require up to twice the rate of movement to perceive that an object's motion-in-depth is approaching, and require significantly longer to perceive that a vehicle is moving closer at a constant speed (Hills, 1975). The Staplin et al. (1993) study investigating causes of older driver over-involvement in turning crashes at intersections, building on the previously reported decline for detection of angular expansion cues, did **not** find evidence of overestimation of time-to-collision. At the same time, a relative insensitivity to the speed of an approaching vehicle was shown for older versus younger drivers; this result supports the notion that older drivers rely primarily or exclusively on perceived distance to perform gap-acceptance judgments, reflecting a reduced ability to integrate time and distance information with increasing age. Thus, a principal source of risk at intersections is the error of an older, turning driver in judging gaps in front of fast vehicles.

Compounding the varied age-related deficits in visual performance, an overall slowing of mental processes has been postulated as individuals continue to age into their seventies and beyond (Cerella, 1985), and a decline has been demonstrated in a number of specific cognitive activities with high-construct validity in the prediction of driver and pedestrian safety (Stelmach and Nahom, 1992). The cognitive functions included in this processing stage perform attentional, decisional, and response-selection functions crucial to maintaining mobility. Complementary functions essential to the safe and effective use of intersections are selective attention, attention switching, and divided attention, which together comprise the core of what is often termed "situational awareness." Older drivers appear to benefit disproportionately from interventions that compensate for divided attentional deficits during a high-workload task such as negotiating an intersection, for example, cuing drivers with advanced notice of protected versus permissive movement regulations through a redundant upstream posting of advisory signs (Staplin and Fisk, 1991). Related studies suggest that if older drivers must increase their attention to inconspicuous or confusing features to make appropriate maneuver decisions during an intersection approach, a deficit in the discrimination of peripheral targets (e.g., other vehicles or pedestrians) is likely (Brouwer, Ickenroth, Ponds, and Van Wolffelaar, 1990).

Finally, the execution of vehicle control movements by an older driver, or walking movements by an older pedestrian, is likely to be slowed due to a number of factors. A study by Goggin, Stelmach, and Amrhein (1989) linked response slowing by older individuals to abbreviated stimulus exposure times and interstimulus intervals. Also, these researchers have shown that older persons will have greater difficulty in situations where planned actions must be rapidly altered, and corrections during movement execution are slower and much less efficient. The spacing of vehicle control movements required of drivers to negotiate intersections, therefore, may be expected to strongly influence the ability of older individuals to respond in a safe and timely manner; thus, the potential for older driver difficulties at sites which require weaving or successive lane changes within a restricted timeframe increases substantially. In Simon and Pouraghabagher's (1978) study, older adults demonstrated slower reaction times than younger adults when faced with response uncertainty, indicating greater risk when older road users are faced with two or more choices of action. This exacerbates intersection negotiation problems in any situation where older road users are called upon to execute multiple responses in quick succession.

Perhaps most common is the age-related decline in head and neck mobility. Joint flexibility has been estimated to decline by approximately 25 percent in older adults, due to arthritis, calcification of cartilage, and joint deterioration. This restricted range of motion reduces an older driver's ability to effectively scan to the rear and sides of his/her vehicle to observe blind spots, and can also hinder the timely recognition of conflicts during turning and merging maneuvers at intersections (Ostrow, Shaffron, and McPherson, 1992). Reduced neck flexibility also penalizes older pedestrians who must detect potential conflicts without unreasonable delay to accomplish intersection crossings within a protected signal phase.

IDENTIFIED PROBLEMS WITH INTERSECTION USE

Other studies within the large body of evidence showing dramatic increases in intersection crash involvements as driver age increases have revealed detailed patterns of data associating specific crash types and vehicle movements with particular age groups, and in some cases have linked such patterns to the driving task demands in a given maneuver situation (see Campbell, 1993; Council and Zegeer, 1992; Staplin and Lyles, 1991).

Another approach to characterizing older driver problems at intersections was employed by Brainin (1980), who used in-car observations of driving behavior with 17 drivers ages 25 to 44, 81 drivers ages 60 to 69, and 18 drivers age 70 and older, on a standardized test route. The two older age groups showed more difficulty making right and left turns at intersections and negotiating traffic signals. The left-turn problems resulted from a lack of sufficient caution and poor positioning on the road during the turn. Right-turn difficulties were primarily a result of failing to signal. Errors demonstrated at STOP signs included failing to make complete stops, poor vehicle positioning at STOP signs, and jerky and abrupt stops. Errors demonstrated at traffic signals included stops that were either jerky and abrupt, failure to stop when required, and failure to show sufficient caution during the intersection approach.

Complementing crash analyses and observational studies with subjective reports of intersection driving difficulties, a statewide survey of 664 senior drivers by Benekohal, Resende, Shim, Michaels, and Weeks (1992) found that the following activities become more difficult for drivers as they grow older (with proportion of drivers responding in parentheses):

- Reading street signs in town (27 percent).
- Driving across an intersection (21 percent).
- Finding the beginning of a left-turn lane at an intersection (20 percent).
- Making a left turn at an intersection (19 percent).

- Following pavement markings (17 percent).
- Responding to traffic signals (12 percent).

Benekohal et al. (1992) also found that the following highway features become more important to drivers as they age (with proportion of drivers responding in parentheses):

- Lighting at intersections (62 percent).
- Pavement markings at intersections (57 percent).
- Number of left-turn lanes at an intersection (55 percent).
- Width of travel lanes (51 percent).
- Concrete lane guides (raised channelization) for turns at intersections (47 percent).
- Size of traffic signals at intersections (42 percent).

Comparisons of responses from drivers ages 66 to 68 versus those age 77 and older showed that the older group had more difficulty following pavement markings, finding the beginning of the left-turn lane, and driving across intersections. Similarly, the level of difficulty for reading street signs and making left turns at intersections increased with increasing senior driver age. Turning left at intersections was perceived as a complex driving task. This was made more difficult when raised channelization providing visual cues was absent, and only pavement markings designated which were through versus turning lanes ahead. For the oldest age group, pavement markings at intersections were the most important item, followed by the number of left-turn lanes, concrete guides, and intersection lighting. A study of older road users completed in 1996 provides evidence that the single most challenging aspect of intersection negotiation for this group is performing left turns during the permitted (green ball) signal phase (Staplin, Harkey, Lococo, and Tarawneh, 1997).

During focus group discussions conducted by Benekohal et al. (1992), older drivers reported that intersections with too many islands are confusing, that raised curbs that are unpainted are difficult to see, and that textured pavements (rumble strips) are of value as a warning of upcoming raised medians, approaches to (hidden or flashing red) signals, and the roadway edge/shoulder lane boundary. Regarding traffic signals, study subjects indicated a clear preference to turn left on a protected arrow phase, rather than making "permitted phase" turns. When turning during a permitted phase (green ball) signal operation, they reported waiting for a large gap before making a turn, which frustrates following drivers and causes the following drivers to go around them or blow their horns at the older drivers. A general finding here was the need for more time to react.

Additional insight into the problems older drivers experience at intersections was provided by focus group responses from 81 older drivers in the Staplin et al. study (1997). The most commonly reported problems are listed below:

- Difficulty in turning head at skewed (non-90°) angles to view intersecting traffic.
- Difficulty in smoothly performing turning movements at tight corners.
- Hitting raised concrete barriers such as channelizing islands in the rain and at night due to poor visibility.
- Finding oneself positioned in the wrong lane—especially a "turn only" lane—during an intersection approach, due to inadequate design or poor visibility (maintenance) of

pavement markings or the obstruction of roadside signs informing drivers of intersection traffic patterns.

- Difficulty at the end of an auxiliary (right) turn lane, at channelized intersections, in seeing potential conflicts well and quickly enough to smoothly merge with adjacent-lane traffic.
- Merging with adjacent-lane traffic when a lane drop occurs near the intersection (e.g., when two lanes merge into one lane).

Although these problems are by no means unique to older drivers, the various functional deficits associated with aging appear to exacerbate difficulties for this user group.

RESEARCH METHODOLOGY

This section of the report first presents an overview of the test situation in which data collection was performed, while explaining the project's relationship to a concurrent California Department of Motor Vehicles (CA DMV) study utilizing a significant number of shared resources, and without which this research would not have been feasible. The subject selection procedures and sample characteristics are described next. The section closes with a comprehensive description of the study variables, performance measures, instrumentation and apparatus, and procedures for data collection and scoring.

OVERVIEW OF TEST SITUATION

This study included a combination of laboratory (office) measures of vision and perceptual skills developed by the Contractor, labeled *MultiCAD* (*Multiple Competency Assessment for Driving)*, plus on-road drive tests. The *MultiCAD* test battery was administered by a graduate research assistant working temporarily for CA DMV, and the drive tests were administered by specially-trained examiners employed by CA DMV; in each case, these persons were dedicated to a concurrent project performed under a cooperative agreement with NHTSA (DTNH22-93-Y-05330), directed by Dr. Mary Janke. The test site for both research efforts was the Santa Teresa, CA, DMV facility.

The subjects in this study were all referred to the DMV for reexamination by physicians, family, the law enforcement or judicial system, or other DMV staff. All were compelled to complete the functional test battery *and* two, on-road tests of driving skill: (1) a standard test route, common to all subjects, that began and ended at the Santa Teresa DMV facility; and (2) a route developed in the area near each subject's home, including travel to frequently visited destinations. The two routes, which represent a contrast in the level of familiarity and expectancy for vehicle control requirements during the test drives, both required roughly equal travel times, but did not necessarily include intersections with closely-matched characteristics or traffic conditions.

All subjects first completed the *MultiCAD* test battery, then the standard drive test, then, on a following day, the home area drive test. The examiners conducting the drive tests could discontinue and conclude testing at any time, during either on-road test, due to safety concerns.

STUDY VARIABLES AND PROCEDURES

The independent (predictor) variables examined in this study included a set of functional status indicators describing age-related changes in vision and perceptual skills, plus contrasting (relatively lower versus higher) levels of familiarity of subjects with the test routes on which their driving competency was evaluated. The dependent (criterion) variables included a weighted error score derived from the structured observations of trained DMV examiners during the test drives, plus probabilities of occurrence of specific behavioral errors derived from videotapes recorded in the subjects' own vehicles as they drove over each test route.

The description of the *MultiCAD* battery of functional tests is presented first below. For convenience, this discussion integrates the test contents and test scoring, data collection apparatus, and protocol for administration of the test battery. Similarly, the following discussion of the drive test procedures includes a description of test route development, test protocol, and scoring by the DMV examiners. Finally, the equipment and procedures used to obtain videotaped observations of driver behaviors and views of the road and traffic conditions on each test route are described.

Measuring the Functional Status of the Study Sample

A PC-based tabletop testing system was delivered to the CA DMV by the Contractor and was used to conduct limited functional assessments of all 82 subjects. The test battery used a combination of video clips of driving scenes and computer-generated images to maintain a high level of face validity for everyday driving situations. It was constructed to assess a restricted set of candidate "minimum qualifications thresholds," rather than to obtain a precise psychophysical measurement of capability level. The battery of nondriving tests in this research was designed to measure a variety of competencies deemed critical to safe vehicle operation, based on the review of previous research findings conducted earlier in the project.

The *MultiCAD* protocol displays dynamic, suburban arterial driving scenes on a 27-inch screen capable of accepting both video (NTSC TV standard) and computer graphics (SVGA) inputs. As described below, these measures required subjects to respond to the test scenes using a hand-held, 3-button response pad in a 3-alternative, forced-choice paradigm, to identify stimulus features as requested in a series of audio/visual instructions. A brake and accelerator pedal assembly was used for stop-and-go decisions, and brake reaction measures.

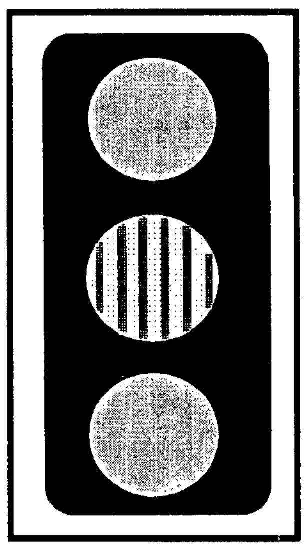

Figure 4. Example of *MultiCAD* acuity test stimulus.

Static Acuity. This test used *MultiCAD* to measure drivers' ability to resolve fine detail on a stationary target under high contrast conditions. The subject was shown a driver's eye view of travel along a suburban arterial, approaching and then stopping at an intersection with a traffic signal in plain view. The image centered and then zoomed on the signal until it filled the screen, while the subject was instructed to use the 3-button response pad to identify which face on the (conventional, 3-face) signal looked different than the other two. Instead of solid red, yellow, and green circles, however, the signal faces contained acuity test stimuli. Square wave gratings with vertical bars were used, such that one signal face contained a high contrast test stimulus (90 percent contrast) and the other two faces showed a uniform luminance (without bars). The ability to discriminate which two signal faces were "blank" versus which one contained the vertical bars defined the subject's static acuity level. An example acuity stimulus target is shown in Figure 4. Three levels of testing were conducted—20/40 (15 cycles per degree), 20/80 (7.5 cycles per degree), and 20/200 (3 cycles per degree)—with a pass/fail score assigned at each level. A passing score was defined as at least two correct responses out of the three presentations for each level tested. Mean response time was also calculated for correct responses at each level. Three replications of each measurement were performed.

Dynamic Acuity. This test used *MultiCAD* to measure drivers' visual acuity, for a target that was moving relative to the observer, under high contrast conditions. The same type of stimuli as described for *MultiCAD* static acuity were shown again while moving at a predetermined rate from one side of the screen to the other. The same "which signal is different?" discrimination was required of the subject, using the 3-button response pad. The rate of movement across the screen (12 degrees per second) corresponded to a driver trying to read a street sign posted at roadside while passing by at a moderate (40 to 64 km/h [25 to 40 mi/h]) rate of speed. Three replications of each measurement were performed—20/40, 20/80, and 20/200—with a pass/fail score assigned at each level. A passing score was defined as at least two correct responses out of the three presentations for each level tested. Mean response time was also calculated for correct responses at each level.

Static Contrast Sensitivity. This test used *MultiCAD* to measure drivers' sensitivity to differences in brightness, as required to detect edges between adjacent lighter and darker areas in the roadway environment. The subject was asked to use the 3-button response pad to indicate which of three signal faces contained a test pattern. The traffic signal image remained stationary during this test. The test patterns were the same as used for the static acuity test for 20/40 (15 cycles per degree) and 20/80 (7.5 cycles per degree), and were presented at 2 contrast levels (high contrast=20.6 percent; low contrast = 4.9 percent). Three replications of each measurement were performed with a pass/fail score assigned at each level. A passing score was defined as at least two correct responses out of the three presentations for each level tested. Mean response time was also calculated for correct responses at each level.

Dynamic Contrast Sensitivity. This test used *MultiCAD* to measure drivers' contrast sensitivity for a target that is moving relative to the observer. Immediately following the *MultiCAD* static contrast sensitivity test, exactly the same type of stimuli were shown while moving at a predetermined rate (12 degrees per second) from one side of the screen to the other. The same "which signal face is different?" discrimination was required of the subject, using the 3-button response pad. Three replications of each measurement were performed with a pass/fail score assigned at each level. A passing score was defined as at least two correct responses out of the three presentations for each level tested. Mean response time was also calculated for correct responses at each level.

Angular Motion Sensitivity. This test used *MultiCAD* to measure drivers' ability to rapidly detect changes in the relative motion of their own versus other vehicles. A video of suburban driving scenes was used which presented a driver's eye view of travel along an arterial route with light traffic, following a lead vehicle (that the subject was told to pay attention to) at varying distances. Subjects were required to depress the brake in the *MultiCAD* assembly whenever the vehicle directly ahead in the same lane applied its brakes or at any other time it would be advisable to stop or slow down under actual driving conditions (e.g., an adjacent-lane driver encroaches into the lane of travel). The lead vehicle brake lights were illuminated when it slowed for 12 of the angular motion sensitivity trials.

For three other angular motion sensitivity trials, the lead vehicle's brake lights were disabled during filming of the video, so that the subject was required to detect the change in headway without the additional brake light cue. These three trials were intermixed with the trials in which the brake lights were illuminated.

Measures of effectiveness were: (1) mean brake reaction time across 12 trials, to slowing/stopping lead vehicle <u>with</u> brake light activation, for <u>correct responses</u>; (2) percent error for these trials (e.g., percent of the trials where the vehicle ahead slowed <u>and</u> the brake lights were clearly visible, but the subject did <u>not</u> press the brake pedal); (3) mean brake reaction time across three trials, to slowing/stopping lead vehicle with <u>no</u> brake light activation, for <u>correct responses</u>; and (4) percent error for these three trials.

<u>Useful (Functional) Field of View</u>. This divided attention test used *MultiCAD* to measure drivers' ability to remain vigilant and respond in a timely and appropriate manner to events that occurred directly ahead, in the travel path, while also detecting unexpected events of a safety-critical nature that occur in the areas of peripheral vision. After angular motion sensitivity data were obtained, the same driving video continued to use the lead vehicle target as a "foveal task" (i.e., located centrally along the driver's line of sight). At predetermined intervals in relation to a (lead vehicle) brake light stimulus, vehicles and pedestrians were introduced unexpectedly in the periphery of the driver's forward vision, offset at angles of approximately 15 degrees and 30 degrees to the left and right sides. The motion of these peripheral targets brought them into potential conflict with the driver within several seconds' travel time.

For threats intersecting from the periphery at approximately a 15-degree angle of eccentricity (2 trials), the measures of effectiveness were: (1) mean reaction time for correct response to (a) a vehicle pulling out from behind a building on the right side of the scene and (b) a vehicle backing out of a parking space from behind a (blocking) U-Haul van on the left side of the scene; and (2) percent error for these two trials.

For threats intersecting from the periphery at approximately a 30-degree angle of eccentricity (1 trial), the measures of effectiveness were: (1) mean reaction time for correct response to a pedestrian stepping off the curb and entering the driver's path; and (2) percent error.

In addition to the tests described above, a manual measure of neck flexibility was obtained using a goniometer to measure degrees of head/neck rotation to the left and to the right.

Data collection using the *MultiCAD* functional test driving simulator proceeded in the following manner. After an initial greeting, the participant was escorted to the simulator and asked to sit in the simulator chair ("driver's seat"). The test administrator obtained demographic information, and then measured the subject's neck flexibility. A goniometer attached to the back of the driver's seat was lowered to a position slightly above the participant's head. The participant was told to look straight ahead and the goniometer was set at 0 degrees. The participant was then asked to turn his/her head left to the maximum point where there was no discomfort and then to the right with the same instructions. The maximum head turning angles were recorded. The goniometer was then taken out of the back of the driver's seat.

The driver's seat was adjusted horizontally so that the individual could easily reach the accelerator and brake pedals. The seat was adjusted vertically so that the individual's eye height was at the mid-point of the monitor. A 30 inch eye-to-screen distance was set by moving the monitor assembly along a track.

The *MultiCAD* battery contains multimedia (audio and visual) instructions, presented on-screen through pre-recorded video of a "talking head" (a staff member employed by the Contractor). This allowed for identical delivery of instructions to each participant. The test administrator informed the participant to follow along with the instructions presented to him/her on the monitor by the moderator from the video program. The test administrator then initialized the video program. Before the visual and perceptual tests were presented, the "talking head" requested the participant to press each of the response switches (3-button response pad, accelerator pedal, brake pedal) to ensure that responses were being recorded by the data collection computer. The correct operation of these response devices was confirmed by the test system before the automated data collection protocol was allowed to continue.

Measuring Driving Competency on Less Familiar and More Familiar Test Routes

Standard Route Drive Test. As noted earlier, the CA DMV Field Operations Division office in the Santa Teresa area of southern San Jose was used as the test site. The driving exam for the standard (low familiarity) route began and ended at this DMV office.

A reconnaissance of the surrounding area within a 0.5-hour radius from the DMV was performed to identify potential intersection locations suitable for inclusion in the standard route driving exam. The intersection types sought were those providing examples of high demand intersection geometric and operational situations identified in an intersection negotiation task analysis performed earlier in the project (see *Volume II* of this report).

A preliminary test route was then developed that incorporated as many of the high-criticality intersection maneuver/geometry/operation types as possible. A second traversal was conducted to refine the test route to accommodate the requirements of DMV driver exam testing (i.e., route must be no more than 0.5 hours from start to finish, and must include all DMV driver exam scoring situations). In addition to the maneuvers performed in the parking lot, the DMV requires that the driver performance examination include:

- Four left turns.
- Four right turns.
- Eight non-turn (through) intersections (stop-controlled, signal-controlled, and uncontrolled).
- Left lane change.
- Right lane change.

These stipulations limited the ability for the study to include all of the intersection maneuver/operational situations originally planned. As the route was finalized, site characteristics essential for later data reduction and analysis purposes were noted.

Table 1 identifies high criticality intersection types, selected on the basis of the maneuver requirements (e.g., right turn, left turn, straight through), geometry and operational factors (e.g., presence of left-turn bays and auxiliary right-turn lanes, number of through lanes), and traffic control elements (e.g., traffic signal, stop sign, pavement markings). It should be noted that this list is not exhaustive; other intersection types (such as T-intersections) and maneuvers (lane changes, parking, backing) occurred along the standard exam route, which are not listed here.

Table 1. Characteristics of high-criticality intersections included on the standard test route.

Maneuver Requirement	Intersection Type*	Traffic Control
Right Turn (on green or red after stop)	4-lane by 4-lane with opposing dual left-turn lanes (Type 13) •2 left-turn only lanes •1 through lane •1 right-turn only lane •pedestrian refuge island between right-turn only lane and through lane.	•3 vertical 3-lens signals with solid red, solid yellow, solid green balls •2 vertical 3-lens signals, containing solid red ball, solid yellow ball, and left-turn green arrows •2 pedestrian signals with "hand" for Don't Walk and "walking person" for Walk. •Turn-only lanes (2 left and 1 right) marked with "ONLY" pavement markings
Through (on steady green ball)	Divided 4-lane by 4-lane with opposing left-turn lanes (Type 14) •1 channelized left-turn bay •1 right-turn bay •2 through lanes •pedestrian refuge island between right-turn only lane and through lane	•3 vertical 3-lens signals with solid red, solid yellow, solid green balls •2 vertical 3-lens signals, containing solid red ball, solid yellow ball, and left-turn green arrows •2 pedestrian signals with "hand" for Don't Walk and "walking person" for Walk. •Turn-only lanes (1 left and 1 right) marked with "ONLY" pavement markings

* See *Volume II* for definition and schematic drawing of each intersection Type.

Table 1. Characteristics of high-criticality intersections included on the standard test route (Continued).

Maneuver Requirement	Intersection Type*	Traffic Control
Left Turn (on steady green ball)	2-lane by 2-lane with opposing dual left-turn lanes (Type 7) •1 left-turn lane •1 combined through and right-turn lane	•4 vertical 3-lens signals containing solid red, solid yellow, and solid green balls •2 pedestrian signals with "hand" for Don't Walk and "walking person" for Walk. •Left-turn only arrow pavement marking in left-turn lane; no markings in right/through lane
Right Turn (on steady green ball or red ball after stop)	Divided 4-lane by 4-lane with opposing left-turn lanes (Type 14) •1 left-turn lane •1 right-turn lane •2 through lanes •There is a bike lane and the right-turn lane is divided by an island	•4 vertical 3-lens signals containing solid red, solid yellow, and solid green balls •2 vertical 3-lens signals containing red arrow, solid green ball, solid yellow ball •Left-turn only arrow pavement marking in left-turn lane
Through	2-lane by 2-lane with no auxiliary lanes (Type 4)	•4-way stop signs
Left Turn	2-lane by 2-lane with opposing left-turn lanes (Type 7)	•4-way stop signs •Left-turn only pavement marking
Left Turn (on steady green ball)	2-lane by 2-lane with right turn lane (Type 5) •1 shared left/through lane (unmarked) •1 right-turn only lane (marked)	•3 vertical 3-lens signals containing solid red, solid yellow, and solid green balls •2 pedestrian signals with "hand" for Don't Walk and "walking person" for Walk. • Right turn only pavement marking
Through (on steady green ball)	4-lane by 4-lane with opposing left-turn lanes (Type 14) •1 left-turn bay •3 through lanes	•3 vertical 3-lens signals containing solid red, solid yellow, and solid green balls •1 vertical 3-lens signal with left-turn green arrow, left-turn yellow arrow, solid red ball

* See *Volume II* for definition and schematic drawing of each intersection Type.

Table 1. Characteristics of high-criticality intersections included on the standard test route (Continued).

Maneuver Requirement	Intersection Type*	Traffic Control
Right Turn (on steady green ball or red ball after stop)	2-lane by 2-lane on driver's side (Type 4) 2-lane by 2-lane with opposing left-turn lane on opposite side (Type 7) •no lane lines were marked on pavement	•4 vertical 3-lens signals containing solid red, solid yellow, and solid green balls •2 pedestrian signals with "hand" for Don't Walk and "walking person" for Walk. •Sight distance to left is blind; applicant must creep forward if light is red, to see to the left.
Left Turn (green arrow)	4-lane by 4-lane with opposing left-turn lanes (Type 14) •1 left-turn bay •1 channelized right-turn lane •3 through lanes	•4 vertical 3-lens signals containing solid red, solid yellow, and solid green balls •2 vertical 3-lens signals, with leading left-turn green arrow, solid yellow ball, solid red ball Left-turn only pavement marking

* See *Volume II* for definition and schematic drawing of each intersection Type.

The examination protocol used in this study was, of necessity, the same as for the concurrent project (DTNH22-93-Y-5330). This protocol was a modification of the Driver Performance Examination (DPE), which California plans to adopt as its standard road testing instrument for both novice drivers and some experienced, but functionally impaired drivers. It employs a fixed number of maneuvers that are scored at specific locations ("structured maneuvers"), resulting in a fixed number of possible errors and objective scoring criteria. The road test was conducted by two DMV examiners who have extensive training in the effects of functional impairments on driving, and much experience in administering special drive tests in California.

During the on-road exam, a test examiner sat beside the subject driver and used a score sheet to indicate whether the structured maneuvers at predesignated points on the route were performed unsatisfactorily (e.g., inadequate traffic check, poor lane position). If so, a driving error was recorded. In addition to the simple occurrence of a driving error, two additional categories of errors could also be denoted: critical errors and hazardous errors. These are defined as follows:

- *Critical Errors* — Errors which would in normal circumstances cause test termination. These included: driver strikes object; drives up/over curb/sidewalk; drives in oncoming traffic lane; disobeys sign/signal; inappropriate reaction to school bus; inappropriate reaction to emergency vehicle; inappropriate speed; inappropriate auxiliary equipment use; and turn from improper lane.

- *Hazardous Errors* — A subset of critical errors, such that any critical error which is judged to involve a dangerous maneuver or that required examiner intervention, is also termed hazardous.

As noted above, the number of possible errors was fixed, with the exception of critical driving errors, which were recorded as they occurred. Hazardous errors are a subset of critical errors, and critical errors a subset of total errors.

In the analyses performed by Janke and Hersch (1997), a weighted error score was calculated as the total number of errors committed during a subject's drive test, plus twice the sum of critical and hazardous errors. This weighting scheme is discussed further in the next section of the report.

Home Area Drive Test. The second on-road driving performance examination was conducted in a subject's home area, usually the day following the standard route drive test. Unlike the standard exam, the home area test route was not pre-planned; structured maneuvers could not be assigned to specific points on the route. However, other than arranging to meet at the subject's home or at some other location convenient to subjects, protocols and procedures for the second drive test paralled those implemented during the first drive test. A count of total errors, critical errors, and hazardous errors was obtained from examiner scoresheets for the home area drive test in a manner identical to the standard route exam, and the home area test was conducted by the same DMV examiners.

Obtaining Videotaped Observations of Driver Behavior and Situational Factors

Drivers' performance on both on-road exams was videotaped to obtain more precise information about the subjects' errors in two broad categories: *maneuver errors* and *errors of observation*. A video recording that documents where a subject looked, and the roadway view in front of and behind the subject's vehicle, was selected to meet this objective data requirement.

The videotape data collection system was comprised of the following components: 3 mini-cameras; a portable mini-monitor; 3 12-volt, AC compatible video cassette recorders (VCRs) attached together with a bracket; power supply (car battery); photographic flash attachment; and an accelerometer with display unit. The system was designed to be portable and able to be installed in any vehicle within 10 minutes.

Subjects performed the on-road exams after completion of the *MultiCAD* battery. Each participant was asked to park his/her vehicle near the back doorway of the DMV building, to permit installation of the video data collection system. This was performed by the same research assistant who had administered the functional test battery.

The mini-cameras covered three fields of view: (1) the forward roadway view; (2) a view of the driver's face; and (3) a view out of the rear window of following traffic and of an accelerometer placed on the rear dashboard. The forward roadway view mini-camera was clamped onto the passenger-side visor and pointed out toward the center of the road. Camera wires were concealed above the visor and were run across the top of the visor to the floor of the passenger side and then to the rear floor of the vehicle, where they were connected to a VCR unit and the power supply. The driver head/eye view mini-camera was wedged into the top of the dashboard at the bottom of the windshield toward the left side of the steering wheel. The mini-camera pointed toward the subject's face. Camera wires were wedged along the edge of the bottom of the windshield across the front of the vehicle to the passenger side and then to the rear floor where they were connected to another VCR unit and the power supply. The third mini-camera was set up in the rear center of the subject's vehicle. This camera was clamped to a metal rod connected to the accelerometer, which was positioned along the back compartment of the rear seats. The camera pointed out the back window, viewing the accelerometer display and the road behind the subject's vehicle. Camera wires were connected to the VCR unit and the power supply. Accessories and additional clamps were available to accommodate affixing the mini-cameras to a variety of dashboards, visors, and compartments behind the rear seats. Prior to each drive test, proper aiming of the cameras was confirmed using a mini-monitor that was easily connected and disconnected to each camera.

The VCRs were positioned in the rear floor of the participant's vehicle. The VCRs were powered by a 12-volt auto battery, which was recharged each night after use. VHS 60-min videotapes were used with each VCR. These tapes were loaded into the VCR units before each run. Each participant required three tapes to record performance on the standard exam and three tapes to record performance on the home area exam on the following day, for a total of six videotapes per subject.

Once the mini-cameras and VCRs were installed, powered on, and had started recording, all three cameras were aimed at a photographic flash attachment and the flash attachment was triggered. The flash provided a discreet moment visible to all cameras that could be used to synchronize data from all tapes. This procedure was necessary to enable data reduction and coding of events. Once this procedure was completed, all cameras were aimed using the mini-monitor, all wires were concealed, and the VCRs and power supply were covered with a black dropcloth.

At that point, the study participant and the CA DMV driver examiner were requested to enter the participant's vehicle to begin the standard on-road exam. The data collector informed the participant that the equipment set up in the vehicle was used to monitor the view of the road. Then, the driver examiner explained where he wanted the participant to drive. Once the road exam was completed the videotape data collection system was disassembled and removed from the vehicle. The home area driving performance examination was then scheduled, usually for the following day. The same procedure was followed for setting up the videotape equipment in the subject's vehicle for the home area drive test.

After each on-road exam was completed by each subject, the tapes were rewound, then were labeled (by view) and mailed to the project staff who would subsequently reduce and code the observational data for planned analyses in this study.

CHARACTERISTICS AND FUNCTIONAL STATUS OF TEST SAMPLE

Test Sample Characteristics

Participants were selected from individuals who were referred to the CA DMV Driver Safety Office for reexamination because of a medical condition, a series of license failures, a flagrant driving error, or some other indicator of driving-related problems. CA DMV staff further screened individuals to include only those who were over the age of 60, with English literacy. These individuals were then scheduled for their driving examinations.

The test sample in this study included 82 individuals (54 males and 28 females) over the age of 60. The age range was 61 to 92; the mean age was 77 and the median was 78. Ninety-six percent of the participants were 65 years of age or older. Sixty-five percent of the group was 75 years of age and older. The study sample distribution by gender, and by five-year age groups (61-65, 66-70, 71-75, 76-80, 81-85, and 86+) is shown in Figure 5.

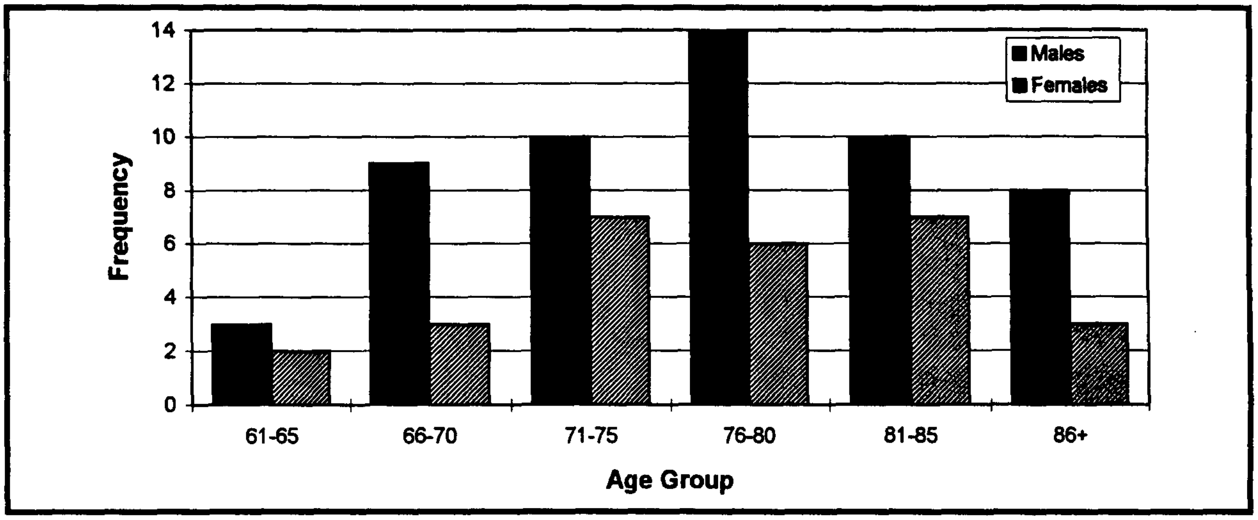

Figure 5. Distribution of study participants by age and gender.

The average number of years of driving reported by the group was approximately 56 years and the average number of miles driven annually was 6,150. The participants reported that they drove most of the time (89 percent) in daylight hours; and that most of their driving (76 percent) was on local (non-freeway) roads.

None of the participants, when asked, mentioned consuming any alcoholic beverages within the 4 hours preceding their examinations. However, 56 percent of the participants had taken prescription medication within the past 8 hours.

Participants were referred to the CA DMV Driver Safety Office for several reasons. Police referral was the most common reason (24 percent of the group). The police had either investigated a crash or stopped the driver for a violation or some other erratic maneuver and decided (based on observation or noticing a physical impairment) to send a referral. The next most common reasons for referral were related to the person recently having a stroke (20 percent of the group); the person showing some form of dementia (20 percent of the group); or the person having a vision problem (18 percent of the group). In these cases, physicians, family members, or driver examiner referrals were made. Other conditions of the participants also provided reasons for referral, including neurological disorders, musculoskeletal conditions, and endocrine-related disorders (e.g., diabetes mellitus, hypoglycemia, hyperthyroidism).

Functional Status of Test Sample

In this section, the performance capabilities of two older driver populations are summarized. Results are presented for the group of 29 subjects ages 61 to 74 (termed "young-old") and for the group of 53 subjects age 75 and older (termed "old-old"). This division was chosen in light of the fact that crash-involvement and fatality rates increase sharply per mile driven, as drivers reach age 75. Supporting graphics are presented in Appendix A, in Figures A-1 through A-11.

<u>Static Acuity</u>. The sample's static acuity capabilities are presented in Figures A-1 and A-2 for *each* of the *three levels* of test stimuli that were presented—20/40, 20/80, and 20/200. Figure A-1 presents the percent of the sample which meets the indicated performance level for young-old vs. old-old drivers, while Figure A-2 presents the mean response times for correct responses for these age groups. These data indicate, surprisingly, that fewer subjects correctly discriminated the 20/200 targets than the 20/40 or 20/80 targets. However, this is interpreted as a practice effect: static acuity measurement was the initial test procedure, and as in conventional vision test protocols, the lowest resolution targets (20/200) were always presented first, when subjects' lack of familiarity with the novel *MultiCAD* procedures would be most likely to impact their performance. This interpretation is supported by the latency data for correct responses, which show a consistent decrease in response time for the lower resolution versus the higher resolution stimuli. There were no clear trends in the data presented in Figures A-1 and A-2 as a function of subject age group, except for an increase in response time at all acuity levels for the old-old subjects.

<u>Dynamic Acuity</u>. The sample's dynamic acuity capabilities are documented in Figures A-3 and A-4. For *each* of the *three levels* of test stimuli that were presented—20/40, 20/80, and 20/200—the following results are summarized: percent of sample which meets the indicated performance level, for young-old vs. old-old drivers (Figure A-3); and mean response time for correct responses for these age groups (Figure A-4). A sharp drop in performance was noted for the 20/40 versus both the 20/80 and 20/200 stimuli, for both age groups. Slower response times were noted for the old-old subjects, for two of the three levels of target resolution (20/80 and 20/200).

<u>Static Contrast Sensitivity</u>. The sample's static contrast sensitivity capabilities are presented in Figures A-5 and A-6. For *each* of the *four levels* of test stimuli that were presented—two spatial frequency levels (15 and 7.5 cycles/degree), each at low and high contrast—the following results are summarized: percent of sample which meets the indicated performance level, for young-old vs. old-old drivers (Figure A-5); and mean response time for correct responses, for these age groups (Figure A-6). These data show clearly superior

contrast sensitivity performance by the study sample as a function of decreasing target resolution and increasing target contrast, as expected. The effect of age was most apparent in the performance deficits manifested by the old-old subjects, specifically for the low contrast, low resolution targets; at a high contrast level, performance deteriorated somewhat with increasing age for the high resolution targets. In terms of response time, subjects required an average of 1.5 seconds longer to respond to the low contrast, high resolution targets than to the high contrast, low resolution targets. The old-old subjects were slower to respond to all targets than the young-old subjects, with the greatest disparity in performance for the high resolution, high contrast targets.

Dynamic Contrast Sensitivity. The sample's dynamic contrast sensitivity capabilities are presented in Figures A-7 and A-8. For *each* of the *four levels* of test stimuli that were presented—two spatial frequency levels (15 and 7.5 cycles/degree), each at low and high contrast—the following results are summarized: percent of sample which meets the indicated performance level, for young-old vs. old-old drivers (Figure A-7); and mean response time for correct responses for these age groups (Figure A-8). These data show trends quite similar to the static target presentations, with the poorest performance at high spatial frequency and low contrast levels. Generally, a lower percentage of subjects in the old-old group were able to resolve the targets compared to subjects in the young-old group, and when they could, they were longer to respond.

Neck Flexibility. The sample's neck flexibility, expressed in terms of degrees rotation of the head to the left and right, is presented in Figure A-9. Slightly greater flexibility was demonstrated for a head turn to the right than for a turn to the left, and for young-old subjects compared to old-old subjects.

Angular Motion Sensitivity and Useful (Functional) Field of View. Figures A-10 and A-11 document the error rates and brake reaction times, respectively, for the study sample in response to central and peripheral visual targets representing potential threats or conflicts. As a reminder, four stimulus types were presented: (1) lead vehicles slowing with brake lights activated; (2) lead vehicles slowing without brake lights activated; (3) vehicles at 15-degree offset moving on intersecting (90°) path; and (4) pedestrian at 30-degree offset moving on intersecting (90°) path. For approximately 20 to 40 percent of the events where a brake response would have been appropriate in the *MultiCAD* driving video, subjects failed to respond. Generally, the old-old subjects failed to respond to potential threats more frequently than the young-old subjects, especially in the case of a lead vehicle braking without brake lights activated. However, young-old subjects demonstrated almost twice the error rate of the old-old subjects, when the target was a pedestrian at 30 degrees of eccentricity. Looking at response times for correct responses, there was very little difference as a function of age group. The longest latencies were shown for a lead vehicle ahead that stopped or slowed without its brake lights activated. Subjects responded close to 5 seconds after the lead vehicle began to decelerate, for this particular set of driving scenarios.

RESULTS

This section describes the data reduction and analysis procedures applied in this study, and presents results in two areas. To begin, the classification of driving errors resulting from the present study is developed, from two sources. First, specifics of the reduction and coding of behavioral errors videotaped during the test drives are explained; then, a procedure for translating DMV examiner scoresheet entries into categories and events describing each subject's errors related to intersection negotiation is detailed. The distributions of errors, so defined, are then presented according to each route type (standard/low familiarity *vs* home area/high familiarity) on which subjects were tested in this study.

To conclude this section, a weighted error score serving as a criterion variable denoting driving competency (on the standard exam route) is defined, then multiple regression and correlation analyses document the following relationships of interest in this study. Initially, the prediction of driving competency (weighted error score) by the functional measures obtained using the *MultiCAD* protocol is reported. Then, the relationship between behavioral errors coded from the videotaped observations and the weighted error score adopted as the overall measure of competency during the on-road exam is analyzed.

CLASSIFICATION OF INTERSECTION DRIVING ERRORS

A central objective of the research was to create an older driver intersection error classification. A two-level classification was conducted. First, a classification was developed from the data coded from the videotaped observations of driving performance during the on-road examinations; exhaustive review of these data identified not only behaviors thought to be associated with driving errors, but also subjects' levels of exposure to situations where such errors would be most critical. This classification thus provides a description of intersection *maneuver errors* and *errors of observation*, <u>and</u> their associated probabilities of occurrence, for both the standard and home area routes.

A second classification was developed based on supplemental data reduction from DMV scoresheets. The DMV examiners' scoresheets for the standard area exam and the home area exam, provided by CA DMV, included a standard checklist of possible errors plus a comments section. The examiners provided rich descriptions of maneuver and observation errors, in addition to marking the errors on the standard checklist. However, while such error frequency counts could be reduced from the standard checklist, they were <u>not</u> exposure-based (i.e., it is unknown to what extent errors were not scored because the opportunity was not present, when the same behavior in another situation would be recorded as an error, nor is it known how <u>many</u> times a given error occurred—only whether it was scored or not scored for each subject on each route). Therefore, it was meaningless to compare simple error counts for drivers who passed versus failed the exams, and comparisons of frequencies among the error types would not be reliable. Instead, the most useful approach in creating a classification of errors from the DMV score sheets, was to determine what proportion of drivers committed each error, for each exam route.

Together, these approaches to the analysis and summary of intersection driving errors provide a comprehensive picture of the behaviors evidenced by the present sample of older (referred) drivers. Procedures for reducing data from the videotapes and scoresheets are described below, followed by the driver error classifications.

Videotape Data Reduction Procedures

Each road test produced video data for the three views (forward traffic scene, driver's face, and the rearview traffic scene with accelerometer); participants who completed both the standard and home area exams generated six videotapes of data. However, several participants did not complete the standard route exam because the examiners terminated the test for reasons of safety; and, others who completed the standard exam were not given the opportunity to take the home area exam, because of their hazardous performance on the standard route test. Video equipment difficulties also contributed to missing data for some participants. Videotape observations were available for 62 subjects on the standard exam route and 51 subjects on the home area exam route.

Data were reduced from each videotape, and were coded and entered into an electronic (Microsoft Access) database. Specialized video equipment and software were used so that time code information could be sent directly from the video playback deck to the database. This way time code data could be recorded quickly and without the risk of keying errors. All data were initially recorded as times at which behaviors occurred. In this database, each case represented a single intersection traversed. These data were subsequently analyzed using the Statistical Package for the Social Sciences (SPSS) to generate counts of errors and opportunities for errors. In some cases, the fact that a time was recorded for a behavior signified that an error had taken place (e.g., if a time was recorded for "cuts corner when making turn," an error had occurred). In other cases, it was necessary to compare variables and use formulas to identify errors (e.g., if a driver made a lane change and there were no visual observations in the direction of the lane change within a certain time prior to beginning the lane change, an error had occurred).

Although all subjects traversed the same route during the standard exam, differing traffic situations and signal phases reduced the opportunities for errors to occur for some subjects at some intersections. In addition, some subjects did not complete the standard exam due to extremely hazardous performance, and thus had less opportunity to commit errors. Comparing error frequencies for intersection types, error types, or route type would therefore be meaningless. To normalize error frequency, a count of errors in addition to a count of opportunities to commit an error was entered into the spreadsheet for each subject at each intersection. If an error was observed from the videotape, a "1" was entered into the database for that subject, for the particular error, for a particular intersection. A "0" was entered if the opportunity to commit the error was present, but no error was committed. Using frequency of errors committed and number of opportunities that presented themselves for an error to occur, an error probability was calculated. Once errors and opportunities for errors had been determined for each intersection, a file was created which contained scores for each error type, for each subject, for each route type, aggregated across all intersections. This file was then matched with data from the other measures for analysis.

From the videotape showing the forward view camera, the following data were entered into the database:

- Intersection type/geometry.
- Type of traffic control.
- Direction of intended maneuver.
- Time driver left prior intersection.
- Time when driver changed lane prior to the left turn at the intersection.
- Time driver completed lane change.
- Time of brake light activation of vehicles slowing/stopping ahead and point when driver reaches lead vehicle.
- Minimum headway while slowing/stopping for traffic signal.
- Time when driver reaches traffic signal.
- Time of traffic signal change.
- Driver stops before, during, and through intersection (if any).
- Available gap openings and closures with crossing traffic at the intersection.
- Driver swings wide prior to making turn.
- Time driver begins crossing/merging maneuver, then stops.
- Time driver enters intersection entrance.
- Driver swings wide when making turn.
- Driver "cuts" corner when making turn.
- Driver uses incorrect lane (i.e., right or straight through lane) to cross intersection.
- Driver enters far lane (instead of near lane) when turning and stays in far lane.
- Time driver is out of intersection (turn completed).
- Driver changes lane after making turn.

From the videotape that showed the driver's face and top portion of the steering wheel, the following data were entered into the database:

- Driver makes visual checks to side view mirror to the left.
- Driver makes visual checks to side view mirror to the right.
- Driver makes visual checks to blind spot to the left.
- Driver makes visual checks to blind spot to the right.
- Driver makes visual checks to inside rearview mirror.
- Driver makes visual checks to oncoming traffic.

From the videotape that showed the rear camera view, the following data were entered into the database:

- Starting point of deceleration of driver's vehicle to intersection.
- Decelerations greater than 0.3 g.
- Accelerations greater than 0.3 g.
- Maximum lateral acceleration and magnitude of change.
- First intersecting traffic which crosses road that driver was on before making turn.
- Following vehicle reaches the point at which driver completed a lane change.

To determine the probability of occurrence of each error type, errors were aggregated across all intersections within each exam route. Table 2 presents the classification of driver maneuver errors and errors of observation as reduced from the videotaped data, and the probability of occurrence for the standard exam and the home area exam. Where the occurrence of an error is operationally defined in terms of the commission or omission of an action, within a definite timeframe or in relation to other specific actions or events, the defining conditions are noted explicitly in Table 2. Time/distance values adopted as thresholds for the scoring of errors in this formidable task were based on the understanding of relevant human factors and traffic safety design principles by the research team.

Table 2. Classification and associated probability of occurrence of intersection maneuver errors (unshaded) and errors of observation (bold and shaded), for the standard and home area exams.

Description of Error	Exam Route	
	Standard (n=62)	Home Area (n=51)
Infringes on others' right-of-way when changing lanes (lane change made with less than 2 s between vehicles)	0.90	0.57
Fails to observe behind within 5 s prior to beginning deceleration for intersection	**0.87**	**0.96**
Fails to look to the sides while in intersection	**0.75**	**0.75**
Fails to check right mirror within 5 s prior to right lane change	**0.73**	**0.77**
Fails to look to the sides during approach to intersection (within 5 s prior to entering intersection)	**0.36**	**0.44**
Fails to check right blind spot within 5 s prior to right lane change	**0.35**	**0.33**
Fails to check left mirror within 5 s prior to left lane change	**0.31**	**0.35**
Fails to check either right mirror or right blind spot	**0.30**	**0.23**
Fails to check left blind spot within 5 s prior to left lane change	**0.29**	**0.37**
When lane change is necessary to cross intersection, changes lanes too close to intersection (less than 5 s between lane change and entry into intersection)	0.19	0.12
Fails to check to the left (upstream) within 5 s prior to entering intersection when turning right from a stop or yield sign (to check for potential conflict vehicles/make gap judgments)	**0.17**	**0.15**
Fails to check to the right (downstream) within 5 s prior to entering intersection when turning right from a stop or yield sign (to look for pedestrians or a traffic queue in the intended travel path)	**0.15**	**0.09**
Deceleration greater than -.3g (abrupt or panic stop)	0.15	0.29

Table 2. Classification and associated probability of occurrence of intersection maneuver errors (unshaded) and errors of observation (bold and shaded), for the standard and home area exams (Continued).

Description of Error	Exam Route	
	Standard (n=62)	Home Area (n=51)
Rejects a safe gap (during a gap selection task, a subject arrives at an intersection and the first car to cross the subject's path is greater than 10 s away)	0.13	0.06
Lateral acceleration greater than +/- .3g during turns	0.10	0.13
Changes lanes prematurely in anticipation of left turn (crosses solid paint line to get into turn lane)	0.08	0.10
Acceleration greater than +.3g	0.08	0.13
Fails to check either left mirror or left blind spot	**0.07**	**0.10**
Enters far lane during turn	0.04	0.06
Swings wide after turning	0.02	0.03
Accepts an unsafe gap (during a gap selection task, a subject negotiates an intersection with less than 6 s between his/her intersection exit and the first car to reach the subject's path)	0.02	0.03
Cuts across lane of intersecting roadway during turn	0.01	0.01
Turns into oncoming traffic lane or median strip	0.007	0.002
Uses incorrect lane to cross intersection	0.005	---
Fails to come to complete stop at stop sign	0.004	0.001
Stops for no apparent reason	0.003	---
Hits object	0.002	0.001
Drifts into another lane on straight driving section	0.001	0.001
Backs up after stopping at an intersection	0.001	---
Swings wide before turning	0.001	0.001
Changes more than one lane at a time	0.001	---

The maneuver error with the highest probability of occurrence on both test routes was infringing on the right-of-way of other drivers when changing lanes. The probability of an unsafe lane change increased substantially on the unfamiliar route. A possible explanation for a lower incidence for the familiar route could be that the drivers, rather than the examiners, determined where they would drive. If a driver planned to turn at a particular intersection, and knew ahead of time what lane he/she should be in to execute the maneuver, the driver could change lanes as far away from the intersection, and at any particular time he/she was ready to execute the lane-change maneuver. There are many anecdotal reports of older drivers who drive in the left lane for several blocks in preparation for a left-turn maneuver at an intersection to avoid the requirement to make a lane change closer to the intersection. On the standard route, the examiner directed all maneuvers, and thus, there was more opportunity for a lane change to be executed without as much preparation time as was available for drivers on the home area route. It should be noted that the opportunity to commit this error was only present for a small number of drivers (5 to 7), but the high error rate indicated that this error occurred almost every time it was possible.

The next maneuver error listed, changing lanes too close to the intersection, occurred more often on the standard route (in 19 percent of the opportunities presented) than on the home area route (in 12 percent of the opportunities). The same factors noted in the paragraph above are possible explanations for this behavior.

Next, errors of observation, of several types, occurred with relatively equal probabilities for both route types. It should be noted that many more opportunities for these error types to occur were present and many more drivers contributed to these errors than for the lane-change maneuver error described above. Drivers almost always (87 to 96 percent of the time) failed to observe the traffic situation behind them prior to decelerating for an intersection. Drivers also frequently failed to look to the sides while in the intersection (75 percent of the time on each route). There were 883 occurrences on the home area route by 41 drivers, and 931 occurrences by 52 drivers on the standard exam route of failing to check traffic while in the intersection; since videotaped data were available for only 67 subjects (across both routes), this indicates that failure to observe to the sides while traversing an intersection is a behavior that was common for a significant majority of drivers in this study. The fact that these error types occurred with similar frequencies on both routes, given the fact that the poorest performers who committed multiple critical or hazardous errors were eliminated from the subset of drivers who took the home area test (i.e., 17 subjects failed the standard area exam and were not given the opportunity to take the home area exam), further indicates that "good" drivers and "bad" drivers alike commit these kinds of errors.

Other errors of observation centered around checking mirrors and blind spots prior to changing lanes. Drivers failed to check their right mirrors prior to changing lanes to the right approximately three-quarters of the time for both routes, but only failed to check either the right blind spot (head check) or the right mirror 20 to 30 percent of the time. Drivers were slightly more likely to check the right blind spot on the home area route than on the standard route. Conversely, drivers were less likely to check the left blind spot (head check) prior to a left lane change on the home area route than on the standard route.

Drivers were almost twice as likely to execute a hard braking maneuver on the home area route (in 29 percent of the opportunities) than on the standard route (in 15 percent of the opportunities). This may have reflected varying expectancies across the two test routes; alternatively, drivers may have been more vigilant about observing lead vehicle performance on the standard exam, after having completed the *MultiCAD* battery on the same day.

Finally, the videotaped data were aggregated across error types to explore the relationship between error rates and intersection traffic control and operations, as a function of route familiarity level. Table 3 presents the mean error rate across all observation and maneuver errors, for the standard and home area routes, by drivers' movements and type of traffic control at intersections encountered on the test routes. These results indicate that (relative) route familiarity level had little to no effect on error rates exhibited at signalized intersections, where through maneuvers accounted for the highest proportion of errors. At stop-controlled intersections, through maneuvers again accounted for the highest proportion of errors; these errors were committed in 12 to 13 percent of the opportunities, regardless of route familiarity. Left-turn and right-turn errors at stop-controlled intersections, although infrequent, were committed in different proportions as a function of route familiarity. Slightly higher percentages of errors were observed for left-turn maneuvers on the standard route compared to the home area route, but the error rate for right-turn maneuvers on the more familiar (home area) route was almost twice that on the standard, less familiar route.

At yield-controlled intersections, left-turn errors occurred equally often (in about 7 percent of the opportunities) for both route types. However, for right turns, errors occurred on the standard route at almost twice the rate of those occurring on the home area route. This may have resulted from drivers "knowing what to look for" as a result of experience in familiar areas.

At uncontrolled intersections on the standard route, errors occurred during right-turn maneuvers in approximately one-fourth of all opportunities that existed for errors to occur. In contrast, on the familiar route, right-turn errors only occurred in 9 percent of the opportunities presented. Again, it appears that when drivers know where and when to look for potential conflicts, and are cognizant of the intersection demands, they can approach and negotiate an intersection with fewer errors.

DMV Scoresheet Data Reduction Procedures

As described earlier, the DMV scoresheets list the scored maneuvers, and the types of errors that could occur. If a driver commits an error at a scored location, a mark is made on the scoresheet next to the error, but multiple errors of the same type are only tallied if the maneuver is required at multiple locations. Certain errors were elaborated upon in the "comments" section of the scoresheet. For example, "unnecessary stop" is listed as an error for the four left and right turn approaches, but in several instances, the examiners wrote "driver stopped at 'stop ahead' pavement markings." Another example would be descriptions of the "intervention by examiner" critical error, such as "driver drove straight for pedestrian crossing the road; I had to intervene."

To create a classification of driver errors, errors from each subjects's standard area exam and home area exam scoresheets were entered into a table that contained simple descriptions of the scored maneuvers by subject number and route type. If an examiner provided descriptive information about particular errors, this information was included in the table of errors. A count of the number of subjects who made each error was made, then the frequency was translated into percent of subjects who committed each error, based on the number of subjects who took each drive test. The results of this data reduction activity are

Table 3. Mean error rate* (percent) based on analysis of video observational data, across all error types and subjects, for standard (unfamiliar) and home-area (familiar) routes, by intersection control type and direction of movement.

Route Type	Intersection Control Type and Direction of Movement											
	Signalized			Stop			Yield			Uncontrolled		
	Through Mvmt.	Left-Turn Mvmt.	Right-Turn Mvmt.	Through Mvmt.	Left-Turn Mvmt.	Right-Turn Mvmt.	Through Mvmt.	Left-Turn Mvmt.	Right-Turn Mvmt.	Through Mvmt.	Left-Turn Mvmt.	Right-Turn Mvmt.
Standard	19.8	11.6	8.8	12.9	9.4	4.5	---	7.9	13.6	---	9.5	26.0
Home Area	18.9	11.4	9.6	12.4	7.6	8.3	20.0	7.4	7.5	14.3	6.9	9.2

*error rate was calculated by dividing the number of errors that occurred by the number of opportunities/situations that allowed for an error to occur.

presented in Table 4. Errors are presented in the following general categories: scanning, compliance with traffic control devices, lane use, speed control, reaction to other traffic/hazards, and use of vehicle controls and auxiliary equipment. Also, unlike the classification produced from the videotaped observations, the results presented in Table 4 include but are not limited to intersections. The errors recorded at sites other than intersections have been preserved for this presentation in the broad interest of documenting older driver difficulties and, in some cases, because of their presumed generalizability to intersection as well as non-intersection locations (e.g., "disregarded pavement markings").

It should be noted that 80 subjects took the standard exam (28 passed and 52 failed) and 61 subjects took the home area exam (25 passed and 36 failed). Two subjects who completed the *MultiCAD* test battery did not take either road test; one of these subjects was judged by the examiner to be too visually impaired to drive, and the other subject was unable to get his vehicle into safe driving condition in order to participate in road testing. Because it was hypothesized that drivers might demonstrate greater competency in familiar areas (and DMVs have the authority to restrict drivers to driving within a specific radius from home, rather than remove all driving privileges), drivers who failed the standard exam were permitted to take the home area exam, *unless* the standard exam was terminated due to extremely hazardous performance. The examiners terminated the standard exam for 17 subjects whose performance was unduly hazardous. For two additional subjects who failed the standard exam, one was unable to schedule an appointment to take the home area exam within the study period, and the other started the home area exam, but was unable to complete it because of the mountainous terrain and the lack of intersecting roadways.

Table 4. Classification of driving errors from DMV score sheets, and associated percent of sample committing each error, as a function of on-road exam route type.

Driving Error	Exam Route	
	Standard (n=80)	Home Area (n=61)
Scanning		
Failure to look left and right at through intersections (stares straight ahead)	76%	85%
Failure to check traffic on approach to turns	54%	43%
Failure to check traffic when changing lanes or merging	69%	57%
Failure to check traffic when pulling to and from curb	63%	62%
Failure to look left when turning right (to check for approaching traffic)	5%	0%
Attempted to run blind intersection without looking left or right	5%	0%
Backs up using mirror(s) only	5%	0%
Backs up with no look at all	8%	3%

Table 4. Classification of driving errors from DMV score sheets, and associated percent of sample committing each error, as a function of on-road exam route type (Continued).

Driving Error	Exam Route	
	Standard (n=80)	Home Area (n=61)
Compliance with Traffic Control Devices		
Failure to come to complete stop at stop sign	53%	57%
Stops over limit lines	45%	28%
Ran red light (went through, turned left, or u-turn)	5%	7%
Ran stop sign	6%	3%
Made illegal left or right turn	0%	3%
Wrong-way maneuver (entered parking lot in exit only driveway; turned left on left side of island)	6%	2%
Slow reactions to stop signs and red lights	1%	0%
No reaction to flashing signal at railroad crossing	0%	2%
Sat at green light waiting to make right turn	8%	2%
Sat through most of green light, waiting for green arrow (where there was no green arrow phase)	1%	0%
Disregarded pavement markings (lane lines) in parking lot	0%	2%
Stops for no reason (e.g., in middle of intersection, mid-lane on approach to turn, at stop limit on green light for right turn, at uncontrolled right turns, or before pulling over to park)	39%	26%
Stopped at "Stop Ahead" sign or pavement marking	13%	2%
Unsure of right-of-way, creating confusion	1%	3%
Lane Use		
Turns too wide or too short	46%	26%
Executes left turn from center or right lane, ignoring left-turn lane	4%	13%
Executes left turn from left side of double yellow line	5%	2%
Pulls into left turn lane late	1%	2%
Completes left turns in opposing traffic lane (on wrong side of street)	9%	7%
Drives in center left turn lane after completing left turn	0%	2%
Executes right turn from outside lane (or too far from curb)	4%	7%
Drives in shoulder, parking lane, or bike lane after completing right turns	1%	5%

Table 4. Classification of driving errors from DMV score sheets, and associated percent of sample committing each error, as a function of on-road exam route type (Continued).

Driving Error	Exam Route	
	Standard (n=80)	Home Area (n=61)
Used turn-only lane for through maneuver	0%	2%
Changes more than 1 lane at a time	1%	3%
Drives in far right of lanes (or in parking or bike lanes), confusing other drivers	10%	3%
Drives on left lane lines (on raised pavement markers)	1%	0%
Straddles lanes/drifts in and out of lanes	10%	15%
Speed Control		
Brakes before changing lanes or at other unnecessary/inappropriate time	19%	8%
Traverses intersections too fast	3%	10%
Changes lanes too quickly	1%	2%
Consistently drives too slow (e.g., 20 mi/h on 45 mi/h boulevard; 10-15 mi/h under speed limit)	24%	5%
Consistently drives too fast (5-10 mi/h over speed limit)	4%	15%
Does not coordinate accelerating and braking smoothly	1%	2%
Reaction to Other Traffic/Hazards		
Unsafe left turn gap acceptance (near collision)	22%	15%
Unsafe right turn gap acceptance (in front of approaching cross traffic); near collision	16%	8%
Slow reactions to cross traffic (several attempts to pull out were aborted)	1%	0%
Accelerated toward (or no response to) vehicle stopped ahead in same lane	0%	5%
Infringes on others right-of way when changing lanes (near miss)	8%	23%
Struck object (curb when backing, median after turning left, or object in parking lot)	18%	0%
Near miss (pedestrian or car) other than during gap acceptance	16%	20%
Follows too close	0%	2%
Unsafe passing maneuver	0%	3%
Approached road work area by going into opposing left lane instead of around on the right side	0%	2%

Table 4. Classification of driving errors from DMV score sheets, and associated percent of sample committing each error, as a function of on-road exam route type (Continued).

Driving Error	Exam Route	
	Standard (n=80)	**Home Area (n=61)**
Use of Vehicle Controls and Auxiliary Equipment		
Failure to use turn signals for turning, lane changing, or merging	65%	20%
Erratic Steering	4%	2%
Forgot car was in reverse	1%	0%
Frequently/always fails to cancel turn signal	0%	2%
Could not locate turn signals or defroster; had to try every accessory	1%	0%

As might be expected, different kinds of errors were noted at each level of the classification. With respect to the videotaped driving observations, there were times when data were not available for a particular view, either because the camera's field of view did not include a target/event of interest, or because of equipment malfunction. The human observer (examiner), however, experienced no such restrictions. Further, an understanding of subjects' behavior in context was available to the examiners that was not available during the coding of the videologs. At the same time, the videolog provided the opportunity "after the fact" to code errors on a micro level that may have gone unnoticed by examiners who were looking for gross commissions/omissions in subjects' behavior during the road test, and greater reliability in the scoring of performance could be achieved with the coded video observations than may have been possible between examiners. Also, it may be noted that objective criteria were consistently applied in the coding of all subjects' behaviors for the purpose of defining errors in this classification; e.g., a precise interval (2 s) was applied as a minimum clearance ahead of an adjacent-lane vehicle to define a "safe" maneuver when the subject changed lanes.

Examination of Table 4, reveals that *scanning errors* were committed by the largest proportion of drivers. A majority (over 75 percent) of the subjects on each test route failed to check traffic when traversing (through) intersections, but a higher percentage failed to do so on the home area route. A large proportion of subjects also failed to check traffic on the approach to intersections, but slightly more subjects failed to do so on the standard route. Failure to check traffic when changing lanes or pulling to and from the curb was recorded for approximately 60 percent of the subjects on each test route. *Compliance with traffic control devices* also was a problem for drivers on both routes. Slightly over half of the subjects who took each on-road exam failed to stop completely at stop signs. A large proportion of drivers also failed to stop behind the limit lines at intersections; a larger percentage of drivers committed this error on the standard area route than on the home area route. A greater proportion of drivers committed errors such as running a stop sign, performing a wrong-way maneuver, stopping at a green light to turn right, and stopping for no reason on the standard route than on the familiar home area route. With the exception of stopping for no reason, the differences in the percentages are relatively small. On the other hand, a larger percentage of drivers ran a red light, made an illegal turn, and did not react to a flashing railroad crossing signal on the familiar route than on the standard route; again, however, the difference in percentages is small (1 or 2 subjects).

Regarding *lane use*, approximately twice as many drivers turned too wide or too short on the standard area route than on the home area route, and more drivers on the standard route drove too close to the curb or in bike/parking lanes than on the home area route. However, a larger percentage of drivers on the home area route executed a left turn from the wrong lane, drove in the center lane after completing a turn, and executed a right turn from an outside lane.

Comparing *speed control errors*, a larger percentage of drivers on the standard route drove too slow, and a larger percentage of home area route drivers drove too fast. More drivers applied their brakes before changing lanes when driving on the standard route than when they drove on the home area route. Driving too slow and braking before changing lanes are characteristic of older drivers who, in unfamiliar locations, compensate for slower information processing capability by reducing their speeds.

Considering *errors committed when reacting to other traffic*, higher percentages of drivers made unsafe left- and right-turn gap acceptance errors when driving on the standard route than when driving on the home area route. Familiarity with the operational characteristics of intersections, and/or negative past experience in their home areas, may explain these differences. Similarly, the only incidences of striking an object occurred on the standard area drive test. However, a higher percentage of drivers on the familiar route had a near miss with another vehicle when changing lanes or with a pedestrian, than on the standard route. This could be explained by the "looked but did not see" phenomenon, where familiarity may reduce vigilance for certain tasks.

In the *use of vehicle controls* category, a much greater percentage of drivers did not use their turn signals when driving on the standard route than when they drove on the home area route. This difference could be the result of drivers planning their own course when driving in their home area, and knowing farther in advance where and when they were going to turn. Conversely, not having advance information about the route configuration—allowing anticipation of where to turn—may have contributed to an overload condition on the less familiar route, resulting in the "shedding" of turn signal activation as an unnecessary or low priority task.

CORRELATION AND REGRESSION ANALYSES

To determine the efficacy of the *MultiCAD* tests in predicting on-road driving performance, correlational analyses were performed to determine the strength of the relationship between each test and a weighted error score on the standard exam. As described earlier, the test examiners used a standard form to record when "structured maneuvers at predesignated points on the route were performed unsatisfactorily" (Janke and Hersch, 1997). Examples of structured maneuver errors are "inadequate traffic check," "poor lane position," and "turns too wide or too short." A subset of errors defined as *critical driving errors* were listed in a separate section of the DMV score sheet. These are serious errors; under normal testing circumstances (i.e., other than a research situation), a driver's test would immediately be terminated. Critical errors included: examiner intervention; driver strikes object; drives up/over curb/sidewalk; drives in oncoming traffic lane; disobeys sign/signal; dangerous maneuver; inappropriate reaction to school bus; inappropriate reaction to emergency vehicle; inappropriate speed; inappropriate auxiliary equipment use; turn from improper lane. A subset of critical errors was also defined by Janke and Hersch as *hazardous errors*, with the belief that these errors are predictive of driving impairment. These included "dangerous maneuver" and "examiner intervention."

The decision to use a weighted error score as the primary criterion (dependent) variable for these analyses, instead of a total error score, was based on the findings by Janke and Hersch (1997). A weighted error score, designated MSCORE, was calculated by adding the total number of errors on the standard exam (regardless of severity) to twice the sum of critical and hazardous errors. Since hazardous errors are a subset of critical errors, and critical errors are a subset of total errors, this scheme weighted hazardous errors by a factor of five and other critical errors by a factor of three.

Table 5 presents the simple Pearson product-moment correlations between each test in the *MultiCAD* battery and the weighted error score (MSCORE), and their probability levels. A total of 82 subjects completed the *MultiCAD* battery; of this number, 26 were cognitively impaired and 56 were cognitively unimpaired as per classification criteria of Janke and Hersch. Due to missing cells in the correlation matrix, the N's involved in these analyses ranged from 36 to 79. A correction was applied in the reported analyses. Also, the correlation matrix indicated that intercorrelations between measures ranged up to .84. Therefore, it cannot necessarily be concluded that significant relationships between isolated measures and the weighted error score criterion which follow connote functional deficits exercising separate influence on safe driving behavior.

As evidenced by the *shaded* entries in Table 5, multiple significant relationships exist between visual performance and driving competency, predominantly when visual performance is measured as *time to respond*. Response *accuracy* significantly related to MSCORE much less often. This pattern of results suggests that significant correlations between driving performance and the acuity measures are likely due to a choice-reaction time element, rather than to acuity in and of itself.

Table 5. Correlations between *MultiCAD* variables and MSCORE, with significant relationships ($p < .05$) shaded, and in bold font. (Reported by Janke and Hersch, 1997).

Measure	**r with MSCORE**	**Nominal *p***
Static acuity accuracy @ 20/40	.0855	.457
Static acuity accuracy @ 20/80	-.0799	.487

Table 5. Correlations between *MultiCAD* variables and MSCORE, with significant relationships ($p < .05$) shaded, and in bold font (Continued). (Reported by Janke and Hersch, 1997).

Measure	r with MSCORE	Nominal p
Static acuity accuracy @ 20/200	-.0048	.966
Static acuity response time @ 20/40, correct trials	**.3395**	**.004**
Static acuity response time @ 20/80, correct trials	**.4230**	**.000**
Static acuity response time @ 20/200, correct trials	.1970	.090
Dynamic acuity accuracy @ 20/40	-.1418	.219
Dynamic acuity accuracy @ 20/80	-.1211	.294
Dynamic acuity accuracy @ 20/200	**-.2283**	**.046**
Dynamic acuity response time @ 20/40, correct trials	**.3092**	**.010**
Dynamic acuity response time @ 20/80, correct trials	**.3256**	**.005**
Dynamic acuity response time @ 20/200, correct trials	**.3297**	**.004**
Static contrast sensitivity accuracy @ 20/40, high contrast	.0519	.654
Static contrast sensitivity accuracy @ 20/40, low contrast	**-.2477**	**.030**
Static contrast sensitivity accuracy @ 20/80, high contrast	-.0582	.613
Static contrast sensitivity accuracy @ 20/80, low contrast	-.1513	.189
Static contrast sensitivity response time @ 20/40, high contrast, correct trials	.1666	.181
Static contrast sensitivity response time @ 20/40, low contrast, correct trials	.1926	.240
Static contrast sensitivity response time @ 20/80, high contrast, correct trials	**.3884**	**.001**
Static contrast sensitivity response time @ 20/80, low contrast, correct trials	.0747	.561
Dynamic contrast sensitivity accuracy @ 20/40, high contrast	-.0705	.548
Dynamic contrast sensitivity accuracy @ 20/40, low contrast	.0643	.586
Dynamic contrast sensitivity accuracy @ 20/80, high contrast	**-.2575**	**.024**
Dynamic contrast sensitivity accuracy @ 20/80, low contrast	-.2030	.081
Dynamic contrast sensitivity response time @ 20/40, high contrast, correct trials	.0401	.782
Dynamic contrast sensitivity response time @ 20/40, low contrast, correct trials	-.2059	.180
Dynamic contrast sensitivity response time @ 20/80, high contrast, correct trials	**.2466**	**.049**
Dynamic contrast sensitivity response time, @ 20/80, low contrast, correct trials	-.0947	.500

Table 5. Correlations between *MultiCAD* variables and MSCORE, with significant relationships ($p < .05$) shaded, and in bold font (Continued). (Reported by Janke and Hersch, 1997).

Measure	r with MSCORE	Nominal p
Mean brake response time with visible brake lights, correct trials (12 trials)	.0861	.457
Proportion error, trials with visible brake lights	**.2801**	**.013**
Mean brake response time with no visible brake lights, correct trials (3 trials)	-.0238	.841
Proportion error, trials with no visible brake lights	.1994	.080
Mean brake response time to threats at 15 degrees, correct trials (2 trials)	.1891	.144
Proportion error, threats at 15 degrees	**.2430**	**.043**
Mean brake response time to threats at 30 degrees, correct trials (1 trial)	.1181	.429
Proportion error, threats at 30 degrees	.1675	.163

Specifically, response time for correct responses to static acuity targets at 20/40 and 20/80; to dynamic acuity targets at 20/40, 20/80, and 20/200; to high-contrast static contrast sensitivity targets at 20/80; and to high-contrast dynamic contrast sensitivity targets at 20/80 was significantly correlated to driving competency, operationalized using the weighted error score measure. As would be expected, these correlations were all positive, i.e., increasing response times were associated with higher error scores. Similarly, dynamic acuity response accuracy (using a 20/200 target) and static contrast sensitivity accuracy (using a 20/40, low contrast target) were significantly, though inversely, related to MSCORE: as response accuracy decreased driving errors increased for these isolated relationships.

A different pattern of results was demonstrated for the relationships between *MultiCAD* tests measuring perceptual capability and MSCORE. It was response accuracy—rather than response time—that best predicted on-road driving performance in these analyses (see Table 5). For the angular motion sensitivity tests, only the proportion of errors on trials where the lead vehicle brake lights were activated correlated significantly with weighted error score. On the useful (functional) field of view tasks, only the proportion of errors on trials where a threat entered from the periphery, at a 15-degree angle of eccentricity, was significantly correlated with the weighted error score criterion.

A further goal was to determine whether any of the tests measuring functional ability discriminated the cognitively impaired referral drivers from the cognitively unimpaired referral drivers. Cognitive impairment was determined in this case using information provided on the referral or medical evaluation forms. Not surprisingly, the cognitively impaired drivers exhibited a general trend of inferiority in road test performance (e.g., higher weighted error score) on the standard exam, compared to that of the cognitively unimpaired drivers. On the *MultiCAD* tests, a significantly higher mean error score was demonstrated for cognitively impaired versus cognitively unimpaired drivers responding to a lead vehicle braking, with visible brake lights. Specifically, the mean error score for the cognitively impaired drivers on this test was 0.473 (errors were made on 47 percent of the trials of this type); this was more than twice that of the cognitively unimpaired drivers, who demonstrated a mean error rate of 0.210. As per Janke and Hersch (1997) this difference, nominally significant at $p < .001$, was significant at the $p < .05$ level using a Bonferroni-type correction. As such, this measure was the strongest discriminator between cognitively impaired and cognitively unimpaired subjects in the test sample.

Four additional measures in the *MultiCAD* battery that Janke and Hersch (1997) reported as useful discriminators between these groups included: (1) brake response time for the pedestrian intersecting the driver's path at 30° in the driving video; (2) response time to the static, high contrast, low resolution (7 cycles/degree) contrast sensitivity targets; (3) accuracy of response to the dynamic, high contrast, high resolution (15 cycles/degree) contrast sensitivity targets; and (4) accuracy of response to the dynamic, high contrast, low resolution contrast sensitivity targets. The mean response time to the pedestrian target was 1.871 seconds for the cognitively impaired drivers, and 1.493 seconds for the cognitively unimpaired drivers. This difference was nominally significant ($p = 0.026$). The mean response time for correct responses to the static, high contrast, low resolution contrast sensitivity targets was 2.053 seconds for cognitively impaired drivers, and 1.666 seconds for the cognitively unimpaired drivers. This difference was nominally significant ($p = 0.051$). Regarding accuracy of response to the high contrast dynamic contrast sensitivity targets, the average score[1] for the high resolution targets was .231 for cognitively impaired drivers and .451 for cognitively unimpaired drivers (nominal $p = 0.050$); for the low resolution targets, average scores were .500 and .774 for the cognitively impaired and cognitively unimpaired drivers, respectively (nominal $p = 0.023$).

Finally, Table 6 reports the results of analyses which describe the relationship with MSCORE of the driving errors reduced from the videotapes of driving behavior recorded during the test drives, separately for errors of observation and maneuver errors. Unfortunately, finer analyses within these categories of videotaped driving errors were precluded due to missing data; a missing observation for any single behavior among the many component behaviors within an error category (see Table 2) resulted in *all* observations for that subject being excluded from entry into the multiple regression equation.

As apparent in Table 6, these relationships were quite weak. Overall, the model was not significant ($F(3,51) = 1.125$), and accounted for only six percent of the variance in these data. It must be concluded that, while all drivers in the study sample committed behaviors that could be interpreted as errors according to the objective criteria adopted for reduction/coding of these observational data, such behaviors were only rarely and not

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[1] In the Janke and Hersch analysis for measures scoring accuracy as 0 vs. 1, subjects correct on at least 2 of the 3 trials at each stimulus level were scored 1; otherwise, they were scored 0.

systematically associated with the occurrence of the critical or hazardous errors toward which the MSCORE criterion variable is strongly weighted.

Table 6. Multiple linear regression using aggregated videotaped measures to predict MSCORE (n=52).

Measure	r with MSCORE	Nominal *p*
Videotaped errors of observation	0.2392	0.672
Videotaped maneuver errors	-0.1003	0.869

GENERAL DISCUSSION

This research produced an empirically-based, exposure-corrected classification of older drivers' errors during intersection negotiation; and, measured the relationships between performance on a battery of selected functional tests and driver competency, an hypothesized surrogate for crash risk. The present findings yielded a profile of negligent driving behavior at intersections that is highly descriptive, though only weakly predictive of crash risk, while underscoring both the potential and the limitations of functional capabilities testing in driver licensing or reexamination programs.

Data described herein give evidence that route familiarity—an assumed correlate and predictor of response expectancy—and driver intention (type of planned maneuver) interact to influence the likelihood of behavioral errors, but in different ways at intersections with different types of traffic control. Across all subjects, a common pattern and strikingly similar magnitudes of errors at signalized intersections were reduced from videotape for the standard ("unfamiliar") and for the home area ("familiar") test routes: the highest error rates were noted for movements straight through the intersection—roughly double those during turning movements—and slightly lower error rates were observed when right turns versus left turns were being performed. At stop-controlled intersections, on the standard test route, the highest error rates were again noted for through movements, and those observed during left turns again exceeded those during right turns. On the home area route, however, an error rate of eight percent (rounded) was observed during left and right turns alike. These key findings were displayed earlier in Table 3 on page 36.

It deserves mention that the demand on the driver to perform rapid, directed visual search behaviors for conflicts with unexpected entries into an intersection—where peripheral target detection and processing speed in a divided attention task combine to operationally define driving competency—is greatest for through movements, less for left turning movements, and lowest for right turns.

At intersections where traffic movements were neither protected nor prohibited (i.e., traffic control was always in a permissive state), the highest error rate was observed during performance of right turns on the standard test route. And in all cases, right turn error rates exceeded left turn error rates at these intersections. The opportunity for errors during through movements did not exist on the standard test route, either for uncontrolled intersections or for those marked only with a yield indication. Such opportunities *did* exist on the home area route—where driver expectancy was presumably strongest—and error rates during through movements were higher than during turning movements, as observed at the signalized and stop-controlled locations.

These data reinforce prolific anecdotal reports that traffic control devices have increased salience for older drivers. Again with reference to the data displayed in Table 3, signalization appears to outweigh all other factors in influencing drivers' intersection negotiation behaviors. At such locations, behavioral errors—when they occur—directly reflect the information processing demands for conflict avoidance under alternative maneuver scenarios. Results at stop-controlled intersections repeated this pattern, except in one respect: the increased expectancy associated with traversal of the home area test route (versus the standard route) was associated with an upturn in visual search errors in the lowest demand situation (right turns). Where there was a complete absence of traffic control devices, the most pronounced change in behavior observed (i.e., at uncontrolled intersections) was subjects' responses to (reduced) situational demand, particularly on the standard (less familiar) test route; performance under these conditions resulted in a peak in the rate of videotaped driving errors.

Older drivers would thus appear to exhibit greater competency (and thus experience lower risk) when traversing routes where traffic signals regulate movements at intersections. This conclusion applies to familiar and unfamiliar routes. Where older drivers are exposed to nonsignalized intersections, there would appear to be some benefit to restricting driving to frequently-traveled routes; at least, the *relative* exaggeration in difficulty with left turns documented in recent crash analyses (cf. Staplin and Lyles, 1991; Council and Zegeer, 1992) may diminish, to the point where such maneuvers are no more risky than any other movement.

One inevitable conclusion from these findings is that older and cognitively impaired drivers, like *all* drivers, commit many common errors both during the stage of information acquisition and in the execution of vehicle control movements that appear to have little bearing on the likelihood of crash involvement—or rather, that the variance that can be accounted for by differences in these behaviors will always be lower than that accounted for by situational factors. For example, almost all drivers failed to look both ways before entering intersections to execute a through maneuver during the green (permissive) phase, and instead, treated their movement as one that was protected. Such "common," or *nondiscriminating* errors are therefore poor candidates for the validation of screening indices, or for identifying individuals deserving one sort of intervention or licensing action from another. Dobbs (1997) similarly has advocated the segregation of nondiscriminating from discriminating or hazardous errors in the development and application of screening instruments for driving competency.

The present interest in functional testing—specifically, upon the relationship between physical and psychophysical response capabilities measured out of context, and driving competency (driving errors and error rate)—reflects a broad consensus that, while older drivers are overrepresented for certain crash types in exposure-based analyses, it is not age *per se* that governs crash risk. As the performance distributions for sensory function, and especially for perceptual and cognitive abilities flatten and extend in range for older cohorts of drivers, the need to control exposure for the most at-risk individuals while preserving as many mobility options as possible for all seniors grows more acute. Accordingly, there have been numerous efforts to develop and validate measures of functional status as predictors of crash risk in recent years (Ball, Owsley, Sloane, Roenker, and Bruni, 1993; Brown, Greaney, Mitchel, and Lee, 1993; Gianutsos, 1994; Hennessy, 1995; Keyl, Rebok, Bylsma, Turn, Brandt, Teret, Chase, and Sterns, *in press*; Johansson, Seidman, Kristoffersson, Lundberg, Lennerstrand, Hedin, and Viitanen, 1997; NPSRI, 1991; Stutts, Stewart, and Martell, 1998; Tallman, Tuokko, and Beattie, 1993; and Temple, 1989). In this research, a battery of measures including static and dynamic vision, perceptual and (divided) attention measures, and an index of neck flexibility for head rotation were examined in relation to driving competency (errors) demonstrated during on-road testing.

Interestingly, the dimension of functionality—response accuracy versus latency—that was most predictive of driving competency in this research varied according to the domain of functional abilities being tested. For sensory (visual) ability, it was response time rather than accuracy of response that related most strongly to MSCORE; but, in the domain of attentional and perceptual skills assessment, where a maneuver or vehicle control decision (performed in the context of a simulated driving scenario) was the measure of interest, the strength of relationship with MSCORE for response correctness was superior to response latency. Other analyses of an expanded set of data collected at the Santa Teresa, CA DMV site, as reported by Janke and Hersch (1997), confirm this pattern of results. Also, McKnight and Lange (1997) found that for cognitive tasks included in their Automated Psychophysical Test (APT) higher correlations were attained for error measures than for time measures, for both elderly referral and volunteer subjects. Under actual operating conditions, a driver must perform <u>all</u> stages of processing preceding a vehicle control movement (i.e., detection/recognition, decision, response selection/initiation) successfully to avoid a crash, and slower response speed at one stage may be compensated for by greater efficiency at another stage, such that a crash is avoided. A demented driver, by contrast, can have excellent sensory function yet commit a decision error from which there is no recovery. Thus, it makes sense that the test battery measure that best discriminates between cognitively-impaired versus cognitively-unimpaired subjects would also have the strongest relationship to on-road performance, as measured in terms of "critical" or "hazardous" error criteria.

Limitations both in the reliability and feasibility of functional status measurement were also highlighted by this research. The counterintuitive finding of lower response accuracy for 20/200 acuity targets than for 20/40 targets was noted earlier; this artifact of stimulus presentation order draws attention to a broad range of potential biases from practice and learning effects in the administration of vision tests, and perhaps tests in other domains as well. Such threats to reliability must be anticipated, and test methodologies carefully designed to counter them, in any formal screening program which affects licensing decisions.

Next, the *MultiCAD* battery of functional tests administered in the Santa Teresa CA DMV facility required an average time of approximately 40 minutes per subject[2]. For a screening tool, this is excessive. Of course, the present intent was to explore relationships involving a wider set of measures than would be envisioned for adoption in any formal program—or would be administered to any single driver. Yet a practical constraint on time-per-driver for functional testing that could be limited to 30 minutes in many jurisdictions, and as little as 5-10 minutes in some[3], mandates that only those screening measures and test procedures that are highly sensitive *and* specific will be viable. Unfortunately, the present results do not permit such test selection.

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[2] *MultiCAD* was one test battery in an overall program of functional testing performed by the CA DMV which required 2-2½ hours per subject.

[3] American Association of Motor Vehicle Administrators (AAMVA) Survey of United States and Canadian Provinces, Draft Report, May, 1997.

Further questions emerging from this study concern the methodologies best suited to obtain functional status measures. There are alternative approaches to the measurement of an overlapping set of constructs, some of which rely on proprietary materials or technology and some of which are in the public domain. There is a clear need to systematically document the functional capabilities assessed by each battery, device, or program applied in published reports as a driver screening tool; identify their unique contributions as well as their shared measurement objectives and techniques; and contrast their respective strengths and weaknesses. Certainly, test reliability and predictive validity are key. Also, as a practical matter, the ability to "bundle" tests which meet these criteria—but are now administered using separate materials and/or apparatus—on a common platform offers obvious advantages for implementation in a DMV setting. And, to the extent that techniques for performing such functional assessments can utilize *in-context* measures of functional capability, with realistic test stimuli, public acceptance of their results as determinants of licensing actions is likely to be heightened.

To help realize the potential of functional screening for driving competency, and contribute to efforts now underway to update a national model for driver screening and evaluation in the U.S.[4], several additional guidelines may be suggested. With a specific focus on individuals referred to a DMV through any one of a growing network of public agencies, private caregivers, and friends and family members, and who are thus identified as posing a potentially disproportionate risk to themselves and others, a policy of first screening only for a set of "minimum qualifications requirements" in core competencies offers certain advantages. By avoiding any attempt to precisely measure functional ability level at the earliest contact with the licensing authority and instead seeking only to insure that a performance threshold is met, economies in test administration time, standardization in test procedures, and the perceived equality of all those who meet the common criterion *without regard to driver age* all become more easily achieved. Then, if a weakness in a particular area is indicated, diagnostic tests appropriate to the specific diminished capability could be prescribed—ophthalmological exams for indicators of visual pathology, neuropsychological evaluations for those suspected to suffer from dementia, and so forth.

The approach outlined above is consistent with a more general observation on efforts to employ functional screens to guide licensing actions by State agencies: there may well be a diminishing return in the attempt to refine functional status indicators to the point where "false rejections" reach a level acceptable to society. The classic study by Salthouse (1984) is instructive, which measured component behaviors of typing (e.g., interstrike interval between keys, reaction time, etc.) in an effort to correlate age and overall typing speed. Older typists showed significant declines on the component measures, but there was age equivalence in typing speed. It was demonstrated that the older subjects processed a larger string of characters in advance than younger subjects, and that this compensatory mechanism at the tactical level allowed them to maintain equivalent performance despite declining efficiency for the component processes of the task. The finding in Waldman and Avolio's (1986) meta-analysis that there was no consistent relationship between age and job performance carries a consistent message. For complex, expert, highly-practiced

[4] *cf.* U.S.DOT Contract DTNH22-96-C-05140, "Model Screening and Evaluation Program."

behaviors—such as driving—declines on component behaviors do *not* lead directly and unavoidably to degradation at a molar level of task performance. The number of times an individual failed to scan to the sides before moving straight through an intersection on a green signal (ball) was plainly unrelated to an aggregate index of driving competency as operationally defined in this research. Thus, beyond the detection of gross impairments at the sensory or cognitive level—which can often be discerned through direct observation using relatively quick and inexpensive procedures—the predictive value of (statistically-significant) differences in component functional processes when measured against "bottom line" driving performance and safety indices under actual operating conditions may continue to disappoint.

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APPENDIX A: FIGURES DEPICTING FUNCTIONAL STATUS OF STUDY SAMPLE

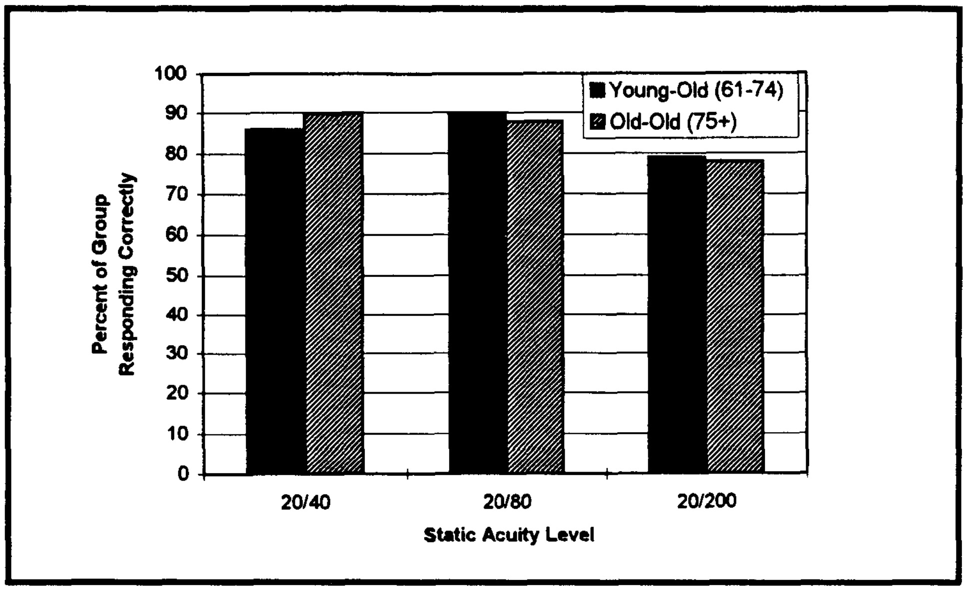

Figure A-1. Proportion of sample which meets or exceeds indicated static acuity performance level, by age group.

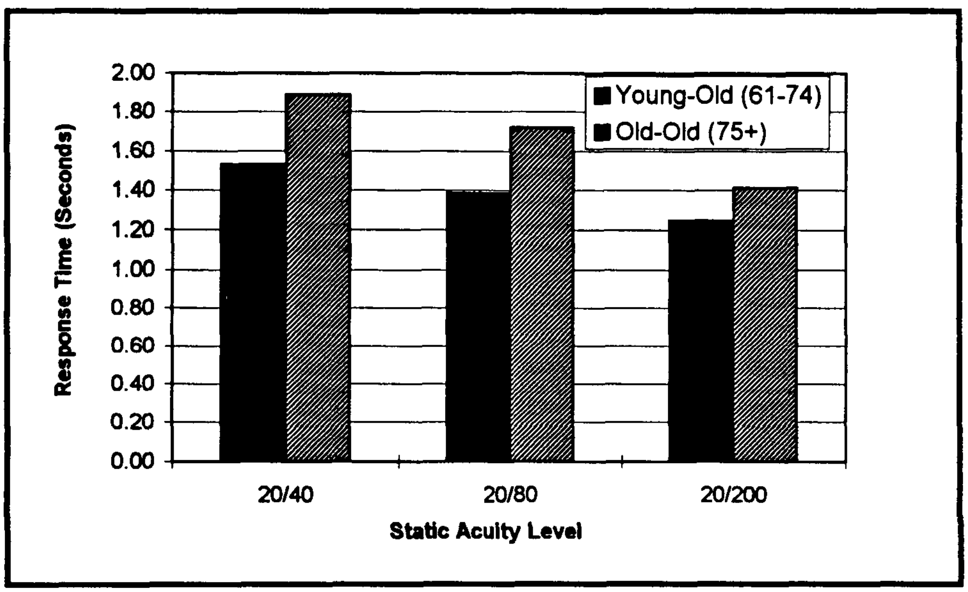

Figure A-2. Mean response time (in seconds) for correct responses to static acuity targets, by age group.

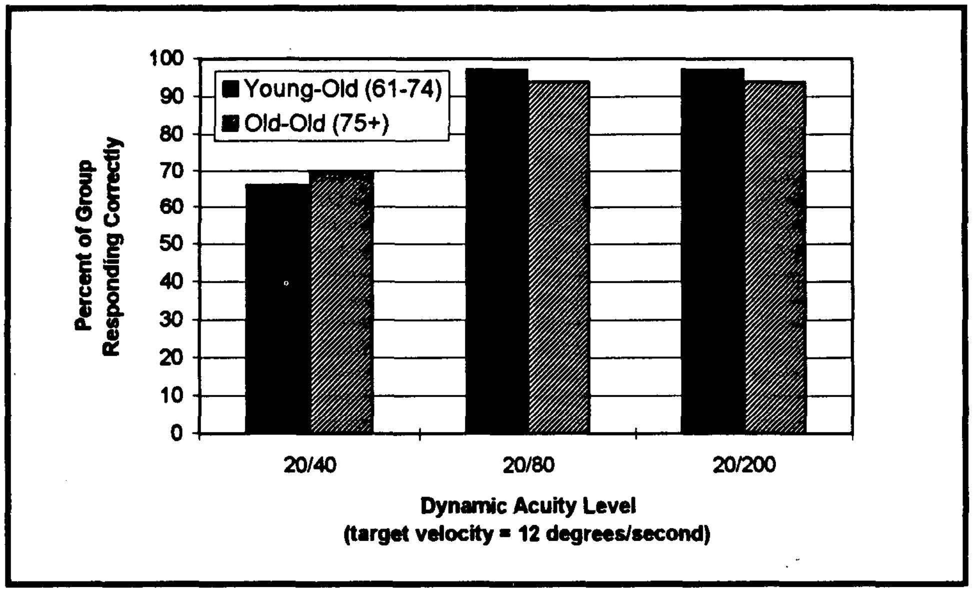

Figure A-3. Proportion of sample which meets or exceeds indicated dynamic acuity performance, by age group.

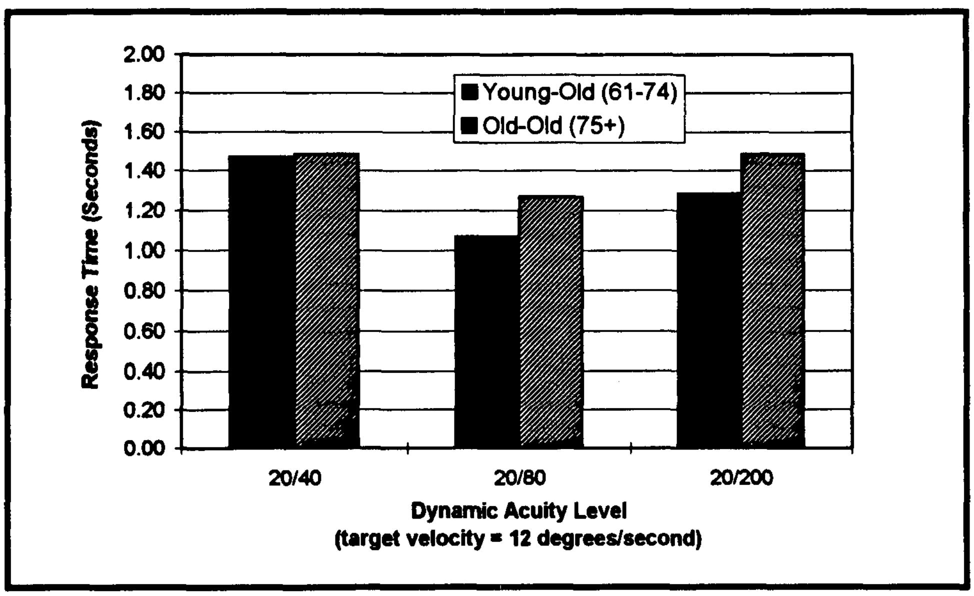

Figure A-4. Mean response time (in seconds) for correct responses to dynamic acuity targets, by age group.

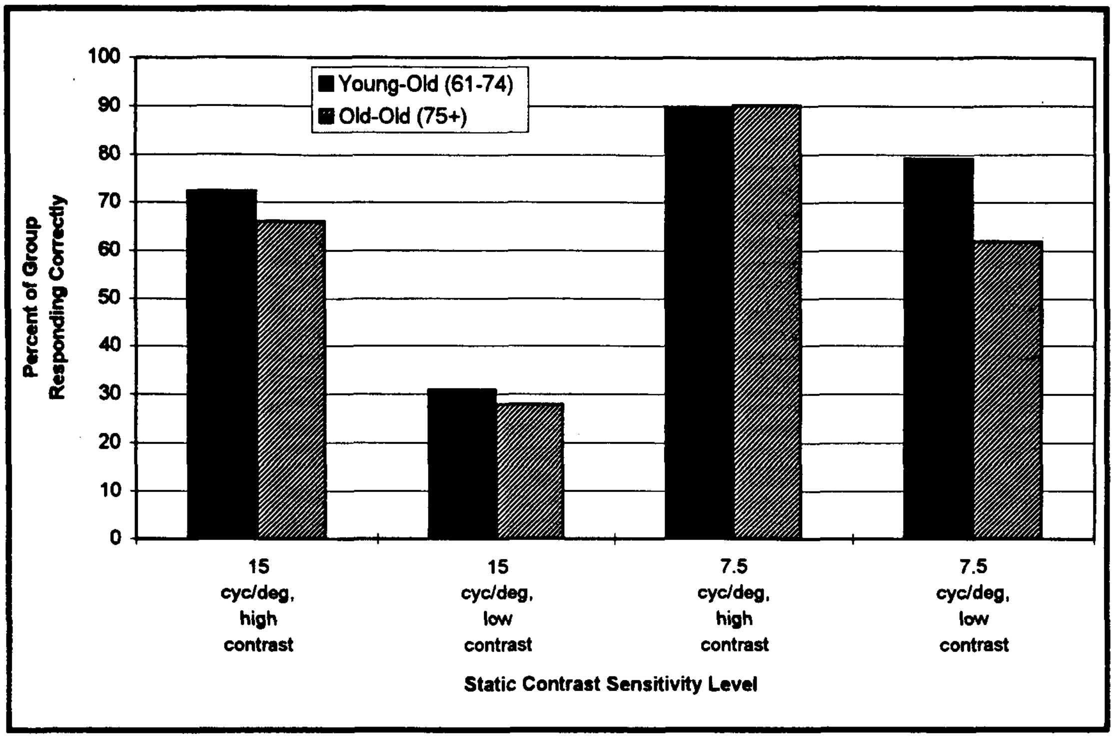

Figure A-5. Proportion of sample which meets or exceeds indicated static contrast sensitivity performance level, by age group.

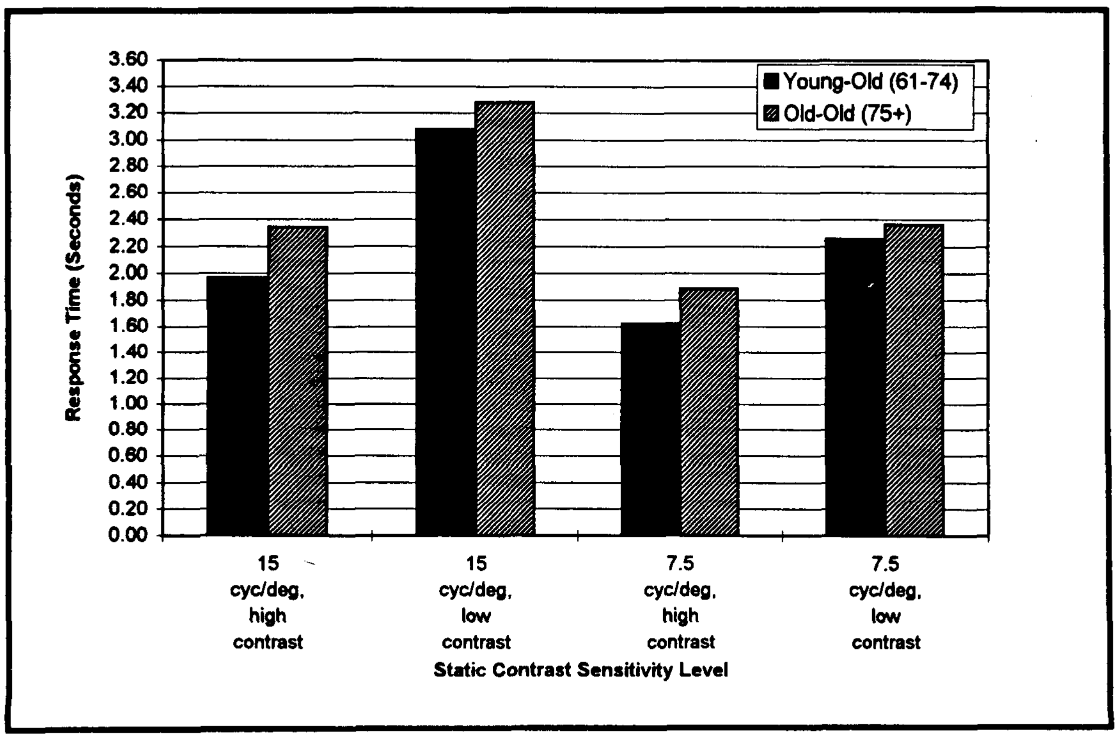

Figure A-6. Mean response time (in seconds) for correct responses to static contrast sensitivity targets, by age group.

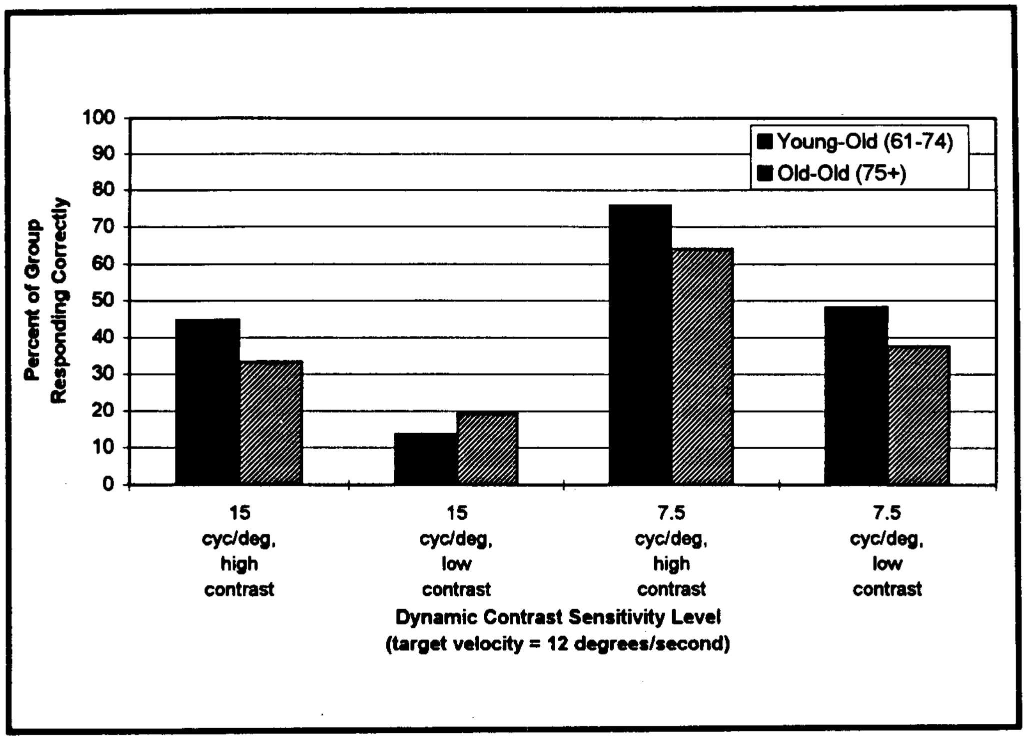

Figure A-7. Proportion of sample which meets or exceeds indicated dynamic contrast sensitivity performance level, by age group.

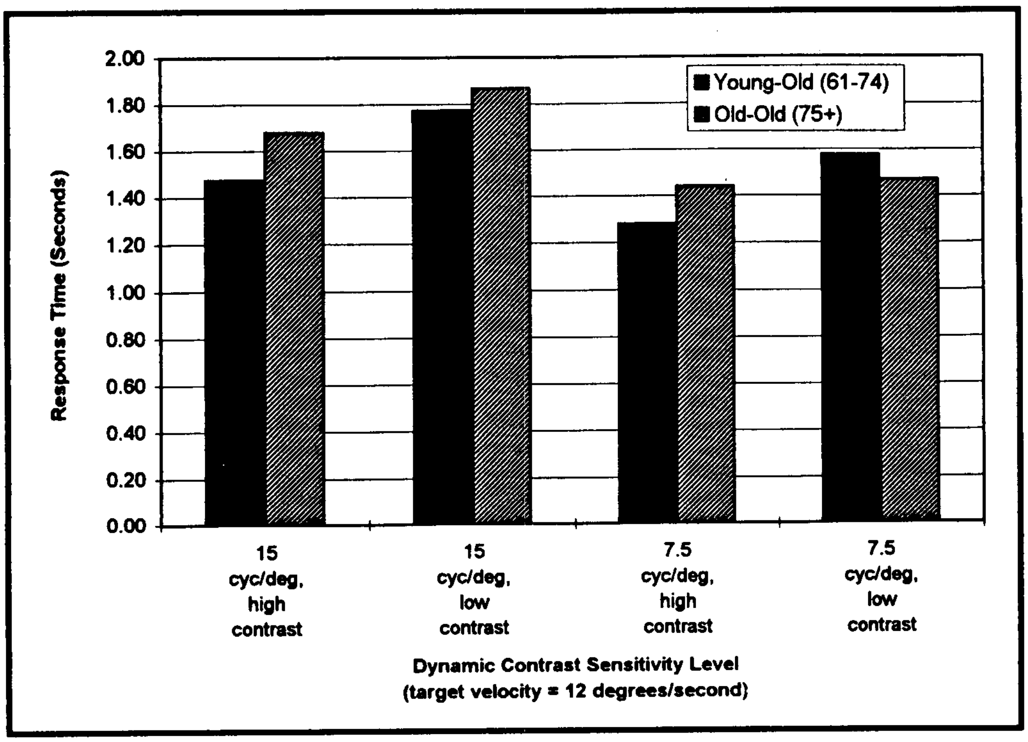

Figure A-8. Mean response time (in seconds) for correct responses to dynamic contrast sensitivity targets, by age group.

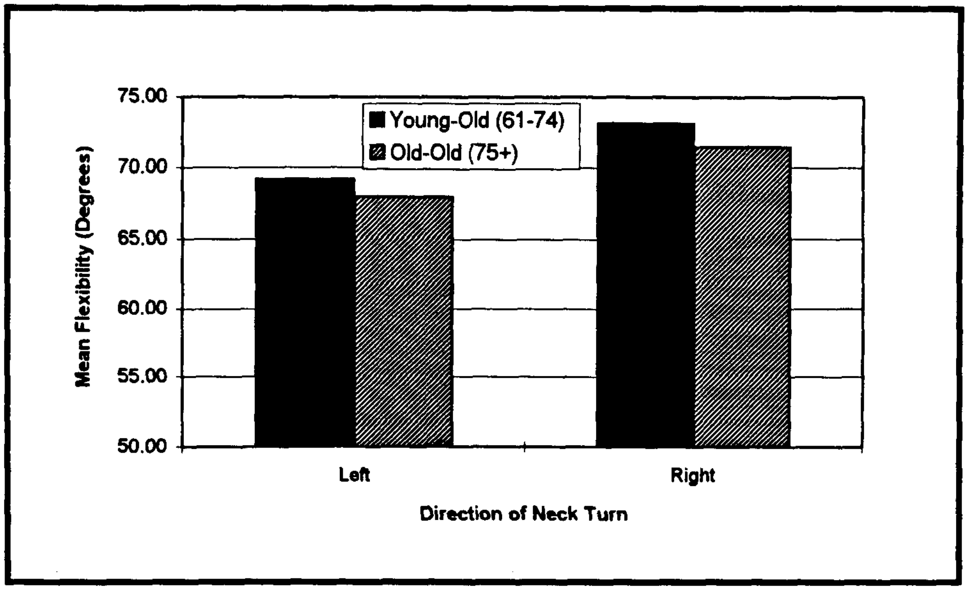

Figure A-9. Mean neck flexibility (degrees) to the left and right, by age group.

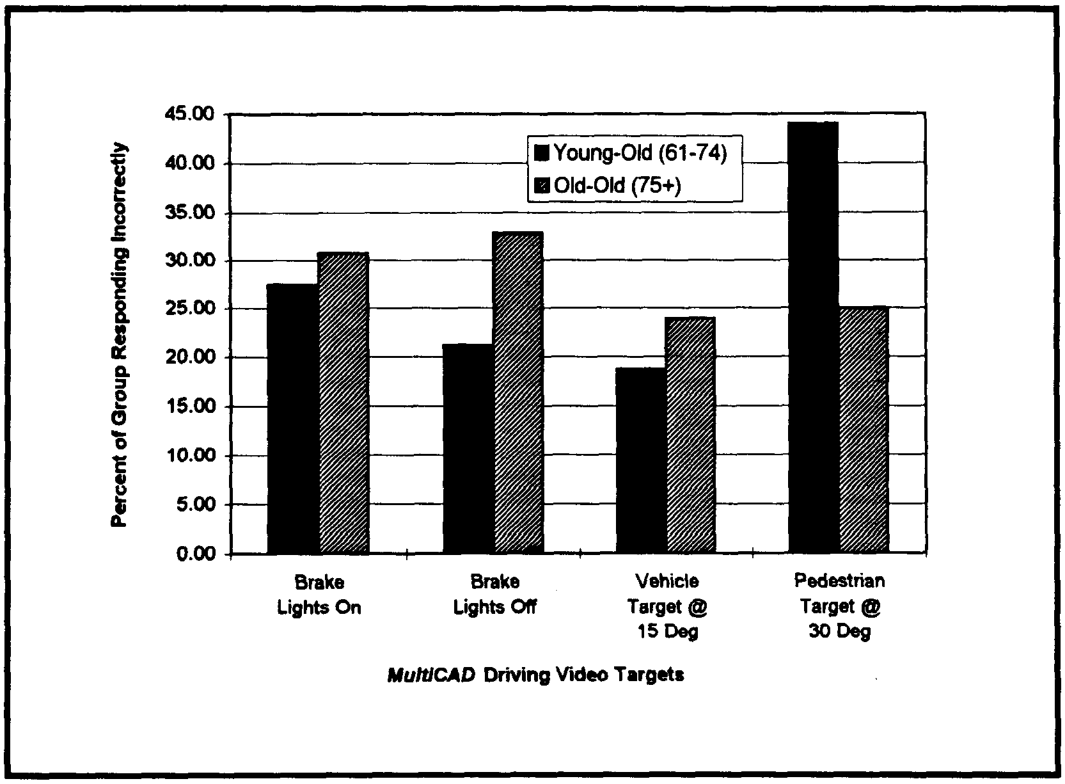

Figure A-10. Mean error rates (subjects did not brake) for a lead vehicle stopping or slowing, with and without brake lights activated, and to potential threats intersecting from the periphery at 15 and 30 degrees, by age group.

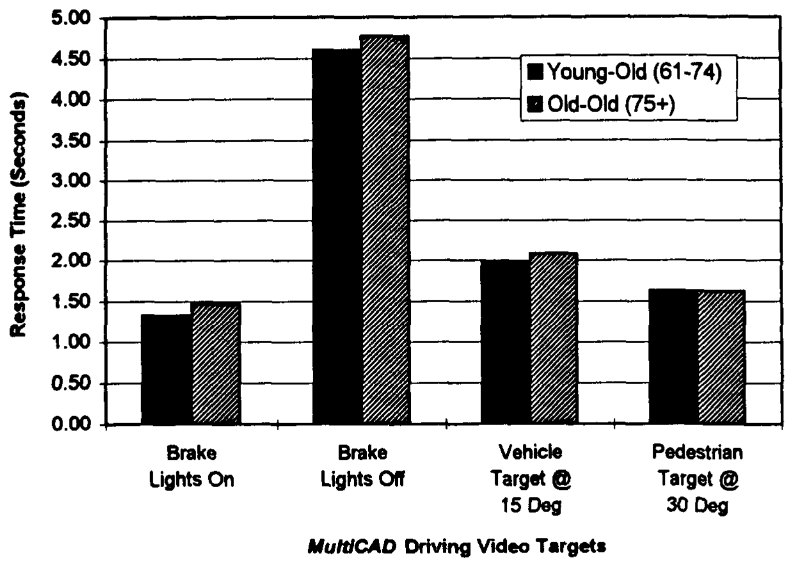

Figure A-11. Mean brake response time (in seconds) for correct responses to a lead vehicle stopping or slowing, with and without brake lights activated, and to potential threats intersecting from the periphery at 15 and 30 degrees, by age group.

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