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RELATIONS OF DRIVER UNDERSTANDING OF LEFT-TURN DISPLAY AND DRIVER AGE WITH LEFT-TURN ACCIDENTS

By

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ABSTRACT

RELATIONS OF DRIVER UNDERSTANDING OF LEFT-TURN DISPLAY AND DRIVER AGE WITH LEFT-TURN ACCIDENTS

By

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This study analyzes older driver comprehension of left-turn signal displays based on a previously conducted laboratory experiment, and accident involvement based on field data.

Laboratory data consists of responses of 191 individuals to 82 signal displays representing permitted, protected, red, change and flashing intervals. Older drivers were found to be more prone to misinterpretations than other drivers, particularly in response to complex (defined according to number, color, and type of simultaneously illuminated signal sections during a particular interval) left-turn signal indications.

The field database includes information on signal section arrangement, left-turn phase type, lead/lag phasing, cycle length, permitted and protected phase duration, number of simultaneously illuminated left-turn signal lenses, major/minor approach designation, number, horizontal and vertical signal head position, intersection type, accident type, driver age and violation, weather, and contributing circumstances. It consists of 3004 signal, 1217 geometric and 187,715 vehicle accident records.

Laboratory results are used to formulate hypotheses about which left-turn display characteristics are most likely to affect older driver safety performance in the field. Left-turn signal displays found to be less well comprehended by older drivers in the laboratory were generally found to be present at locations with high older driver left-turn

accident overinvolvement.

The induced exposure method, i.e., the ratio of the proportion of driver 1 (driver at fault) to the proportion of driver 2 (driver not at fault--innocent victim) involved in multiple vehicle accidents by age is used to provide relative accident involvement rates controlled for environmental and other factors.

Older drivers were found to be over-involved in left-turn accidents, especially during adverse weather conditions and at approaches with protected/permitted left-turn control. Left-turn signal displays were found to be better comprehended and/or be associated with fewer older driver accidents if: flashing yellow or red ball permitted indications were used instead of green ball indications; exclusive left-turn lanes were provided; left-turn signals were placed along the extension of the left-turn lane centerline instead of between the left-turn and through lanes, and, protected stacked-three instead of stacked-four displays were present.

To my parents,
my wife, and George
who taught me how
not to sleep

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CHAPTER 1

INTRODUCTION

1.1. DEFINITION OF THE TRANSPORTATION PROBLEMS FACING OLDER DRIVERS

The number of "older persons" is increasing faster than any other age group in the United States today. Likewise, the percentage of older people that drive is increasing dramatically both because of their continuing need to travel, since more older people are retiring in the suburbs where their transportation needs cannot be satisfied by public transportation or walking, and because they are living longer, healthier lives, and feel capable of driving. Moreover, certain traffic accident patterns have been associated with older drivers, such as a larger percentage of injury and fatal accidents at intersections, especially those involving vehicles turning left. The trend toward more older drivers in the coming decades makes the study of the causes of such accidents urgent, since accident numbers are expected to increase proportionately to the older driver population.

1.2. DEMOGRAPHIC PATTERNS OF OLDER DRIVERS

There is no uniform definition of the term "older driver" in the literature, and the term has been applied to drivers from 55 to those over 75. Some authors use the terms "young-old" and "old-old" in recognition of the fact that a large portion of drivers 55 to 70 years old have no serious physical limitations and go about their everyday lives the same way their younger counterparts do, while a larger portion of drivers over 70 years old experience physical limitations that may interfere with everyday activities among which is driving. The "graying of America" has been well established demographically. Moreover, since younger age cohorts are smaller in size, there will be a higher percentage of older persons in the population. Thus, the fastest growing age cohort both in absolute and relative terms is that containing older persons (80, 104, 139).

Since only a small percentage of the older population is institutionalized and taken care of with the help of special care providers, attention needs to be given to the majority of older persons that have no serious physical limitations, live healthy and active lives, and are dependent on their own means to satisfy their transportation needs (80, 104, 139).

Available data (104) show that most persons choose to retire in or near the communities where they lived and worked for most of their lives. Thus, the migration to warmer parts of the country is not expected to have significant impacts on the numbers or percentages of older persons in the majority of states. This point notwithstanding, there will still be some states that experience greater problems than others because their climate attracts some older persons from other parts of the country.

1.3. TRANSPORTATION PATTERNS OF OLDER PEOPLE

The vast majority of older persons continue to rely on the automobile for their transportation needs such as shopping, visiting doctors, worshiping, and socializing (80). More older people in the near future will need and want to use their automobile since the majority of them will live in suburbs and will, in all likelihood, continue to make inter-suburb trips much as they do today.

The 1983 National Personal Travel Survey (NPTS) data indicate that the number of daily trips and annual travel miles for ages 5-15 are 2.3 and 5,800 respectively; these numbers peak at 3.1 and 12,700 between ages 40 and 49 and decline thereafter so that for people older than 65 years of age they are 1.8 and 4,400, respectively. Despite the decline in miles driven by age, the number of drivers over 65 years of age and the average miles driven by this group have been increasing steadily (78, 139).

The next most popular mode of transportation among the elderly is walking. Given that the length of walking trips diminishes with age, the percentage of trips contained within the limits of their neighborhood increases. Provision of public transit for inter-suburb trips is typically unrealistic in terms of service and cost (139). It has also been shown that older persons avoid using public transit because they perceive it as dangerous in terms of exposure to crime and unsafe in terms of increased chances for injury as well as exposure to weather-related and contagious diseases.

Thus, provision of safer and adequate transportation for the elderly will have to be focussed on the provision of a roadway environment suited to the needs of the older driver.

1.4. TRAFFIC SAFETY ISSUES FACING OLDER PEOPLE

Given the predominance of the private auto and walking modes among older people and the steeply increasing number of older drivers, traffic safety professionals need to focus their attention on providing a safe environment for older drivers. Certain accident patterns, such as increasing accident rates, an increasing concentration of driver fatalities at intersections and changes in manner of collision associated with advancing driver age have been identified in research efforts across the country. Older driver physical and mental parameters have commonly been used as explanatory variables of accident trends leading to suggestions about a variety of safety countermeasures some of which fall within the purview of the traffic engineer and can be readily applied in the field in order to alleviate, to some extent at least, older driver safety problems. Such countermeasures may include, for example, the use of larger and/or more luminous signs and signals to alleviate problems with visual acuity, or provision of longer sight distances to allow for longer decision-making time.

Within the intersection environment, older drivers tend to be overrepresented in accidents when attempting a turn, especially a left-turn. From a traffic engineer's point of view, addressing this accident category is desirable for at least two reasons: i) the high concentration of traffic conflicts and serious accidents at intersections provides an ideal opportunity to benefit more drivers with safety countermeasures applied within the limited confines of the intersection; and ii) information on the safety ramifications of certain

left-turn control attributes (such as leading or lagging protected phasing, use and duration of all-red intervals, particular signal lens arrangements, and signal head positioning) is either lacking or based on younger driver observations. Thus, the engineer is currently left without well-documented guidance for making choices associated with left-turn phasing, especially where older driver safety is an important concern.

1.5. SCOPE OF PRESENT RESEARCH

Given the severity of left-turn accidents (particularly for older drivers) and the variety of left-turn signal displays currently in use, it is unfortunate that relatively limited work has been done on relations between driver comprehension of different left-turn signal faces, left-turn accidents, and driver age. The present effort addresses this void in the current literature in an attempt to bring a better understanding of the causes of older driver overinvolvement in left-turn intersection accidents. In terms of number of variables examined and extent of the time period covered, this research is unique and addressed the need of providing definitive guidance for the traffic engineer in terms of the proper application of a wide spectrum of left-turn signal configurations for the purpose of better accommodating the older driver.

The first stage of the research consists of an extensive literature review of efforts attempting to shed light on the causes of older driver accident involvement. Subsequently, the results of a laboratory experiment designed to measure older driver comprehension of left-turn displays are analyzed based on information gathered during the literature search. Hypotheses are formulated about which left-turn display characteristics emerge as most likely to affect older driver comprehension. The final stage of the research involves testing these hypotheses with field data. The extensive field data include accident, signal/sign configuration, and geometric variables that are compatible to a considerable extent with the laboratory variables. Thus, testing hypotheses based on laboratory variables can be readily accomplished using field data. Based on the results of the hypothesis testing, recommendations are made about left-turn signal attributes that are found to be beneficial/detrimental to older drivers.

CHAPTER 2

LITERATURE REVIEW

2.1. INTRODUCTION

A considerable volume of research has been dedicated to older driver safety issues (5, 20-22, 33, 41, 60, 100, 103, 144, 149). One of the most crucial issues identified so far has been the higher concentration of older driver serious accidents within the intersection environment. The nature of such collisions needs to be examined as a first step in determining their underlying causes. While accident information can be used to identify any patterns associated with older drivers, the investigation into the causes must rely on resources such as information about older driver driving behavior, driver-perceived difficulties with the driving task, driver preferences in seeking a safer driving environment, and driver examination scores.

Thus, citations issued to drivers involved in accidents can provide helpful leads into why drivers get involved in an accident; driver ranking of the most serious problems faced in the field can be used to help the engineer alleviate identified problems to the extent possible; driver preferences can be kept in mind when designing intersections; and driver examination scores may be used to assess relationships between driver comprehension of traffic situations and probability to be involved in an accident. In addition, commonly held beliefs about the contribution of older driver physical and mental limitations to accident experience need to be addressed and assessed based on the most current information available.

A crucial element in correctly assessing the extent of the older driver safety problem is the use of an accident exposure measure that will compensate for peculiarities of older driver travel behavior such as avoidance of peak hour driving, avoidance of bad weather, and nighttime driving.

2.2. OLDER DRIVER ACCIDENT CHARACTERISTICS

Some uncertainties that surfaced through research into older driver accident involvement remain to be resolved: although the majority of accidents involving older drivers has been found to follow patterns identical to those of other drivers, particular trends emerge for older driver accidents that, despite concerning a minority of accidents, become a major source of concern because they are associated with a higher severity; yet, for another minority of accidents, researchers disagree on whether differences exist between driver ages.

Indeed, the majority of accidents caused by older drivers are on dry roads (73) (71), during weekdays, in clear weather, on straight and level roadways, and more likely to involve local residents (71). Most injury and fatal accidents occur at non-intersection locations (139, 155). Some disagreement exists among researchers about whether significant differences are present between daytime and nighttime older driver intersection accident involvement: three studies report a higher involvement in daytime accidents (71, 86, 134) while a Michigan study (73) found no differences between daytime and nighttime accidents.

Many researchers however, agree on a variety of findings (based on a minority of accidents) that, taken together define what may be construed as an older driver "accident profile" which sets older drivers apart from other driver age groups. There is wide agreement, for example, on the finding of increasing involvement in multi-vehicle accidents with increasing driver age (4, 52, 71, 85, 86, 145). Consistent with these studies is the finding that older drivers are less likely to be involved in single-vehicle rollover accidents (134).

Perhaps the most important accident pattern related to older drivers is an increase in fatal accident rates with increasing driver age. A Wisconsin DOT publication (153) identified drivers over 75 years of age as the second highest ranking driver group (after young drivers) in fatalities with 4.0 fatal accidents per hundred million vehicle miles traveled. Verification and explanation of this pattern should be given a high priority given the dramatic increase in the number of older drivers expected in the next few decades and the need to come up with appropriate countermeasures.

In the urban fringe environment where most older drivers currently live and are expected to continue to live in the coming decades, drivers over age 64 were found to have a higher involvement in intersection than mid-block accidents (4, 73) while the highest concentrations of older driver intersection accidents were found to be at high-volume intersections controlled by traffic signals or stop signs (77). Not only were older drivers found to have a higher propensity than other drivers for intersection accidents, a number of studies found a higher involvement in injury and fatal accidents in intersections. A disproportionate concentration of older driver injury and fatal accidents at intersections has also been noted for 1985 nationwide statistics (table 2.1.). While 36.7% of older driver fatalities and 59.8% of the injuries occur at intersections, other age groups have only about 17% of their fatalities and 44-48% of their injuries at intersections (155).

Table 2.1. U.S. Driver Intersection Accidents, 1985

Age	% of Age Group	
	Injury	Fatal
15-25	44.0	16.4
26-64	48.2	17.7
64+	59.8	36.7

Source: (139 Vol. 2, p 201)

The intersection problems of older drivers are also supported by the findings of large sample studies in Michigan (73) and Virginia (4) which used three years of state-wide accident data: drivers over age 60 were found to be highly overinvolved in fatal, and slightly overinvolved in injury, accidents in intersections.

There have been a variety of attempts to explain the

disproportionate concentration of older driver fatal and injury accidents at intersections. Evans, for example, claims that the pattern could simply be attributed to increased older driver frailty, claiming that an impact of similar severity will cause a more severe injury to an older driver than a younger one due to bone frailty and a lower ability to recover from injuries. This argument is further supported by findings that the proportion of intersection fatal accidents climbs to more than 50% for drivers over 80 years-old drivers (52), and that the probability of surviving a vehicle crash is reduced significantly after age 70 and is reduced again after age 80 (86). In summary, according to this line of thinking, the higher concentration of older driver intersection fatalities may simply be a consequence of increased frailty with age.

A closer examination of intersection accidents reveals that other aspects of the older driver "accident profile" may offer an alternative explanation (at least in part) for the observed serious accident pattern: changes in the manner of collision as drivers age show that older drivers are more likely to be involved in accident types that are associated with higher injury severity regardless of driver age. While the majority of intersection accidents involve vehicles moving straight, there is a shift toward turning vehicle involvement with increasing driver age that is statistically significant when drivers over age 65 are compared to those 50-64 years old in the urban intersection environment (4). A Nebraska study supported a similar finding, but identified statistically significant differences in left-turn accident involvement only between drivers over 75 years of age and mid-aged drivers. Although not statistically significant, the percent of crashes caused by a driver turning left was found to be substantially higher for drivers over age 65 (25%) than for all drivers (about 12%) (150). The same study found that left-turning driver accident involvement increased by 35% (from 17.09% to 23.13%) for older drivers. Similar conclusions are supported by a study by Garber et al.(4).

The observations regarding the shift from intersection accidents involving vehicles moving straight to those involving turning vehicles with increasing driver age are similar to findings reported by others. Garber et al. (4) and McKelvey et al.(73) document older driver underinvolvement in rear-end intersection accidents (involving, for the most part, vehicles moving straight), and a statistically significant higher involvement in head-on collisions with a left-turning vehicle. The latter account for 20% of older driver fatalities according to the former study. Both of these efforts identified a statistically significant older driver overinvolvement in angle accidents; they were responsible for 27% of older driver fatal signalized intersection accidents (73).

It is reasonable to expect that older driver overinvolvement in turning, head-on, and angle accidents (that are associated with higher injury severity than rear-end collisions for all driver ages), will be accompanied by a correlated increase in older driver injury severity, regardless of any synergistic frailty effect.

In addition to the already discussed aspects of the older driver accident profile that may be related to the observed increase in accident severity, other accident characteristics that have emerged from research efforts include the finding that older drivers are involved in a higher proportion of backing and parking accidents (71, 73) and that accidents involving a driver turning right increase by approximately 40% (from 5.35% for mid-aged drivers to 7.47% for older drivers) with increasing driver age (150). Older drivers were also found to be overinvolved in sideswipe-same-direction intersection accidents (4, 73).

Analyses of citations issued to drivers involved in accidents reveal an emerging older driver "citation profile" that enhances the overall older driver profile. Older drivers tend to be found at fault by the officer at the scene of an accident more often than other drivers but are less likely than their younger counterparts to be cited for speeding, driving while intoxicated, and following too closely when

involved in signalized intersection accidents (134). By contrast, older drivers are disproportionately more likely to be cited for failure to yield the right of way and illegal turns--particularly in head-on and right-angle intersection accidents (4, 71, 73, 90, 115, 153). Finally, illness, fatigue, glare, and inattention are also commonly cited contributing circumstances in accidents involving older drivers (75).

Since head-on and right-angle collisions are, as previously stated, responsible for a large portion of serious intersection accidents involving older drivers, many efforts attempting to explain the older driver accident profile have naturally focused on older driver characteristics that may underlie their tendency to be cited for failure to yield the right of way and undertake illegal turns in such situations. In this vein, a considerable body of information about the decline of physical and mental capabilities with age has been used in attempts to explain the unusually high occurrences of certain accident types, citations, and contributing circumstances found for older driver involved accidents. A detailed presentation of such endeavors is undertaken in the next section.

2.3. DRIVER PHYSICAL LIMITATIONS RELATED TO ACCIDENTS

Since the highest proportion of drivers with diminished capabilities is found in the oldest age cohort, accident analyses attempting to explain older driver accident patterns have often used driver age as a surrogate for diminished driver capabilities. A significant number of accident studies have attempted to statistically link physical condition parameters that are more likely to deteriorate with age. These include characteristics such as ocular (92) and auditory fitness, increased perception-reaction time (i.e., the time that lapses from the first visibility of an event to the initiation of an appropriate response), increased decision-making time, a higher tendency towards confusion, inattention, and forgetfulness. Attempts have been made to relate such characteristics to accident proneness measured in driving violations, number of accidents, accidents excluding those caused by nonvisual

factors, and daytime and nighttime accidents--unfortunately causative relationships have not been empirically validated.

Although there is consensus among researchers about the fact that older drivers run a higher risk of being involved in accidents, there are some fundamental questions about assumptions underlying efforts to link physical condition parameters with safety measures of effectiveness. Some of these were summarized by Lerner (65) and are discussed in the following paragraphs.

2.3.1. PHYSICAL CONDITION RELATED TO AGE

The assumption that physical condition parameters deteriorate uniformly among all individuals with age is only partially true, since many researchers have found that there is higher variability in physical condition parameters among older than younger subjects (107, 152). For example, certain ocular parameters as well as reaction times of physically active older subjects were found to be better than those less physically active (131). In addition, frequent drivers among older subjects were found to have better reaction times (109); exercise therapy was found to improve cognitive performance and retrieval activity (133); and perceptual therapy was found to improve visual scanning, spatial perception, visual discrimination, and figure-ground perception abilities (71). A number of research efforts point to an overall decline in physical performance parameters, such as:

1. A decline in information processing ability starting in the mid-40s (14);
2. A decline in dual task performance after age 60 (102);
3. A doubling of the time needed for a task involving extensive peripheral search (83);
4. Two seconds longer to determine what to do when crossing an intersection (40);
5. Two seconds longer to decide on left-turn safety (51);
6. An accelerated loss of peripheral vision after age 50 (23); and,
7. A decrease in dynamic acuity (older persons are not able to accurately track objects moving slowly across their visual field at angular velocities equal to, or greater than 10 degrees per second).

However, other researchers recognize that individuals "age" at different rates (112, 152). Wide differences in physical abilities among older individuals prompt researchers to loosely define relationships of driver age to physical abilities. Willis (152) states that "most individuals will show some decline in physical abilities by age 80," and that accumulated skills are offset by physiological and cognitive changes that accompany aging by age 75 (139). Nonuniform loss of physical ability with age has been the motivation behind efforts on the definition of a "functional age" (14, 16, 56), that is, a measure of overall individual performance based on basic skills performance.

In conclusion, it should be stressed that, although researchers resort to using definitive "older" driver age limits for practical purposes, these limits do not represent "turning points" after which driver abilities can be assumed to decline sharply. Nonetheless, the use of "artificially" defined age groups is valid in view of the fact that, despite the wide variability in older driver abilities, there is no disagreement about a general ability decline with age, on average, and that persons having diminished capabilities are, in fact, more prevalent in older age cohorts. Comparisons between driver age groups, especially if such groups have wide boundaries to account for the large variability within the older driver population, are still meaningful in examining age effects on driver ability.

2.3.2. PHYSICAL CONDITION RELATED TO ACCIDENTS

Although lower than average physical condition parameters typically associated with older drivers, such as increased perception-reaction times, may have some impact on accident experience, studies have shown that for the most part such relations are quite weak. Older drivers may compensate to a large extent for the most common problems associated with aging such as reduced night vision and increased perception-reaction times by avoiding situations that are more demanding on those physical parameters where they feel deficient (24, 99). For example, they often avoid driving at night (in order to compensate for nighttime vision deficiencies) and drive slower (in order to compensate for increased perception-reaction time). As an indication of older drivers successfully compensating for reduced physical abilities, accidents that would be expected to be related to increased perception-reaction times such as rear-end or fixed object accidents are not prevalent among older drivers. Also older drivers have reduced involvement to nighttime compared to daytime interstate accidents (73), presumably because they limit their nighttime freeway travel. Thus, only older drivers with better than average physical fitness driver when conditions are more physically demanding.

The "self-control" mechanism described above explains some counterintuitive findings, such as the lower involvement of older drivers in rear-end and nighttime accidents. However, it falls short in explaining why overall accident rates increase with driver age. A logical explanation for this apparent discrepancy between theoretical expectations of lower overall accident rates (if older drivers are indeed capable of self-control) and the observed increase in accident rates can be that older drivers may not be aware of limitations in certain areas of their abilities.

For example, older driver overrepresentation in intersection head-on collisions while turning left (responsible for a large portion of severe driver injuries) has been attributed to diminished ability to judge time to collision and oncoming vehicle speed, and diminished depth perception. It can be theorized that drivers may be less aware of decreasing abilities in these areas, while they are more aware of their nighttime visibility and perception-reaction time limitations.

Regardless of the causes for older driver underinvolvement in certain accident categories, benefit/cost oriented research should focus on analyzing the most serious accidents (associated with higher costs) and revealing their causes. The theory of older driver self-control (if proven to be true) further supports a concentrated effort on the analysis of serious accidents. Moreover, the next generation of older drivers, given their longer and more intense relationship with the private auto mode and where they are likely to be living (the urban fringe area), may be far less likely to exercise such self control.

2.3.3. RELATIONSHIP BETWEEN LABORATORY AND FIELD MEASUREMENTS

The assumption that laboratory experiments designed to measure older driver performance are directly applicable to roadway situations may not always be true. Laboratory experiments often test a single (or at best a few) variable(s) at a time, while the driving task involves a constant flow of decision-making based on a large variety of interacting variables. Contrary to expectations, while laboratory experiments designed to measure perceptual and cognitive parameters indicate increased reaction times for older subjects, field tests show no significant differences between younger and older drivers (49, 61, 87). The exact compensatory mechanism used in the field is not clear (66).

Those that attempt to explain laboratory and field test discrepancies point out older driver compensatory mechanisms such as anticipatory behavior, preprocessing information, driving slower, and the possibility of limiting the number of monitored information sources by, for example, allowing for more fixations on the vehicle ahead, not checking gauges as often. In addition, problems with the definition and measurement of a "stimulus" and a "response" as well as the large variability in response time complicate field measurements and might result in masking the real differences between young and old drivers in field observations (64). Incompatibility of laboratory test results and actual field measurements may also be due to measurements of laboratory variables that cannot be directly translated into measurements of field variables. For example, visual search time needed to identify particular patterns among a variety of shapes in a laboratory environment cannot necessarily be directly translated into visual search time needed in the field in order to identify a traffic signal, since there are a number of visual cues that a driver can use to identify the position of a signal in the field, such as the position of signals in previous intersections and the behavior of other drivers.

The counterintuitive results mentioned above may also be partially

explained by the process of "self selection" of subjects involved in road tests. Perhaps those among older drivers that feel most fit for the driving task are more likely to participate in road tests compared to more infirm older individuals, while younger subjects may not be as hesitant to participate. Such a bias would naturally result in the diminished differences observed in the field among age groups.

2.3.4. PREVIOUS RESEARCH ON DRIVER PHYSICAL LIMITATIONS RELATED TO ACCIDENTS

In view of the shortcomings regarding the links between laboratory tests of driver physical fitness and driver safety measures such as accident experience and number of violations, it is easy to understand why a number of studies have failed to establish any statistically significant relations (20, 21, 22, 37, 84, 135) even in large sample studies (45, 48, 120). However, certain physical parameters such as low light recognition threshold, glare recovery, and horizontal extent of visual field tend to be marginally related to accident experience. Some positive relations have been identified between dynamic visual acuity and visual field with accident involvement and driver rate of convictions (28, 44, 47, 55, 119).

Stronger yet relationships have been shown to exist between particular accident types, mental demands placed on the driver, and/or exacerbated driver physical limitations. Studies supporting such findings are presented in the following paragraphs.

Older driver propensity for accident involvement was found to increase with increasing complexity of the driving task, for example, where they have to adjust to other drivers' behavior as is the case in merging, emerging from minor streets, and turning left at intersections (74, 77, 126). In addition, multi-vehicle accidents on freeways (where less interaction with other drivers is necessary) present less of a risk to older drivers than accidents on non-limited access highways. By contrast, younger drivers are overinvolved in freeway accidents and underinvolved in non-limited access roadway accidents (76). Freeway

interchanges are a higher risk to older drivers than non-interchange freeway accidents, presumably because driving on freeway non-interchange sections is less demanding on quick decision-making abilities while interchange driving involves interactions with other drivers and is more demanding on the mental abilities of the driver.

Extent of useful field of view (i.e., the visual field extent needed for a specific visual task) and mental status test scores were found to have a statistically significant relationships to accidents in a 57-subject study with an average age of 70 years. The subject's useful field of view was found to be reduced when a secondary central task is added (12, 62), when a target is embedded in distractors, when similarity between target and distractor is increased, and, finally, when stimulus duration is decreased. The impact of these factors was found to be much greater for older adults than for other driver ages (13, 114, 115).

A model incorporating extent of useful field of view and mental status score explained up to 40% of the variance in total and intersection accidents and driver multiple accident involvement for experiment subjects. Older drivers with restricted useful field of view and poor mental status test scores had three times more accidents than those without these problems. Subjects with restricted useful field of view had 15 times more intersection accidents than those with normal useful field of view (90, 115). These findings were theorized to be due to any combination of the following: a reduced speed of visual information processing, inability to ignore distractors, and, finally, inability to divide attention (13).

Older drivers with unusually highly restricted physical capabilities are more likely to be involved in accidents and/or commit more moving violations. For example, individuals with less than 20/50 binocular visual acuity and below normal specific contrast sensitivity were found to have a higher total and nighttime accident rate per million miles driven (54, 55). Furthermore, a study on 117 impaired drivers 55-88

years of age found statistically significant relations between accident involvement, on-road driving test scores, depth perception, peripheral vision, reaction time, figure-ground perception, and visual discrimination (71). In a 1983 study of ten thousand drivers, those with severe visual field loss in both eyes had accident and traffic violation conviction rates (an indication of accident involvement potential) twice those of the general population (55).

In conclusion, increased older driver accident involvement is more readily explainable for drivers with severely restricted physical abilities while minor physical ability limitations do not seem to be linked to accident experience, at least to a detectable degree. In addition, older drivers are disproportionately represented in accident types associated with driving situations placing a heavier demand on driver mental functions such as merging, emerging from minor streets, and turning left at intersections.

2.4. DESIGN STANDARDS APPLICABILITY TO OLDER DRIVERS

In view of the link between accident proneness of the older driver and his/her diminished physical capabilities, it has been pointed out that some standards currently used in highway design, such as assumptions for gap acceptance, reaction times, and signal/sign legibility and complexity may adversely affect older drivers (124, 140).

Reviews of the technical basis for a wide variety of standards and recommendations in the ***Manual of Uniform Traffic Control Devices*** (MUTCD) identified many standards that had no empirical basis or were based on empirical data from younger drivers (66, 117). Concerns about the applicability of highway design and operational standards to older drivers were also expressed in a study by McGee et al. (72).

2.4.1. PERCEPTION-REACTION TIME

Existing design standards for perception-reaction times required for stopping in response to a traffic signal and turning left through opposing traffic were calculated (71) (table 2.2.) based both on sequential (upper value) and parallel (lower value) information

processing models using data from the literature on older drivers.

Table 2.2. Perception reaction times in seconds

Maneuver	Design value	Older Drivers
Stop in response to traffic sign	1.0 (106)	1.0 - 2.1
Turn through opposing traffic	2.8 (101)	1.9 3.8

The somewhat slower older driver perception-reaction times reported in table 2.2. do not necessarily mean that those drivers are not adequately provided for by current design values, since various assumptions built in the current standards allow for some redundancy. For example, braking distance assumptions incorporate conservative friction coefficient (travelling at the design speed-wet pavement) and deceleration rate values (less than that necessary to lock the wheels) that allow for some safety margin. Thus, even if older drivers take a longer time to react, they may still be provided with adequate distance to stop safely (64) considering that they are more likely to be driving slower than the design speed and avoiding adverse weather conditions. However, the longer reaction times required by older drivers while turning left through opposing traffic (assuming that the sequential information processing model is applicable) may place them in serious jeopardy, especially when the synergistic effect of depth perception deficiency is taken into account: older drivers turning left may not only incorrectly assess the distance to and speed of an oncoming through vehicle, they may also be slow to decide on the appropriate maneuver required to safely complete the turn or avoid an imminent collision.

2.4.2. TRAFFIC SIGN/SIGNAL DESIGN STANDARDS

Traffic signs are often used to supplement left-turn signal displays by providing information not immediately evident to the driver by mere signal placement and appearance, such as the meaning of certain signal intervals, the traffic movement a signal head is addressed to, or lane assignment. Supplemental left-turn signs, to be effective, need to: i) be easily identifiable; ii) be placed in a manner that allows enough

time for driver response; iii) convey a concise message; and, finally, v) not overburden the driver with information. It is in this context that signal legibility distance is examined: longer legibility distances (i.e., earlier sign detection) allow drivers to perform the necessary maneuvers in a timely and safe manner. By contrast, short legibility distances deprive drivers of valuable decision-making and reaction time. Older drivers will most likely be the first to be adversely affected in situations allowing brief decision-reaction time windows, since, on average, they require longer than other drivers to perceive and react to stimuli.

Since stimulus complexity has been shown to adversely affect older driver reaction times, the following questions require attention: i) do the explanatory benefits of a left-turn sign outweigh the additional information processing burden placed on the driver by the mere presence of the sign? and, ii) Does the answer to the previous question depend on sign message/placement and left-turn strategy interactions? Conclusions of a number of recent research efforts addressing sign relations to accidents and/or driver age are presented in the discussion that follows.

Current standards for highway sign legibility assume 50 feet legibility distance per inch symbol height, which corresponds to a vision of 20/25 (1). According to Bailey et al.(10) this standard cannot accommodate 40% of persons 65-74 years of age who have vision worse than 20/25 and 95% of people older than 75 who have 20/40 or worse vision.

Age-related legibility problems are further compounded at nighttime when legibility distance was found to be 15% less than daytime (7, 38) and average older driver corrected vision was found to be 20/42 (123). According to Kline et al.(59), older driver nighttime vision problems are exacerbated by a higher sensitivity to glare and decreased contrast sensitivity. Supporting these findings are the conclusions of a laboratory experiment testing driver response times to signs with respect to fixed illuminating source type, headlight type, and

daytime/nighttime illumination where no differences between sexes or ages were found, but statistically significant differences were identified in driver response times between day and night; color specification; and fixed light source type (113).

In a study of sign legibility distance involving 40 subjects with visual acuity 20/40 or better, younger males had the longest distance legibility (statistically significantly different than any other age and sex group). Older and female driver distance legibility was found to be 70%-87% and 84%-92% that of young male drivers respectively. Both differences were statistically significant (57).

Based on the above mentioned findings about reduced older driver visibility distance and diminished nighttime visual capabilities, a number of federally funded highway improvement projects were undertaken with the explicit goal to improve traffic control device (TCD) visibility in an effort to provide a safer environment for older drivers. Typical corrective measures incorporated in these projects included improved sign and pavement marking reflectivity and the installation of larger traffic signal lenses and backplates (71). However, a report summarizing the safety effects of eight such projects undertaken in the states of Florida, Arizona, and Nevada noted that they tended to be more beneficial (in terms of accident reduction) to other ages rather than older drivers in particular (85). Older driver nighttime accident involvement was lower than that of other driver ages before the TCD improvement projects, a situation supported by findings of other accident analyses (73, 76) that showed no older driver overinvolvement in nighttime accidents. Despite the TCD upgradings, no significant reduction in such accidents was evident in the after period.

An explanation for this outcome may be that older drivers avoid nighttime driving as has been documented in the National Personal Travel Survey (NPTS) (80). Perhaps those older drivers that are at highest risk to be involved in nighttime accidents are the ones that choose not to drive at night.

Presence or absence of supplemental left-turn signs as well as sign message effects on driver comprehension of particular left-turn signal displays have been addressed in a number of research efforts. Typical findings as reported by Hummer (77), are: for protected signal displays, the presence or absence of a supplemental sign had no significant impact on driver comprehension; for protected-permissive displays, the message "left-turn on green or arrow" performed better than the no sign situation and much better than the "left-turn on green ball" message.

In conclusion, although certain supplemental signs have been found to enhance driver comprehension of left-turn signals, the presence or absence of such signs has not been found to contribute significantly to left-turn accident experience in research efforts to date. Thus, inability to detect such signs by drivers with reduced visual acuity (the majority of which is found among older drivers) should not be expected to have a serious impact on accidents related to left-turn signal/sign displays. The importance of findings of reduced nighttime vision among older drivers is moderated by the fact that older drivers seem to avoid nighttime driving and accident analyses show that older driver involvement ratios are not higher for nighttime accidents. Avoidance of nighttime driving could be due to older drivers correctly assessing (even overcompensating for) their vulnerability under such conditions.

2.5. LEFT-TURN ACCIDENTS, LEFT-TURN PHASE TYPE AND SIGNAL CHARACTERISTICS

The preponderance of left-turn accidents among older drivers is a source of concern for traffic engineers seeking to provide a safe driving environment for all drivers. Traditionally, the choice of particular left-turn phase strategies has been dependent on traffic engineering evaluations based on overall accident and delay considerations ignoring differences in accident experience among age groups. However, it is widely recognized that existing design standards may need to be updated and additional criteria may need to be

incorporated in the decision making process in order to adequately accommodate the needs of older drivers.

A number of research efforts discussed in the following sections have examined driver comprehension and preferences of left-turn signal displays as well as signal characteristics relations to left-turn accidents and driver age. Such endeavors may eventually lead to more comprehensive guidelines about the proper use of left-turn phasing to better accommodate older driver safety needs.

2.5.1. DRIVER COMPREHENSION AND PREFERENCES OF SIGN/SIGNAL DISPLAYS

Among 2000 subjects over age 55 taking the standard test required to renew a driver's license in Nebraska, two predominant patterns were identified for percent correct answers: first, an overall decline with age; and, second, percent correct answers for three questions related to right-angle accidents and four questions related to left-turn accidents declined with age (table 2.3. source (71)).

Table 2.3. Percent correct answers in driving knowledge test scores (*)

	Age		
	55-64	64-74	74+
Right-Angle questions	83%	78%	72%
Left-turn questions	86%	82%	73%

(*) Passing score: 80%
Source (71)

Hummer et al. (50) classified questionnaire responses of 402 individuals to eight left-turn signal display understanding questions as correct, close errors ("actions that would probably not have catastrophic consequences in traffic"), and gross errors ("actions that would likely result in a catastrophe in traffic"). It was found that protected phasing was far better understood than permissive, and permissive was better understood than protected/permissive. The same study found no statistically significant comprehension differences in terms of respondent age, sex, and urban or rural residence. This result disagrees with McCoy's (71) conclusions in terms of age-related

comprehension differences. Although McCoy's sample size is considerably larger, direct comparisons of the two studies are not appropriate since they were based on different sets of questions.

Hummer did not find statistically significant relations between presence of supplemental signs and comprehension of protected displays, except when a left-turn green arrow was simultaneously illuminated with a through green ball, in which case the "no sign" situation was found to be superior to displays using a sign, while for permitted/protected displays the sign "left-turn on green or arrow" was found to perform better than the "no sign" condition and much better than the "left-turn yield on green ball" sign. A simple explanation for the observed comprehension patterns could be that protected displays are simpler, relying on a green arrow lens with a unique, concise meaning that needs no reinforcement from a supplemental sign, while protected/permitted displays can easily confuse the driver displaying either a left-turn green arrow and/or a green ball during different intervals. Drivers might get confused by the message "left-turn yield on green ball" when the green arrow is simultaneously illuminated with the green ball, not knowing whether they have the right of way (green arrow message) or they should yield (sign-green ball message). The information is also discordant--yield means yield while green ball typically means go.

Hummer's analysis of driver preferences found that protected is preferred to permitted and protected/permitted, and protected/ permitted is preferred to permitted. Preferences were found to be statistically different by respondent age, with protected/permitted being the top preference only for 16-25 year-olds. Reasons given by respondents for a higher overall preference of protected phasing were that it is less confusing, safer, and results in less delay. Apart from the arguable accuracy of the perception of lower delay at protected left-turn locations, drivers' preferences based on ease of comprehension and safety are in line with the comprehension analysis results based on the same subjects and accident analyses by other researchers to be presented

in the following section.

Finally, Hummer found a preference for leading protected phasing versus lagging with almost one-fourth of the respondents having no preference. There were no statistically significant differences in the preference for leading phasing, except for drivers residing in rural communities who preferred lagging left-turn phasing.

The most common general problems identified for the intersection environment in a survey of 425 drivers 75 years of age or older (71) were: i) right turn on red (RTOR), ii) proper turn lane identification, and, iii) seeing the signal. Among the same individuals the most common problems related to left-turns were found to be: i) view blocked by vehicles in opposite left-turn lane, ii) proper turn lane identification, iii) identification of acceptable gaps that allow enough time for a safe turn, iv) identification of left-turn signal meaning, and v) proper turning path.

The author does not indicate whether the same problems are equally high in the priority list of other driver ages, however, they can be directly related to the previously presented studies on older driver mental and physical abilities.

RTOR presents older drivers with one of the most complex situations in which the driver has to perform an extensive visual scan of the intersection to identify any vehicles and/or pedestrians that legally have the right of way, decide about the adequacy of available gaps, and finally accelerate and perform the maneuver. The required extensive physical and mental effort can be reasonably expected to be perceived as one of the major problems for older drivers at intersections.

Reduced visual acuity and increased sensitivity to glare associated with aging can be expected to be the reasons behind the difficulty in identifying proper turn lane and proper turning path, since these factors are logically related to identifying pertinent traffic control devices such as lane lines and lane assignment signs.

The laboratory-observed difficulty of older drivers to identify a

stimulus in visual clutter or when secondary tasks become more complex expresses itself in the field as driver difficulty in spotting the signal among various visual distractions (such as advertising signs) and mental distractions (such as traffic moving in many directions) present within the intersection environment.

Reduced depth of field of perception and difficulty in tracking objects moving across the visual field associated with older drivers can be readily related to difficulty in identifying acceptable gaps. Although older drivers are sometimes aware of this situation being a problem, their overinvolvement in left-turn accidents may be construed as an indication that they are not aware of the full extent of their problem. It should be recalled here that, by contrast, in the case of nighttime driving, older drivers not only seem to be aware of their limitations, but they seem to be able to accurately assess their risk and thus often avoid nighttime driving.

2.5.2. RELATIONSHIP OF ACCIDENTS TO LEFT-TURN PHASE AND SIGNAL TYPE

In view of a higher percent of older drivers correctly understanding the meaning of protected left-turn phasing, and a stated preference for protected (and particularly leading) left-turn phasing based on perceptions of improved safety and message clarity, it is interesting to examine whether better comprehended and more widely preferred left-turn phase types are actually associated with lower older driver accident involvement.

A before-after study with approximately one-year before and after periods (6) based on approaches with left-turn phasing at 24 intersections found that a change from permitted to protected left-turn phasing in intersections with comparable average annual daily traffic resulted in a decrease of left-turn accident rates (number of left-turn accidents per million left-turning vehicles) from 3.76 to 0.86, while total intersection accident rates were not affected significantly due to a shift from left-turn (a decline of 85%) to rear-end accidents (an increase of 33%). Since left-turn accidents tend to be more severe than

rear-end accidents, percentage injury accidents declined slightly (particular information on injury severity was not provided).

A before-after Arizona study based on four years of accident data for 523 intersection approaches with separate left-turn lanes (143) concurs with the findings of the previous study, concluding that exclusive phasing is the safest form of left-turn phasing. Conclusions are more robust since they are based on comparisons of permitted phasing with all other forms of left-turn phasing and four years of accident data instead of two. A Michigan study based on four years of accident data (125) supported the same conclusions for drivers over age 70 while no differences were found for drivers up to age 70.

The Arizona study found that left-turns across two opposing lanes with permitted/protected (lagging) phasing had the worst accident rate (in accidents per million vehicles turning left), followed by protected/permitted (leading) left-turn phase, and permitted. For left-turns across three opposing lanes, protected/ permitted (leading) was the most dangerous, followed by permitted, and permitted/protected (lagging).

A study that concentrated on accident statistics for older drivers found that permitted left-turn phasing is present at most older driver high accident involvement locations (Nebraska) (71). Drivers between 60 and 69 years of age had a higher involvement in head-on left-turn and rear-end left-turn accidents at permitted left-turn locations (Michigan) (125).

The Arizona study showed that changes in left-turn phasing on a particular intersection are directly related to changes in left-turn accidents. For example, when a permitted approach with two opposing lanes is changed to protected/permitted, there is a left-turn accident reduction, while a change from protected/permitted to permitted is accompanied by an increase in accidents. The only anomaly observed was that, for approaches with three opposing lanes, a change from permitted to protected/permitted was accompanied by an increase in accidents.

However, many intersection approaches included in the study had short before or after periods and results cannot be considered conclusive for all signal phasing changes included in the study.

An accident analysis using four years of accident data from 14 intersection approaches with lagging left-turn phasing and 15 approaches with leading left-turn phasing found no statistically significant differences between approaches with leading and lagging left-turn phasing based on the number of left-turn accidents per million vehicles turning left. However, left-turn accident rates per million total approach vehicles were statistically significantly higher for approaches with a leading phase than approaches with lagging left-turn phasing (50). A Michigan study (125) based on an extensive accident database also concluded that lagging left-turn phasing was safer for drivers between 70 and 74 years of age while no differences were found for drivers of other ages. Traffic conflict studies have been used to provide an estimate of accident potential associated with certain signal phasing sequences in situations where accident data are lacking. A left-turn conflict analysis based on data from three intersections showed a dramatic reduction in left-turn conflicts of the order of 69% to 94% when left-turn phasing was changed from permitted to protected phasing (6). These findings were expanded in a more recent traffic conflict study (50) evaluating leading versus lagging left-turn phasing. Based on observations collected from six intersections in Indianapolis, the conclusion was that lagging left-turn phasing was associated with fewer conflicts under similar opposing volumes. Most of the differences between the two interval sequences were due to drivers turning on the yellow arrow at the end of the leading phase.

In conclusion, older drivers tend to be less involved in accidents at intersections with protected left-turn phasing while they are more involved at intersections with permitted left-turn phasing. Furthermore, lagging left-turn phasing was found to be associated with fewer traffic conflicts and lower accident rates per million entering vehicles. Older

driver perception about improved safety afforded by protected left-turn phasing is verified by accident experience observations, however, their perceptions of leading left-turns being safer have not been found to be true.

2.6. DISCUSSION OF ACCIDENT EXPOSURE MEASURES

Many traffic accident studies have shown an over-involvement of older persons in accidents based on various accident rate measures (5, 21, 22, 42, 60, 96, 98, 149). The magnitude and starting point of the "accident proneness" of older persons has been shown to depend on the denominator of the chosen accident rate. For example, fatality rates per licensed driver show an over-involvement for persons over age 65 with men being involved more than twice as often as women (31, 34, 139) (150-250 fatalities per million licensed male drivers compared to 50-100 fatalities per million licensed female drivers) while the fatality rate per mile driven shows an identical increase in involvement for both sexes (34) starting at age 50 with 8 fatalities per billion miles travelled and reaching 40 fatalities per billion miles travelled by age 85 (1).

The argument of increased frailty of older persons (often attributed to, for example, reduced bone strength, fracture tolerance and residual brain dysfunction following initial injury) as drivers and passengers is widely accepted among researchers (26, 121, 139, 147, 148). It is theorized that older persons have a much higher probability of being fatally injured as a result of an accident that would only injure younger persons.

Thus, the occurrence of accidents where an older driver is fatally injured is not necessarily a direct indication of impact severity: the estimated number of crashes of sufficient impact to kill an 80-year old driver declines dramatically up to age 65 and increases slightly there after for male drivers, while the decline for female drivers continues until age 85. Thus, a higher older driver fatality rate is not necessarily an indication that older drivers are behaving differently

that other driver ages, it may simply be a manifestation of increased older driver frailty. Fatal or injury accident rates should, therefore, not be used to detect changes in impact severity with driver age without controlling for increased frailty.

Some biases are inherent in traditional exposure measures, such as number of accidents per number of licensed drivers or miles driven. The use of the number of licensed drivers per age group as an accident exposure measure seems to be biased by the fact that fewer older persons actually make use of their driver's license than younger persons--making fewer and shorter trips.

Use of the number of licensed drivers by sex shows an over-involvement of male versus female drivers perhaps for a similar reason (more male drivers actually use their licenses than female drivers).

Using exposure measures based on distance travelled, although the most common measure for accident rates, does not necessarily provide a fair comparison between age groups in terms of the environment in which they travel, especially with the older age group in urban areas. The National Personal Travel Survey (80) shows that older people have significantly different travel patterns than the rest of the population (such as avoidance of peak hours and nighttime, trip origins and destinations in the suburbs, avoidance of bad weather driving). Moreover, accurate travel estimation differentiated by age groups are difficult to obtain.

Left-turn accident involvement based on an exposure of left-turning volume (number of accidents per million vehicles turning left) would be more appropriate for the present study, but this involvement measure is incomplete without information on turning driver age since older drivers may prefer to turn left at intersections with certain types of left-turn control while avoiding intersections with left-turn control they perceive as unsafe or they may choose to turn right around the block more often than other drivers, if they perceive that it is safer to do so.

Involvement statistics based on number of licensed drivers per age group may similarly be biased because a smaller number of older holders of drivers' licenses actually drive.

The intent of the present study is to make use of an accident involvement measure that will reveal whether older drivers are significantly under- or over-involved in certain types of accidents while controlling for environmental exposure *per se*. Within this context, the ratio of the proportion of driver 1 (driver at fault) to the proportion of driver 2 (driver not at fault--an innocent victim) involved in multiple vehicle accidents by age will be used to provide relative accident involvement rates controlled for environmental and other factors.

Driver-at-fault/innocent victim ratios (referred to as D1/D2 in what follows) provide an ideal older driver accident involvement measure, since the older "innocent victims'" (D2) distribution in the traffic stream provides, in essence, a relative exposure measure for older drivers that reflects older driver travel behavior.

Any age group with a ratio of 1.0 is neither over- or under-involved, since equal proportions of drivers are identified as driver 1 and driver 2. A ratio of less than 1.0 indicates that drivers in this age group are more likely to be the victim than the cause of an accident (i.e., they are under-involved in accidents--they are "safer" drivers), while a ratio of over 1.0 shows that drivers in this age group are more likely to be the cause of an accident than the "innocent victim" (i.e., they are over-involved in accidents--they are not less "safe" drivers). Such an exposure measure can reflect the travel patterns of all age groups, since it is the ratio and not the absolute numbers of driver 1 and driver 2 that are of importance.

2.7. THE PRESENT RESEARCH: NEED AND SCOPE

The need to study the source of older driver over-representation in accidents and take corrective action is urgent since the population of older drivers is expected to increase even faster than the increase of

the older age cohort (139). Moreover, the next generation of older drivers may well make more and longer trips than the current one. Key among older driver safety problems is their particular overrepresentation in the intersection environment, relative to other drivers.

At the same time, the intersection environment is suitable for engineering measures designed to correct accident problems because of the severity and heavy concentration of accidents in a relatively limited area where corrective measures may benefit a larger number of drivers. By contrast, mid-block accidents are less serious and dispersed over a larger area thus, corrective measures for mid-block locations need to be applied over a larger area to achieve similar accident savings.

Previous research efforts attempting to explain increasing driver accident involvement with driver age have had varying degrees of success. Higher accident involvement by older drivers is most commonly assumed to be an expression of reduced driver physical capabilities with increasing age. However, not all physical attributes that were commonly found to deteriorate with age were found to be significantly related to accident experience. Older drivers seem to be able to realize the existence and extent of a number of their limitations (e.g., visual acuity at night) and successfully compensate for them as mentioned previously. On the other hand, older drivers do not seem to be able to recognize the extent of their physical limitations in other areas (e.g., detection of motion across their visual field) and are more prone to accidents associated with such limitations (e.g., left-turn accidents). While severe physiological limitations have also been found in a number of research efforts to be associated with older driver accident overinvolvement, the number of older drivers with such limitations is small and does not explain the much wider trend of accident overinvolvement of older drivers. For example, a study by Johnson et al. (55) found that drivers with severe visual field loss in both eyes

had accident and conviction rates twice those of the general population, but there were only 196 such drivers among the 10,000 included in the study.

Laboratory tests measuring the mental capabilities of drivers as well as interactions of mental and physical capabilities (e.g., extent of useful field of view) have successfully correlated poor laboratory test scores with poor performance in the field. The success of such efforts stems from a close relationship between demands placed on the driver in real world situations and those tested in the laboratory. Field-measured older-younger driver reaction time similarities to simple stimuli may be attributed to younger drivers spending more time monitoring secondary information in addition to the main task while older drivers concentrate on the main task. However, as the main task becomes more complicated, older drivers become handicapped compared to younger ones since task complexity starts to exceed their processing capacity while younger drivers can use reserve mental processing capacity previously occupied in secondary tasks.

In this context, the intersection environment presents one of the greatest challenges for driver mental capacity due to the presence of conflicting vehicular and pedestrian traffic movements, and the need for quick decision-making regarding reactions to signs, signals, other driver actions and so forth. Within the intersection environment the through maneuver may be assumed to be the simplest since the driver has the right of way and only needs to keep safe distances from other cars and be ready to stop for a changing signal, while turning maneuvers require much more information and more intense processing of it. The right-turn maneuver requires the driver to identify both other vehicles and gaps in other movements having the right of way while simultaneously watching for pedestrians. The left-turning maneuver is by far the most demanding on the driver since it requires clear differentiation of the shape and meaning of a green arrow from a green ball, interpretation of a protected/permitted sign and signal display, identification of the

proper turning path, and, finally, successfully identification of acceptable gaps in oncoming traffic and the pedestrian stream crossing the side street.

Identification of the proper turning path is considerably harder for drivers turning left than those turning right, since, contrary to a right turn where the driver is guided by the edge of pavement or curb, during the left-turn operation the driver has guides only at the beginning and at the end of the maneuver; namely, the centerline of an undivided crossroad or median edge of a divided crossroad, and the curved median end. For the central part of a left-turn the driver has no physical guidance (except where "puppy trails" are provided). Thus, drivers with limited physical abilities are at a considerable disadvantage compared to other drivers when turning left.

Judgment of acceptable gaps for a left-turn maneuver is a process considerably more complex than that facing right-turning drivers, since pedestrians are further from the turning driver, making judgment of their speeds harder (especially for persons with limited physical abilities), and completing the turn requires the identification of sufficient simultaneous gaps in pedestrian and vehicular traffic. In addition, an emergency stop to yield for a pedestrian leaves the left-turning driver exposed to a far greater risk than the right-turning driver: in the case of a right turn the vehicle may be susceptible to a rear-end collision, while a left-turning vehicle is not only susceptible to a rear-end collision, but also to a much more potentially hazardous right-angle collision with a vehicle moving in the opposing through direction.

Older driver accident experience is consistent with the above observations about maneuvers of increasing complexity and the previously hypothesized older driver accident involvement mechanism. Indeed, there is a higher concentration of accidents at intersections with advancing age, and, within the intersection environment, there is a shift to accidents involving turning vehicles, especially left-turning ones.

In this context, the present effort attempts to link driver comprehension of left-turn signal displays to accident experience and driver age. It is expected that, since the left-turn maneuver places a heavy burden on older driver physical and mental capabilities, left-turn signal displays that are easier comprehended, and thus place less demands on driver mental capacity, will be related to lower older driver accident involvement. The results of tests of driver comprehension of left-turn signal displays in a laboratory are analyzed with respect to signal display complexity and the message conveyed to the driver. The data analysis includes direct tests of driver comprehension of left-turn maneuver right-of-way rules (no physical limitation interference is allowed through the experiment design). Thus, it is assumed that comprehension variations among signal displays are a result of mental capabilities rather than a manifestation of varying physical limitations among subjects. The design of the laboratory analysis is directed to identifying signal display characteristics that may place a heavier mental load on the subject either by conveying a complex message requiring interpretation, or leading the subject to an erroneous interpretation of the meaning of a signal display by mere signal placement and/or color of simultaneously illuminated through signal sections. Variables examined in the analysis include number and position of left-turn signal heads, supplemental sign message, signal face arrangement, number of through signals, and color configurations of simultaneously illuminated left-turn and through signals.

Once signal characteristics that are related to driver confusion have been identified in the laboratory experiment, hypotheses are formulated about signal configurations that are expected to cause driver confusion and thus be related to higher accident experience in the field, as well as those that are expected to be better comprehended and thus be related to lower accident experience. The hypotheses are subsequently tested against field data collected over a ten-year period for 324 signalized intersections in Michigan. Database records include accident, signal, and geometric information and allow the identification of the intersection approach on which a vehicle was moving prior to the accident. Thus, the specific left-turn signal/sign configuration facing the driver-at-fault and the innocent victim can be identified and the hypotheses regarding signal comprehension can be tested.

Considerable compatibility exists between laboratory and field variables allowing extensive testing of hypotheses. For example, driver age, signal position, supplemental sign presence and message, left-turn strategy, flashing (nighttime) operation configuration, existence of left-turn lane, and signal sections simultaneously illuminated are included in both the laboratory and field databases. Additional hypotheses are subsequently formulated and tested based on variables exclusive to the field database, such as type and duration of change interval, roadway width and lane configuration, cycle length, left-turn phase duration, and weather conditions at the time of the accident.

The results of the analyses of laboratory and field data lead to suggestions about left-turn signal display attributes and strategies that should be used and those that should be avoided in order to improve older driver safety in the intersection environment.

CHAPTER 3

ANALYSIS METHODOLOGY

3.1. INTRODUCTION

As has been pointed out in the literature review, although higher accident involvement by older drivers is most commonly assumed to be an expression of reduced driver physical capabilities with increasing age, not all physical attributes (such as reduced visual acuity and nighttime vision) that were commonly found to deteriorate with age in laboratory measurements were found to be significantly related to accident experience. Some older drivers seem to be aware of certain physical limitations and adequately compensate for them by driving in a conservative manner (e.g., avoid nighttime and bad weather driving). Furthermore, no significant differences have been found between older and other drivers in field tests measuring reactions to simple stimuli (e.g., braking in response to a leading vehicle braking). However, laboratory tests measuring driver mental capacity have been more successful: poor laboratory test scores have been positively correlated with poor accident experience, perhaps because older drivers are unable to compensate for intellection and decision deficiencies rather than physical or reaction time deficiencies. Accident trends reinforce the notion that older drivers tend to have more accidents than other driver ages in more complex driving environments, e.g., they tend to have relatively more serious accidents within the intersection environment where more decisions need to be made, and especially when executing the most complex intersection maneuver i.e., turning left. Thus, it is reasonable to assume that, if indeed driver comprehension is the most critical link between driver age and accident experience, an ideal departing point for research efforts attempting to link driver age with accident experience is left-turn accidents where such relationships will most likely be the most pronounced.

Context of current research

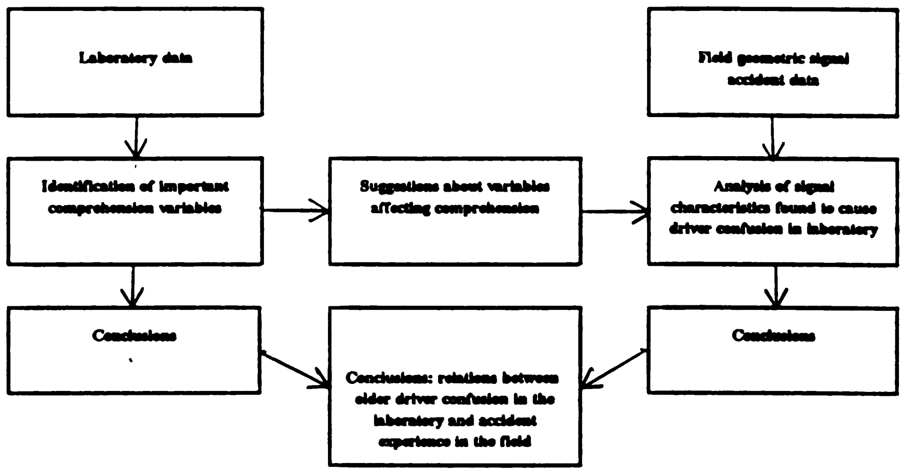
Based on these observations of relations between laboratory measurements and accident experience, the present research focuses on analyzing older driver comprehension rather than physical limitation relations to accident experience. The first phase of the present effort involves an investigation of signal display characteristics affecting driver comprehension based on laboratory data collected during an earlier research effort. A second phase involves the analysis of accident, geometric, and signal field data collected during the present effort. The latter analysis is focused on the evaluation of the effects of various signal and geometric characteristics on the accident performance of older drivers.

Although the data and analyses for the two phases are independent, an effort is made to use the knowledge gained from laboratory data in analyzing the field data. Connections between the two databases rely primarily on a number of variables present both in the laboratory and field databases. Thus, it is possible to examine, for example, whether signal characteristics found to be associated with erroneous answers in the laboratory environment are also present at intersections where older drivers have higher accident involvement. Compatibility of conclusions based on the laboratory and field data sets is discussed in the final chapter. A schematic representation of the relationships between the two phases of the work is presented in figure 3.1. The present chapter includes, in turn, the laboratory and field data, hypotheses, and analysis procedures.

3.2. THE LABORATORY EXPERIMENT

A laboratory experiment to measure driver comprehension of various left-turn signal head/sign configurations was part of a 1988 study funded by the Federal Highway Administration (FHWA) (122) to investigate driver comprehension and accident experience in relation to left-turn signal characteristics. The study, titled "*An Evaluation of*

Figure 3.1. Analysis flowchart.



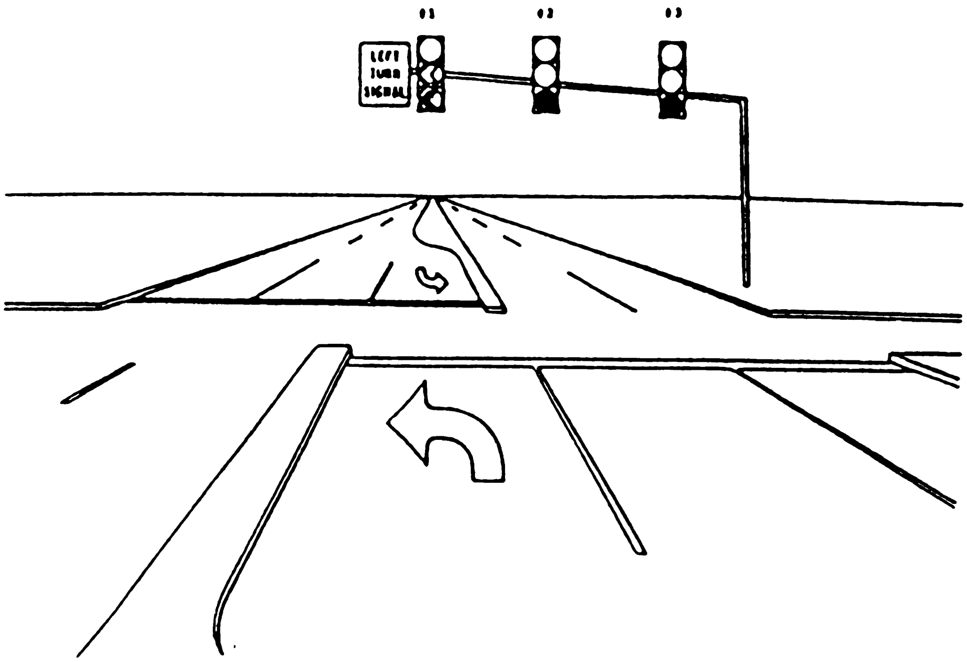
Left-Turn Signal Displays" (FHWA contract DTFH61-85-C-00164), was contracted to JHK and Associates, which in turn subcontracted Ketron Inc. to conduct the laboratory experiment.

Driver comprehension was evaluated based on the responses of 191 individuals to a set of slides depicting 82 different signal intervals representing 17 signal displays, similar to the one depicted in figure 3.2, used in permitted, protected, and permitted/protected left-turn phasing. (Permitted/protected is used throughout to denote the left-turn phasing scheme where both a permitted and a protected phase are present, but <u>not</u> in any particular order unless otherwise indicated.)

Subject selection

Subjects were recruited through newspaper advertisements in Philadelphia, Pennsylvania; Seattle, Washington; Dallas, Texas; and Lansing, Michigan; and paid $25 to participate in the two-hour experiment. The research plan was to recruit equal numbers of male and female subjects for each of four age groups (16-30, 31-45, 46-60, and 61 and older). General characteristics of the subjects in the experiment are summarized in table 3.1.

Figure 3.2. Typical stimulus display.



Source: Final report FHWA contract DTFH61-85-C-00164 "Signal Displays for Left-turn Control"

Experiment protocol

The experiment protocol involved using a set of slide projectors set up to simulate the color, shape (ball or arrow), and mode of operation (steady or flashing) of real signal displays (see figure 3.2). Each stimulus replicated an interval of one of seventeen left-turn signal/sign configurations, referred to as signal face arrangements (SFA) in what follows. Eighty-two stimuli (see appendix A) were shown to subjects in two prearranged random sequences, not necessarily following the interval and phase order of individual signal/sign configurations. Two groups with similar sex and age distributions were formed at each testing location and each group was assigned one of the

Table 3.1. Subject demographic and driving experience information

LOCATION	AGE	SEX: MALE	SEX: FEMALE	MILES DRIVEN ANNUALLY: 0-7k	8-10k	11-15k	15k+	YEARS DRIVING EXPERIENCE: 0-12	13-24	25-38	38+
PHILADELPHIA	16-30	6	6	3	1	1	0	6	2	0	0
	31-45	6	6	2	1	1	1	0	5	0	0
	46-60	8	5	1	1	0	3	0	1	4	2
	60+	6	4	1	0	0	0	0	0	1	4
sub-total		26	21	7	3	2	4	6	8	5	6
DALLAS	16-30	10	7	2	3	8	4	14	3	0	0
	31-45	11	6	1	3	6	6	1	10	6	0
	46-60	7	7	0	5	4	4	1	1	11	1
	60+	4	3	2	1	2	0	0	0	0	7
sub-total		32	23	5	12	20	14	16	14	17	8
SEATTLE	16-30	6	3	3	5	1	0	7	2	0	0
	31-45	6	5	2	2	4	2	1	9	1	0
	46-60	5	5	2	2	3	3	0	1	8	1
	60+	6	5	4	2	2	2	0	0	2	9
sub-total		23	18	11	11	10	7	8	12	11	10
LANSING	16-30	7	5	5	3	1	3	11	1	0	0
	31-45	6	5	3	1	3	4	0	8	3	0
	46-60	5	6	4	2	3	2	0	0	6	5
	60+	8	6	4	6	1	3	0	1	1	12
sub-total		26	22	16	12	8	12	11	10	10	17
TOTAL		107	84	39	38	40	37	41	44	43	41

NOTE: TOTALS ACROSS VARIABLES MAY DIFFER DUE TO MISSING CASES

prearranged stimuli sequences at random. This was done to provide some control over order-of-presentation effects since resource limitations did not allow for a completely randomized experimental design.

Subjects were provided with a test booklet consisting of a page of instructions and six pages of response sheets each of which contained a number of multiple choice answer boxes corresponding one to one to the presented stimuli (figure 3.3.).

Figure 3.3. Multiple choice answer box for scene number 1.

Scene Number	1.	a)	Y	N
1		b)	Y	N
		c)	Y	N
		d)	Y	N
		e)	Y	N
2.	1 2 3 4 5			

After being given a brief introduction about the purpose of the experiment, subjects were shown sample slides depicting stimuli (similar to figure 3.2) and were told to imagine that they were driving in the left-turn lane and wanted to turn left. They were instructed to answer yes or no for each slide to each of the following five options for action:

a) Turn left, you have the right-of-way.

b) Turn left without stopping unless you have to wait for a large enough gap in the opposing traffic.

c) Stop. Then turn left when there is a large enough gap in the opposing traffic.

d) Stop. Then turn left when there is a large enough gap in the cross street traffic.

e) Stop. Wait until the signal changes to indicate that you may proceed.

Subjects were to record their answers to item 1 in the box corresponding to the appropriate scene number on the answer sheet (see

figure 3.3). If, for example, the left-turn stimulus was a left-turn green arrow, the correct answers to options a) through e) were respectively Y, N, N, N, N. If the individual's response was N, Y, N, N, N, then, that response was incorrect. Thus, a subject's answer could be classified either as "correct" or "incorrect" according to whether the response agreed with a set of predetermined correct answers.

For each display, experiment participants were asked to provide the degree of confidence they felt about the chosen answer. The degree of confidence was coded on a scale from one to five (a score of five indicating the highest degree of certainty) and corresponds to item 2 in each response box (see figure 3.3). Subjects were instructed to ask questions if the color or shape of a lens or word message of a sign were not clear, but were not allowed to ask questions pertaining to the meaning of a stimulus. The experimenter would ask if everybody was done before proceeding to the next slide. Five example slides were used to familiarize subjects with the method, followed by the series of 82 stimuli of interest to the experiment (only 81 of which are analyzed in the present effort). Following the stimuli presentation, individuals were asked to provide additional information on the last answer sheet about their age, sex, miles driven annually, and years of driving experience.

Differences between original and current analysis

The original study addressed driver age only in terms of comparing correct answer rates for each display among age groups. Only displays showing statistically significant correct answer rate differences among age groups were discussed (approximately half of the analyzed stimuli showed such differences). Correct answer rates were found to typically decline with driver age. Displays were categorized by mode of operation (normal or flashing) and interval (i.e., permitted, protected, and protected/permitted operation). Typical conclusions were that older subjects had: half the correct answer rate as their youngest

counterparts for an interval including a protected left-turn display simultaneously illuminated with a through green ball; one-fourth the correct answer rate of the youngest drivers for protected/permitted displays using a fast flashing yellow interval for permitted left turns; and particular comprehension difficulties with clearance intervals.

No comparisons among alternative signal configurations that can be used to convey the same message were offered for older drivers, and there was no attempt to explain comprehension differences between older and younger drivers. Thus, it was felt that the analysis needed to be modified if: i)older drivers were to become the focal point of the analysis, and, ii)signal attributes that are beneficial/detrimental to older driver signal comprehension were to be identified.

Furthermore, the categorization of driver responses into correct and incorrect used in the original analysis was deemed inadequate for the present study since not all signal display comprehension errors are believed to be equally grave. If, for example, drivers chose to stop when they had the right of way, the error was considered to be less serious than if their answer indicated they thought they had the right of way when in fact they did not. Thus, errors were separated into minor and serious errors, respectively.

The literature search indicated that driver mental load is an important factor in explaining differences in the performance of the driving task among driver age groups. It is therefore reasonable to expect that signal displays requiring some degree of interpretation are more likely to be misinterpreted by drivers than those conveying a simple message. For example, an illuminated green ball section has a different meaning for the through driver (proceed, you have the right of way) than a driver turning left (proceed without stopping if there is no opposing traffic). Thus, some potential exists for turning drivers to mistakenly assume that they have the right of way, especially at busy intersections where drivers are distracted by other decisions associated with the driving task. By contrast, a left-turn green arrow is only

used for the left-turn maneuver and the presence of an arrow always gives the driver the right of way--therefore, confusion of turning drivers can be expected to be minimal with respect to such displays.

Based on expectations about signal display characteristics that might contribute to driver confusion, a number of "complexity" variables were defined. These characteristics include the number, color, and shape of simultaneously illuminated lenses; signal placement; and number of left-turn and through signals. All of these may contribute to driver confusion. A detailed discussion about complexity variables can be found within the sections discussing displays used for particular left-turn phases.

In summary, three innovations to the original study are introduced in the re-analysis of the laboratory data:

i) Emphasis is placed on older driver performance.

ii) Individuals' answers are analyzed based on a three-level of correctness concept--answers considered "incorrect" in the previous study are further categorized into "minor errors" and "serious errors" depending on whether subjects incorrectly chose to give away their right of way or to violate other drivers' right of way respectively; and,

iii) Stimulus complexity is introduced in the analysis as an explanatory variable of driver comprehension.

3.3. LABORATORY DATABASE RECORDS

The database used for the re-analysis of laboratory data consists of 191 records, one per subject. Data collected in the original laboratory experiment were recoded to convert each set of five yes/no answers for each stimulus into a "1" indicating a correct answer, a "2" indicating a minor error, or a "3" indicating a serious error. Thus, for each individual, answer correctness level was represented by a set of 81 digits (ranging from one to three). Each record contains subject number, age, sex, miles driven per year, years of driving experience, answer correctness, and a series of 81 digits (ranging from one to five) representing the degree of confidence each individual felt about each stimulus. The database layout is illustrated in table 3.2.

Table 3.2. Laboratory database variables
MONTH
DAY
LOCATION
SUBJECT
AGE
SEX
YEARS OF DRIVING EXPERIENCE
MILES DRIVEN PER YEAR
CORRECTNESS OF ANSWER TO QUESTION 1
⋮
CORRECTNESS OF ANSWER TO QUESTION 82
CONFIDENCE IN ANSWER TO QUESTION 1
⋮
CONFIDENCE IN ANSWER TO QUESTION 82

3.4. LABORATORY DATA ANALYSIS

Two major directions were identified in the literature review for studies attempting to explain the poor driving performance of older drivers: a number of authors cite a general deterioration of physical abilities, while others believe that it is mainly caused by a deterioration in mental abilities. Laboratory experiments measuring mental abilities have shown better correlations with poor driver performance in the field than similar experiments measuring physical abilities. Thus, the present research is geared towards identifying signal attributes that tax driver mental rather than physical abilities.

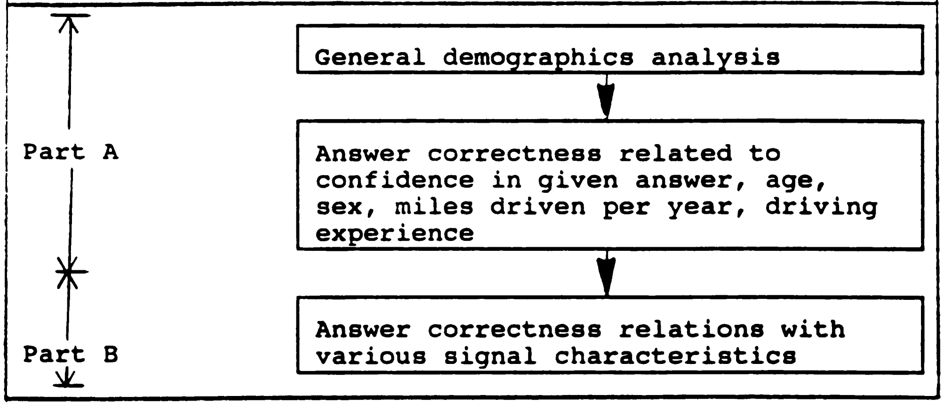
Indeed, the experimental protocol precluded any consideration of physical limitations (individuals were free to ask questions about the physical appearance of stimuli--e.g., wording of sign messages, shape of lenses) while it measured driver mental load (albeit indirectly), by measuring answer correctness and confidence in given answer. The analysis of signal characteristics that contribute to better/poorer driver comprehension of signal displays in the laboratory environment provides useful insights into which signal characteristics could be important in improving older driver signal comprehension in the field.

A correct answer, especially one given with a great degree of certainty, is an indication that a signal message is concise and will not require a great share of driver attention to be understood in the field, allowing the driver to concentrate on the other tasks involved in turning left and contributing to diminished risk of an accident. By contrast, a hard-to-understand or ambiguous display may lead to driver confusion or incorrect action and will require a larger share of available driver mental processing capacity--diverting attention from other crucial tasks involved with turning left, possibly leading to an accident.

The main interest in the laboratory data analysis is identifying signal display characteristics that affect older driver comprehension. However, before the more detailed analysis of such characteristics, an examination of subject demographic information is used as a starting point to establish background statistics about the experiment subjects. Overall relations between answer correctness (regardless of stimulus meaning and signal display characteristics) and various driver-related variables are analyzed to establish a base for signal comprehension, with which the detailed analysis can be compared. Thus, questions such as whether older drivers show significantly decreased comprehension, whether more experienced drivers show better comprehension, and whether any comprehension differences exist between sexes can be addressed before undertaking a more detailed examination of which signal meanings or particular signal display characteristics affect driver comprehension.

The analysis of laboratory data is divided in two major parts: a general introductory analysis focusing on demographic and general driver comprehension-related information, performed in part A, and a detailed analysis of driver comprehension relations with signal meaning, characteristics, and driver age, performed in part B. This analysis is graphically presented in figure 3.4.

Figure 3.4. Laboratory data analysis flowchart



The issue of designating a "cutoff age" for the purpose of defining "young" and "old" drivers has been extensively discussed in the literature review. As has been mentioned, although mental and physical abilities associated with the driving task generally deteriorate with age, a large variation in mental and physical abilities exists among individuals, even within the same age group. Thus, age cutoff limits are employed for practical purposes only; they are used to study broader trends related to driver age and are not related to specific physical and psychological changes that take place at certain precise ages. The limited number of subjects available, and the need to have adequate age group sample sizes for statistical inferences, allowed for consideration of four age groups: 16-30, 31-45, 46-60, and older than 60 (the same age groups as used in the original analysis). The age cutoff for the older group (60 years) is compatible with typical cutoff ages for "older" drivers used by the majority of authors which range from 55 to 65 years of age. Thus, the results here can be easily compared to previously published findings.

Subject characteristics analysis

The first part of laboratory data analysis involves a broad overview of subject characteristics and their relationship to answer correctness. Overall trends in miles driven per year by age group are examined to test whether subject sample characteristics are consistent with national trends towards less miles driven per year as drivers age reported in the 1983 National Personal Travel Survey (80); sex differences in miles driven per year are also examined.

Although the number of subjects (here) is very small for inferences about the entire driving population, any differences in miles driven by age and sex among study participants have significant ramifications for the appropriateness of the use of traditional million vehicle mile-based accident rates, particularly when investigating differences among driver ages and sexes: if older drivers drive significantly more (less) miles than other drivers, overall accident rates based on accidents per million vehicle miles need to be adjusted downwards (upwards) to correct for driver age.

It is also important to know whether subjects that felt confident about their answers were more likely to have chosen a correct answer or not. Ideally, correct answers should be chosen with a high degree of certainty indicating that the message conveyed by signal displays is concise, and erroneous answers should be associated with a high degree of uncertainty, indicating the existence of some confusion about the correct signal message. A worst case scenario would involve serious error answers chosen with a high degree of confidence, indicating that a signal conveys precisely the wrong message--a situation that should clearly be avoided. Thus, relations between subject confidence in the given answer and answer correctness will be addressed in this part of the analysis. Answer correctness is addressed in terms of correct, minor error, and serious error percentages among all answers for each individual. The corresponding terms used throughout this text are correct, minor error, and serious error rate, respectively.

It is reasonable to expect that the more miles individuals drive, the better their comprehension of signals will be, since they have more opportunities to familiarize themselves with the driving environment. The question arises about whether miles driven per year can be used as a predictor of how well an individual comprehends left-turn signal displays. If subjects reporting a low number of miles driven per year

have reduced comprehension scores, drivers in the low mile per year category could be given special attention, such as additional signal comprehension instruction.

Finally, the more experienced drivers are, the better their comprehension of signals can be expected to be. However, older drivers that are most likely to have the highest number of years of experience are expected to show low comprehension scores according to the literature review. Thus, it is of interest to investigate statistical relationships between driver comprehension and years of driving experience in order to identify the age at which comprehension peaks due to increasing years of driving experience without noticeable adverse comprehension impacts due to advancing driver age.

Research hypotheses and statistical methods-general comprehension analysis

Database information is presented through general descriptive statistics, and appropriate null and alternative hypotheses (presented in table 3.3) are tested for statistical significance. Typical testing procedures are presented below while a full presentation of results can be found in chapter 4.

As stated above, older subjects are expected to have reported less miles driven per year than younger ones. General descriptive statistics will be used to provide an overview of database information before proceeding to verify whether statistically significant differences exist between age groups. An example of null and alternative hypotheses to be tested is illustrated below:

H_0: There are no statistically significant differences in miles driven per year among driver age groups.

H_1: Miles driven per year differs at a statistically significant level among driver age groups.

These hypotheses are tested using an analysis of variance (ANOVA) model where miles driven per year is the dependent variable and driver age is the independent variable. A 95% confidence interval is nominally used as the criterion for statistical significance throughout this

Table 3.3. Tested hypotheses for comprehension analysis--part A	
H_0:	There are no statistically significant differences in miles driven per year among driver age groups.
H_1:	Miles driven per year differ at a statistically significant level among driver age groups.
H_0:	There are no statistically significant differences in miles driven per year among driver sexes.
H_1:	Miles driven per year differ at a statistically significant level among driver sexes.
H_0:	There are no statistically significant differences in miles driven per year by each age group among sexes.
H_1:	Miles driven per year by each age group differ at a statistically significant level among sexes.
H_0:	Correct answer(serious error) rates are not statistically significantly different among miles driven per year categories.
H_1:	Correct answer(serious error) rates are statistically significantly different among miles driven per year categories.
H_0:	Correct answer (serious error) rates are not statistically significantly different among driver experience groups.
H_1:	Correct answer (serious error) rates are statistically significantly different among driver experience groups.
H_0:	Correct answer (serious error) rates are not statistically significantly different among sexes.
H_1:	Correct answer (serious error) rates are statistically significantly different among sexes.

analysis. A high F-statistic value supports a rejection of the null hypothesis with a high degree of confidence and indicates that, for the above example, significant differences in miles driven per year among age groups exist, and H_0 is rejected. Conversely, a low F-value indicates that no significant differences exist among age groups and H_0 cannot be rejected. The hypotheses to be tested in this manner are shown in table 3.3. The Statistical Package for the Social Sciences (SPSS) is used to compile ANOVA tables for each of the hypotheses listed in table 3.3. An example is shown in table 3.4.

In table 3.4 the F-statistic value of 1.772 for factor age

Table 3.4. Miles per year by age

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	942855462.635	3	314285154.21	1.772	.155
AGE	942855462.635	3	314285154.21	1.772	.155
Explained	942855462.635	3	314285154.21	1.772	.155
Residual	26605785789.5	150	177371905.26		
Total	27548641252.1	153	180056478.77		

191 Cases were processed.
37 Cases (19.4 PCT) were missing.

corresponds to a significance of 0.155. That is, the statement that miles driven per year are statistically significantly different among age groups is correct only 84.5% (100-15.5) of the time, which is lower than the desired 95% certainty, thus H_0 cannot be rejected.

A similar ANOVA model can be used to test whether vehicle miles driven per year are statistically significantly different between sexes.

Once basic age and sex differences in miles driven per year have been assessed, the interaction between age and sex can be investigated in order to decide whether sex is differentially related to miles driven per year according to subject age. The hypotheses to be tested are stated as:

H_0: There are no statistically significant differences in miles driven per year by each age group among sexes.

H_1: Miles driven per year by each age group differ at a statistically significant level among sexes.

A multivariate ANOVA model with age and sex as the independent variables and miles driven per year as the dependent variable will be used to test the hypothesis.

In table 3.5 the F-statistic value of 2.095 obtained for age corresponds to a significance of 0.103, an insignificant value. The F-statistic value of 2.095 obtained for the effect of sex corresponds to a significance level of 0.002 which indicates statistically significant differences among sexes. The combined effect of age and sex has an

Table 3.5. Miles per year by age and sex

Source of Variation	Sum of Squares	DF	Mean Square	F	Signif of F
Main Effects	2580676750.55	4	645169187.64	3.918	.005
AGE	1035217075.90	3	345072358.63	2.095	.103
SEX	1637821287.91	1	1637821287.9	9.945	.002
2-way Interactions	923426094.556	3	307808698.19	1.869	.137
AGE SEX	923426094.556	3	307808698.19	1.869	.137
Explained	3504102845.10	7	500586120.73	3.040	.005
Residual	24044538407.0	146	164688619.23		
Total	27548641252.1	153	180056478.77		

191 Cases were processed.
37 Cases (19.4 PCT) were missing.

F-statistic of 1.069 and is associated with a significance level of 0.137, indicating that sex effects are not significantly different across age groups.

Other analyses will be focused on examining relations between driver comprehension scores and certainty in the given answer, subject age and sex, miles driven per year, and years of driving experience. Statistically significant comprehension differences among age groups are similarly tested.

In order to simplify the analysis, number of miles driven per year are classified into four categories: up to 7,000 miles, 7,001-10,000, 10,001-15,000, and more than 15,000; and driving experience is classified into four categories: up to 12, 13-24, 25-38, and over 38 years of experience.

Answer correctness relations with various signal characteristics

The second part of the laboratory data analysis (part B--figure 3.4) is concerned with determining whether comprehension differences exist among driver age groups based on stimulus meaning. Although it is anticipated that, in general, older drivers will have lower correct answer rates and higher serious error rates, it is also expected that for certain stimuli there may be particularly pronounced comprehension differences among age groups while comprehension differences may be less pronounced among age groups for other stimuli. Displays that are particularly difficult for older drivers to comprehend need to be identified since they pose a threat to their safety, and the confusing displays should be avoided to the extent feasible. A broader analysis of driver comprehension differences based on signal interval and driver age precedes the more detailed investigation of which stimulus, among alternatives used for the same interval, is best understood by older drivers. Thus, the first analysis stage involves comprehension comparisons among stimuli used for the permitted, protected, and protected/permitted left-turn intervals, the red interval, the change interval, and flashing mode operation in order to identify which signal interval(s), if any, is (are) more likely to be misinterpreted by older drivers.

Since comprehension scores are compared between groups of stimuli used for different signal intervals, this component of part B comprehension analysis is called the **inter-interval** analysis. Comparisons are based on comprehension scores (i.e., correct, minor error, and serious error rates) compiled for the groups of stimuli belonging to each interval for each individual. A correct answer rate, a minor error rate, and a serious error rate are compiled for each individual for all stimuli representing a red interval. A separate set of answer rates is compiled for all stimuli representing permitted intervals, and so on. The results of this analysis will determine whether particular emphasis needs to be directed to specific signal intervals. The segregation of stimuli into stimulus meaning categories allows the rank ordering of subsequent inquiries: low comprehension of the red interval, for example, is more likely to lead to serious accidents since drivers will violate another driver's right of way, while low comprehension of a protected left-turn arrow may not have such dire consequences, since drivers facing such displays already have the right of way.

The last component of part B of the comprehension analysis

involves comprehension comparisons within groups of stimuli used for the same signal interval in order to identify which display among alternative signal displays better conveys the same message to drivers, particularly older ones. Since comparisons are made within groups of stimuli conveying the same message, this part of the analysis is designated as the **intra-interval** analysis. The detailed stimulus analysis allows an examination of the effect of supplemental signs, signal head position, signal section arrangement, and other stimuli characteristics that may benefit/handicap the comprehension of particular intervals while they may have no effect (or even the opposite effect) on other intervals.

Based on the literature search, it is expected that increasing display complexity will be inversely related to older driver comprehension. Thus, seven traits of signal display complexity are examined in this analysis:

1) The simultaneous illumination of two sections on the left-turn signal face (ILLUMINATED--e.g., a yellow ball simultaneously illuminated with a green arrow);
2) The concurrence or discordance of the messages of two simultaneously illuminated sections on the same left-turn signal face (AGREELT);
3) The concurrence or discordance of the illuminated left-turn signal section(s) with the through signal message (AGREETH);
4) The presence of multiple through signals (NoTHRU);
5) The presence of a supplemental sign (SIGN);
6) The presence of more than three sections on the left-turn signal (NoSECTIONS); and, finally,
7) The presence of an arrow on the left-turn signal (ARROW).

All of the above signal face arrangement (SFA) characteristics require the identification and processing of more than one (or a hard-to-identify) piece of information present in an SFA in order to arrive at a decision about the driver's right-of-way privileges associated with a left turn and may lead to driver confusion especially for older drivers. A comprehensive list of variables used for intra-interval comprehension comparisons is presented in table 3.6.

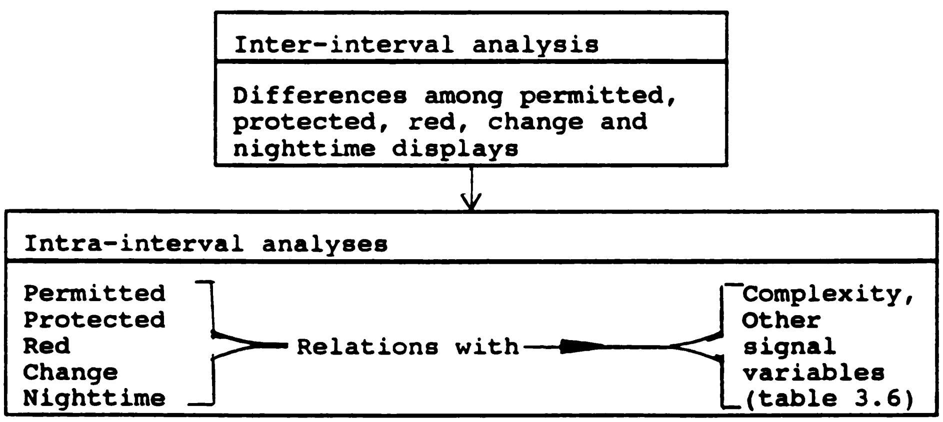
The results of this analysis provide information for the design of better comprehended signal displays based on knowledge about which signal characteristics are most likely to lead to better comprehension

Table 3.6. Signal variables used in comprehension analysis

VARIABLE NAME	VARIABLE DESCRIPTION
Complexity Variables	
AGREELT	Concurrence/discordance of simultaneously illuminated left-turn signal sections
AGREETH	Concurrence/discordance of left-turn and through signal indications
ARROW	Presence of left-turn arrow signal section
ILLUMINATED	Number of simultaneously illuminated sections on left-turn signal
NoSECTIONS	Number of left-turn signal sections
NoTHRU	Number of through signal faces
SIGN	Sign related to left-turn signal
Other variables	
ARRANGEMENT	Stacked three, stacked four, doghouse signal face arrangement
CHANGE	Colors illuminated on left-turn signal during change interval
COLORS	Left-turn and through signal color configurations
FLASH	Flashing signal operations configuration
HPOSITION	Horizontal signal position (in feet to the left of driver)
LFTFLSH	Left-turn signal section type used in flashing operations (dark, arrow, ball)
THRUCOL	Through signal color
VPOSITION	Vertical signal position

of each interval displayed in a particular signal configuration. The organization of part B of the laboratory data "reanalysis" is shown in figure 3.5.

Figure 3.5. Part B laboratory data reanalysis



Hypotheses and statistical methods used for the inter- and intra-interval analysis

Null and alternative hypotheses used to examine comprehension differences among (and within) stimulus meaning groups presented here are tested for statistical significance and the results are presented in the next chapter. Typical testing procedures and statistics are described below.

Based on the literature review, older drivers are expected to have higher error rates. However, practitioners need to know whether older driver comprehension difficulties are significantly different from those of other drivers and whether such differences are more pronounced during specific signal intervals. Stimuli categories associated with significantly higher serious error rates should be addressed immediately. Typical null and alternative hypotheses for the inter-interval analysis are:

H_0: There are no statistically significant differences in correct answer rates (serious error rates) among stimulus meaning categories between age groups.

H_1: Statistically significant differences in correct answer rates (serious error rates) among stimulus meaning categories between age groups exist.

These hypotheses will be tested using a multivariate multi-group analysis of variance model, appropriate for multiple-response data. Subjects (considered a random effect) are nested within age groups (AGE) and crossed with stimulus meaning groups (MEANING), while age and stimulus meaning are completely crossed. Each stimulus group serious error rate is examined as a separate dependent variable. Subjects and stimulus meaning groups are the independent variables. The following three questions are answered in turn:

1) Does stimulus comprehension vary among age groups;
2) Is stimulus comprehension dependent on stimulus meaning; and,
3) Does an interaction between comprehension of stimulus categories and driver age exist.

A summary of typical ANOVA model results is presented in table 3.7.

Table 3.7. Inter-interval serious error rate comparison

Source of Variation	SS	DF	MS	F	Sig of F
Main effects					
AGE	.26	3	.09	5.65	.001
MEANING	1.47	3	.49	38.31	.000
2-way Interactions					
AGE BY MEANING	.13	9	.01	1.11	.354

Comprehension (measured in serious error rate) is statistically significantly different among driver age groups (F-value 5.65, significance 0.001). It is also statistically significantly different among stimulus meaning categories given an F-value of 38.31 and a significance of 0.000 for variable MEANING. Finally, the F-statistic value for AGE by MEANING interactions of 1.11 corresponds to a significance of 0.354 which is not statistically significant, indicating that comprehension of stimulus group meaning is not statistically significantly different among age groups. An example of statistics for age and stimulus meaning groups compiled for each ANOVA model are presented in table 3.8.

Based on the results presented in table 3.8, the mean serious error rate for change interval stimuli is .010 (1%). This average is calculated based on the answers of all subjects (N = 186). Drivers 61 to 75 years of age have an average serious error rate of .014 (1.4%) for the same stimuli. Older subject results are based on a sample of 42 subjects, and the 95% confidence interval for the older subject average is a serious error rate between .003 and .026.

Hypotheses tested using similar models are presented in table 3.9. Following inter-interval hypotheses analysis, intra-interval hypotheses will be examined using similar statistics. Hypotheses tested in the intra-interval analysis are presented in table 3.10. A complete discussion of findings can be found in the next chapter.

Table 3.8. Serious error rate statistics for inter-interval analysis

Permitted interval stimuli

FACTOR	RANGE	Mean	Std. Dev.	N	95 percent Conf.Intvl.	
AGE	16 TO 30	.040	.100	48	.011	.070
AGE	31 TO 45	.091	.183	51	.039	.142
AGE	46 TO 60	.082	.119	45	.046	.118
AGE	61 TO 75	.125	.172	42	.071	.179
For entire sample		.083	.150	186	.062	.105

Red interval stimuli

FACTOR	RANGE	Mean	Std. Dev.	N	95 percent Conf.Intrl.	
AGE	16 TO 30	.014	.044	48	.001	.027
AGE	31 TO 45	.021	.107	51	-.009	.051
AGE	46 TO 60	.038	.073	45	.016	.060
AGE	61 TO 75	.083	.142	42	.039	.127
For entire sample		.037	.100	186	.023	.052

Nighttime operations stimuli

FACTOR	RANGE	Mean	Std. Dev.	N	95 percent Conf.Intvl.	
AGE	16 TO 30	.103	.138	48	.063	.143
AGE	31 TO 45	.107	.154	51	.064	.151
AGE	46 TO 60	.144	.143	45	.101	.187
AGE	61 TO 75	.154	.146	42	.109	.200
For entire sample		.126	.146	186	.105	.147

Change interval stimuli

FACTOR	RANGE	Mean	Std. Dev.	N	95 percent Conf.Intvl.	
AGE	16 TO 30	.011	.035	48	.001	.022
AGE	31 TO 45	.008	.035	51	-.001	.018
AGE	46 TO 60	.006	.020	45	.000	.012
AGE	61 TO 75	.014	.036	42	.003	.026
For entire sample		.010	.032	186	.005	.015

Table 3.9. Tested hypotheses, inter-interval comprehension analysis

H_o: There are no statistically significant differences in correct answer rates (serious error rates) among stimulus meaning categories between age groups.

H_1: Statistically significant differences in correct answer rates (serious error rates) among stimulus meaning categories between age groups exist.

H_o: There are no statistically significant differences in correct answer rates (serious error rates) among stimulus meaning categories for older drivers.

H_1: Statistically significant differences in correct answer rates (serious error rates) among stimulus meaning categories exist for older drivers.

Table 3.10. Tested hypotheses, intra-interval comprehension analysis

Permitted interval	
H_0:	There are no statistically significant differences in correct answer rates (serious error rates)[1] based on: signal horizontal position (HPOSITION)[2] concurrence/discordance of left-turn signal with through signal (AGREETH) number of through signals (NoTHRU) presence of supplemental sign (SIGN) between age groups (among older drivers)[1].
H_1:	Statistically significant differences in correct answer rates (serious error rates) based on the above variables exist between age groups(among older drivers).
Protected interval	
H_0:	There are no statistically significant differences in minor error rates[3] based on: signal horizontal position (HPOSITION) signal vertical position (VPOSITION) concurrence/discordance of left-turn signal with through signal (AGREETH) concurrence/discordance of simultaneously illuminated left-turn signal sections (AGREELT) presence of supplemental sign (SIGN) number of simultaneously illuminated sections on the left-turn signal (ILLUMINATED) through signal color (THRUCOL) between age groups (among older drivers).
H_1:	Statistically significant differences in minor error rates based on the above variables exist between age groups(among older drivers).
Red interval	
H_0:	There are no statistically significant differences in serious error rates[4] based on: signal horizontal position (HPOSITION) signal vertical position (VPOSITION) presence of supplemental sign (SIGN) signal face arrangement (ARRANGEMENT) presence of a left-turn arrow (ARROW) between age groups (among older drivers).
H_1:	Statistically significant differences in serious error rates based on the above variables exist between age groups(among older drivers).

Table 3.10. (cont'd). Tested hypotheses, intra-interval comprehension analysis
Change interval
H_0: There are no statistically significant differences in correct answer (serious error rates) based on: signal horizontal position (HPOSITION) signal vertical position (VPOSITION) concurrence/discordance of left-turn signal with through signal (AGREETH) concurrence/discordance of simultaneously illuminated left-turn signal sections (AGREELT) presence of supplemental sign (SIGN) number of simultaneously illuminated sections on the left-turn signal (ILLUMINATED) through signal color (THRUCOL) number of through signals (NoTHRU) between age groups (among older drivers). H_1: Statistically significant differences in correct answer (serious error rates) based on the above variables exist between age groups(among older drivers)
Flashing operations
H_0: There are no statistically significant differences in correct answer (serious error rates) based on: signal horizontal position (HPOSITION) signal vertical position (VPOSITION) presence of supplemental sign (SIGN) through signal color (THRUCOL) number of through signals (NoTHRU) left-turn signal indication (LFTFLSH) left-turn action (FLASH) between age groups (among older drivers). H_1: Statistically significant differences in correct answer (serious error rates) based on the above variables exist between age groups(among older drivers)
1. Separate models for correct answer rates and serious error rates, all drivers and older drivers 2. See table 3.6 3. No serious error rates possible for protected interval stimuli, since drivers have the right of way 4. No minor error rates possible for red interval stimuli, since drivers do not have the right of way

3.5. FIELD DATABASE

Field database records represent vehicles involved in accidents. Each record contains vehicle, driver, and accident information as well as geometric and signal information about the approach on which the vehicle was moving when it was involved in the accident. The data, covering a span of 10 years and 324 intersections, were assembled in separate databases and then combined.

Each geometric file record represents conditions at a given intersection approach that consists of information about intersection type, lane assignment and other variables (see table 3.11). Geometric information was obtained from Michigan Department of Transportation (MDOT) archives and dates that geometric changes were enacted were obtained from work contracts.

Table 3.11. Geometrics file variables
Intersection type: Tee Four-leg two two-way streets Four-leg one two-way one one-way street
Number and position of signals (signal profile)
Horizontal and vertical signal position
Lane assignment (geometric profile)
Number of left-turn lanes
Number of opposing-through lanes
Left-turn sign

Signal information was obtained from MDOT intersection files and controller configuration printouts. Each signal file record corresponds to an intersection approach and contains variables pertaining to phasing, signal display complexity, and other signal-related variables (see table 3.12).

Table 3.12. Signal file variables

Approach ID	
Signal section arrangement	
Controller type:	Mechanical Actuated Solid State
Left-turn phase type:	Permitted Protected Protected/permitted
Protected phase type:	Lead Lag
Cycle length in sec.	
Permitted duration in sec.	
Protected duration in sec.	
Number of simultaneously illuminated left-turn signal lenses	
Concurring or discording left-turn and through signal indications during the: Red Phase Yellow Phase Permitted Phase Protected Phase Flashing operations mode	
Major or minor approach	

Multiple records were coded in the corresponding files for intersection approaches where changes were made to geometric and/or signal approach parameters; beginning and ending dates (defining the period during which a particular configuration was in effect for a particular approach) were coded for each record. Only intersection approaches with a left-turn movement facing an opposing through movement were coded in the two files: for example, there is only one leg with left-turns facing an opposing through movement present at T-intersections, the one allowing left-turns off the main direction onto the Tee leg. Similarly, at intersections of one-way with two-way streets, there is only one approach for which left-turning drivers face

opposing traffic.

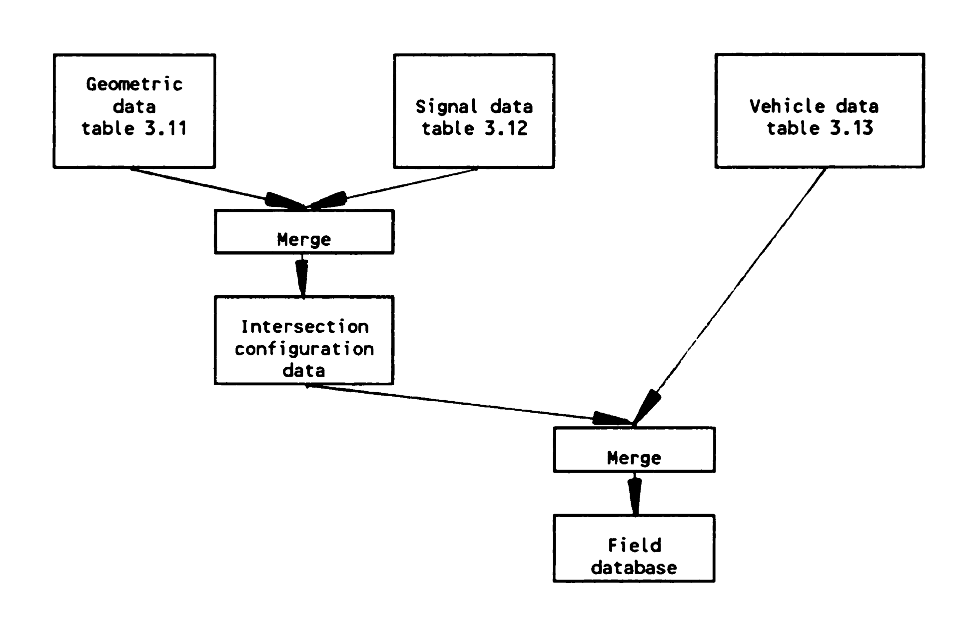
Accident records were obtained from accident records maintained by MDOT. All accidents within 150 feet from each study intersection were selected based on milepoint information coded in the accident record. Each original accident record containing information about all vehicles involved in an accident was separated into vehicle records, one for each vehicle involved in the accident (accident-related variables contained in the database are shown in table 3.13). Vehicle direction before the accident, from the original accident record, was used to assign vehicles to intersection legs.

Table 3.13. Accident variables
Hour, month and year accident occurred
Weather, light, and road surface, conditions
Injury severity
Accident type
Vehicle type
Driver age
Driver residence sex violation
Contributing circumstances
Visual obstructions

In all, 3004 signal, 1217 geometric, and 187,715 vehicle (accident) records were entered in the corresponding files. Geometric and signal information records were merged into an intersection configuration file in such a manner that each new record represents a time period during which the approach signal and geometric configuration remained unchanged. The intersection configuration file contains a total of 3444 records. Finally, each vehicle record was merged with the appropriate intersection configuration record according to where (i.e.,

which intersection leg) and when an accident occurred. This final merge produced the field database (figure 3.6). The field database allows the analysis of the effects that particular signal and geometric configurations have on the occurrence of an accident. Information at the intersection approach level is necessary because in many instances different approaches of the same intersection use different left-turn signal phasing and have dissimilar geometric configurations.

Figure 3.6. Field database



3.6. FIELD DATA ANALYSIS

Based on the literature review, it is expected that as drivers age, they have a higher tendency to become involved in accidents. Furthermore, older driver propensity for higher accident involvement is expected to be more pronounced for more complex intersection maneuvers. The purpose of the field data analysis is to answer a number of questions:

1) Does accident involvement increase with increasing age;
2) Is older driver accident (over)involvement related to intersection maneuver (driving straight through the

intersection versus turning left or right);

3) Is older driver accident (over)involvement present during both normal (daytime) and emergency/ nighttime signal operations;
4) Is older driver accident (over)involvement related to left-turn signal control type;
5) Which approach geometric and signal variables are associated with higher left-turn accident involvement, especially for older drivers; and, finally,
6) What are the most prominent accident characteristics differences that set older drivers apart from other driver age groups.

The field data analysis closely follows the organization of laboratory data analysis in order to facilitate comparisons between findings from the two efforts. Thus, for example, accidents during daytime and nighttime left-turn signal operations are examined separately, also accidents at approaches with permitted, protected, and protected/permitted operations are examined individually, closely following the laboratory data analysis format. Based on signal controller information daytime is defined as the period between 7:00am and 10:59pm and nighttime as the remainder of a 24-hour period. Intersections with 24-hour full-color operations were excluded from nighttime statistics to avoid the introduction of bias due to differential older driver daytime/nighttime performance at full color locations. The abundance of accident information allows the introduction of finer (i.e., narrower) driver age groups than those used in the laboratory data analysis. The original age group limits are augmented depending on the amount of information available. Thus, comparisons between the two analyses are still possible, but a more refined pattern of changes in accident statistics is obtained. However, throughout the field data analysis driver age groups identical to those used for the laboratory data are maintained allowing direct comparisons between the two analyses.

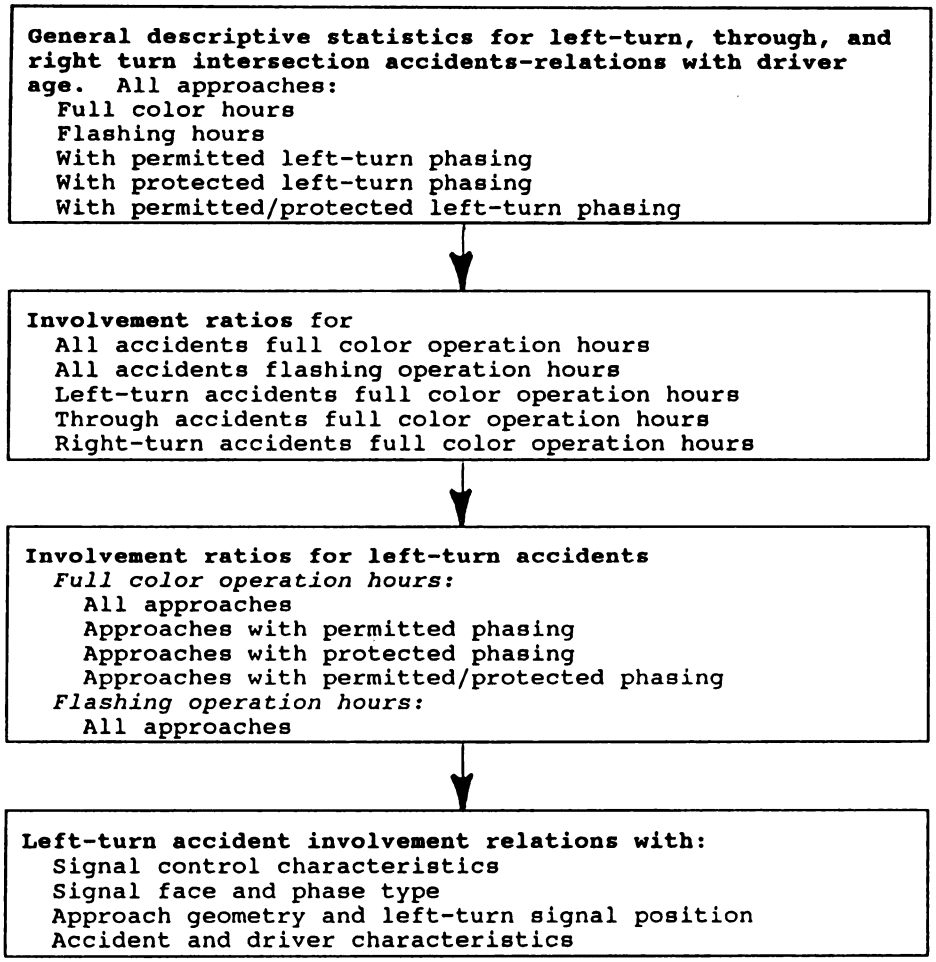
A summary of intersection configuration information can be found in table 3.14. Field database analysis is organized into four parts as outlined in figure 3.7, proceeding from general descriptive statistics analyzing relations of driver age with intersection maneuver to an

Table 3.14. Intersection configuration information	
GENERAL INFORMATION	Number of records
INTERSECTION CONFIGURATION FILE MATCHED RECORDS	
Both geometric and signal information available	2409
Missing geometric record	441
Missing signal record	594
APPROACH IS MAJOR/MINOR	
Major approach	1240
Minor approach	1182
INTERSECTION CONFIGURATION	
Tee	173
4-leg two two-way streets	2681
4-leg two-way & one-way	147
SIGNAL PROFILE (most common configurations)	
1 Left turn 1 Through & right-turn	1653
1 Left turn 1 Through	170
1 Left turn 1 Through 1 Through & right-turn	872
2 Left turn 1 Through & right-turn	116
LEFT TURN SIGNAL HORIZONTAL POSITION (feet left of driver)	
up to 3 feet	1466
4-16 feet	1759
17-38 feet	219
CONTROLLER TYPE	
Mechanical	2194
Actuated	224
Solid State	432
LT PHASE TYPE	
Permitted Green Ball	1864
Protected Green Arrow	400
Protected Green Arrow + Green Ball	40
Protected/Permitted Flashing Red ball, Green Arrow	337
Protected/Permitted Green Ball + Green Arrow	152
CYCLE LENGTH	
45-60 sec.	918
65-75 sec.	726
80 sec.	875
90-120 sec.	224

Table 3.14. (cont'd).

PERMITTED PHASE	Number of records	
DURATION IN SECONDS		
up to 21 sec.	772	
22-27 sec.	549	
28-35 sec.	467	
36-66 sec.	521	
PROTECTED PHASE	**Number of records**	
PHASE TYPE		
Lead	211	
Lag	555	
DURATION IN SECONDS		
up to 6 sec	256	
11-52 sec	334	
7-10 sec	226	
FLASHING OPERATIONS	**Number of records**	
	LEFT-TURN SIGNAL	THROUGH SIGNAL
Flashing yellow	706	894
Flashing red	1046	910
Dark	56	
24-hour operation	1032	1032

Figure 3.7. Field data analysis flowchart



examination of involvement ratios for particular intersection maneuvers (e.g., left turn, through, right turn) and further focusing the analysis into a detailed examination of left-turn accident involvement ratios for each left-turn phasing strategy present in the database (permitted, protected, permitted/ protected). The analysis concludes with an extensive examination of relations of signal control, approach geometry, and driver and accident characteristics, with older driver left-turn intersection accident experience.

Statistical method used for field database analysis

In view of the lack of a measure of exposure that is not age-biased, the driver-at-fault/innocent victim ratio method (D1/D2) discussed in detail in the literature search is used in the present analysis, since it provides a differential measure of exposure based on driver age. Over- (under-) involvement of each driver age group is based on whether more (less) drivers within a particular age group tend to be at-fault than innocent victims in multi-vehicle accidents.

Based on information presented in table 3.15, the involvement

Table 3.15. Male driver D1/D2 table for daytime left-turn accidents at intersections with permitted left-turn phasing

		Driver not at fault (D2) age				
		15-19	20-45	46-60	60+	Row total
Driver at fault (D1) age	15-19	91	293	66	41	491
	20-45	188	800	123	87	1198
	46-60	56	230	33	20	339
	60+	65	296	52	38	451
	Column total	400	1619	274	186	

ratio of 15-19 year-old male drivers involved in daytime left-turn accidents at intersections with permitted left-turn phasing is:

$$\frac{D1}{D2} = \frac{491}{400} = 1.227$$

Similarly, the involvement ratio for drivers 20-45 is 0.74; for drivers 46-60, 1.237; and for drivers over 60, 2.42. These involvement ratios indicate that among male drivers, only those between the ages of 20 and 45 are underinvolved in this particular type of accidents. Drivers from this age group are at fault on 1198 occasions, while they are innocent victims on 1619 occasions out of a total of 2817 occasions when a driver from this age group was involved in an accident. There were 800 accidents where both involved drivers were males between ages 20 and 45. The total number of accidents for this gender and age group is 1619 + 1198 - 800 = 2017. All other male driver age groups were overinvolved in accidents (i.e., the involvement ratios are greater than 1), with drivers over age 60 showing the most pronounced overinvolvement at a ratio of 2.42.

CHAPTER 4

ANALYSIS OF LEFT-TURN SIGNAL COMPREHENSION IN THE LABORATORY

4.1. INTRODUCTION

The material that follows is organized into three major parts as outlined in the analysis methodology (figure 3.4):

I) General subject demographic information;
II) Answer correctness relations with:
 confidence in given answer,
 subject sex,
 miles driven per year, and
 driving experience; and,
III) Answer correctness relations with various signal characteristics.

Demographic information (part I above) is analyzed with general descriptive statistics and analysis of variance (ANOVA) models (summarized in appendix B). Comprehension (parts II and III above) is evaluated using two criteria, namely the overall and older driver error and correct answer rates. The comprehension analysis is organized into paragraphs following similar outlines with an introduction, a presentation of error rates and correct answer rates for all and older drivers and a section summary.

4.2. SUBJECT CHARACTERISTICS ANALYSIS-GENERAL COMPREHENSION ANALYSIS

Of the 191 subjects in the laboratory experiment, fifty-six percent (107) were males. Subjects were distributed fairly evenly over the four age groups: ages 16-30 (50 subjects), 31-45 (51), 46-60 (48), >60 (42) so that enough individuals are present in each group for statistical inferences (see table 3.1.). A graphic summary of various demographic and driving characteristics of the subjects is presented in figures 4.1-4.3. About 86% of the respondents in the youngest and oldest age groups drive less than 15,000 miles per year compared to about 72% for the other two age groups. About 62% of the youngest drivers drive less than 10,000 miles per year. This percentage drops to 44% for the 31-45 year-olds, and then increases until it becomes 75% for the oldest driver group (figure 4.1). The youngest and oldest drivers tend to drive less than the other two age cohorts with the oldest group

Figure 4.1. Miles driven annually by age

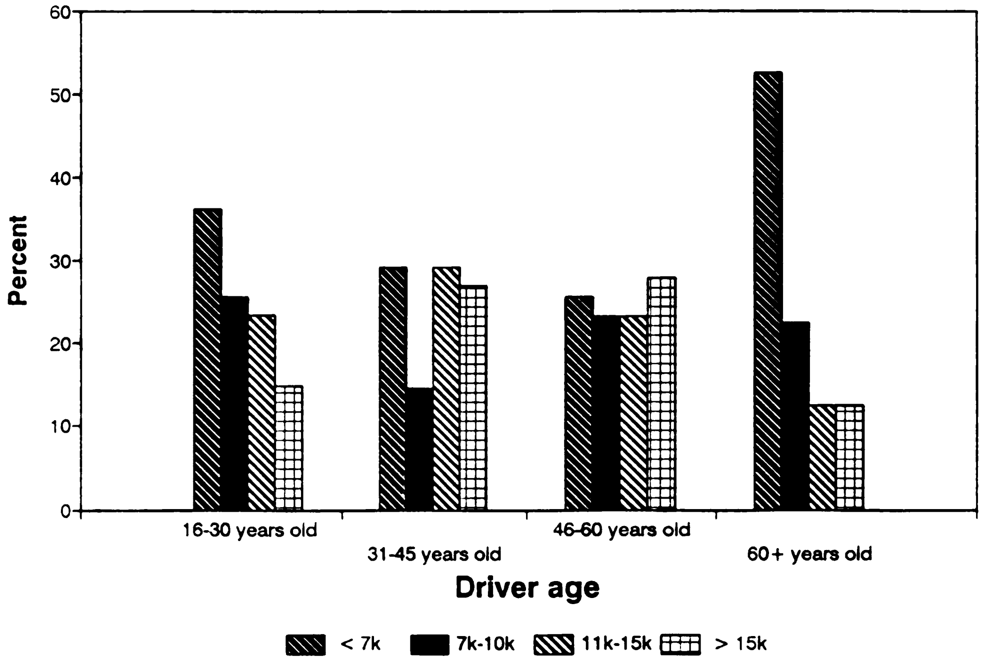


Figure 4.2. Miles driven annually by age (male drivers)

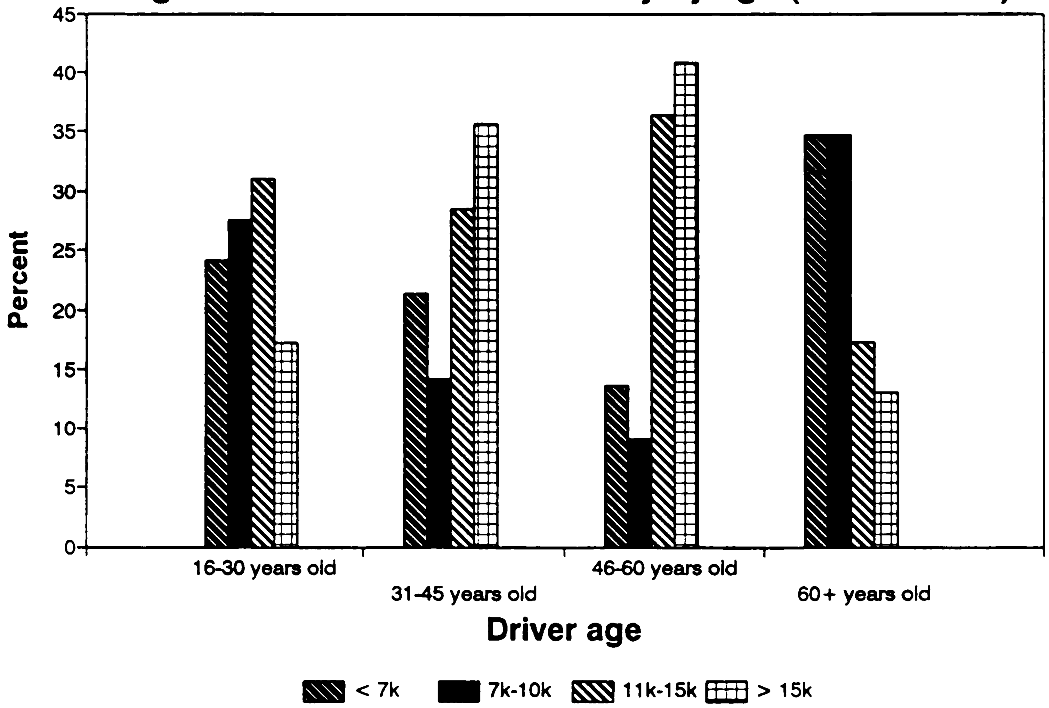
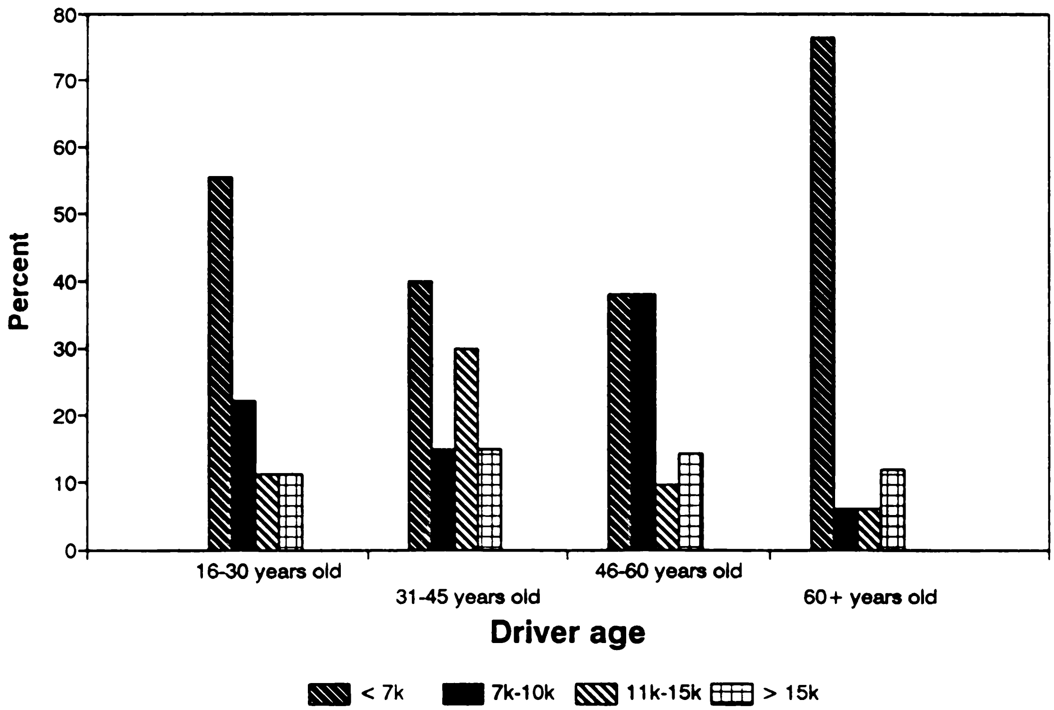


Figure 4.3. Miles driven annually by age (female drivers)



driving less than any other.

When mileage is further analyzed by sex (figures 4.2 and 4.3), an important difference between male and female subjects becomes evident: a larger percentage of female drivers tend to drive less than 10,000 miles per year for all age groups. This difference is especially striking for the 46-60 year-old drivers 71% of female drivers drive less than 10,000 miles per year compared to 22% of male drivers.

Male drivers drive more miles per year as they age, until age 60. Males older than 60 show a dramatic decrease in miles driven as they drive even less than the youngest drivers. A similar trend was observed for female drivers, except there is a drop in miles driven for the 46-60 year- old drivers and this trend continues through the oldest driver group where 76% drive less than 7,000 miles per year. The percent of female drivers that drive 15,000 miles or less annually remains around 87% for all age groups while for males this percentage represents only the youngest and oldest drivers. About 65% of the other male age groups are within this range. Analysis of variance (ANOVA) models were developed to analyze miles driven per year (dependent variable) by subject age and sex. Using AGE as the only independent variable, statistically significant differences in miles driven per year were found ($F_{ratio} = 2.62$, $F_{Prob} = .053$). A model including both sex and age as independent variables, showed statistically significant differences for main effects ($F_{ratio} = 3.95$, $F_{Prob} = .004$), while the age-sex two-way interaction was not found to be statistically significant. A multiple classification analysis shows a sample average of approximately 12,000 miles driven annually with the youngest and oldest drivers driving less than the average (-650 and -4700 miles per annum--adjusted for other independent variables-- respectively), and drivers 31 to 45 and 46 to 60 years old driving above the average (+1800 and +3100 miles per annum respectively).

Relations of answer correctness to estimated miles driven, driver age, years of driving experience, and sex are presented in figures

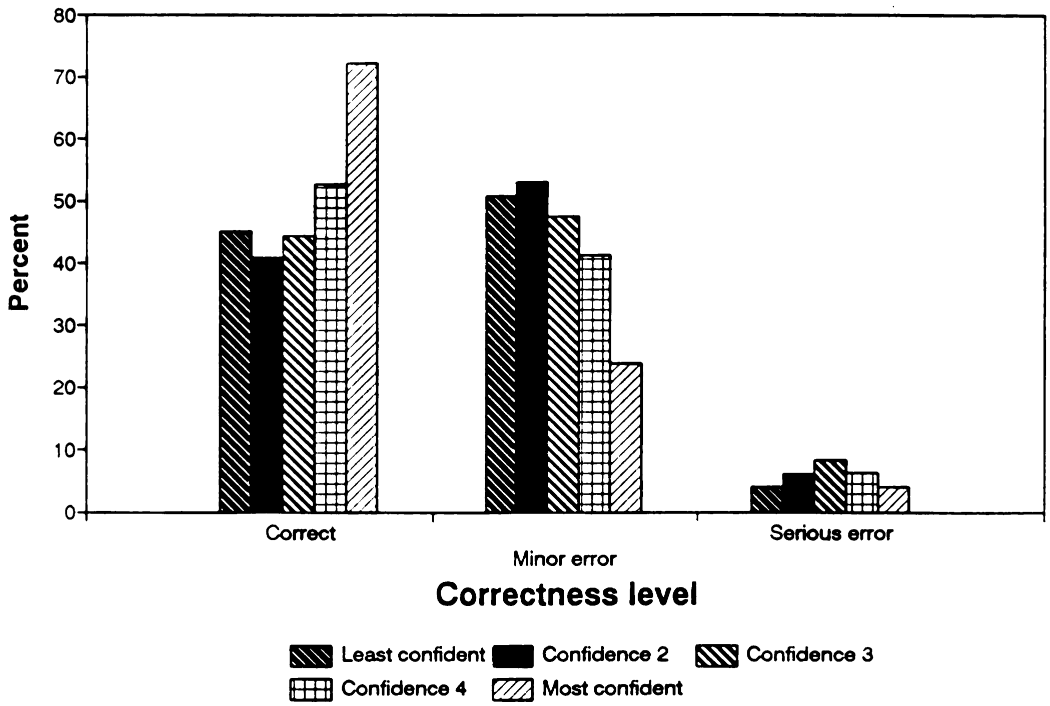
4.4-4.8. For both sexes, the percent correct responses among confident answers (confidence score of five) is higher than the percent correct responses among less confident answers (approximately 72% for confident responses compared to an average of about 46% correct answers for less than confident responses--see figure 4.4). However, the number of correct plus minor error responses tends to be reasonably constant among levels of confidence (about 94%). This is an indication that, when drivers are not certain about the correct action, they tend to behave in a conservative manner since both drivers who are confident in their responses and those who are not tend to commit a relatively small number of serious errors (about 6%). Answer correctness at various levels of answer confidence is similar for both sexes.

For both sexes, the percent of correct answers increases from about 57% for under 7,000 miles driven annually to about 71% for 11-15,000 miles driven annually and drops to about 62% for over 15,000 miles driven annually. Correct plus minor error answers are about 95% regardless of miles driven (figure 4.5).

Two ANOVA models using annual mileage driven as the independent variable and correct and serious answer rates as the dependent variables respectively, showed the following: correct answer rates differ between annual miles driven categories (F_{ratio} = 5.99, F_{Prob} = .001) while no significant differences were found for serious error rates (F_{ratio} = 0.86, F_{Prob} = .462). The highest percentage of correct answers, and at the same time lowest rates of minor and serious errors, were attained by individuals driving 10-15,000 miles annually.

The percent of correct answers decreases with age in a similar fashion for both sexes: the youngest group correctly answered about 70% of the questions, and this percentage declines steadily to the oldest group which correctly answered only 51%. When the correct plus minor error rate is considered, the differences between age groups follow the same trend but are less pronounced--the range is from 96% to 93%. The oldest group appears to make up for lack of comprehension by acting in a conservative manner-e.g., giving the right-of-way to other drivers

Figure 4.4. Answer correctness by confidence in given answer



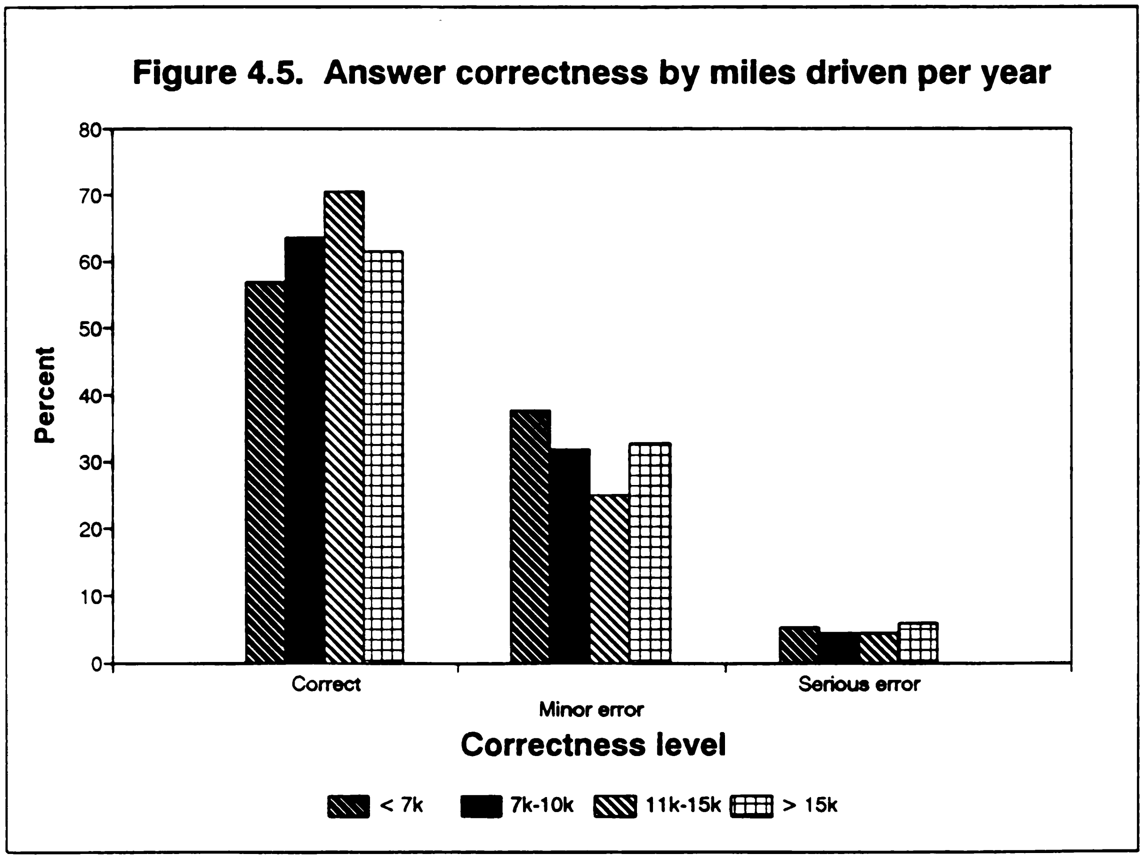
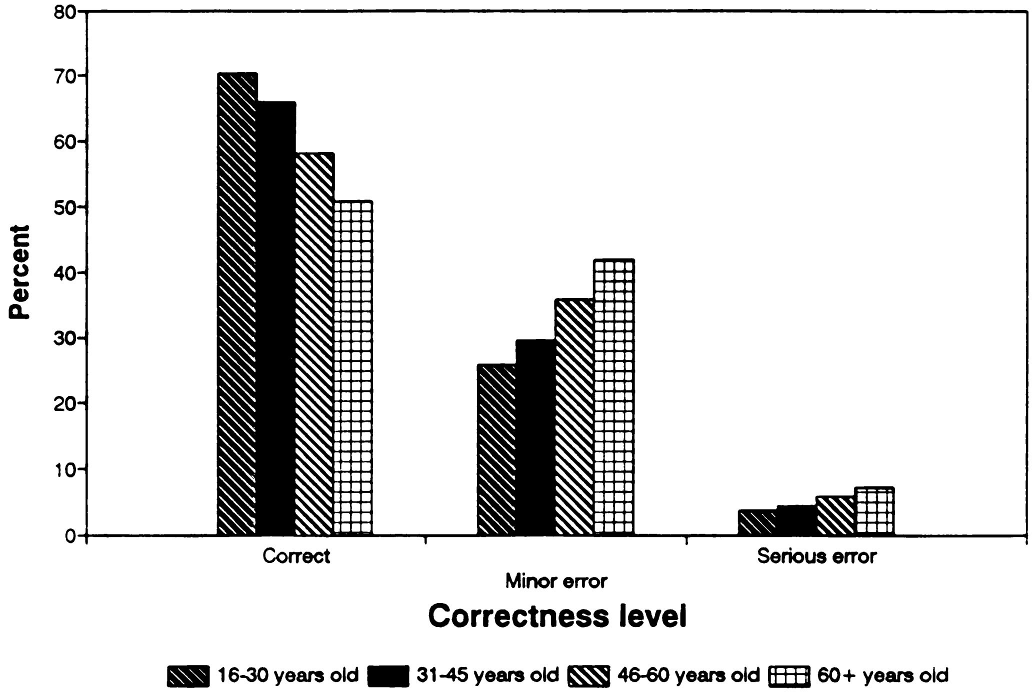


Figure 4.5. Answer correctness by miles driven per year
Percent
80
70
60
50
40
30
20
10
0
Correct
Minor error
Serious error
Correctness level
< 7k
7k-10k
11k-15k
> 15k

Figure 4.6. Answer correctness by driver age



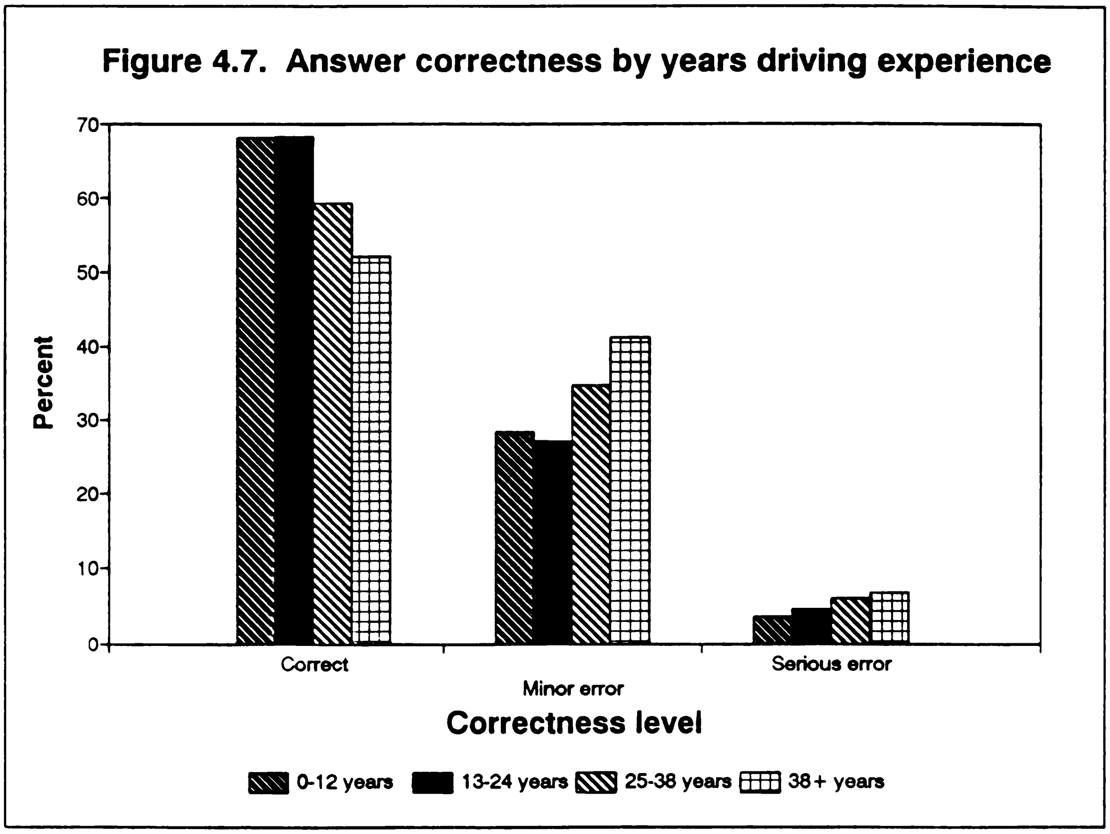
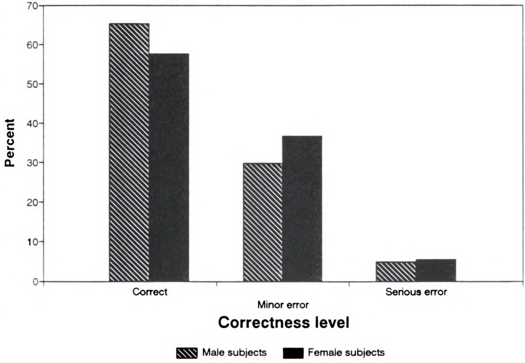


Figure 4.7. Answer correctness by years driving experience
Percent
70
60
50
40
30
20
10
0
Correct
Minor error
Serious error
Correctness level
0-12 years
13-24 years
25-38 years
38+ years

Figure 4.8. Answer correctness by sex



(figure 4.6). Drivers with less than 24 years of driving experience have a correct answer rate of approximately 68 percent. From that point on there is a continuous decrease in the number of correct answers with increasing driving experience until it becomes 52% for drivers with more than 38 years of driving experience (figure 4.7). Although figure 4.7 does not make intuitive sense by itself, it is in line with the discussion about driver age, since the more experienced the drivers, the older they are (in general). It also implies that experience may not overcome other problems for older drivers.

Significant differences among driver experience groups were found for correct answer rate (F_{ratio} = 8.74, F_{Prob} = .000) as well as a serious error rate ANOVA model (F_{ratio} = 3.08, and F_{Prob} = .029).

It has been observed that the causes for over-representation in accidents are different for the youngest and oldest drivers. Younger drivers tend to be cited for driving too fast and, although they have better comprehension and reaction times, they tend to overestimate their capabilities and those of the vehicles they drive. Older drivers tend to be conservative but have problems with stimulus comprehension and reaction times (73, 74, 126). Figures 4.6 and 4.7 suggest that signal comprehension might be one area where the youngest and oldest drivers differ--the oldest drivers show a much lower rate of correct interpretation of left-turn stimuli than their younger counterparts.

Female subjects had about 58% correct answers while their male counterparts had about 65% correct answers. Again, when correct and minor error answers are combined, the sexes are tied at 95% (figure 4.8). While correct answer rates were found to differ among sexes (F_{ratio} = 10.75, F_{Prob} = .001), serious error rates are essentially identical (F_{ratio} = 1.07, F_{Prob} = .302) at seven percent.

Other than the differences mentioned above, none of the data presented in figures 4.4-4.8 had any significant differences among sexes.

Summary of subject characteristics analysis findings

Youngest and oldest drivers drive less miles per year than other drivers. Female drivers drive less than their male counterparts with the most pronounced differences being among the older than 45 year-old drivers. Drivers of both sexes drive more miles until a certain age cutoff and then drive less (even less than the youngest drivers). The reduction in miles driven with progressing age occurs for 46-60 year-old female drivers and continues through the oldest female drivers, while for male drivers it is only evident for the oldest age group.

As would be expected (and hoped), a significantly higher rate of correct answers is found among confident answers (with a confidence score of five) than among less than confident answers. Cumulative correct and minor error answers are at an almost constant level indicating that when drivers are not certain about the meaning of a display, they choose to surrender their right-of-way.

The rate of correct responses increases with annual miles driven up to about 15,000 miles/year and then declines. Statistically significant differences in correct answer rates among levels of miles driven annually were verified using ANOVA; no such differences were found for serious error rates.

The youngest drivers have the highest rate of correct answers and the oldest drivers have the lowest, with correct answer rates steadily declining with age. The cumulative correct and minor error rates follow the same trends although with a much less pronounced decline in the differences with progressing age.

The rate of correct answers steadily declines with increasing driver experience, a trend associated with driver age. A much less pronounced increase in serious error rates is present across driving experience levels. However, ANOVA models for both correct and serious error rates show statistically significant differences in the distribution of answer correctness across driver experience groups. Individuals with up to 24 years driving experience have the best comprehension rates. Statistically significant correct answer rate differences were found among sexes with males having a significantly higher rate of correct answers. However, no comprehension differences in serious error responses were found among sexes.

4.3. ANALYSIS OF ANSWER CORRECTNESS RELATIONS WITH VARIOUS SIGNAL CHARACTERISTICS

The analysis of relationships between signal characteristics and answer correctness consists of two components (see chapter 3), the inter- and intra-interval comprehension comparisons (figure 3.5). Inter-interval comparisons were used to examine the existence of comprehension differences across age groups based on interval type. Intra-interval comparisons were used to identify the existence of comprehension differences across age groups among stimuli used for the same interval type. Comprehension effects of individual signal characteristics as well as interactions among such characteristics were investigated.

Inter-interval analysis

Four ANOVA models are used to address the inter-interval analysis hypotheses presented in table 3.9. In the first model, serious error rate is used as the independent variable to examine driver comprehension of interval meaning by driver age. Included in the database are all subject responses to permitted, change, and red intervals as well as flashing operations stimuli. A second model, restricted to older subjects, uses the same dependent variable and interval meaning as an independent variable. Responses to stimuli used for the protected phase are not included in these models since no serious errors are possible when drivers have the right-of-way. The models are used to derive conclusions about which phases are least understood by drivers to the extent that they may violate other drivers' right-of-way (i.e., commit serious errors) and potentially become involved in serious accidents.

Finally, two ANOVA models, similar to the ones mentioned above (i.e., one for all subjects and one for older subjects) are constructed to examine correct answer rates as the dependent variables. Protected stimuli are included in the database. Intervals with low correct answer rates need particular attention by traffic engineers; those with high correct answer rates may be given preference. The results of all four ANOVA models are summarized at the conclusion of this section.

Serious errors-all drivers

Responses indicating that the driver would violate the right of way of other drivers are classified as "serious errors." Serious errors are, therefore, not possible for stimuli indicating a protected left-turn phase.

When serious error rates (regardless of stimulus meaning) are compared across age groups using a one-way ANOVA, serious error rate differences are detected between driver age groups (F_{ratio} = 3.15, F_{Prob} = .026). (Note that statistical details are provided in appendix B). Figure 4.9 shows 95% confidence intervals by driver age for serious error rates. There is a statistically significant increase in percent serious errors with increasing age (from 5.3% for the youngest drivers to 9.4% for the oldest). The two youngest driver groups have small comprehension differences, but differences increase in an accelerated fashion as age progresses.

Comprehension scores examined under a multivariate analysis of variance model with repeated measures applied to multiple groups show statistically significant comprehension differences among stimulus meaning categories (F_{ratio} = 38.31, F_{Prob} = .000) across age groups (F_{ratio} = 5.65, F_{Prob} = .001--see appendix B). No significant age-stimulus meaning interaction effect was detected (F_{ratio} = 0.01, F_{Prob} = .354). The 95% confidence intervals of responses to each stimulus group are shown in figure 4.10. Best understood are stimuli used for the change interval with an average serious error rate of only 1.0%. Next are red interval stimuli (3.7%) and permitted stimuli (8.3%). Least well understood are flashing mode stimuli with an average of 12.6% serious error rate. The 95% confidence intervals for any two stimuli groups do not overlap, but the upper limit of permitted stimuli coincides with the lower limit of flashing mode stimuli.

Figure 4.9. All drivers all stimuli serious errors

95% confidence intervals for the means

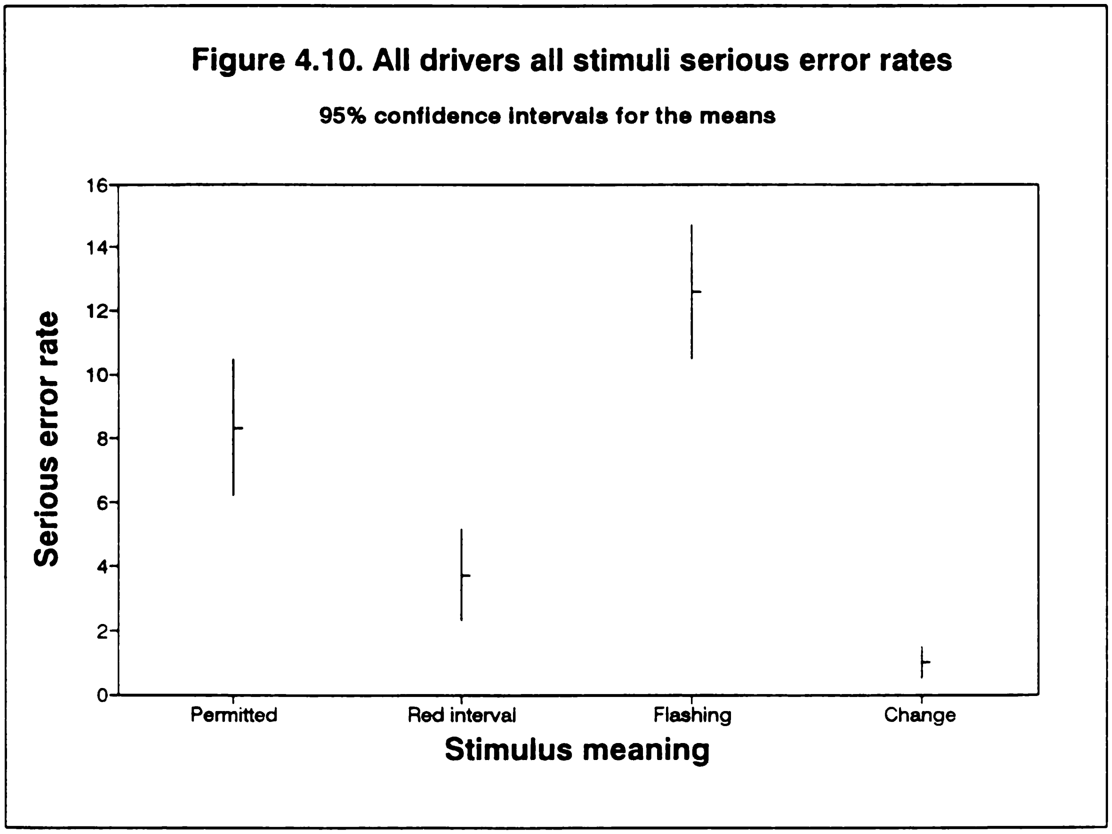


Figure 4.10. All drivers all stimuli serious error rates
95% confidence intervals for the means
Serious error rate
16
14
12
10
8
6
4
2
0
Permitted
Red interval
Flashing
Change
Stimulus meaning

Serious errors-older drivers

A multivariate analysis of variance model with repeated measures applied to older drivers shows statistically significant differences among stimulus meaning groups (F_{ratio} = 9.73, F_{Prob} = .000). The rank of stimulus meaning groups based on stimulus comprehension score remains the same as for the whole driver population as shown in figure 4.11. However, serious error rates are magnified among older drivers. Best understood are stimuli used for the change interval with an average serious error rate of 1.4% followed by red interval stimuli with an average serious error rate of 8.3%, the permitted interval at 12.5%, and, finally, flashing mode stimuli at 15.4%.

Summary and interpretation-serious errors

Stimuli demanding the most "obvious" driver reactions (such as preparing to stop for a change interval or red ball) have the highest comprehension scores and those involving some interpretation because of a special meaning pertaining to the left-turning maneuver have lower scores. For example, flashing mode stimuli require more interpretation because right-of-way rules change depending on the combination of flashing colors on the left and through signals--red with red have a different meaning than red with yellow.

Comprehension differences based on stimulus meaning are similar across all age groups (no significant stimulus meaning-driver age interaction effects were identified). For example, change interval stimuli are best and flashing stimuli least well comprehended for all age groups. However, differences among stimuli groups are more pronounced among older drivers.

Signal complexity may explain both stimulus meaning and age group patterns of serious error rates as demonstrated in the following examples. The most complex situation is that of a flashing red ball where stimulus meaning varies according to the through signal indication. Although the driver always has to stop, a through flashing yellow ball requires the driver proceed if there is no opposing traffic; a flashing red ball requires the driver to proceed if there is no opposing or cross street traffic. The complexity of this situation is clearly reflected by the high serious error rates for such stimuli, especially for older drivers. A steady yellow or red ball, the simplest displays with a singular meaning, i.e., "prepare to stop" or "stop-you do not have the right of way," is associated with the lowest serious error rates both for all driver ages.

Correct answers-all drivers

Comprehension scores examined under a multivariate analysis of variance model with repeated measures applied to multiple groups shows differences among age groups (F_{ratio} = 13.37, F_{Prob} = .000) and stimulus meaning categories (F_{ratio} = 180.32, F_{Prob} = .000). A significant age-stimulus meaning interaction effect was also detected (F_{ratio} = 2.42, F_{Prob} = .004). Here, again, driver comprehension is deteriorating with age (figure 4.6). The ranking of stimuli groups (best comprehended group has a rank of one) is different than that based on serious error rates, the differences being due to the presence of differing "minor error" rates among stimuli groups. Best comprehended are red interval stimuli followed by change, protected, permitted, and flashing operations stimuli.

Correct answers-older drivers

Comprehension varies across stimulus meaning categories in terms of correct answer responses among older drivers (F_{ratio} = 47.38, F_{Prob} = .000). The ranks of stimulus meaning groups based on stimulus comprehension scores are identical to those for all drivers. The 95% confidence intervals of responses to each stimulus group are shown in figure 4.12. Best understood are stimuli used for the red interval with an average correct answer rate of 92%, followed by change interval stimuli (63%), protected (49%), permitted (38%), and finally, flashing operations (32%).

Summary and interpretation-correct answers

Statistically significant stimulus comprehension differences exist across stimulus meaning and driver age groups. Best comprehended are stimuli used for the red phase interval, followed by those used for the

Figure 4.11. Older drivers all stimuli serious error rates

95% confidence intervals for the means

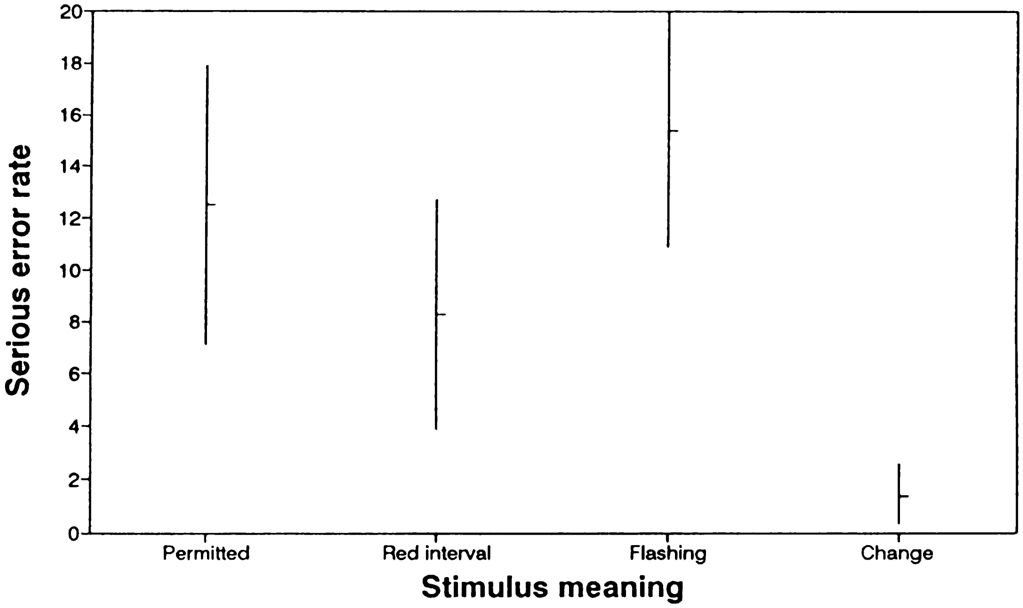
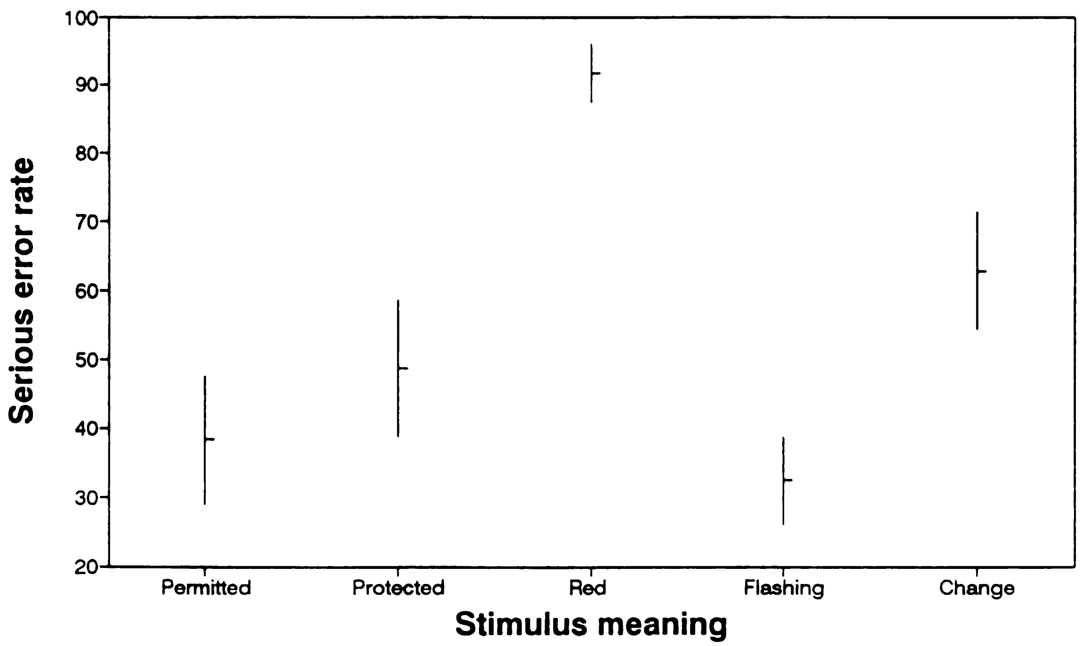


Figure 4.12. Older drivers all stimuli correct answer rates

95% confidence intervals for the means



change, protected, permitted, and flashing intervals respectively. The rank orders of stimulus meaning groups based on correct answer rates are identical for all and older drivers. Stimulus complexity may explain comprehension differences, since simple stimuli (e.g., red, change interval stimuli), with singular meanings, are better comprehended than more complex stimuli (e.g., flashing operations stimuli).

Inter-interval summary

Stimulus comprehension measured both in serious error and correct answer rates has been found to depend on stimulus message, and driver age. It is important to note that stimulus meaning ranks based on the same type of comprehension scores (i.e., serious error, correct answer rates) are identical for all and older drivers. Best comprehended are the simple unambiguous stimuli used for the change and red intervals, while least well understood are those used for flashing operations.

Comprehension was found to deteriorate to a statistically significantly degree with advancing age. Serious error rates are the highest and correct answer rates the lowest for drivers over 60 years of age.

Intra-interval analysis

The intra-interval comprehension analysis includes separate discussions on the permitted, protected, red and change intervals, and, finally, flashing operations. Each paragraph begins with a discussion of driver comprehension explanatory variables that were analyzed relevant to the particular set of stimuli and follows a format similar to the one used in the inter-interval analysis. Specifically, ANOVA models using serious error rate (minor error rate for stimuli used in protected phasing where serious errors are not possible) as the dependent variable and driver age as well as signal position, arrangement, and various complexity variables as independent variables are presented for all and older drivers, followed by similar models using correct answer rate as the dependent variable. A summary of findings concludes each section with an overview of the intra-interval analysis following the discussion on flashing operations.

Permitted stimuli

Eleven stimuli used for the permitted interval are included in this analysis. Independent variables used in the ANOVA models include subject age, signal horizontal position, concurrence or discordance of left and through signal indications, and number of through signals:

i) Signal horizontal position (HPOSITION). A signal placed at the extension of the left-turn lane may lead the driver to different reactions than a signal placed in a "shared" position, between the left-turn and the through lanes. Since the green ball has a different meaning for a left-turning driver (yield to opposing traffic) and a driver moving straight-ahead (you have the right-of-way), signal positioning may be crucial in reinforcing the notion that the driver does not have the right-of-way. It is reasonable to hypothesize that the closer the left-turn signal is to the through signal, the higher the potential for driver misinterpretation, and the further removed from the through signal, the higher the possibility that the driver will correctly interpret the permitted meaning.

ii) The concurrence or discordance of the left-turn signal indication with that of the through signal indication (AGREETH). A concurring indication may lead the drivers to believe they have the right-of-way, since the display itself does not differentiate between right-of-way rules applying to left-turning (proceed if there is no opposing traffic) and through drivers (proceed, you have the right-of-way): proper driver behavior depends absolutely on driver ability to interpret signal meaning relative to his/her movement intentions. On the other hand, a discording indication may make drivers more cautious, since signal faces indicate that through and left-turning movements have distinct right-of-way obligations. It should be kept in mind that only special displays (such as flashing yellow or red ball on the left-turn signal) use discording left-turn messages. Since the through signal is always a green ball, all "conventional" displays using a green ball on the left-turn signal can only be concurring.

iii) The number of through signals (NoTHRU). The presence of two

through green balls may affect driver interpretation of a permitted left-turn compared to stimuli using only one through signal. For example, the presence of multiple signal heads increases stimulus complexity and might adversely affect drivers vulnerable to decision-making problems (e.g., older drivers).

Permitted: serious errors-all drivers

Serious errors during the permitted phase are associated with responses indicating that drivers incorrectly thought they had the right-of-way while turning. The ANOVA results presented in the following paragraphs use serious error rates as the dependent variable.

Serious error rates are not statistically significantly different across subject age levels (F_{ratio} = 0.654, F_{Prob} = 0.582) (see appendix B) while they are significantly different depending on whether the left-turn signal indication is concurring or discording with the through signal indication (F_{ratio} = 43.73, F_{Prob} = 0.000). Concurring left-turn and through signal indications are, as expected, associated with higher serious error rates (13.2%) than discording (1.4%).

No significant comprehension differences were found between stimuli using one and two through signal heads. However, comprehension is significantly different for locations with left-turn signals mounted between the left-turn and through lanes and those where signals are placed along the left-turn lane centerline. Between-lane placement is associated with a lower comprehension rate (12.8%) than the straight-ahead position (6.5%). This result is consistent with the hypothesis that a closer placement to the through signal may lead drivers to mistakenly assume they have the right of way.

Permitted: serious errors-older drivers

Concurrence or discordance of the left-turn signal with the through signal (AGREETH) was found to be related to older driver comprehension (F_{ratio} = 15.23, F_{Prob} = 0.000). As with all drivers, concurring left-turn and through signal indications are associated with higher serious error rates (17.8%) than discording (1.8%), following the same pattern (only exaggerated) identified for the entire subject sample. The number of through signals (NoTHRU) and left-turn signal horizontal position (HPOSIT) were not found to be associated with serious error rates for older drivers.

Permitted: summary and interpretation-serious errors

The meaning of a green ball on the left-turn signal needs driver interpretation to distinguish it from a green ball addressed to the through driver. A permitted phase green ball is a "passive" signal in the sense that it does not actively relate its distinct message to the driver. Three techniques to convert such a "passive" signal into an "active," one that will provide additional information to the driver about its special message were examined here: use of discordant left-turn and through signal displays, positioning of the signal, and number of through signals. (Not enough data were available for reliable statistical inferences on the presence of a supplemental sign).

It is reasonable to assume that situations where the left-turn and through signal meanings are kept distinct will be associated with higher driver comprehension scores. Thus, wider horizontal separation of left-turn and through signals, one instead of two through signal heads, and discording left-turn and through signals were expected to be associated with lower serious error rates. This was found to be the case.

Left-turn signal concurrence or discordance with the through signal message is associated with serious error rates in the same manner for older drivers as for the whole population, only the effect is more pronounced: concurring messages have a detrimental effect on driver comprehension and discording messages have a beneficial effect.

Signal horizontal position impacts driver comprehension when the entire sample was considered. They were not significant in explaining older driver comprehension. Signal placement between the left and through lanes versus along the left-turn lane centerline was found to be associated with lower driver comprehension scores.

However, subject age was not found to contribute to serious error rate differences among subjects.

Permitted: correct answers-all drivers

The only correct answer during the permitted phase is "turn left without stopping, unless you have to yield to opposing traffic." Correct answer rates were found to be significantly different among age groups (F_{ratio} = 7.545, F_{Prob} = 0.000). Moreover, comprehension deteriorates with advancing age with the youngest drivers interpreting 66% of the permitted stimuli correctly and drivers over age 60 correctly interpreting only 38% of the stimuli.

No significant comprehension differences were identified using ANOVA models including age and: concurrence/discordance with the through signal; number of through signals; or signal horizontal placement. No variable other than subject age was found to be statistically significant, and all interactions with age were found to be non-significant.

Permitted: correct answers-older drivers

No statistically significant comprehension differences were identified for concurrence/discordance with the through signal; number of through signals; or left-turn signal horizontal placement.

Permitted: correct answers-summary

Correct answer rates deteriorate with increasing age but no other variables were found to be statistically significant at the .05 significance level.

Permitted: summary and discussion

Permitted phase stimuli have the lowest correct answer rates (average 38%) and highest serious error rates (average 8.2%-see figure 4.10) among stimuli used for normal, non-flashing operations. This finding is especially important in light of the popularity of permitted phasing and the fact that the permitted phase commonly uses a large fraction of intersection green time thus providing ample opportunity for a large number of violations of right-of-way rules by drivers that misinterpret its meaning.

Concurring left-turn and through signal indications had worse performance than discording signals, while one through signal was associated with better than average comprehension, compared to two through signals. Signals placed in the straight-ahead position had better than average performance compared to those placed between lanes. Serious error rates were found to increase with advancing age, but not to a statistically significant degree. No variables, other than subject age, were found to be related to correct answer rates.

Results associating serious error rates with concurrence or discordance of left-turn with through signal displays, number of through signals, and signal horizontal position can be easily translated into practical measures to improve permitted phase comprehension in the field. For example, the typical Michigan display with discording left-turn (flashing red ball) and through (green ball) indications placed in the straight-ahead position can be expected, based on the preceding analysis, to be better comprehended than a typical stacked three display (red, yellow, and green balls--green ball illuminated) mounted between the left-turn and through lanes. Since the same variables affect all drivers regardless of age, and in the same direction, it is expected that engineering measures designed to benefit older drivers, will benefit all drivers as well.

Protected stimuli

Driver comprehension analysis of the twenty stimuli used for the protected interval of minor error rate as the dependent variable. Only correct answers and minor errors are possible for protected phase stimuli, since subjects have the right of way they cannot violate another driver's right of way.

In addition to subject age, independent variables examined in the present section include the presence of a left-turn supplemental sign, and the configuration of illuminated lenses on the left-turn and through signals:

I) Sign presence (SIGN). The presence of left-turn supplemental signs may enhance driver understanding by clarifying the left-turn signal display message. On the other hand, sign presence increases stimulus complexity by adding an extra piece of information to be processed by the driver.

II) Left-turn and through signal illuminated section configuration (COLORS). Several conditions were analyzed:

i) Concurring left-turn signal sections--green arrow alone or with a green ball--simultaneously illuminated with a through signal red ball;

ii) Discording sections on the left-turn signal--green arrow and red ball-- simultaneously illuminated with a through signal red ball;

iii) Concurring left-turn signal sections--same as i) above--simultaneously illuminated with through signal green ball; and finally,

iv) Special stimuli .

The definition of COLORS incorporates a combination of signal display complexity traits, such as: concurrence or discordance of the left-turn and through signal indications; concurrence or discordance of simultaneously illuminated sections on the left-turn signal; and, through signal color. Concurring left-turn and through signal indications may enhance the meaning of a protected left-turn indication (all illuminated signal sections on all signal faces are green) while discording indications may make drivers hesitate while deciding about the correct action (the driver needs to understand that although the through signal shows a red indication he/she still has the right of way). Simultaneous presence of a green ball and a green arrow on the left-turn signal face might confuse drivers not sure whether they should assume a permitted (green ball) or protected (green arrow) indication. A red ball simultaneously illuminated with a green arrow on the left-turn signal might confuse drivers perceiving two seemingly contradictory messages.

Protected: minor errors-all drivers

Minor errors are associated with answers indicating subjects think they have to yield the right of way while turning during the protected phase.

Minor error rates are different across age groups (F_{ratio} = 5.595, F_{Prob} = .001) with driver comprehension declining with age. The 95% confidence interval for mean young driver comprehension (24%) does not overlap with that of drivers over 60 years of age (mean 51%). The mean for 30-45 year olds is 37%, and that of 46-60 year olds is 39%.

the presence and message of supplemental signs was found to be statistically significant (F_{ratio} = 22.17, F_{Prob} = .000), and the sign "left-turn signal" performed better than the no sign condition (average error rates of 31.1% and 37.8%, respectively). COLORS was found to be statistically significant (F_{ratio} = 69.7, F_{Prob} = 0.000). Best performing (i.e., lowest minor error rates) were displays with concurring left-turn signal sections (green arrow alone, or in conjunction with green ball) simultaneously displayed with a through red ball (average minor error rate 23.5%). Next best were displays similar to the previous ones with a through green ball (31.0%), followed by displays with discording left-turn signal sections (green arrow and red ball), simultaneously displayed with a through red ball (43.8%). Finally, special displays (e.g., fast flashing green arrow) had the lowest comprehension rates (53.4%).

A model incorporating both age and supplemental sign showed statistically significant results for both variables (F_{ratio} = 4.81, F_{Prob} = 0.003, and F_{ratio} = 22.16, F_{Prob} = 0.00, respectively) while the age by sign interaction was not significant. Similarly, a model including age and COLORS showed both to be significant (F_{ratio} = 5.55, F_{Prob} = 0.001, and F_{ratio} = 70.50, F_{Prob} = 0.000 respectively) although there were no statistically significant interaction results. Signal position (both horizontal and vertical) and signal head arrangement were not found to significantly affect minor error rates.

Protected: minor errors-older drivers

Both variables SIGN and COLORS were found to be significant (F_{ratio} = 5.82, F_{Prob} = 0.021, and F_{ratio} = 17.93 F_{Prob} = 0.000 respectively), and both were found to affect all and older driver comprehension in a similar manner. For example, locations with a sign "left-turn signal" associated with lower minor errors for all drivers, were also associated with lower minor error rates among older drivers as well.

Protected: summary and discussion

When all drivers were considered, AGE, COLORS, and SIGN were found to be significant in explaining minor error variance. ANOVA examining AGE simultaneously with COLORS or SIGN showed significant main effects, but no interaction effects. COLORS classifies stimuli according to illuminated lens configuration. Best comprehended are stimuli with concurring left-turn signal sections but discording left-turn/ through sections, followed by concurring left-turn sections with concurring through sections. Discording left-turn sections with a through red ball follow, with the special stimuli category being the least understood. Thus, concurrence of illuminated left-turn signal sections is most closely associated with better comprehension, while discordance of left-turn with through signal indication also results in better than average comprehension. Low comprehension associated with special displays can be interpreted as being the result of i) unfamiliar stimuli (fast flashing green arrow for example), or, ii) a confusing supplemental sign ("left-turn must yield on green ball" when green ball and green arrow sections are illuminated simultaneously). The presence of the sign "left-turn signal" was found to be associated with lower error rates.

COLORS and SIGN are also statistically significant when older drivers are analyzed separately. Stimulus categories defined in COLORS and SIGN affect older driver comprehension in the same direction as they do all drivers, but their effects are more pronounced for older drivers.

Minor error rates increase with increasing age. Youngest and oldest driver comprehensions are about 13 percentage points in opposite directions from the grand mean (equal absolute differences), while drivers 31 to 45 and 46 to 60 years old are about one percentage point from the grand mean.

In summary, minor errors in the comprehension of protected left-turn displays are primarily related to the concurrence or discordance of illuminated left-turn signal sections among themselves; the concurrence or discordance of illuminated left-turn and through signal sections; and, finally, the presence of unusual left-turn signal stimuli and the presence or absence of the supplemental sign "left-turn signal."

Red stimuli comprehension

Nine stimuli for the red interval phase are included in the database. All stimuli consist of a through red ball and either a red ball or a red arrow on the left-turn signal. Since only correct and serious error answers are possible for red interval stimuli (any misinterpretation of a red phase stimulus will lead to the violation of another driver's right of way--a serious error), the analysis is limited to the discussion of serious errors.

A number of variables that may affect driver comprehension of a red left-turn display, such as horizontal signal positioning (HPOSIT), number of through signals (NoTHRU), and the presence of a supplemental sign (SIGN), for which adequate information was available, were examined individually and simultaneously with driver age (AGE).

Red: serious errors-all drivers

Statistically significant differences in serious error rates exist among driver age groups (F_{ratio} = 4.59, F_{Prob} = 0.004). In general, driver comprehension deteriorates with advancing age, with drivers 16 to 30 years old having a mean serious error rate of 1.4%, increasing to 8.3% for drivers over 60 years old.

Left-turn signal horizontal position was found to affect driver comprehension significantly (F_{ratio} = 6.44, F_{Prob} = 0.012). Signals placed in the straight-ahead position performed worse (3.1%) than those placed between lanes (0.4%). It is noteworthy that signal horizontal position affects driver comprehension in a manner opposite to that identified for permitted displays, where a placement in the straight-ahead position was less likely to be misinterpreted. This might be due to a carry-over effect from permitted displays: drivers may think that, since a green ball has a different meaning for a driver turning left, the red ball meaning is also different for the left-turning driver. Correct interpretation of left-turn green balls depends on successful differentiation from through green balls; by contrast, correct interpretation of left-turn red balls depends on not differentiating their message from through red balls. Thus, green balls are better comprehended when placed further from the through signal and red balls are better comprehended when placed closer to the through signal.

Driver age-horizontal position interactions were not found to be statistically significant. No significant effects were identified for number of through signals (NoTHRU) or the presence of the left-turn supplemental sign (SIGN).

Red: serious errors-older drivers

Left-turn signal horizontal position (HPOSIT) was the only variable that was found to significantly affect older driver comprehension (F_{ratio} = 4.96, F_{Prob} = 0.031). The straight-ahead position is associated with lower comprehension scores (12.7%) than a placement between lane lines (6.1%), a pattern consistent with that found for the entire subject sample. Number of through signals (NoTHRU) and presence of left-turn supplemental sign (SIGN) were not found to be statistically significant.

Red: summary and discussion

AGE was found to have a statistically significant effect on serious error rates. Driver comprehension deteriorates with age with the youngest age group showing the best comprehension and drivers older than 60 years of age having the worst.

Comprehension of red interval stimuli is of paramount importance, since any misinterpretations of its meaning may have grave consequences while driver age differences were significant, misinterpretations were relatively low. This part of the analysis verified comprehension differences among age groups, and identified a small but statistically significant advantage of a signal placement between lanes over a placement in the straight-ahead position. A possible explanation for the higher rate of misinterpretations of the straight-ahead placement is that drivers may feel that the meaning of a red ball on the left-turn signal differs from that on a through signal so they can turn left whenever they have an opportunity to do so if a signal is placed in a manner that will make clear that it addresses left-turning drivers exclusively. Number of through signals and presence of the sign "left-turn signal" were not found to have a significant impact on driver comprehension.

Change stimuli

Nineteen change interval stimuli are included in the database. Their common trait is a yellow indication on the left-turn signal (either a ball or an arrow). A second lens (red or green ball) may also be illuminated on the left-turn signal for some stimuli, and each of the three through signal sections (red, yellow, or green ball) is represented in the database.

In addition to age relations to serious error rates, THRUCOL (through signal indication) and CHANGE (pertaining to illuminated left-turn signal section configuration) were examined. For CHANGE there were three conditions:

i) Only a yellow ball or yellow arrow section is illuminated;
ii) A yellow arrow is simultaneously illuminated with a red ball; and,
iii) A yellow arrow is simultaneously illuminated with a green ball.

The first two conditions are identical (transition from permitted or protected phases respectively) and require the driver to stop and wait for the signal to change. The last condition indicates a transition from protected to permitted, i.e., the driver may continue without stopping if there is no opposing traffic.

Change: serious errors-all drivers

In this instance driver comprehension was not significantly different across age groups (F_{ratio} = 0.457, F_{Prob} = 0.712). It is interesting, however, to note the irregular serious error pattern across age groups for change interval stimuli: the youngest and oldest driver age groups have higher serious error rates (average 2.8%) than drivers between ages 31 and 60 (average 1.7%). Change interval stimuli, unlike green and red ball indications that may be interpreted differently by turning drivers, convey the unique message that a change in right-of-way priorities is about to happen and that drivers, have to come to a stop, regardless of which maneuver they are executing. Not enough information was available to evaluate the significance of other variables in terms

of serious error rates.

Change: serious errors-older drivers

Not enough data was available to evaluate comprehension effects of the presence of database variables.

Change: summary and interpretation-serious errors

Driver age was not found to have a statistically significant relation with serious error rate. There was not enough information in the database for a detailed analysis involving additional variables. Furthermore, the relatively low serious error rates associated with change interval stimuli make it clear that further investigation of serious errors is not required, since any possible signal display enhancements will have minimal benefits in terms of reducing serious intersection accidents.

Change: correct answers-all drivers

Correct answer rates were found to be significantly different across age groups (F_{ratio} = 6.138, F_{Prob} = 0.001). Drivers 16 to 30 years old have the best correct answer rate at 80% while drivers over age 60 have the lowest rate at 63%.

CHANGE was found to be statistically significant (F_{ratio} = 77.89, F_{Prob} = 0.000). Best comprehended was a yellow ball or arrow (88%), followed by simultaneous yellow arrow and red ball (80%), with simultaneous yellow arrow and green ball in last place (52%). THRUCOL was also found to be statistically significant (F_{ratio} = 43.72, F_{Prob} = 0.000). Sufficient data were available only for the red and green through signal indications. A through signal red indication is better comprehended (82%) than the green ball (67%).

An ANOVA including both age and CHANGE showed significant effects for both age (F_{ratio} = 4.17, F_{Prob} = 0.007) and CHANGE (F_{ratio} = 76.77, F_{Prob} = 0.000), but none for their interaction. A similar model including age and through signal color had significant main effects (F_{ratio} = 6.82, F_{Prob} = 0.000, and F_{ratio} = 43.05, F_{Prob} = 0.000) as well as significant age/color interactions (F_{ratio} = 3.02, F_{Prob} = 0.031).

Change: correct answers-older drivers

When only older drivers were considered, CHANGE was found to be statistically significant (F_{ratio} = 5.36, F_{Prob} = 0.007). The order of best comprehended displays for older drivers was identical to that for all drivers: best comprehended were left-turn signals with an illuminated yellow ball or arrow (76%), while least comprehended were those with simultaneously illuminated yellow arrow and green ball (52%). A yellow arrow simultaneously illuminated with a red ball on the left-turn signal was correctly understood by 65% of older drivers. Through signal indication (THRUCOL) was not statistically significant (F_{ratio} = 0.34, F_{Prob} = 0.562). Change interval stimuli incorporating a red through signal indication are somewhat better comprehended (65%) than those with a green through signal indication (62%).

Change: summary and interpretation-correct answers

Both through signal message (THRUCOL) and CHANGE are statistically significant in explaining correct answer rates for all drivers, however, only CHANGE is significant for older drivers. For the left-turn signal, a yellow ball or arrow is best comprehended followed by the yellow arrow alone or simultaneously illuminated with a red ball, while a yellow arrow simultaneously illuminated with a green ball is least likely to be comprehended. Left-turn change interval is best comprehended when accompanied by through signal red ball. Left-turn change intervals are less well comprehended when accompanied by through signal green ball both among all and older drivers. Comprehension deteriorates with age, and correct answer rate ranks are identical for levels of left-turn and through signal indication variables among all and older drivers.

Change: summary and discussion

Serious error rates for change interval stimuli are at very low levels (range 1.4%-2.4%), thus the differences among age groups have little practical significance. Consequently, the rather low correct answer rates (range 62.9%-80.3%) are due to a preponderance of minor rather than serious errors. This observation suggests that change interval stimuli may not be at the top of the practitioner's agenda of stimuli in need of improvement.

Although serious error rate changes with age are somewhat erratic, correct answer rates consistently deteriorate with advancing subject age. The only significant variable identified in the analysis is CHANGE and the results are consistent with the complexity hypothesis in that simpler displays (a single yellow ball or illuminated arrow section) are better comprehended than displays with multiple illuminated sections (yellow arrow and either red or green ball). Furthermore, among more complex displays, concurrent indications (yellow arrow and red ball--both indicating the transition to a stop) are better comprehended than discordant displays (yellow arrow and green ball--one indicating a transition to a stop, the other that the driver has the right of way) requiring more rigorous interpretation. Display complexity hypotheses are consistent with results for through signal indication: concurrent displays (through red ball) are associated with better comprehension than discordant displays (through green ball). These differences are statistically significant for all drivers but not significant among older drivers.

In summary, a practical method to improve correct answer rates for change interval displays suggested by the analysis would be the use of simpler displays, i.e., displays with a single illuminated yellow lens (either ball or arrow). However, change interval displays do not appear to pose a serious accident involvement threat to drivers due to incorrect stimulus interpretation.

Flashing stimuli

Twenty-two flashing operations stimuli are analyzed in this section. Since all three answer correctness levels are possible for flashing operations stimuli, both serious error and correct answer rate analyses are presented.

FLASH was defined in order to classify stimuli into three conditions according to required driver action in response to particular flashing operations configurations:

i) Stop. Proceed when there is no traffic in both directions

(in response to flashing red balls both on the left-turn and through signals).

ii) Stop. Proceed if there is no opposing traffic (in response to a flashing left-turn red ball and flashing through yellow ball).

iii) Permitted left-turn (proceed with the left-turn without stopping, unless you have to yield to opposing traffic, in response to flashing yellow balls on both the left-turn and through signals).

Through signal color (THRUCOL) and the left-turn signal indication (LFTFLSH) were also examined. LFTFLSH has three conditions: a dark left-turn signal face, a flashing yellow ball, and a flashing red ball.

Flashing: serious errors-all drivers

Although a serious error always means the violation of another driver's right of way, driver actions counted as serious errors vary across the three conditions of FLASH above. For example, not stopping in i) is a serious error, while it is not necessarily for iii). However, simultaneous examination of the three distinct messages in flashing operations is useful in drawing conclusions about their relative comprehension among drivers.

Although drivers younger than age 30 have lower serious error rates (mean 10%) than those over age 60 (mean 15%), no statistically significant differences were found between age groups.

There exist statistically significant comprehension differences between levels of FLASH (F_{ratio} = 83.74, F_{Prob} = 0.000). Stimuli requiring the driver to stop and check both opposing and cross-street traffic before proceeding show the worst performance (mean 27.2%), those requiring a stop and check for opposing traffic before proceeding follow (mean 7.6%), while those used to indicate permitted left-turns show the best performance (mean 1.0%).

Through signal indication (THRUCOL) shows statistically significant differences (F_{ratio} = 109.7, F_{Prob} = 0.000) with flashing red ball showing much worse performance (mean 27.2%) than flashing yellow ball (19%). Left-turn signal section type (LFTFLSH) is also statistically significant (F_{ratio} = 87.65, F_{Prob} = 0.000) with flashing yellow ball best comprehended (0.4% errors) followed by dark left-turn signal heads (12.4%), and flashing red ball worst (20.6%).

Three ANOVA models including variable AGE and one of the variables FLASH, LFTFLSH, or THRUCOL showed no statistically significant age effects and no significant interaction effects.

Flashing: serious errors-older drivers

Results based on older driver comprehension are similar to those based on the entire sample: FLASH is statistically significant (F_{ratio} = 19.97, F_{Prob} = 0.000). Permitted stimuli are best comprehended (average 1.5%), stimuli conveying the message "stop for opposing traffic" follow (11.4%) and, stimuli conveying the message "stop for both opposing and cross traffic" were the least well comprehended (33.0%).

Through and left-turn signal indications are statistically significant (F_{ratio} = 29.26, F_{Prob} = 0.000, and F_{ratio} = 36.07, F_{Prob} = 0.000 respectively). Comprehension differences follow the same patterns as for all subjects with through flashing red ball less well understood (32.2%) than flashing yellow ball (22.3%); flashing left-turn yellow ball stimuli are best understood (0.0%), followed by a dark signal face (11.7%) with flashing red ball stimuli least well comprehended (26.2%).

Flashing: summary and interpretation-serious errors

Driver comprehension of flashing mode stimuli does not differ significantly across age groups. Stimulus message (FLASH) provides insight into driver comprehension of flashing operations since it provides information on the through and left-turn signal configuration. By contrast, through and left-turn signal configuration (THRUCOL, LFTFLSH) do not describe flashing operations sufficiently when examined individually, since right-of-way rules depend on both variables, thus findings on these variables do not have much practical use.

Based on FLASH, left-turn message stimuli were best comprehended, followed by stimuli indicating that the driver has to stop and then proceed if there is no opposing traffic. Least well comprehended were stimuli indicating that the driver has to stop and then proceed if there is no opposing and cross-street traffic.

Driver comprehension is significantly affected by THRUCOL and LFTFLSH. Both among the entire sample and older drivers, a flashing yellow ball on the through signal is better comprehended than a flashing red ball. Flashing yellow ball stimuli are best comprehended by all and older drivers, followed by dark signal sections, with the red ball indication least well comprehended.

Driver comprehension deteriorates as signal message complexity increases. The simplest display, a flashing yellow ball on the left-turn signal is always concurring with the through signal indication (can only be present when a flashing yellow is displayed on the through signal) and is automatically associated with a measure of caution (the left-turning driver knows he/she does not have the right-of-way), but the driver only needs to check for opposing traffic and does not need to stop first.

Next in complexity, the dark left-turn signal head directs driver attention to the through signal display: there are no discording indications that need to be interpreted, however, the driver may mistakenly assume that left-turns have the right of way just like through drivers do, since they receive information from the same signal as through drivers.

Finally, the most complex stimulus, the flashing left-turn red ball, means that the driver has to come to a full stop and must always be considered in conjunction with the through signal: a through flashing yellow indicates that the driver has the right-of-way over cross street traffic, so he/she can concentrate on opposing traffic while a flashing red indicates that both opposing through and cross-street traffic has the right-of-way. A through flashing red indicates a sequence of actions: i) stop, ii) check the through signal, and iii) decide which intersection movement(s) have priority. On the other hand, a through flashing yellow indication does not require actions i) and ii) and is always associated with the presence of opposing traffic only (priority over cross traffic is granted). As the signal message becomes more complex, correct message interpretation becomes less likely, especially for older drivers.

The superiority of dark left-turn signal face over flashing red ball leads to the conclusion that eliminating flashing red left-turn signal indications may enhance driver comprehension (with the added benefit of energy savings).

Flashing: correct answers-all drivers

Correct answer rates were found to be statistically significantly related to subject age (F_{ratio} = 8.56, F_{Prob} = 0.000). Correct rates starting at 55% for the youngest drivers decline to 50% for drivers 31 to 45 years of age, 38% for those between 46 and 60 years old and, finally, 32% for drivers over age 60.

FLASH was also found to be statistically significant (F_{ratio} = 26.16, F_{Prob} = 0.000) with the best comprehension (58% correct) associated with stimuli flashing red balls on both the left-turn and though signals. Permitted stimuli (only yellow ball sections flashing) and stimuli requiring the driver to stop and proceed if there is no opposing traffic had lower correct answer rates (34% and 37% respectively).

Left-turn signal indication is statistically significant (F_{ratio} = 15.14, F_{Prob} = 0.000) with flashing yellow least well comprehended (37%), dark left-turn signals following (41%), with best comprehended flashing red indications (51%).

Through signal indication was found to be statistically significant (F_{ratio} = 43.96, F_{Prob} = 0.000) with flashing red ball better comprehended (58%) than flashing yellow ball (34%). Three models including variable AGE and one of the variables FLASH, LFTFLSH, or THRUCOL showed statistically significant main effects, but no significant interaction effects.

Flashing: correct answers-older drivers

Stimulus message (FLASH) was found to be statistically significant (F_{ratio} = 6.94, F_{Prob} = 0.002). Correct answer rates follow the same order for older drivers as for all drivers i.e., best comprehended are stimuli flashing red balls on both left-turn and through signals (43%), followed by those flashing a red ball on the left-turn and a yellow ball on the

through signal (37%), and last, those flashing yellow balls only (17%). Left-turn and through signal indications were both found to be statistically significant for older drivers as well (F_{ratio} = 9.51, F_{Prob} = 0.000 and F_{ratio} = 8.46, F_{Prob} = 0.006 respectively). The left-turn signal showing a flashing red ball is best understood (42%) followed by dark signals (29%) and least well comprehended, flashing yellow ball (18%). Through signal flashing red ball has a higher comprehension (45%) than flashing yellow ball (23%).

Flashing: summary and interpretation-correct answers

Correct answer rates are influenced by stimulus message: best comprehended are stimuli used to convey the message "Stop. Proceed if there is no opposing and cross street traffic," followed by those conveying the message "Stop. Proceed if there is no opposing traffic." Least often correctly answered were stimuli conveying the message of a permitted left-turn.

While this order is identical for all and older drivers, some differences exist in correct answer rates between the two groups: stimuli indicating "Stop. Proceed if there is no opposing traffic" have virtually identical correct answer rates, but comprehension of the other two message categories drops by approximately 14 percentage points for older drivers.

Driver comprehension is also influenced by driver age with a noticeable decline in correct answer rates with advancing age. Age interactions with stimulus meaning, through, and left-turn signal color are non-significant. It is noteworthy that dark left-turn signal faces are associated with a lower correct answer rate than flashing red displays, a result contradicting serious error rate findings.

Flashing: summary and discussion

Flashing operations stimuli comprehension is the poorest among stimuli categories. The peculiarity of flashing indications lies in the fact that, while correct answer and serious error rates are both affected by stimulus message, they are affected in opposite directions: flashing red balls on the left-turn and through signals, have the highest serious error and correct answer rates, while permitted stimuli have both the lowest serious error and correct answer rates. This phenomenon is due to differing minor error rates among stimulus message categories. Driver comprehension of stimuli conveying the message "Stop. Proceed if there is no opposing traffic" is more similar to that of permitted stimuli in terms of serious error rates (low) and closer to that of flashing red balls only, in terms of correct answer rates (high). Older drivers tend to stop when facing a flashing indication, regardless of its color, thus their response is incorrect for a permitted display (lowest correct rate), but initially correct for a flashing red ball since they must come to a stop for such indications (higher correct rates). Although older drivers grant the right of way to opposing traffic (low permitted serious errors), they fail to recognize the additional right of way obligation to grant the right of way to cross street traffic when both left and trough flashing red balls are present (highest serious errors).

Although stimuli presenting comprehension problems for older drivers have been identified, no design variables (such as signal position and number of through signals for example) have been identified in the database that would help alleviate these problems. The use of dark left-turn signal faces during flashing operations can be recommended if the goal is to reduce serious error rates. It should be kept in mind though that a decrease in correct answer rates (i.e., increase in minor error rate)is to be expected. An increase in minor error rates may be acceptable however, since it may lead to less severe accidents.

Intra-interval summary

Stimulus comprehension measured in correct answer rates has been shown to be significantly related to driver age in every stimulus category for which correct answer rates were examined. However, older drivers do not differ from other age groups in terms of serious error rates for all stimuli categories examined with the exception of red stimuli. Notwithstanding that misinterpretations of red stimuli may have dire consequences, the finding is somewhat moderated given that red

stimuli serious error rates are quite low for all age groups. Although different stimuli characteristics were found to affect driver comprehension depending on stimulus meaning and whether correct answer or error rates are analyzed, a general conclusion is that simpler stimuli are better understood by drivers. A summary of the most important findings in chapter 4 is presented in table 4.1.

Table 4.1. Analysis of left-turn signal comprehension-summary

Subject characteristics analysis-significant variables:

Miles driven per year:

- Older drivers drive less miles per year than any other age group.
- Female drivers drive less than their male counterparts.

Answer correctness relations with driver characteristics:

- Drivers confident about their answers are more likely to comprehend stimuli correctly.
- Drivers that drive 15,000 miles per year are more likely to comprehend stimuli correctly than those driving fewer or more miles per year.
- Older driver answers are more likely to indicate a serious comprehension error.
- Older driver answers are less likely to be correct.
- Drivers of both sexes are equally likely to give answers indicating a serious error.

Inter-interval analysis-significant variables:

AGE: subject age

- Comprehension deteriorates with advancing driver age in terms of errors (higher for older drivers) and correct answers (lower for older drivers), for every stimulus meaning.
- Correct answer rate differences among driver age groups are more likely to be significant than differences in serious error rates.

MEANING: permitted, protected, red, change, flashing stimuli

- Change interval stimuli are best comprehended (least errors), followed by red, permitted, and flashing interval stimuli which are the least well comprehended (most errors).
- Red phase stimuli are best comprehended (most correct answers), followed by change, protected, permitted, and flashing interval stimuli which are the least well comprehended (least correct answers).
- Similar comprehension patterns were observed for all and older drivers, with older drivers showing lower comprehension than other age groups in terms of correct answer rates (low) and serious error rates (high).

Table 4.1. (cont'd).

Intra-interval analysis-significant variables:

Permitted stimuli:

AGE: subject age

- No comprehension differences in terms of error rates were found among driver age groups.
- Comprehension deteriorates with advancing driver age in terms of correct answer rates (lower for older drivers).

HPOSITION: left-turn signal horizontal position

- Placement on the left-turn lane centerline is better comprehended (lower error rates) than placement between left-turn and through lanes (higher error rates) when entire subject sample is analyzed.
- Horizontal left-turn signal placement was not found to affect older driver comprehension in terms of serious error or correct answer rates.

Protected stimuli:

AGE: subject age

- Comprehension deteriorates with advancing driver age in terms of minor error rates (higher for older drivers). Minor error rate differences among driver age groups are significant.

SIGN: presence of sign "left turn signal"

- Sign presence improves driver comprehension in terms of minor errors (lower where sign is present).

COLORS: illuminated lens configuration

- Concurring left-turn signal lenses are associated with lower minor error rates than discording.
- Concurring left-turn and through signal lenses are associated with higher minor error rates than discording.

Red stimuli:

AGE: subject age

- Comprehension deteriorates with advancing driver age in terms of serious errors (higher for older drivers). Serious error differences among driver age groups are significant.

HPOSITION: left-turn signal horizontal position

- Placement between left-turn and through lanes is better comprehended (lower serious error rates) than placement in the straight-ahead position (higher serious error rates).

Table 4.1. (cont'd).

Intra-interval analysis-significant variables:

Change stimuli:

AGE: subject age

- Comprehension deteriorates with advancing driver age in terms of correct answer rates (lower for old drivers).

CHANGE: left-turn signal configuration

- Yellow ball or yellow arrow are best comprehended in terms of correct answer rates (highest rates).
- Yellow arrow simultaneously displayed with red ball is less well comprehended in terms of correct answer rates.
- Yellow arrow simultaneously displayed with green ball is the least well comprehended in terms of correct answer rates (lowest rates).

THRUCOL: Through signal color

- Red ball stimuli are best comprehended in terms of correct answer rates (highest rates).
- Green ball stimuli are not comprehended as well in terms of correct answer rates.
- Through signal indication has no effect on older driver correct answer rates.

Flashing stimuli:

AGE: subject age

- No comprehension differences in terms of minor and serious error rates were found among driver age groups.
- Comprehension deteriorates with advancing driver age in terms of correct answer rates (lower for older drivers). Correct answer rate differences among driver age groups are significant.

FLASH: required driver action for flashing ball indications

- Stimuli with a yellow ball flashing on both the left-turn and through signal were associated with the lowest serious error and lowest correct answer rates among flashing stimuli.
- Stimuli with a red ball flashing on both the left-turn and through signal were associated with the highest serious error and highest correct answer rates.
- Stimuli with a red ball flashing on the left-turn signal and a yellow ball flashing on the through signal were associated with intermediate serious error and correct answer rates.

CHAPTER 5

FIELD DATA ANALYSIS

5.1. INTRODUCTION

Higher older driver accident involvement when turning left or right at intersections has been identified by a number of investigators as discussed in the literature review. The findings presented here are based on the field data analysis, designed to parallel, to the extent possible, the laboratory data investigation. Consistent with the methodology described earlier, a general overview of field data is presented first. The analysis focus becomes progressively narrower examining relationships between through, left-turn, and right-turn accidents and driver age, succeeded by comparisons between intersections utilizing protected, permitted, and protected/permitted left-turn phasing. A discussion on the relationships between driver age and left-turn accident statistics with various approach geometric and signal variables conclude the chapter.

5.2. MANEUVER ANALYSIS

Accidents during full color (referred to as "daytime" in what follows) and flashing (referred to as "nighttime") signal operations account for 86.6% and 13.3% of all intersection-related accidents, respectively. Among daytime intersection accidents, 78% involve an at-fault driver moving straight through the intersection, 4% a driver turning right, and 17% a driver turning left (figure 5.1. and table 5.1).

The percent of accidents involving drivers moving through drops with increasing age (figure 5.1), until it becomes 66% for drivers 60 years of age or older. The drop in through accident involvement is accompanied by a simultaneous increase in left-turn and right-turn accident involvement (from 17% to 28% and from 4% to 6% respectively) as drivers age. Among drivers over 60 years of age, left-turn accidents

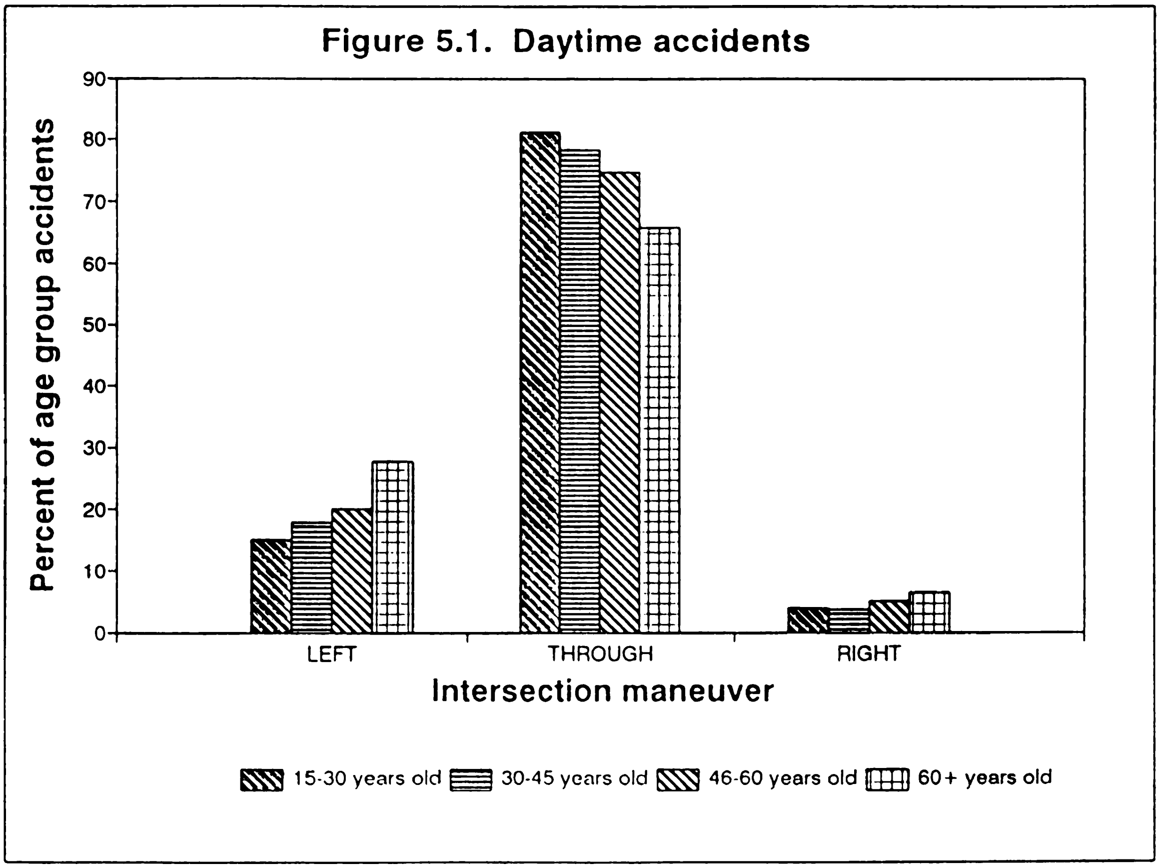


Figure 5.1. Daytime accidents
Percent of age group accidents
90
80
70
60
50
40
30
20
10
0
LEFT
THROUGH
RIGHT
Intersection maneuver
15-30 years old
30-45 years old
46-60 years old
60+ years old

are 59% and right-turn accidents are 51% higher than average for left-turn and right-turn accidents respectively.

Table 5.1. Normal signal operation accident involvement (percent)

	LEFT	THROUGH	RIGHT	TOTAL
All approaches				
Average	17	78	4	100 *
Drivers 60+	28	66	6	100
Permitted				
Average	25	71	5	100 *
Drivers 60+	36	58	6	100
Permitted/protected				
Average	16	81	3	100
Drivers 60+	30	65	4	100 *
Protected				
Average	9	86	4	100 *
Drivers 60+	18	73	9	100

* Totals may not add up to 100% due to rounding errors

When the data are further stratified by left-turn phasing, similar patterns are evident for approaches with permitted, protected, and protected/permitted left-turn phasing, i.e., a heavy concentration of through accidents declining with driver age and a simultaneous increase in turning accidents with a preponderance of left-turn accidents. However, each left-turn phasing type is associated with unique characteristics, as summarized in table 5.1 and figures 5.2, 5.3 and 5.4. Permitted phasing is associated with the highest percentage of left-turn accidents (36%) for drivers 60 years old or older while protected phasing establishes the other (low) end of the spectrum with left-turn accidents accounting for 18% of the accidents. Protected/permitted phasing falls between the two extremes (30%).

These findings are consistent with those identified in the literature review and are compatible with driver comprehension findings. Protected displays are the simplest and drivers are more likely to understand them correctly. Since drivers have the right-of-way during

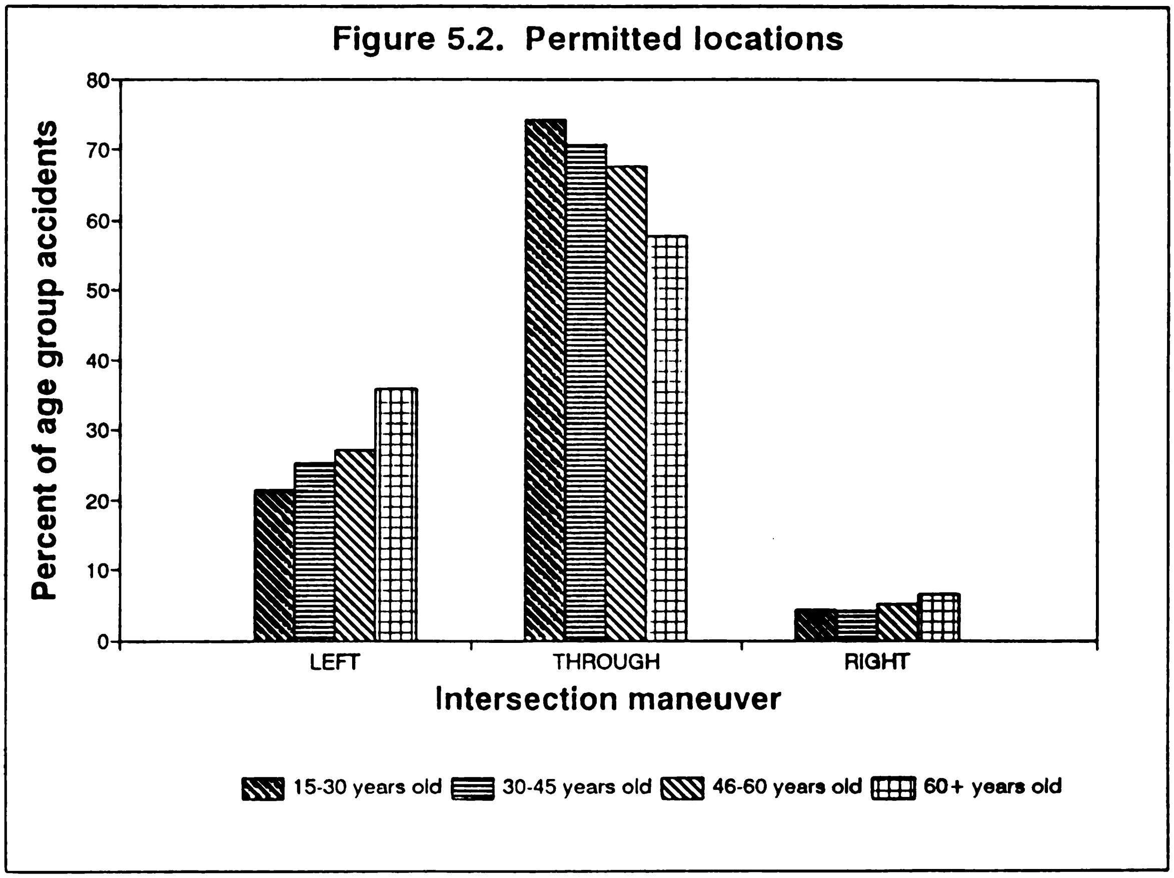


Figure 5.2. Permitted locations
Percent of age group accidents
80
70
60
50
40
30
20
10
0
LEFT
THROUGH
RIGHT
Intersection maneuver
15-30 years old
30-45 years old
46-60 years old
60+ years old

Figure 5.3. Protected locations

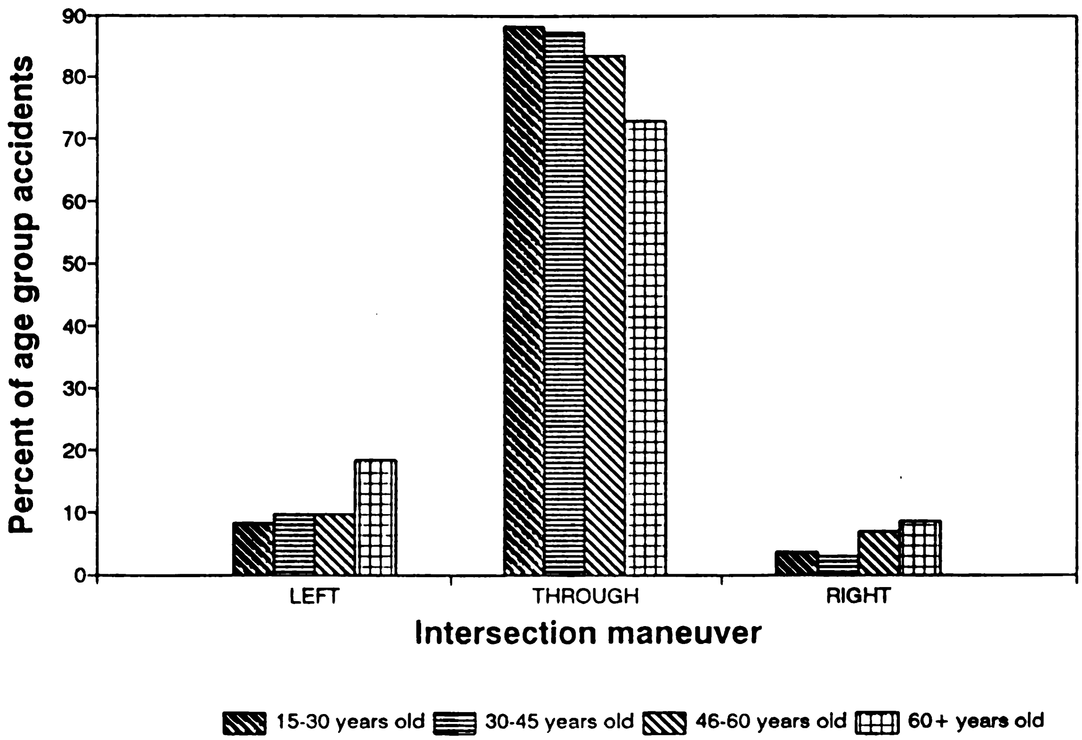
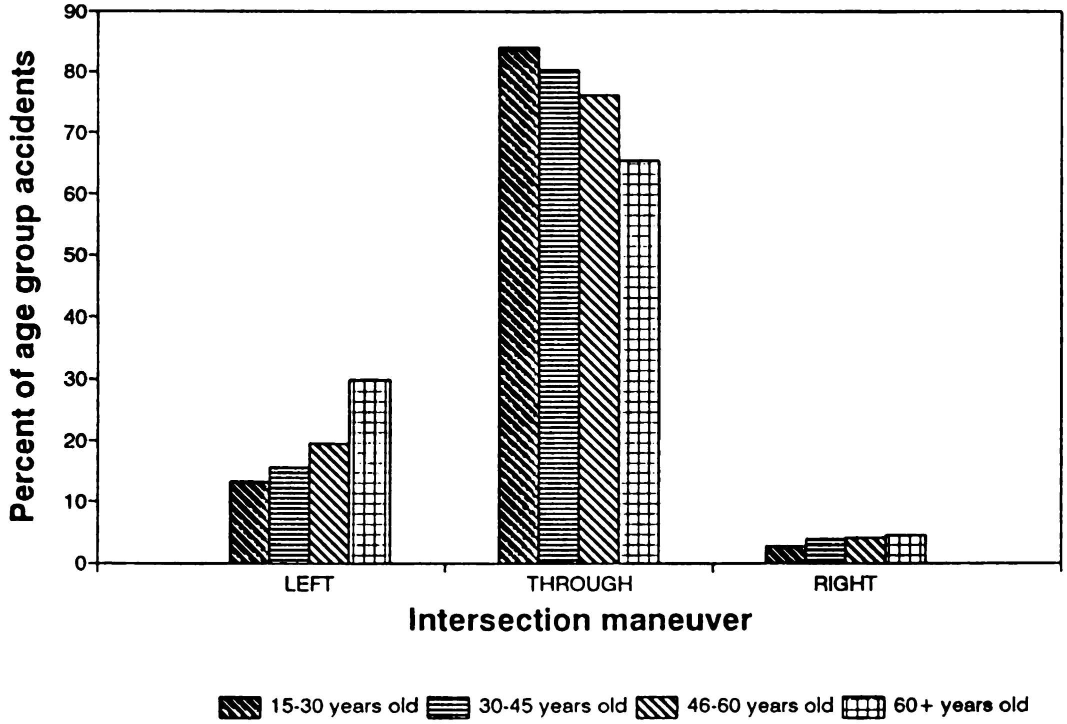


Figure 5.4. Permitted/protected locations



the protected interval, it is highly unlikely that they will be at fault while turning left. Permitted displays have been shown in the comprehension analysis to be associated with a significant number of errors among drivers (especially older ones): drivers mistakenly thinking they have the right of way during the green ball interval are likely to be the driver at fault in a left-turn accident. Permitted and protected phasing (shown to be associated with higher and lower percentage of left-turn accidents respectively) are present in protected/permitted displays. However, permitted interval durations usually dominate left-turn green time at such locations, providing a possible explanation of left-turn accident percentages closer to those of approaches with permitted rather than protected phasing.

Nighttime left, through, and right turn accident characteristics are within a couple percentage points of those of daytime accidents (figure 5.5). Right-turn accident involvement remains approximately constant with age (table 5.2 and figure 5.5), and, thus changes in the types of accidents associated with different driver age groups are confined to shifts between through and left-turn accidents. Patterns are similar to those for daytime conditions with a decrease in through accidents while left-turn accidents increase with increasing driver age. However, drivers older than 60 have a lower percentage of nighttime (23%) than daytime (28%) left-turn accidents. This finding may be attributed to a number of factors, among which are: i) the presence of lower traffic volumes during flashing operations; and, ii) a conservative older driver response to flashing operation stimuli identified in the laboratory analysis. Older drivers have lower correct answer rates due to minor, not serious errors, i.e., they tend to give away their right of way when facing a flashing indication. By contrast, older drivers are more likely to think they have the right of way when facing a left-turn green ball during daytime. The above findings (tables 5.1. and 5.2. and figures 5.2. through 5.5) are consistent with the hypothesis of higher

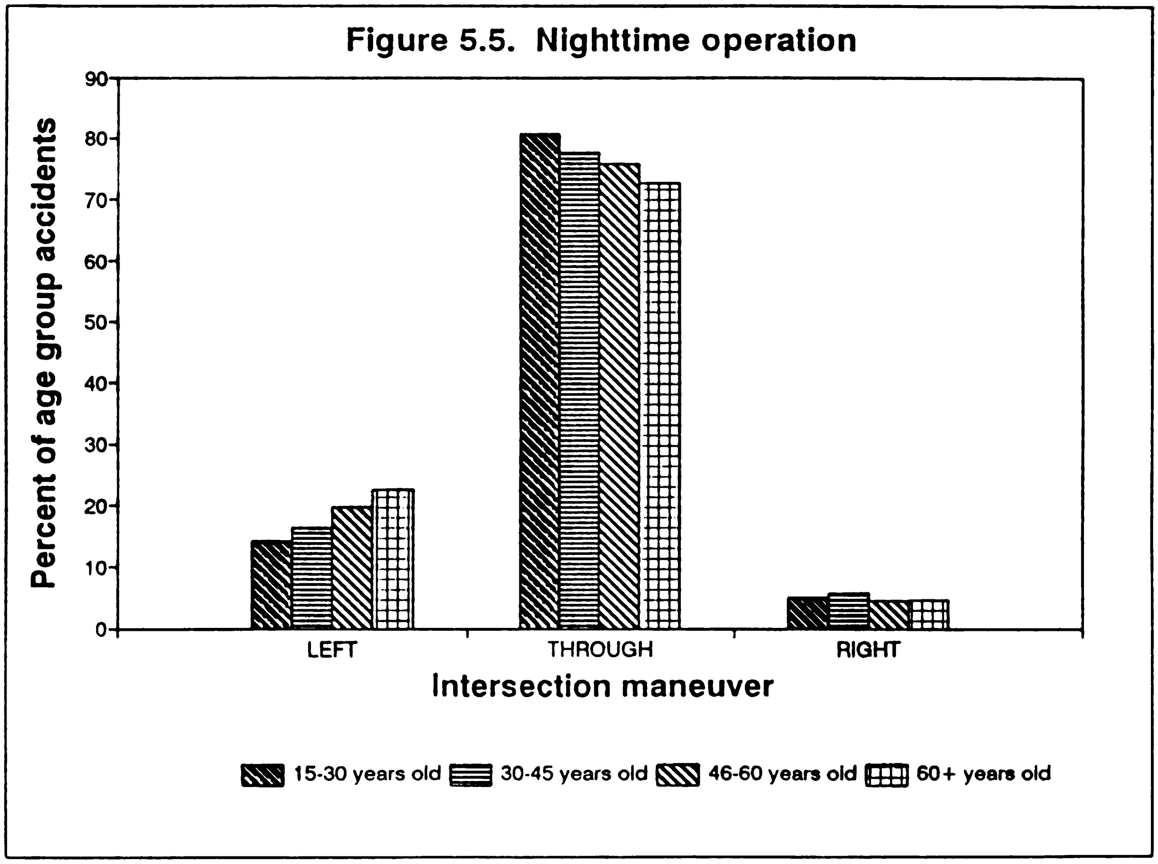


Figure 5.5. Nighttime operation
Percent of age group accidents
0
10
20
30
40
50
60
70
80
90
LEFT
THROUGH
RIGHT
Intersection maneuver
15-30 years old
30-45 years old
46-60 years old
60+ years old

accident involvement in more complex situations for older drivers. A shift from accidents involving straight-moving vehicles (simple maneuver) to those involving drivers attempting a turn (more complex maneuver) is evident with increasing driver age. Among turning movements, the most significant increase with driver age is for left-turn accidents, both in terms of percentages and absolute numbers.

Table 5.2. Nighttime signal operations accident involvement (percent)

	Left	Through	Right	Total
Average	15	80	5	100
Driver 60+	23	73	5	100 *

* Totals may not add up to 100% due to rounding errors

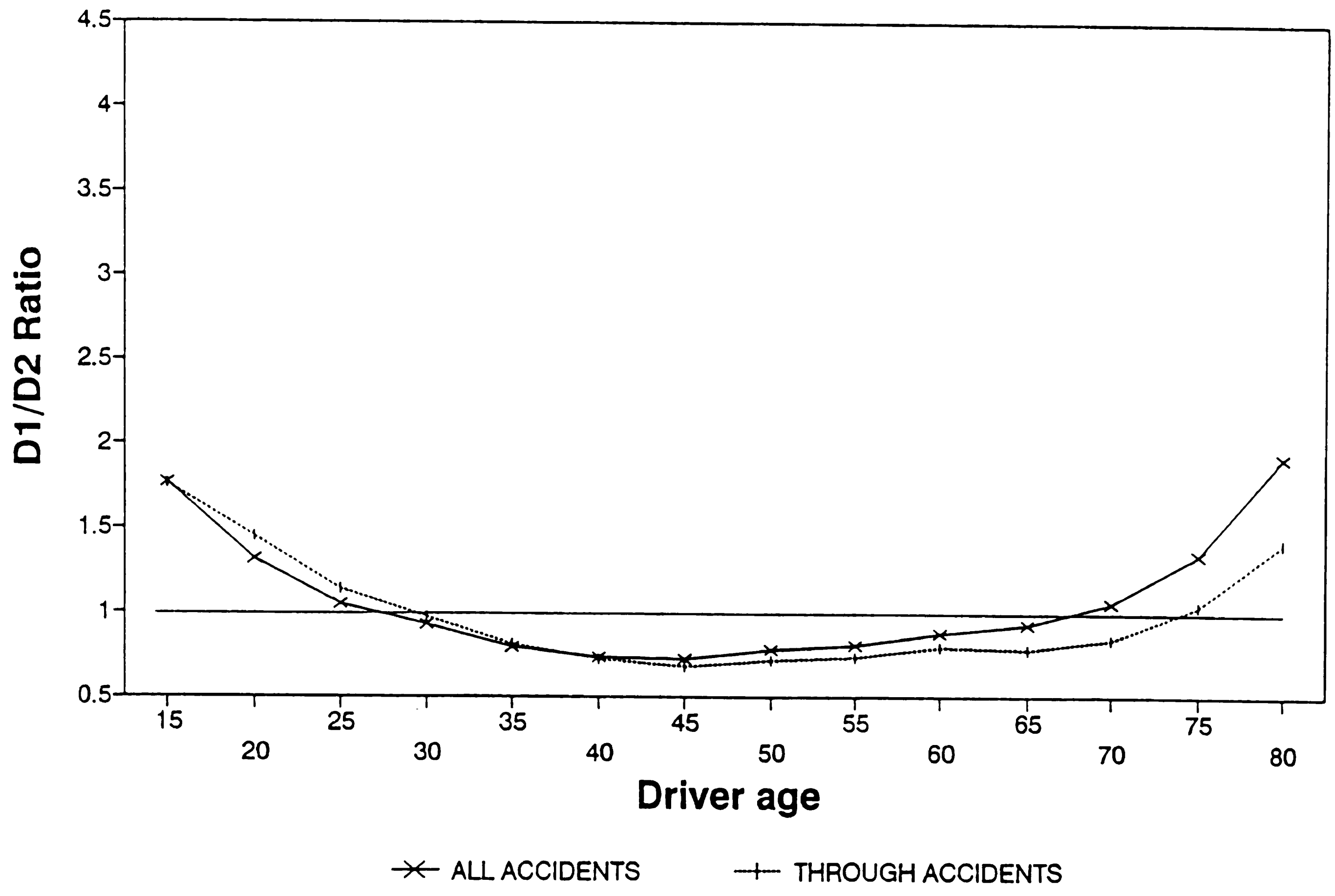
Involvement ratio graphs for all, through, right-turn and left-turn daytime, and nighttime intersection-related accidents are depicted in figures 5.6 through 5.9. The abundance of data available for this analysis allowed for a large number of age cohorts (table 5.3).

Table 5.3. Age cohorts used for figures 5.6 through 5.9

Age cohort	Represented by value
up to 17	15
18 through 22	20
23 through 27	25
28 through 32	30
33 through 37	35
38 through 42	40
43 through 47	45
48 through 52	50
53 through 57	55
58 through 62	60
63 through 67	65
68 through 72	70
73 through 77	75
78 through 98	80

Involvement ratios were calculated for each age cohort shown in table 5.3. Continuous lines connecting 14 distinct points at which D1/D2 ratios were calculated and a horizontal line D1/D2 = 1 indicating the point at which drivers are neither over- nor under-involved in

Figure 5.6. Daytime accident involvement ratios



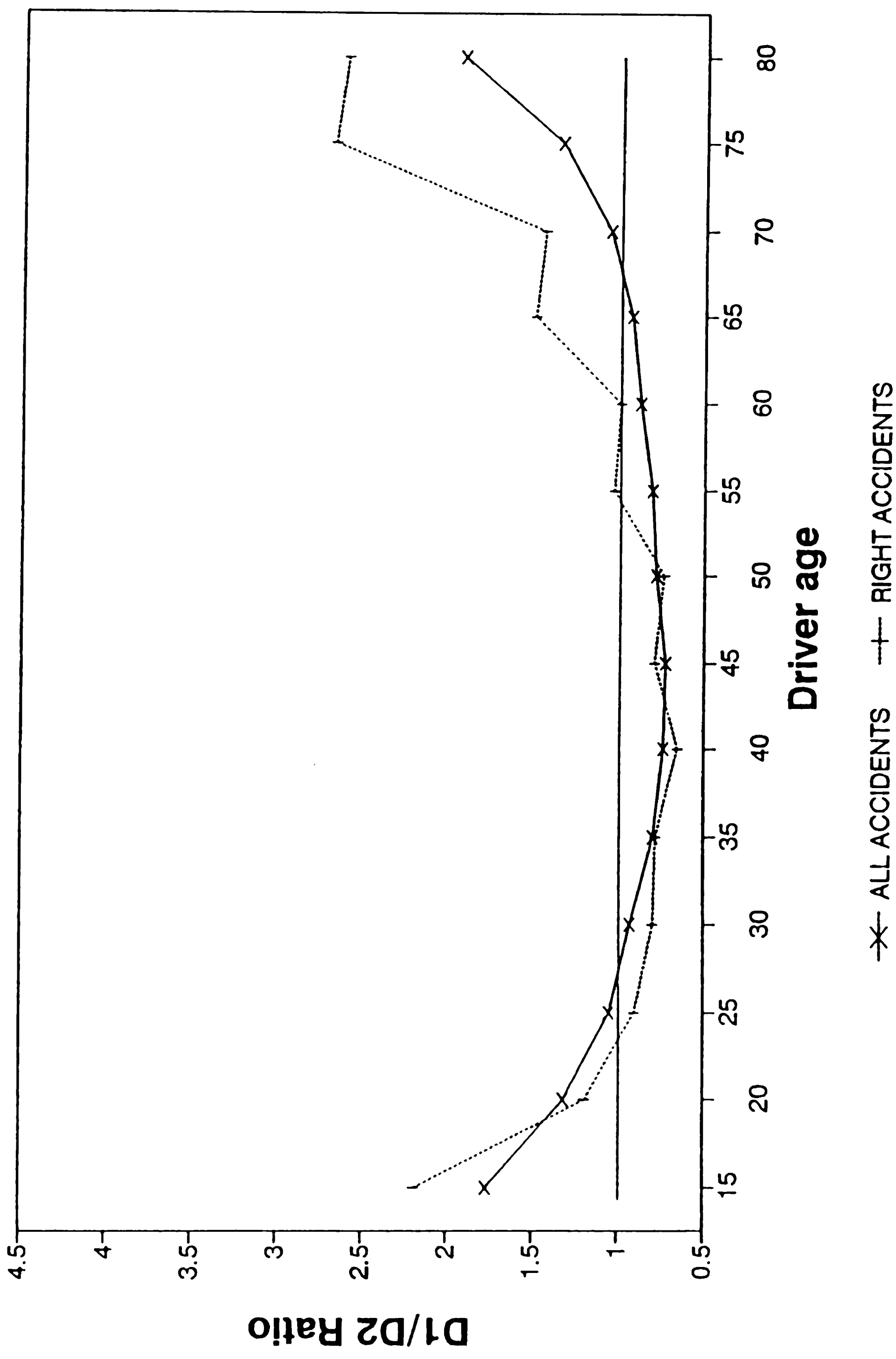
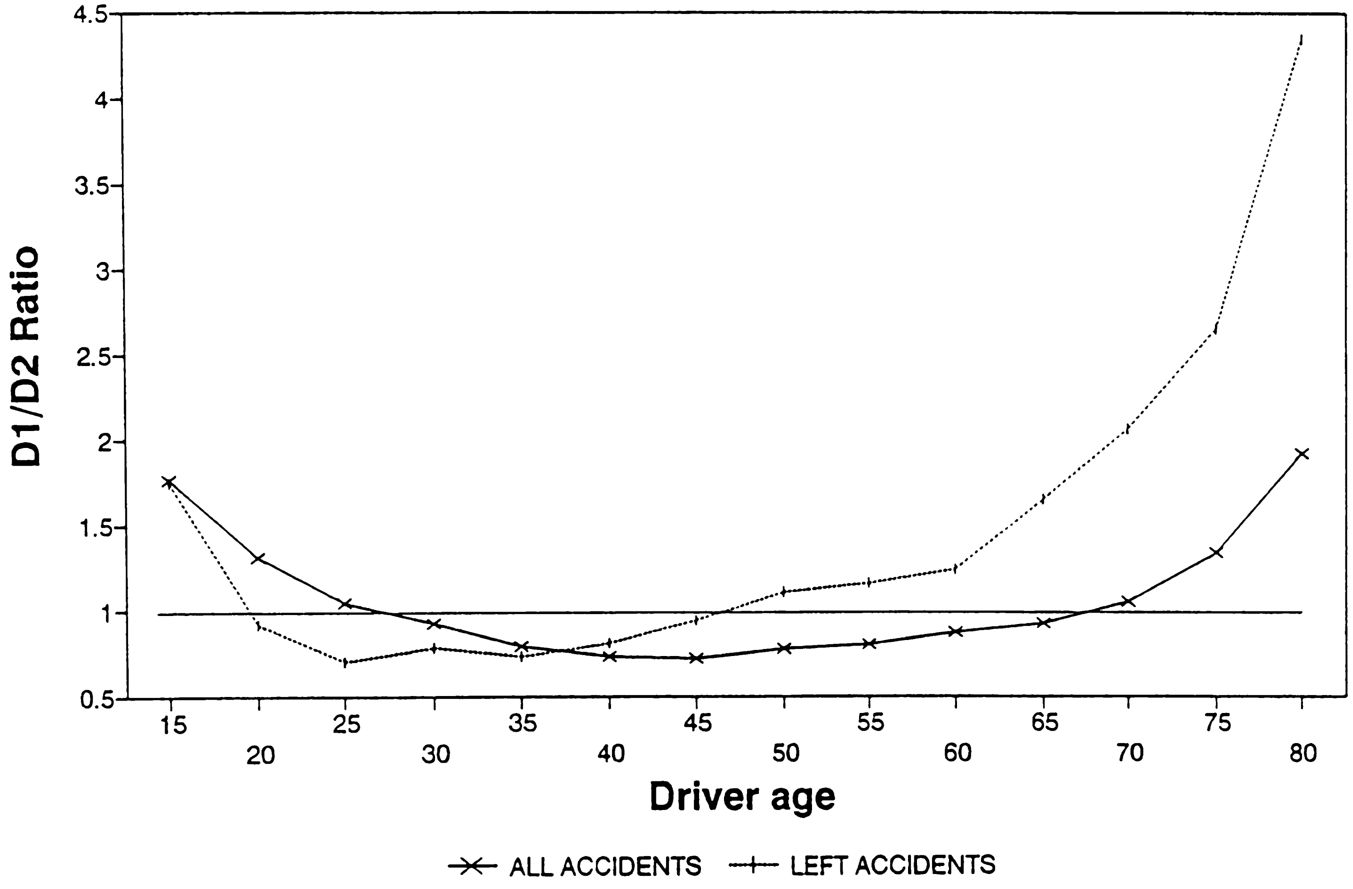


Figure 5.7. Daytime accident involvement ratios

Figure 5.8. Daytime accident involvement ratios



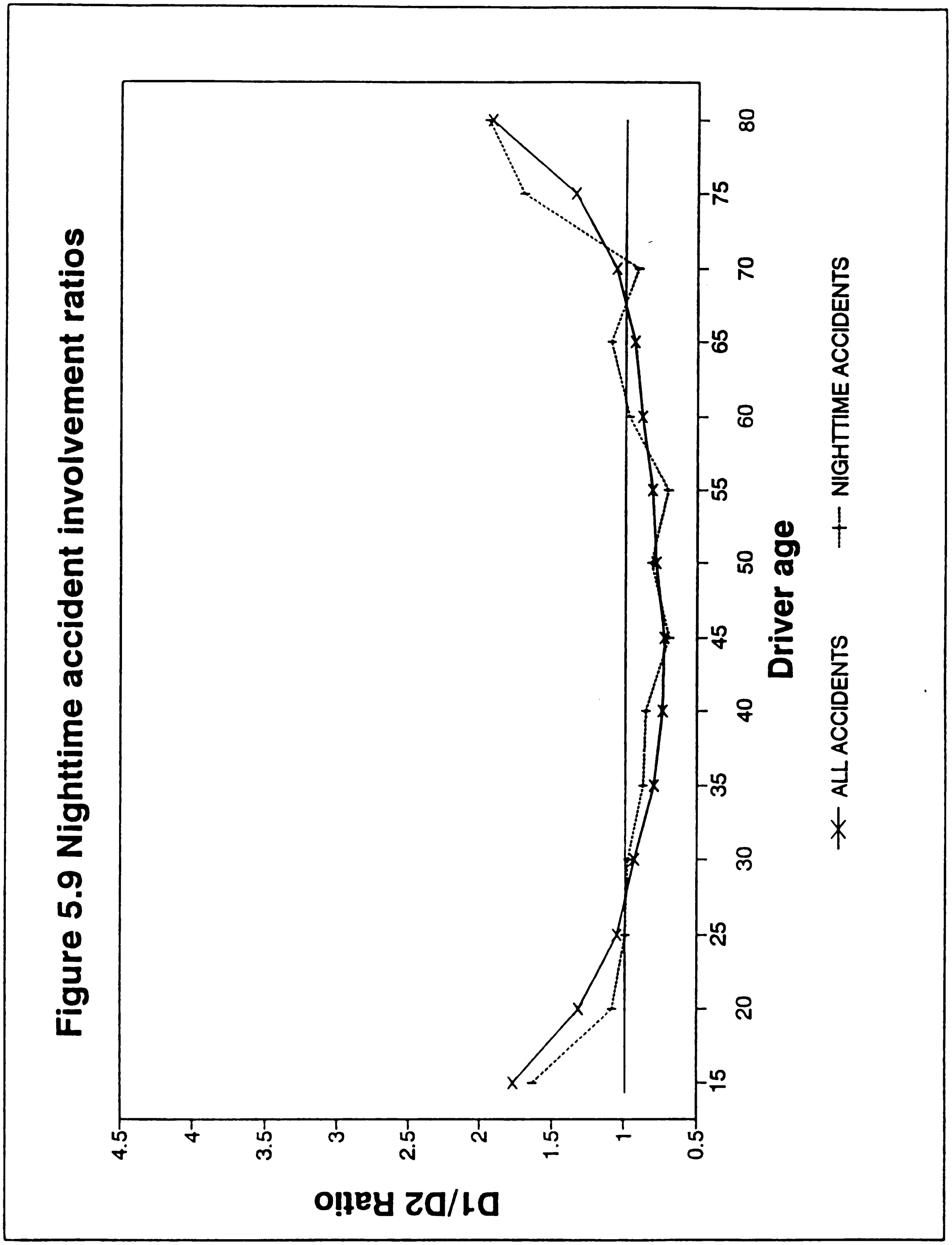


Figure 5.9 Nighttime accident involvement ratios

accidents are presented to facilitate visual pattern recognition and do not signify the computation of "continuous" involvement ratios across ages.

A consistent "U-shaped" pattern of younger and older driver accident overinvolvement and "middle aged" driver underinvolvement is clearly identifiable for all types of accidents. Thus, involvement lines cross the equilibrium line twice in a driver's life, once downwards (i.e., from over- to under-involvement) and once upwards (i.e., from under- to over-involvement) as the driver ages. However, differences exist among accident types for the ages at which involvement lines cross the equilibrium line, in the rate of change of the involvement ratio, and extreme values of over- and under-involvement. As mentioned in the methodology chapter, age limits used in figures 5.6 through 5.9 are defined as a matter of "convenience" rather than based on definitive changes in driving behavior occurring at particular ages. In the same context, figures 5.6 through 5.9 cannot be used to pinpoint exact ages when drivers become over- or under-involved in accidents or calculate exact rates of change of involvement with age since there is significant variability with regard to driving ability within age groups, especially among older drivers. The figures are meant to illustrate general tendencies occurring over decades throughout a driver's life. A line representing all daytime accidents is present in every figure to facilitate comparisons among different types of accidents across figures.

The line representing all daytime accidents in figures 5.6 through 5.9 is based on 86.6% of the accidents in the database and shows young driver (age cohort 15--see table 5.3 for definitions) involvement of 1.77 (overinvolvement). Risk declines with increasing age, reaches equilibrium between the latter half of the third and beginning of fourth decade, and a minimum (.72) in the fifth decade of a driver's life. From that point, there is a monotonic increase in involvement, and,

equilibrium is reached again between the seventh and eighth decades. Drivers over age 78 have a maximum involvement of 1.92. Daytime through accidents (representing almost three-quarters of the database-figure 5.1 and table 5.1) closely follow total daytime trends (figure 5.6) with a nearly identical young driver involvement (1.76) that drops with age but at a lower rate than that for total accidents, crossing the equilibrium line at about the end of the third decade. Through-accident involvement eventually crosses the total accident involvement line between the middle of the fourth and fifth decades and represents the lowest involvement among examined accident categories for all drivers after the fourth decade. An all-age minimum involvement (.68) is reached around the middle of the fifth decade and from that point involvement increases with increasing age; equilibrium is reached around the eighth decade. Drivers over 78 years of age have an involvement ratio of 1.41.

Right-turn accident involvement (figure 5.7) is the highest among examined accident type categories for the youngest age cohort (2.18). A sharp decline with age, leads to equilibrium during the third decade and a minimum (.65) between the fourth and fifth decades. Starting during the sixth decade, involvement increases in a step-wise fashion reaching equilibrium between the sixth and beginning of seventh decades. A sharp increase is observed during the eighth decade. Involvement becomes 2.68 for drivers older than 78 years of age, a value significantly higher than that for all and through accidents for the same age group.

The most dramatic fluctuations with driver age among examined accident categories (figure 5.8) are evident when considering left-turn accident involvement. Starting at 1.74 for the youngest drivers, involvement drops dramatically with age, reaches equilibrium during the second decade and a minimum (.70) during the third decade. Experiencing some fluctuation during the third and throughout the fourth decade, a steady increase is noted during the rest of the driver's life. Equilibrium is reached again during the fifth decade. Drivers older

than 78 years of age have an involvement ratio of 4.34, the highest among all accident categories examined.

Nighttime accident involvement closely follows daytime patterns (figure 5.9). Involvement is the lowest among the youngest drivers (1.62) among all accident categories examined; equilibrium is reached during the third decade; a minimum (0.69) is reached between the fifth and sixth decades; and involvement fluctuates around the equilibrium during the last half of the sixth decade and increases rapidly during and after the eighth decade (1.94).

Maneuver analysis: summary and discussion

The figures in the preceding section serve to illustrate that intersection accident involvement characteristics change with driver age. The most important findings are highlighted below and followed by suggestions for explanatory mechanisms based on the literature review and laboratory comprehension analysis results.

There is a shift from through to left-turn and right-turn daytime accidents with increasing driver age. For nighttime accidents a shift is observed strictly between through (decrease) and left-turn accidents (increase) with right-turn accidents remaining constant with advancing driver age. Nighttime left-turn accident increase is less pronounced than daytime, a finding that corresponds to a relatively high incidence of serious errors for permitted interval stimuli and low serious error rate for flashing left-turn red ball stimuli among older drivers.

The percentage of daytime left-turn accidents at approaches with permitted left-turn control is higher than that at approaches with protected/permitted and protected control. These findings correlate well with stimulus comprehension findings showing that protected stimuli are better comprehended than permitted stimuli. Protected/permitted location percentages are between those of permitted and protected locations, an expected result, since part of the green time is treated as a protected and part as a permitted interval.

An overinvolvement of younger and older drivers and underinvolvement of "mid-aged" drivers has been observed for all daytime and nighttime accidents, regardless of intersection maneuver (i.e., left-turn, through, right-turn). The age at which younger drivers cross the equilibrium line (i.e., the line D1/D2 = 1) and that at which older driver accident overinvolvement begins is different for each intersection maneuver, with the most pronounced differences shown for the left-turn maneuver, for which overinvolvement begins during the fifth decade (earlier than any other maneuver) and remains more pronounced than that of any other maneuver throughout the remainder of a driver's life.

Older driver involvement ratios vary significantly depending on intersection maneuver. Through accidents are the least hazardous for older drivers (1.41) followed by nighttime signal operations (1.94), right-turn (2.68) and left-turn (most hazardous--4.34). Older driver accident involvement is consistent with the hypothesis of higher involvement for more complex intersection maneuvers: The through movement representing the simplest task for a driver in the intersection environment is associated with the lowest involvement. The next higher step in intersection maneuver complexity is that of turning right, involving monitoring the traffic signal, while simultaneously maintaining a safe distance from the leading vehicle, and observing pedestrian traffic. Increased complexity of the mental and physical tasks associated with a right-turn maneuver is reflected in higher involvement ratios for right-turn accidents compared to the simpler through maneuver. Finally, the left-turn maneuver, the most complex task among the ones examined here, involves (depending on the type of left-turn phasing) locating the left-turn traffic signal and supplemental signs, and correctly interpreting their message, while simultaneously monitoring leading vehicles and pedestrian traffic on the cross street, identifying and safely using acceptable gaps in the

opposing traffic, and correctly identifying the turning path. Task complexity places a heavy mental load on the driver and accident involvement reflects the relative inability of the older driver to successfully negotiate left turns compared to all other intersection maneuvers.

Nighttime involvement ratios closely follow daytime accident involvement trends with minor deviations. This finding appears to be counter-intuitive given the common perception of increased older driver accident involvement due to physical limitations, according to which older drivers would be expected to have a higher accident involvement during nighttime. For example, since older drivers cannot see as well as their younger counterparts under nighttime (low intensity illumination) conditions, they run a higher risk of hitting poorly illuminated objects or running off the road. The absence of older driver increased involvement in nighttime accidents can be explained as a result of interactions of a number of factors: i) only the most physically fit older drivers drive at night--those that feel they have physical limitations do not drive; ii) older drivers commit fewer serious comprehension errors (see definition in comprehension analysis chapter) when facing a flashing red signal than any full color display; and iii) the presence of lower traffic volumes during nighttime allows for selection of longer acceptable gaps and more opportunity for collision-avoidance maneuvers by drivers about to collide.

In summary, two trends have been identified as drivers age: a shift from straight through to turning accidents and a higher involvement ratio for turning accidents, more pronounced for left than right turns. A higher percentage of older drivers are involved in left-turn accidents at locations with permitted left-turn phasing than locations with protected left-turn phasing. All identified trends can be related to maneuver and signal display complexity.

5.3. LEFT-TURN ANALYSIS

It was just shown that there is a significant shift towards left-turn accidents with increasing driver age. Furthermore, the proportion of left-turn among all intersection accidents was shown to depend on left-turn phasing type. Differences in left-turn accident percentages among left-turn phasing types warrant separate examination of accidents at approaches controlled by permitted, protected, and protected/permitted phasing. (It should be noted that the exact instant that an accident occurred during a cycle is not known thus an exact apportionment of accident contribution for each interval displayed on a left-turn signal is not possible.) In the absence of precise temporal information, the assumption is made that right-of-way rules associated with a particular left turn control scheme have an overall effect on accident experience. Furthermore, it is assumed that most left-turn conflicts occur during the green and change left-turn intervals.

Given this context, left-turn accidents are segregated into three groups according to left-turn control (i.e., permitted, protected, and protected/permitted), and individual involvement ratios are compiled for each group. Age groups defined in table 5.4 are used for involvement ratio graphs (figures 5.10 through 5.12) and do allow direct comparisons with age groups used in the comprehension analysis earlier. Figures

Table 5.4. Age cohorts used for figures 5.10 through 5.12

Age cohort
15-30 years old
31-35 years old
46-60 years old
61+ years old

5.10 through 5.12 are similar to the ones presented previously with some minor changes: i) a line representing left-turn accidents at all approaches is present to serve as a reference; and, ii) since fewer observations are available for each figure (e.g., left-turn accidents at

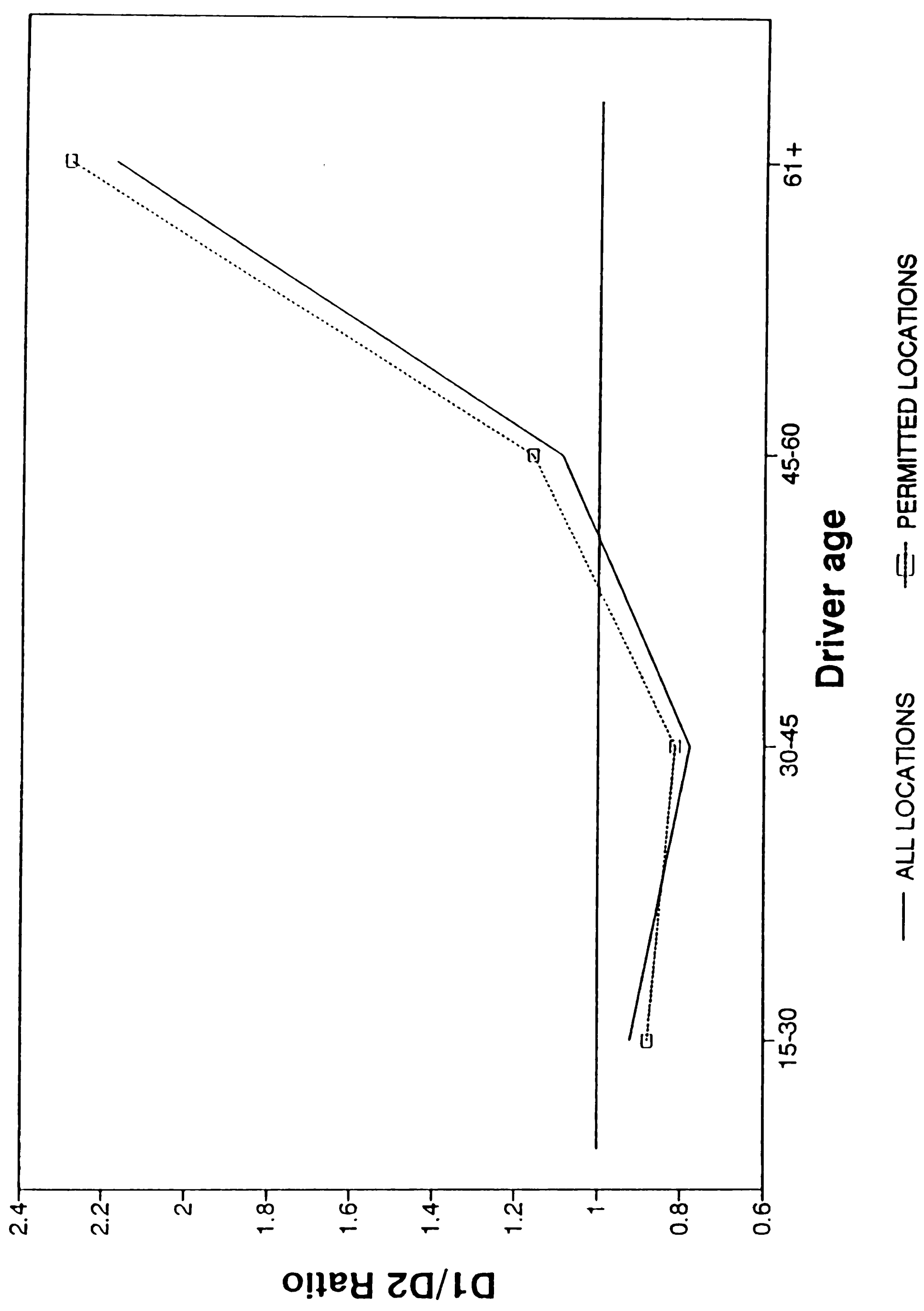


Figure 5.10. Daytime left-turn accident involvement ratios

Figure 5.11. Daytime left-turn accident involvement ratios

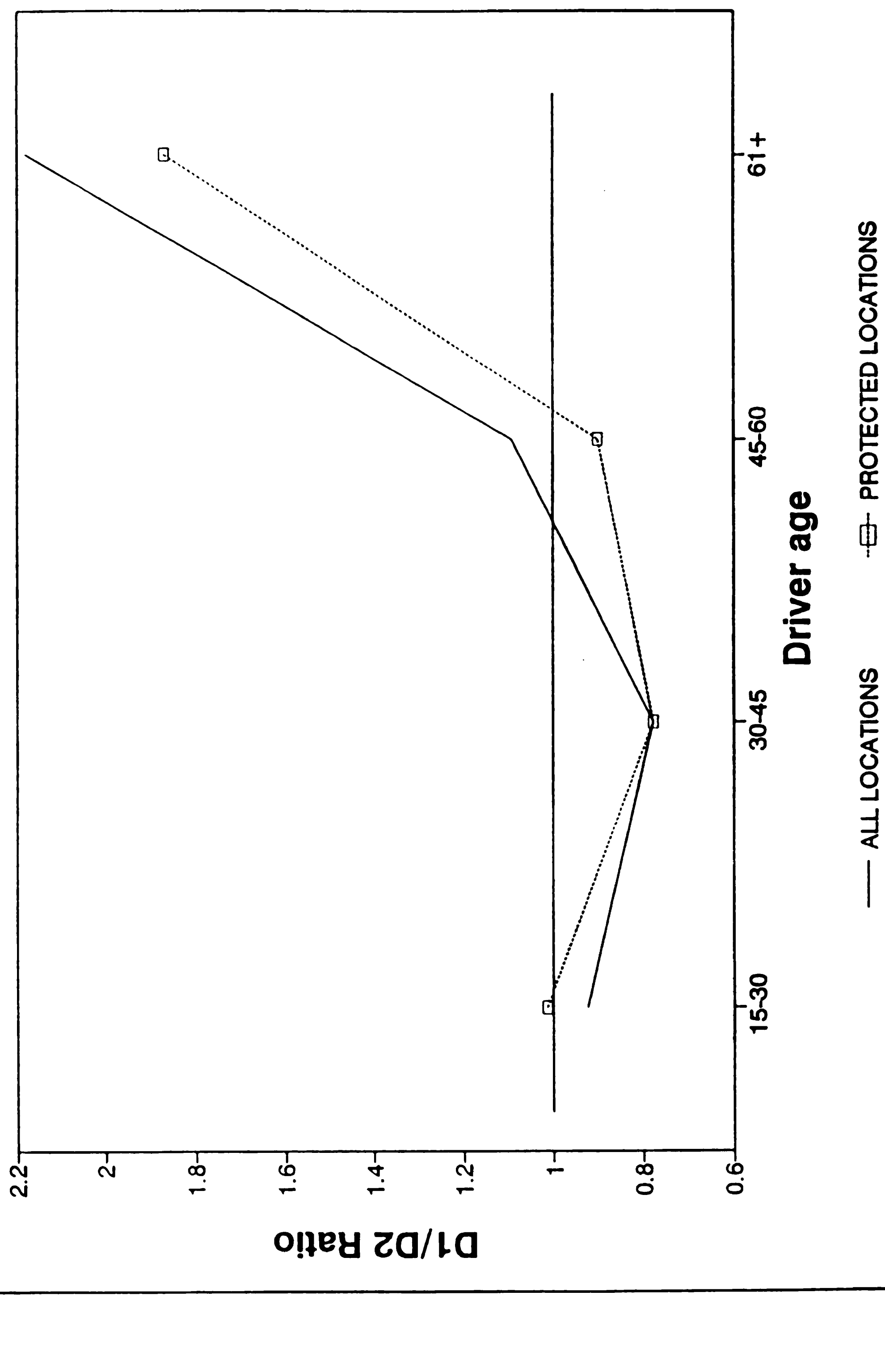
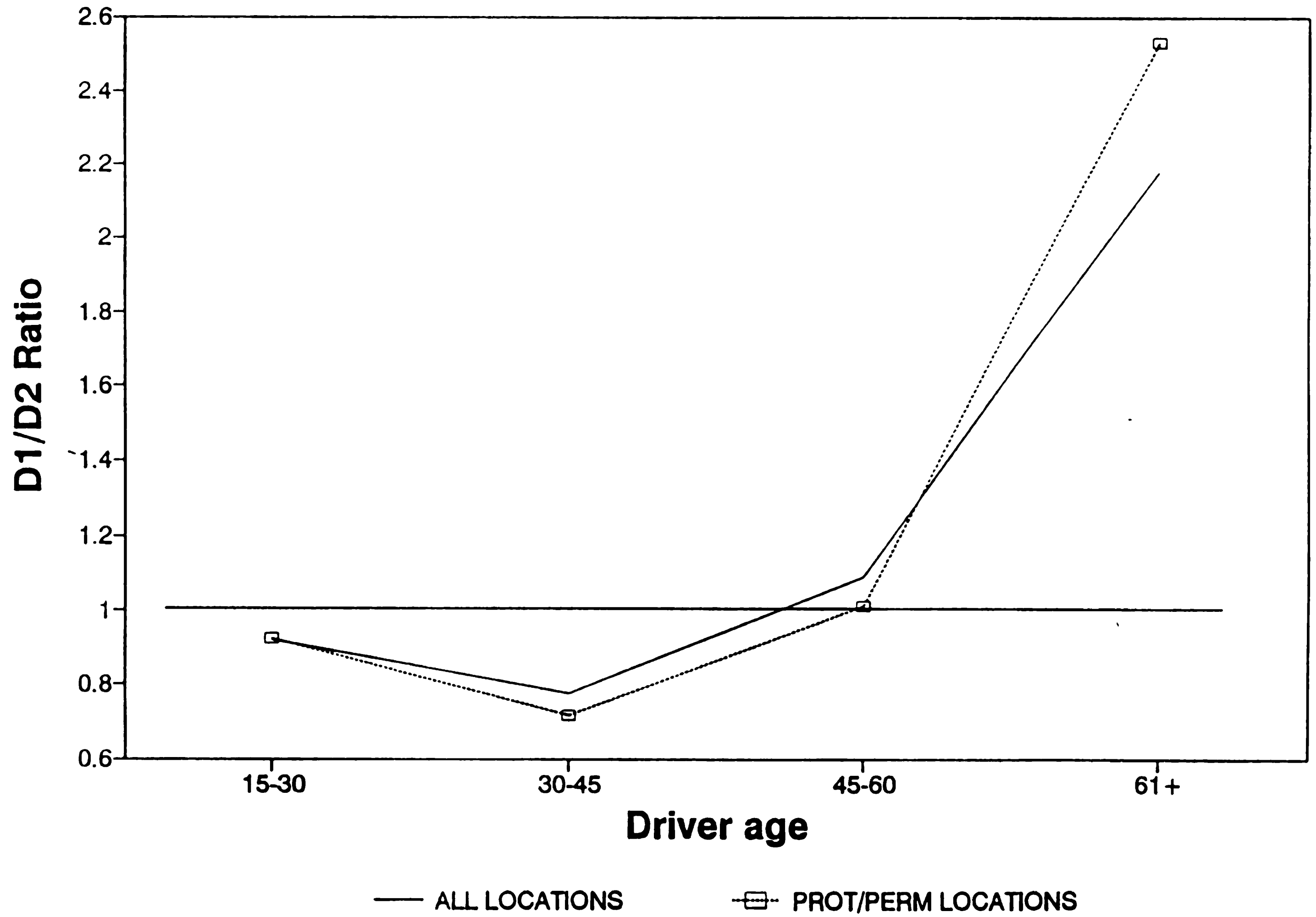


Figure 5.12. Daytime left-turn accident involvement ratios



permitted locations), fewer age groups were used than in figures 5.6 through 5.9 in order to include a significant number of data points in each age group (some loss of detail is evident--compare lines representing all left-turn accidents between figures 5.10 and 5.8 for example).

Based on figures 5.10 through 5.12 older driver overinvolvement in left-turn accidents is most pronounced at locations with protected/permitted control (2.53), followed by locations with permitted control (2.29). Locations with protected control are the safest for that age group (1.87). Protected/permitted stimuli convey the most complex message, requiring drivers to correctly understand right-of-way rules associated with protected and permitted phasing and identify which rules are applicable at any particular instant, thus confusion potential is highest for such displays, leading to a higher older driver involvement ratio.

Figure 5.13 is a comprehensive presentation of involvement ratios intended to provide an overall view of older driver involvement in intersection accidents. Information is stratified by: i) daytime or nighttime accident occurrence; ii) approach left-turn phasing type (i.e., protected, permitted, or protected/permitted); and, iii) intersection maneuver. Although right turn and through accident involvement ratios are presented for the sake of completeness, no attempt is made to provide interpretations of results since these maneuvers are beyond the scope of the present effort. Age group limits used in figure 5.13 were set based on insights gained through the overall field database analysis (figures 5.6 through 5.9) and the following criteria: a) age groups should be broad enough to include enough observations for the derivation of meaningful statistics; b) they should be compatible with those used in the comprehension analysis for cross-referencing purposes; and, finally, c) break points for age groups should allow comparisons between under-involved "mid-aged" drivers

Figure 5.13. Involvement ratios by intersection maneuver and left-turn approach control.

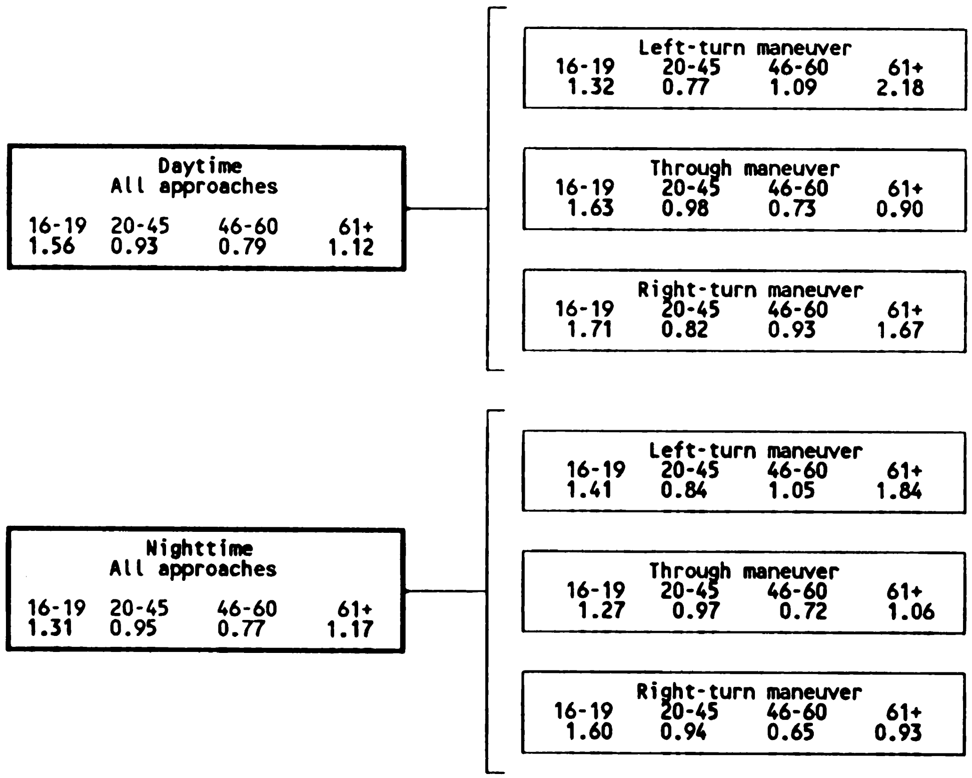
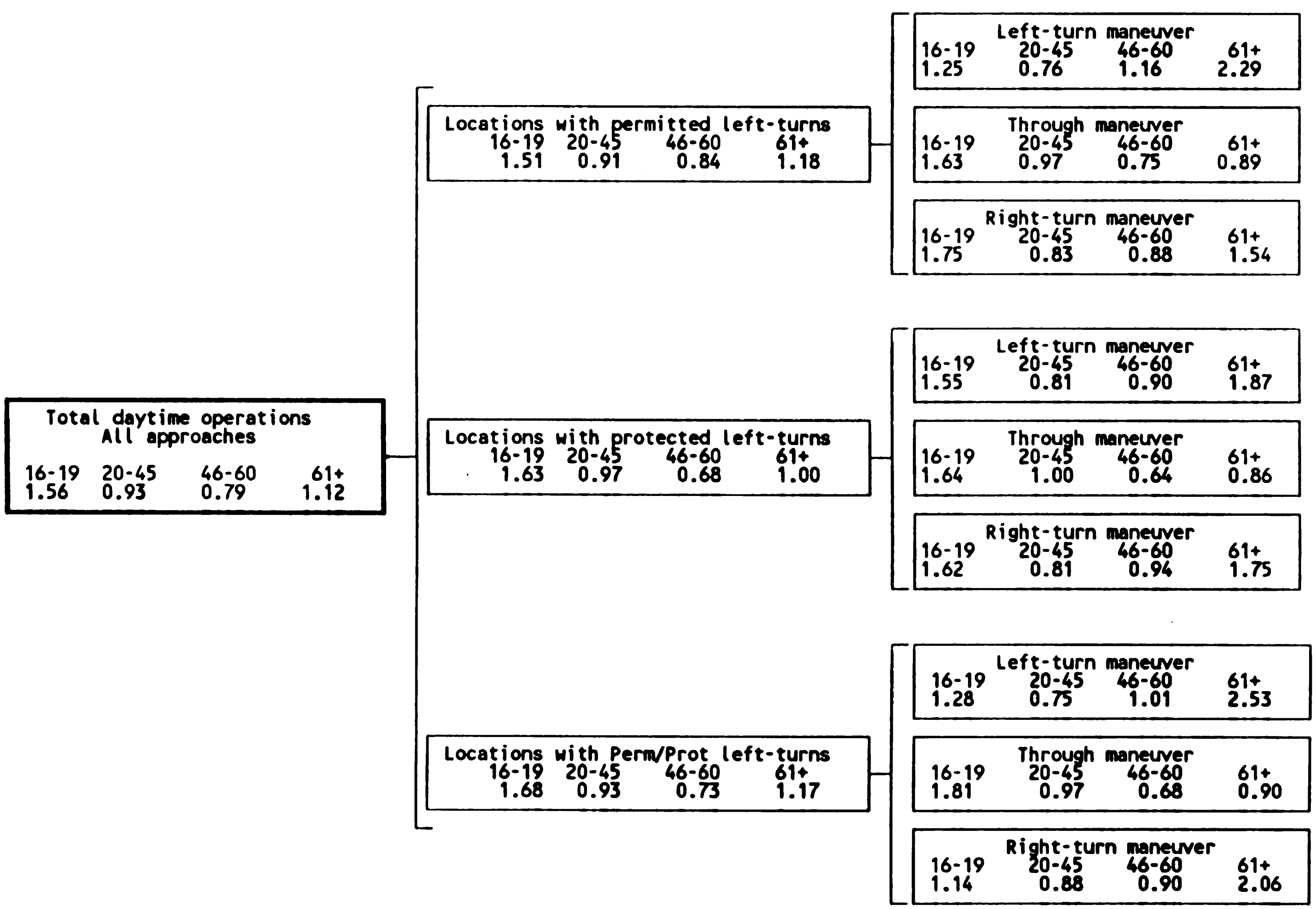


Figure 5.13. (cont'd).



(serving as a "control" group) and over-involved older drivers. Thus, ages 46 and 60 used for the comprehension analysis were preserved as age group limits since they fulfill all three of the above criteria. However, it was felt necessary to establish a new age group limit at 20 years of age in order to separate overinvolved younger drivers from those between 20 and 45 years of age who are clearly underinvolved. The four established age groups (16 to 19, 20 to 45, 46 to 60, and 61+) are used throughout the rest of this analysis.

Left-turn analysis: summary and discussion

Older driver left-turn accident involvement ratios are lowest under protected, highest under protected/permitted, and intermediate under permitted phasing. Drivers turning left under protected phasing have a relatively simple task to accomplish: they need not worry about opposing traffic interference, and can instead concentrate on keeping a safe distance from the leading vehicle following the proper turning path, and avoiding pedestrians crossing the cross-street. The task is more complicated for drivers turning left under permitted phasing, since, in addition to the previously detailed sub-tasks, they must also identify and successfully use acceptable gaps in the opposing traffic. Finally, protected/permitted left-turn phasing presents drivers with a combination of the above listed situations. However, under this type of left-turn control, the duration of the protected phase is usually a small fraction of the permitted duration, and driver decisions become even more complex than those involved in permitted phasing, since the driver has to be aware of which left-turning rules are in effect (i.e., those pertaining to permitted or protected turns) at any given moment--a process involving interpretation of signal information in addition to monitoring other traffic behavior. Although accident involvement for all and older drivers is affected in similar ways by left-turn signal phasing, age differences become more pronounced as tasks of increasing complexity are added to the left-turning maneuver. It is interesting to observe that, although protected/permitted locations do not account for the largest percentage of older driver left-turn accidents (figure 5.4), they present the highest risk to older drivers. This finding points out that, although protected/permitted phasing is harder to comprehend than protected phasing for all age groups (thus the higher percent of left-turn accidents), older drivers are much more adversely affected by the complexity of the situation than other drivers (thus the highest involvement ratios for protected/permitted locations).

In summary, older driver left-turn accident involvement ratios are related to approach left-turn control. The simple protected control is associated with the lowest involvement ratios, while protected/permitted control, the most complex phasing scheme, is the highest. Older drivers are underinvolved in through accidents and overinvolved in right-turn accidents.

5.4. INVOLVEMENT RELATED TO SIGNAL, GEOMETRIC, AND ACCIDENT ATTRIBUTES

Given that older driver accident involvement appears to be affected by left-turn control type, the analysis is now directed to assessing the effects of geometric, signal, and accident variables under each type of left-turn control.

Intersection accident involvement ratios are calculated for a variety of variables for five accident categories: i) all daytime, ii) all nighttime, iii) left-turn accidents at permitted locations, iv) left-turn accidents at permitted/protected locations; and, v) left-turn accidents at protected locations. A comprehensive accident involvement table for all driver ages can be found in table 5.5. Accident involvement ratios are presented for each of the previously defined driver age groups, for a number of signal-, intersection geometry- and accident-related variables. Where less than five observations are present in the smallest involvement ratio numerator and/or denominator for any age group, no involvement ratios are calculated and the line is left blank. For example, not enough information was present for actuated controllers at protected/permitted locations.

Table 5.5. Accident involvement ratios

	ALL DAYTIME ACCIDENTS			DAYTIME Left-turn ACCIDENTS ONLY: PERMITTED LOCATIONS			DAYTIME Left-turn ACCIDENTS ONLY: PROT/PERM LOCATIONS			DAYTIME Left-turn ACCIDENTS ONLY: PROTECTED LOCATIONS			ALL NIGHTTIME ACCIDENTS		
	20-45	46-60	61+	20-45	46-60	61+	20-45	46-60	61+	20-45	46-60	61+	20-45	46-60	61+
Controller															
Mechanical	0.92	0.80	1.18	0.76	1.15	2.42	0.74	1.04	2.57	0.84	0.94	1.74		N/A	
Actuated	0.96	0.74	0.99	0.80	1.16	1.41				0.81	0.72	1.73			
Solid State	0.94	0.73	1.09	0.72	1.22	1.73	0.83	0.84	2.50						
Cycle length															
45-60 sec.	0.91	0.84	1.12	0.77	1.01	2.24	0.78	1.22	1.88						
65-75 sec.	0.93	0.87	1.15	0.77	1.09	2.79	0.70	1.20	2.50					N/A	
80 sec.	0.93	0.72	1.20	0.74	1.36	2.39	0.76	0.83	2.84	0.82	1.00	2.13			
90-120 sec.	0.95	0.74	1.01	0.80	1.30	1.00				0.81	0.84	1.84			
Permitted duration (sec.)															
up to 21	0.90	0.80	1.30	0.77	1.06	2.15	0.80	0.93	1.95						
22-27	0.90	0.86	1.12	0.76	1.39	1.86	0.77	1.05	2.37		N/A			N/A	
28-35	0.92	0.79	1.12	0.75	1.03	2.29	0.66	1.07	2.81						
36+	0.93	0.80	1.19	0.74	1.16	2.99	0.80	0.97	3.19						
Protected duration (sec.)															
up to 6	0.96	0.67	1.00				0.83	0.98	1.78						
7-10	0.95	0.68	1.16		N/A		0.72	1.04	3.11	0.81	0.87	2.67		N/A	
11+	0.92	0.75	1.24				0.72	0.88	3.33	0.76	1.15	2.50			
Left-turn signal configuration															
Permitted GB	0.91	0.84	1.18		ALL										
Protected GA	0.98	0.67	0.98							0.83	0.86	1.73			
Protected GA + GB	0.91	1.00	1.30							0.74	1.20	2.63		N/A	
Protected/permitted FR, GA	0.94	0.69	1.12				0.76	0.84	2.43						
Protected/permitted GB+GA	0.90	0.86	1.39				0.75	1.33	2.68						
Protected GB	1.04	0.53	1.53												

Table 5.5. (cont'd).

	ALL DAYTIME ACCIDENTS			DAYTIME Left-turn ACCIDENTS ONLY									ALL NIGHTTIME ACCIDENTS		
				PERMITTED LOCATIONS			PROT/PERM LOCATIONS			PROTECTED LOCATIONS					
	20-45	46-60	61+	20-45	46-60	61+	20-45	46-60	61+	20-45	46-60	61+	20-45	46-60	61+
Protected phase type															
Lead	0.95	0.70	1.02	N/A			0.84	1.91	1.22	0.86	0.94	1.91	N/A		
Lag	0.94	0.70	1.17				0.74	0.94	2.93	0.77	1.00	2.36			
Flashing configuration															
Both flashing yellow													0.77	0.75	0.97
Both flashing red	N/A			N/A			N/A			N/A			0.73	0.93	1.14
24-hour operation													0.90	0.69	1.23
Intersection type															
Tee	0.94	0.82	1.10				0.76	1.07	4.00						
Four-leg two two-way streets	0.93	0.78	1.12	0.76	1.19	2.25	0.75	0.96	2.39	0.82	0.86	1.92	0.87	0.74	1.08
Four-leg two-way with one-way	0.86	0.82	1.62				0.79	1.21	2.20						
Presence of left-turn lanes															
Not present	0.93	0.80	1.16	0.74	1.06	2.43	0.71	0.91	3.00				0.81	0.83	1.19
Present	0.94	0.77	1.09	0.76	1.21	2.22	0.76	1.01	2.49	0.82	0.89	1.84	0.87	0.71	1.13
Signal horizontal position															
up to 3 feet	0.91	0.84	1.21	0.76	1.14	2.18	0.76	0.90	2.48	0.82	0.87	1.71	0.96	0.75	1.23
4-16 feet	0.94	0.77	1.09	0.72	1.12	2.43	0.75	1.29	2.52	0.77	1.08	2.88	0.93	0.78	1.16
17-38 feet	0.92	0.79	1.17	0.79	1.33	2.56									

Table 5.5. (cont'd).

	ALL DAYTIME ACCIDENTS			DAYTIME Left-turn ACCIDENTS ONLY: PERMITTED LOCATIONS			PROT/PERM LOCATIONS			PROTECTED LOCATIONS			ALL NIGHTTIME ACCIDENTS		
	20-45	46-60	61+	20-45	46-60	61+	20-45	46-60	61+	20-45	46-60	61+	20-45	46-60	61+
Signal Profile (table 5.16)															
A	0.91	0.84	1.20	0.76	1.20	2.22							0.84	0.80	1.08
B	0.91	0.79	1.34				0.81	1.05	3.60						
C	0.95	0.69	1.04				0.77	0.89	2.43	0.82	0.86	1.78	0.90	0.68	0.91
D	0.89	0.85	0.96	0.81	1.11	2.03									
Weather															
Clear or cloudy	0.93	0.80	1.18	0.76	1.15	2.14	0.75	1.06	2.49	0.82	0.89	1.76	0.86	0.83	1.15
Fog	0.95	0.63	1.17												
Rain	0.93	0.75	0.95	0.70	1.11	3.59	0.76	0.65	2.30				0.78	0.60	1.23
Snow	0.97	0.76	0.86	0.79	1.44	2.82							0.74	0.63	1.42
Road surface															
Dry	0.92	0.81	1.20	0.75	1.13	2.15	0.76	1.07	2.49	0.80	0.92	1.78	0.88	0.79	1.27
Wet	0.94	0.76	1.00	0.76	1.13	2.71	0.71	0.83	2.65	0.85	0.82	2.88	0.77	0.75	1.08
Snow or ice	0.97	0.75	0.90	0.77	1.54	2.53							0.83	0.70	0.91

Table 5.5. (cont'd.)

	ALL DAYTIME ACCIDENTS			DAYTIME Left-turn ACCIDENTS ONLY: PERMITTED LOCATIONS			DAYTIME Left-turn ACCIDENTS ONLY: PROT/PERM LOCATIONS			DAYTIME Left-turn ACCIDENTS ONLY: PROTECTED LOCATIONS			ALL NIGHTTIME ACCIDENTS		
	20-45	46-60	61+	20-45	46-60	61+	20-45	46-60	61+	20-45	46-60	61+	20-45	46-60	61+
Accident type															
Angle-straight	0.93	0.78	1.15										0.72	0.80	1.35
Rear-end	0.98	0.70	0.85										0.91	0.66	0.91
Angle-turn	0.88	0.77	1.36	0.81	0.97	1.52	0.71	0.96	1.56	0.88	0.85	1.09	0.74	0.62	0.75
Rear-end left-turn	0.84	0.98	1.78	0.86	0.95	2.44									
Head-on left-turn	0.83	1.10	1.67	0.73	1.24	2.47	0.74	1.09	3.02	0.74	0.98	2.86	0.94	1.24	2.00
Driver violation															
Speeding	1.01	0.47	0.50												
Fail to yield right-of-way	0.83	0.89	1.65	0.74	1.21	2.30	0.74	1.20	2.67	0.83	0.79	2.09	0.74	0.83	1.57
Improper lane use	0.84	0.92	1.69	1.03	0.58	1.64							0.90	0.71	1.53
Improper turn	0.73	1.09	2.66	0.66	1.13	3.32									
Follow too close	0.99	0.61	0.72	0.82	0.91	1.50							0.86	0.57	0.80
Driver sex															
Female	0.92	0.79	1.16	0.77	1.08	2.15	0.79	1.04	2.12	0.80	1.00	1.67	0.81	0.66	1.03
Male	0.94	0.79	1.10	0.74	1.24	2.42	0.73	0.97	2.89	0.82	0.83	2.11	0.85	0.82	1.23

ALL = Only one category under this variable. Refer to figure 4.8. N/A = Not Applicable GB = Green Ball GA = Green Arrow
FR, GA = Flashing red for permitted phase, Green Arrow for protected phase
GA + GB = Green Arrow and Green Ball illuminated simultaneously

The goal of this analysis is to provide a comparison of older driver accident involvement for different turn phasing strategies and suggest the best among competing alternatives. The discussion in the following paragraphs is focused on older driver involvement ratios unless otherwise stated.

5.4.1. SIGNAL ATTRIBUTES

Older driver involvement ratios for left-turn accidents are presented with respect to signal controller type, cycle length, permitted phase duration, and protected phase duration. Possible explanations for observed older driver involvement ratios are presented within each section.

Controller type

Solid state controllers may alter phase sequence and/or duration between cycles depending on intersection movement demands, while actuated controllers may skip phases. By contrast, mechanical controllers typically follow the same phase sequence with phase duration, offset, and sequence changes occurring only at pre-determined and specified times of the day. While mechanical controllers are cheaper and of known reliability since they have been in service for a number of decades, engineers justify the installation of more advanced equipment based on, among other considerations, intersection delay savings associated with more efficient traffic management. The question arises, however, whether, by allowing alternate phasing sequences and durations to occur frequently, older drivers who are used to a particular phase pattern (sequence and duration) become confused and get involved in relatively more accidents than at intersections equipped with mechanical controllers.

It should be noted that the majority of mechanical controllers are located at two-phase intersections and have typically been in place much longer than actuated and solid state controller types. Thus, it is more likely to find mechanical controllers at intersections where traffic volumes have reached or exceeded capacity since the signal was first installed. When saturated intersections are upgraded to more adequate geometric designs, obsolete mechanical controllers are often replaced with modern technology ones, therefore, it is quite possible, that there are correlations between controller type, adequacy of geometric design (e.g., presence of left-turn lanes) and other intersection parameters. Due to database limitations, it was not possible to further stratify the database and investigate the presence of such correlations.

The database analysis indicates that, for older drivers, actuated controllers are associated with the lowest involvement for all daytime (.99--table 5.6) as well as left-turn accidents under permitted (1.41) phasing. Mechanical controllers are associated with the highest involvement ratios (1.18 and 2.42 respectively) in both categories. No significant differences exist among controller types for locations with permitted/protected and protected phasing. Thus, it appears that actuated controllers have beneficial rather than detrimental effects on older drivers both in terms of all daytime and left-turn accidents at permitted locations. It should be kept in mind though, that these findings may be strongly related to more adequate intersection geometric designs as discussed above.

Table 5.6. Older driver accident involvement ratios for different signal controller types

CONTROLLER TYPE	ALL DAYTIME ACCIDENTS	LEFT-TURN ACCIDENTS		
		PERMITTED	PROTECTED	PROT/PER
Mechanical	1.18	2.42	1.74	2.57
Actuated	0.99	1.41	1.73	(1)
Solid State	1.09	1.73	(1)	2.50

(1) Insufficient data for analysis.

Cycle length

Cycle length is a surrogate for the number of change intervals and stop-and-go procedures per hour. A higher number of accidents

associated with a shorter cycle could be due to a larger number of vehicular conflicts associated with the change interval and stop-and-go operations. On the other hand, a higher number of accidents associated with longer cycles may be due to more opportunity for vehicular conflict during phases other than the change interval such as right turn on red and permitted left-turns during which vehicular conflicts are more likely to occur. The data indicates that older driver involvement increases with increasing cycle length up to 80 seconds and drops dramatically only for cycle lengths 90 seconds or longer. These findings may indicate that there exists an equilibrium between the aforementioned factors (i.e., number of change intervals and phase duration). Thus, for shorter cycles, phase duration seems to be more influential (accident involvement increases with phase duration); for longer cycles number of change intervals becomes more important (less accidents for fewer change intervals, despite longer permitted phase durations). The critical (highest involvement) cycle length for older drivers is different for different accident categories: a decline in involvement ratios is evident for cycle lengths over 90 seconds for all accidents and cycle lengths over 80 seconds for left-turn accidents at permitted locations (table 5.7).

Table 5.7. Older driver accident involvement for different cycle lengths.

CYCLE LENGTH	ALL DAYTIME ACCIDENTS	LEFT-TURN ACCIDENTS		
		PERMITTED	PROTECTED	PROT/PER
45-60 sec.	1.12	2.24	(1)	1.88
65-75 sec.	1.15	2.79	(1)	2.50
80 sec.	1.20	2.39	2.13	2.84
90-120 sec.	1.01	1.00	1.84	(1)

(1) Insufficient data for analysis.

Available information for older driver involvement in left-turn accidents under protected/permitted and protected phasing seems to confirm the suggested pattern.

Permitted duration

Left-turn accident involvement is directly related to permitted interval duration, both for locations with permitted and locations with permitted/protected phasing (see table 5.8) with an exception for

Table 5.8. Older driver accident involvement for different permitted phase durations

PERMITTED DURATION (sec.)	ALL DAYTIME ACCIDENTS	LEFT-TURN ACCIDENTS		
		PERMITTED	PROTECTED	PROT/PER
up to 21	1.30	2.15		1.95
22-27	1.12	1.86		2.37
28-35	1.12	2.29	N/A	2.81
36+	1.19	2.99		3.19

permitted phase durations of 22-35 seconds that are associated with the lowest involvement (1.12).

Older driver involvement ratios seem to be related to conflict opportunity: the longer the permitted phase, the more opportunity exists for conflicts with opposing traffic, and the higher involvement ratios become.

Older driver left-turn accident involvement at locations controlled by protected/permitted phasing is dominated by permitted phase conflicts (i.e., accident involvement increases with permitted phase duration).

Protected duration

Older driver involvement increases with increasing protected duration for all daytime accidents, and left-turn accidents under permitted/protected phasing (table 5.9). However, for left-turn accidents under protected phasing, involvement for a duration between 7 and 10 seconds (2.67) is higher than that for a duration longer than 11 seconds (2.50). Longer protected duration is an indication of a higher demand for left-turns, a situation that may lead to left-turn lane (or bay) overflow into an adjacent through lane depending on a number of factors (such as presence of signal coordination, platoon arrival pattern, leading or lagging left-turn phase), thus potentially creating conflicts with through traffic. In addition, if right-turn-on-red is allowed, there is a higher potential for conflicts between vehicles turning left during the protected phase and opposing traffic turning right on red. However, the simultaneous influence of other factors such as protected left-turn phase type, left-turn signal lens configuration, and concurrence/discordance with through signal indication need to be addressed as well in order to arrive at a better comprehension of older driver involvement relations to protected phase duration. Unfortunately, not enough data is available in the present database to allow further breakdown of the data.

Table 5.9. Older driver accident involvement for different protected phase durations

PROTECTED DURATION (sec.)	ALL DAYTIME ACCIDENTS	LEFT-TURN ACCIDENTS		
		PERMITTED	PROTECTED	PROT/PER
up to 6	1.00	N/A	(1)	1.78
7-10	1.16	N/A	2.67	3.11
11+	1.24	N/A	2.50	3.33

(1) Insufficient data for analysis.

Signal attributes: summary and discussion

Actuated control was found to be associated with the lowest oldest driver involvement and mechanical controllers with the highest for all and left-turn daytime accidents. However, these findings do not imply that a mere substitution of mechanical controllers with modern technology ones will lead to reduced involvement ratios. This variable provides a beginning point for a host of investigations aimed at identifying the actual causative factors behind the observed statistics. For example, actuated controllers are more likely to be present at intersections with improved geometric design and mechanical controllers are more likely to be present at intersections in need of design improvements. Thus, observed statistics may reflect comparisons of

situations where left-turns are constrained due to high volume to capacity ratios or inadequate design with situations where left-turns face no such constraints. Similarly, signal timing at approaches with mechanical controllers may be more likely to be obsolete (not reflect current traffic conditions) than approaches with modern controllers. However, an investigation of these factors is beyond the scope of this study.

Accident involvement in all and left-turn daytime accidents at permitted and protected/permitted locations initially increases with increasing cycle length and then drops dramatically. Both phase duration and number of change intervals per hour influence involvement ratios. Initially, as cycle length increases, increased phase length provides more opportunity for conflicts, but eventually, longer phases that provide more and/or longer gaps in the opposing traffic and a smaller number of change intervals during which conflicts may occur dominate, driving involvement ratios downward.

For similar reasons, increasing permitted interval duration is associated with increased daytime left-turn accident involvement ratios at permitted and protected/permitted locations up to a certain duration, after which accident involvement decreases.

In summary, the higher the opportunity for conflicts either due to the duration and nature of a particular interval (e.g., permitted interval) or the saturation of intersection movements (e.g., obsolete geometric design-mechanical controllers), the higher older driver involvement ratios become.

5.4.2. SIGNAL FACE AND PHASE TYPES

In view of the findings about the significance of signal display complexity on driver comprehension, differences between three and four stacked section displays operating under protected and protected/ permitted phasing are investigated. Effects of leading versus lagging protected left-turn phasing on older driver left-turn accident involvement are also analyzed. The section concludes with a discussion

of the effect of nighttime signal operation configuration on older driver accident involvement.

Signal section configuration

Three alternate protected phasing signal face arrangements are present in the database (table 5.10): protected green arrow (stacked 3), protected green arrow simultaneously illuminated with a green ball (stacked 4), and protected green ball (in split phasing--also a stacked-three configuration).

Table 5.10 Older driver accident involvement for different protected phase signal face configurations

PROTECTED SIGNAL FACE CONFIGURATION	ALL DAYTIME ACCIDENTS	LEFT-TURN ACCIDENTS		
		PERMITTED	PROTECTED	PROT/PER
PROTECTED GA[1] stacked 3	0.98	N/A	1.73	
PROTECTED GB+GA stacked 4	1.30		2.63	2.43
PROT/PER FR/GA Michigan display	1.12			2.68
PROT/PER GB+GA stacked 4	1.39			
Protected GB	1.53		(2)	

(1) GA = Green arrow, GB = Green ball,
FR = Flashing red, / not simultaneously illuminated
\+ = simultaneously illuminated
(2) Insufficient data for analysis.

Comparisons among all daytime accidents at protected locations show that older driver accident involvement is lowest (.98) for common stacked-three displays with a protected green arrow (table 5.10) followed by the stacked three Michigan display (flashing red ball for the permitted and steady green arrow for the protected phase--D1/D2 = 1.12). Stacked four (fourth level green arrow) displays are associated with higher involvement ratios (1.30) than stacked-three protected green arrow, but lower than protected green ball displays (green ball displayed simultaneously with red ball for all other intersection movements) which has the highest involvement ratio (1.53) among all

protected displays. Stacked-four displays are associated with higher involvement ratios (1.39) than the Michigan display at permitted/ protected locations.

As shown in table 5.10 adequate data for left-turn accident involvement is available for four displays, two used for protected/ permitted and two for protected phasing. Between the protected phasing displays, the Michigan configuration performs better (2.43) than the alternative stacked four display (2.68). The common stacked three display performs better (1.73) than the stacked four display (2.63) for protected locations.

Poor older driver performance associated with the protected green ball display may be due to confusion about the unusual situation: the driver has no way of knowing that opposing traffic faces a red phase (i.e., no supplemental sign is provided, nor is he/she given an indication of the change from the protected to a permitted interval, since drivers face a green ball throughout the period opposing traffic faces either a red or a green ball). Among displays using arrow sections, the simplest ones (stacked three) outperform the more complex (fourth level green arrow) with two simultaneously illuminated lenses (green ball and green arrow) in older driver total accident involvement. Simpler (stacked three--common and Michigan) displays outperform the more complex (more sections, two simultaneously illuminated sections) stacked four displays in terms of left-turn accident involvement as well.

Protected phase type

The choice between leading and lagging left-turn phasing is often a matter of local policy or convenience, since no definitive accident patterns have been established for the two phasing sequences. Table 5.11 is a summary of involvement ratios based on the field database.

Leading protected phasing is associated with a lower older driver involvement than lagging for all accident categories presented in table

5.11. Differences are small for all daytime accidents, somewhat higher for left-turn accidents at protected locations, and particularly large

Table 5.11. Older driver accident involvement for different protected phase types

PROTECTED PHASE TYPE	ALL DAYTIME ACCIDENTS	LEFT-TURN ACCIDENTS		
		PERMITTED	PROTECTED	PROT/PER
Lead	1.02		1.91	1.22
Lag	1.17	N/A	2.36	2.93

at protected/permitted locations where leading protected phasing is associated with an involvement ratio of 1.22 compared to 2.93 for lagging protected phasing. The higher left-turn accident involvement at lagging protected phasing locations may be due to conflicts with opposing through vehicles attempting to use the change interval succeeding the permitted interval.

Flashing configuration

Field data analysis results presented in table 5.12 and indicate that locations where both the through and left-turn signal flash yellow balls have the lowest nighttime accident involvement ratios (.97). Locations where both through and left-turn signals flash red balls have higher ratios (1.14) and locations with 24-hour operations have the highest involvement ratios (1.23).

Table 5.12. Older driver accident involvement for different nighttime signal configurations

FLASHING CONFIGURATION	ALL NIGHTTIME ACCIDENTS
Both flashing yellow	0.97
Both flashing red	1.14
24-Hour operation	1.23

These findings are in line with comprehension analysis findings of a higher incidence of older driver serious errors at locations with flashing red than locations with flashing yellow balls.

It may be initially surprising to find that signals under twenty-

four hour full color operation are associated with the highest nighttime accident involvement ratios for older drivers. However, it should be kept in mind that twenty-four hour signal operations are usually reserved for higher nighttime volume intersections. Thus, older drivers may be at a disadvantage at such locations due to shorter available gaps when turning left (higher opposing volumes), and glare from oncoming vehicle headlights that contributes to difficulties with judging oncoming vehicle speeds and distances and identifying proper turning paths.

By contrast, flashing yellow indications on both the left-turn and through signals are usually present at lower volume locations and thus associated with fewer glare problems. Drivers are required to yield only in the presence of oncoming traffic.

Flashing red indications however, require the most complex mental processing and driver action sequence: the meaning of the left-turn flashing red indication depends on the flashing through indication; for a flashing red through signal drivers must come to a stop and proceed only if there is no opposing through and cross-street traffic. Thus, at such locations drivers have to check for traffic on three approaches (compared to one needed for flashing yellow indications). In addition, cross-street traffic speed judgement requires more physical effort (i.e., turning the head in wider angles--a task demanding longer time for older drivers--and judging speeds of vehicles approaching in two opposite directions) than opposing traffic speed judgment.

Higher maneuver complexity is reflected in higher involvement at locations displaying flashing red compared to those displaying flashing yellow indications. A possible explanation for the observing the highest older driver involvement in left-turn accidents at locations with 24-hour signal operations may be found in higher nighttime traffic volumes and the ensuing lower availability of gaps in the opposing traffic commonly present at such locations. Older driver problems with glare and judging opposing traffic speeds may be compounded to a higher

degree than those of other driver groups as nighttime traffic volumes increase.

Signal face and phase types: summary and discussion

Simpler three-section protected displays are associated with lower older driver left-turn and total daytime accident involvement ratios than stacked four (fourth level green arrow) displays. Simpler displays are associated with lower involvement ratios both when used for protected and protected/permitted phasing. This result is compatible with comprehension analysis findings of better comprehension scores associated with simpler displays.

Older drivers have lower involvement in total and left-turn accidents at locations with leading protected phasing than at locations with lagging phasing. Higher lagging location involvement may be due to conflicts with opposing through traffic attempting to use the clearance interval between the permitted and protected phases.

During nighttime operations, locations where flashing yellow balls are used for both the left-turn and through movements are associated with the lowest older driver accident involvement, followed by locations with flashing red balls for both left-turn and through movements. The highest involvement was observed at locations with 24-hour full color operations. Results for 24-hour operations locations may be due to higher volumes at such locations as mentioned previously. Flashing operations involvement ratio results are compatible with comprehension analysis results, i.e., a higher involvement occurs at approaches controlled by displays with lower driver comprehension scores.

5.4.3. GEOMETRY AND LEFT-TURN SIGNAL POSITION

Differences in involvement ratios between approaches controlled by mechanical and those controlled by solid state actuated controllers identified in previous sections are believed to be associated with modernization of geometric design and signal control parameters rather than direct controller effects on accident experience. Thus, it is

desirable to identify relations between intersection geometry information and involvement ratios. The present section is focused on the analysis of the effect of various intersection types, presence of left-turn lanes, left-turn signal horizontal position, and number and position of signals (signal profile) on involvement ratios. Possible effects of these variables on involvement ratios are discussed.

Intersection type

Older driver daytime accident involvement is lowest at Tee (1.10--table 5.13) intersections and four-leg intersections of two-way streets (1.12), and significantly higher at intersections of two-way with one-way streets (1.62). A complete reversal of older driver involvement

Table 5.13. Older driver accident involvement for different intersection types

INTERSECTION TYPE	ALL DAYTIME ACCIDENTS	LEFT-TURN ACCIDENTS		
		PERMITTED	PROTECTED	PROT/PER
Tee	1.10	(1)	(1)	4.00
2-way/2-way	1.12	2.25	1.92	2.39
2-way/1-way	1.62	(1)	(1)	2.20

(1) Insufficient data for analysis.

is recorded for left-turn accidents at protected/permitted locations where involvement is highest at Tee intersections (4.00), lowest at two-way with one-way street intersections (2.20), and intermediate at intersections of two-way streets (2.39). Data for only one intersection type are available for left-turn accidents at locations with permitted and protected control, thus comparisons among intersection types are not possible for these accident categories.

Additional information is necessary in order to interpret these findings, especially the extremely high involvement ratio associated with left-turns at Tee intersections which seems to be counter-intuitive, since fewer vehicular conflicts exist at such intersections and it seems reasonable to expect lower, not higher involvement ratios.

Differences between intersections of two-way streets and those of one-way with two-way streets also need to be investigated further in order to identify their causes.

Presence of left-turn lanes

The presence of a separate left-turn lane is associated with lower older driver involvement in all accident categories under examination (table 5.14--not enough data were available for protected left-turns for

Table 5.14. Older driver accident involvement presence of left-turn lane

LEFT-TURN LANE TYPE	ALL DAYTIME ACCIDENTS	LEFT-TURN ACCIDENTS		
		PERMITTED	PROTECTED	PROT/PER
Not present	1.16	2.43	(1)	3.00
Present	1.09	2.22	1.84	2.49

(1) Insufficient data for analysis.

comparisons). Intersection movement separation with the provision of a left-turn lane reduces traffic conflicts between through- and left-turning vehicles resulting in fewer accidents both for left-turning and through vehicles. Furthermore, a survey of older drivers identified in the literature review (71) shows that older drivers are particularly concerned with identifying the proper lane from which to turn. Thus, provision of a left-turn lane marked as such helps eliminate this problem, and older driver confusion decreases (since they can properly position their vehicles for a turn), and, consequently, involvement ratios become lower.

Signal horizontal position

A left-turn signal positioned zero to three feet to the left of the left-turning driver is associated with the lowest older driver accident involvement for all categories of left-turn accidents (table 5.15). Involvement increases with increasing signal distance from the left-turning driver.

Table 5.15. Older driver accident involvement for different left-turn signal horizontal positions

SIGNAL HORIZONTAL POSITION	ALL DAYTIME ACCIDENTS	LEFT-TURN ACCIDENTS		
		PERMITTED	PROTECTED	PROT/PER
Up to 3′	1.21	2.18	1.71	2.48
4′-16′	1.09	2.43	2.88	2.52
17′-38′	1.17	2.56	(1)	(1)

(1) Insufficient data for analysis.

Signals positioned closer to the driver eliminate the need to scan wide areas in order to locate the left-turn signal. Thus, signals can be detected sooner and older drivers that have narrower peripheral vision can monitor other intersection conditions pertinent to the left-turning task easier. A lower scan time and the ability to easier monitor intersection conditions lead to a better accident performance.

Signal profile

Signals addressed specifically to drivers turning left may ameliorate poor driver performance by eliminating confusion regarding right-of-way rules applicable to left turns. Signal heads addressed to both through and drivers turning left may cause drivers to become confused, especially during the permitted phase when the same indication (green ball) on the same signal head must be interpreted differently by drivers, depending on the intended maneuver.

The most common signal profiles found in the database are shown in table 5.16. Profile A with three signal heads (one addressed to left-turning drivers, one to through drivers, and one to both through and drivers turning right) corresponds to approaches with three lanes. Profile B corresponds to two-lane Tee and approaches intersecting with one-way streets using two signal heads, profiles C and D to two-lane approaches with a left-turn and shared through-right turn lanes. Profile D approaches use two left-turn signals.

For left-turn accidents under permitted phasing, profile A locations are associated with a higher older driver involvement (2.22--

Table 5.16. Signal profile configurations

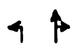
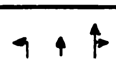
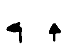
SIGNAL HEADS PRESENT	SIGNAL ADDRESSED TO DRIVERS:	PROFILE
	Turning left Driving through Driving through or turning right	A
	Turning left Driving through	B
	Turning left Driving through or turning right	C
	Turning left (two signals) Driving through or turning right	D

table 5.17) than profile D locations (2.03). Thus, locations with two left-turn and one through signal outperform locations with one left-turn and two through signals. However differences between the two signal profiles are not dramatic. These results agree with comprehension analysis findings that the number of through signals was not significantly related to driver comprehension for permitted displays.

Table 5.17. Older driver accident involvement for different signal profiles

SIGNAL PROFILE	ALL DAYTIME ACCIDENTS	LEFT-TURN ACCIDENTS		
		PERMITTED	PROTECTED	PROT/PER
A 	1.20	2.22	(1)	(1)
B 	1.34	(1)	(1)	3.60
C 	1.04	(1)	1.78	2.43
D 	0.96	2.03	(1)	(1)

(1) Insufficient data for analysis.

Older driver left-turn accident involvement at profile B locations under protected/permitted control (3.60) is higher than profile C locations (2.43). This result concurs with previous findings about higher accident involvement at Tee intersections. However, it is not clear why this phenomenon occurs. Not enough information is available to allow comparisons of alternative signal configurations for Tee and other intersection types.

In summary, configurations using a single through signal have lower older driver left-turn accident involvement ratios at permitted locations than configurations using two through signals at intersections of two-way streets. Older driver left-turn accident involvement at Tee intersections is significantly higher than that at intersections of one-way and two-way streets when a single through signal is used. The underlying cause of this latter phenomenon remains unclear.

Geometry and left-turn signal position: summary and discussion

Involvement in left-turn accidents under protected/permitted phasing is highest at Tee intersections, lowest at two-way with one-way intersections and intermediate at intersections of two-way streets.

Left-turn signals positioned closer to the driver are associated with lower total and left-turn daytime accident involvement. Involvement increases with left-turn signal distance from the driver. These findings are attributed to less physically demanding and more efficient visual scanning patterns associated with displays located closer to the driver.

Left-turn accident involvement is higher at intersections of two-way streets using two through signals than those using one through signal under permitted phasing. This finding concurs with comprehension analysis results. Better comprehension of stimuli using a single through display was attributed to lower stimulus complexity. Lower accident involvement, therefore, may be directly attributed to better comprehension of simpler stimuli.

5.4.4. ACCIDENT AND DRIVER CHARACTERISTICS

The hypothesis that stimulus complexity is related to driver comprehension of signal displays was shown to hold true on many

occasions in the comprehension analysis. It was stated that more complex stimuli were expected to be associated with lower driver comprehension and thus higher accident involvement. Factors affecting the complexity of the driving environment include weather and road surface conditions that may demand a larger share of driver attention, detracting from mental capacity available for the tasks of perceiving and interpreting signal displays. It would then be expected that harsher weather and poor road surface conditions may thus be associated with higher accident involvement ratios, especially for more complex intersection maneuver tasks, such as turning left. To this end, older driver accident involvement ratios for various weather and road surface conditions are investigated in order to assess their impact on older driver accident performance.

Two additional variables examined in this section allow a better definition of the older driver "profile;" information on accident type and driver violation allows the identification of the most hazardous situations for older drivers under each type of left-turn control.

Finally, involvement ratio differences between sexes under each type of left-turn control are presented and discussed. Significant differences in percentages of licensed drivers and driving habits among sexes were identified both in the literature and during the analysis of the comprehension database.

Weather

Older driver daytime accident involvement is lower under adverse weather conditions (rain and snow--0.95 and 0.86 respectively--table 5.18) than clear weather or fog conditions (1.18 and 1.17 respectively). A partial explanation for this phenomenon may be found in speculations by certain authors that older drivers particularly vulnerable under such conditions may refrain from driving in rain and snow. Thus, only those among older drivers that are in the best physical condition attempt to drive during adverse weather conditions. Given their own perceptions of the conditions, it appears that older drivers assess the danger of

Table 5.18. Older driver accident involvement for different weather conditions

WEATHER CONDITION	ALL DAYTIME ACCIDENTS	LEFT-TURN ACCIDENTS		
		PERMITTED	PROTECTED	PROT/PER
Clear/cloudy	1.18	2.14	1.76	2.49
Fog	1.17	(1)	(1)	(1)
Rain	0.95	3.59	(1)	2.30
Snow	0.86	2.82	(1)	(1)

(1) Insufficient data for analysis.

driving in adverse weather conditions than when driving in clear weather. However, despite their overall performance, older drivers are highly overinvolved in left-turn accidents at permitted locations during adverse weather conditions (3.59 in rain, 2.82 in snow), an indication that they may not be aware of the extent of the dangers they face particularly when turning left at such locations under these conditions. Their involvement is lowest in clear weather (2.14).

Under protected/permitted phasing, older drivers are less involved in rainy (2.30) than clear weather (2.49), but differences are not dramatic.

Daytime intersection statistics mainly representing the straight-through maneuver show that older drivers compensate adequately for adverse weather conditions when moving straight, but have a higher involvement during such conditions when turning left at approaches with permitted control. Diversion of attention to tasks related to turning left may be responsible for the observed involvement patterns.

Road surface

Older drivers are less involved in daytime accidents under wet and snow/ice road conditions than on dry roads (table 5.19). However, they are significantly more involved in accidents on wet roads when turning left, regardless of approach left-turn control. Similar trends for total intersection accidents have been reported by others (125). Cumulative daytime statistics overwhelmingly represent through

accidents. Thus, older drivers appear to be able to correctly assess (even overcompensate) for adverse conditions when performing simpler intersection maneuvers (i.e., driving straight-through), but misjudge the risks of getting involved in accidents when executing the more complex maneuver of turning left under adverse roadway conditions.

Table 5.19. Older driver accident involvement for different road surface conditions

ROAD SURFACE CONDITIONS	ALL DAYTIME ACCIDENTS	LEFT-TURN ACCIDENTS		
		PERMITTED	PROTECTED	PROT/PER
Dry	1.20	2.15	1.78	2.49
Wet	1.00	2.71	2.88	2.65
Snow or Ice	0.90	2.53	(1)	(1)

(1) Insufficient data for analysis.

Accident type

Older driver accident involvement in rear-end accidents between vehicles moving straight is the lowest among accident categories analyzed in the present study (.85--table 5.20). Involvement in right-angle accidents between vehicles moving straight is 1.15, and between a vehicle moving straight and a turning vehicle is 1.36. Finally, involvement in head-on collisions between a vehicle turning left and one moving straight is 1.67, and that in rear-end collisions involving vehicles turning left is 1.78.

Table 5.20. Older driver accident involvement for different accident types

ACCIDENT TYPE	ALL DAYTIME ACCIDENTS	LEFT-TURN ACCIDENTS		
		PERMITTED	PROTECTED	PROT/PER
Angle-straight	1.15	(1)	(1)	(1)
Rear-end	0.85	(1)	(1)	(1)
Angle-turn	1.36	1.52	1.09	1.56
Rear-end/left	1.78	2.44	(1)	(1)
Head-on/left	1.67	2.47	2.86	3.02

(1) Insufficient data for analysis.

The following scenario is a logical explanation of differences in over-involvement among accident types. Older drivers can quite effectively keep proper distances from leading vehicles, thus involvement in rear-end accidents is lowest. However, they fail to monitor the through signal with the same efficiency, thus violate red indications and become involved in right-angle (head-on) accidents with vehicles moving straight (turning left) on other intersection legs. When turning left they divert their attention to tasks related to the left-turn maneuver (such as identifying the signal display and comprehending its meaning, identifying the proper turn lane and path) thus failing to monitor their distance from leading vehicles and getting involved in rear-end left-turn accidents. This explains the discrepancy between a low rear-end accident involvement when no left-turning vehicle is involved and a high rear-end involvement when a left-turning vehicle is involved (assuming that the left-turning driver is mostly at-fault). However, these mechanisms remain hypothetical and further research is necessary to validate them.

For older driver left-turn accidents at permitted locations, highest involvement is associated with head-on left-turn accidents (2.47) and rear-end collisions between vehicles turning left (2.44). Collisions at an angle involving a left-turning vehicle have an involvement ratio of 1.52. The previous scenario provides an explanation for these findings as well. Involvement ratios for protected and protected/permitted locations, where the highest older driver involvement is associated with head-on left-turn accidents (3.02 and 2.86 respectively) and lowest with angle-turn accidents (1.56 and 1.09) respectively, are also consistent with the above scenario.

Older drivers can effectively keep their distances from leading vehicles and are less likely to violate a red indication when moving straight through than when turning left at an intersection. They are most likely to violate right-of-way rules and become involved in head-on

collisions when turning left under protected/permitted phasing.

Driver violations

Older drivers are overinvolved in daytime accidents when they are cited for (listed in order from highest to lowest involvement): improper turn (2.66--table 5.21), improper lane use (1.69), failure to yield right-of-way (1.65), following too closely (0.72), and speeding (0.50). The three highest ranking violations are associated with highest ranking intersection problems identified by older drivers in personal surveys (71): older drivers stated they have difficulties identifying the proper turning lane, proper turning path, and locating the left-turn signal. Thus, while drivers are aware of their deficiencies, they seem unable to use a compensatory mechanism as they successfully do under other circumstances. Older drivers tend to drive conservatively, keeping longer distances from leading vehicles and not driving fast, and are less likely than other drivers to be cited for driving too closely to the leading vehicle or speeding. This pattern is consistent with the previously identified lower involvement in rear-end accidents.

Table 5.21. Older driver accident involvement for different driver violations

DRIVER VIOLATION	ALL DAYTIME ACCIDENTS	LEFT-TURN ACCIDENTS		
		PERMITTED	PROTECTED	PROT/PER
Speeding	0.50	(1)	(1)	(1)
Fail to yield	1.65	2.30	2.09	2.67
Improper lane	1.69	1.64	(1)	(1)
Improper turn	2.66	3.32	(1)	(1)
Too close	0.72	1.50	(1)	(1)

(1) Insufficient data for analysis.

For left-turn accidents under permitted phasing, the highest involvement is associated with improper turns (3.32), failure to yield right of way (2.30), improper lane use (1.64), and following too closely (1.50). Permitted left-turn accident patterns are similar to those for daytime accidents.

In summary, older drivers moving straight through are less likely to be speeding or driving too closely to the leading vehicle. They are more likely to make improper lane changes and improper turns or fail to obey the right-of-way rules. These problems are exacerbated when turning left at permitted locations. Failure to yield right of way is more prominent at permitted/protected locations. These findings are consistent with a higher accident involvement where more complex situations are present: left-turn accident involvement is higher than through accident involvement, and violations are highest where right-of-way rules are most complex, i.e., at permitted/protected locations.

Driver sex

Older female drivers have a slightly higher involvement ratio than their male counterparts only for total normal signal operations accidents (1.16 female versus 1.10 male--table 5.22). They are less involved in all other accident categories under examination. Thus, older female drivers, despite driving less miles per year and having

Table 5.22. Older driver accident involvement for driver sex

DRIVER SEX	ALL DAYTIME ACCIDENTS	LEFT-TURN ACCIDENTS		
		PERMITTED	PROTECTED	PROT/PER
Female	1.16	2.15	1.67	2.12
Male	1.10	2.42	2.11	2.89

(1) Insufficient data for analysis.

lower correct answer rates (see comprehension analysis), prove to be more efficient in compensating for situations where they are vulnerable than their male counterparts.

Accident and driver characteristics: summary and discussion

Older drivers overcompensate (i.e., have a lower involvement ratio) for adverse weather conditions when moving straight-through, but are overinvolved in accidents during the same conditions when turning left at permitted locations. The complexity of the left-turning maneuver and weather interference may be the underlying reason that older drivers do not perform as efficiently under these conditions.

Similar patterns are observed for roadway conditions: lowest involvement in daytime accidents is observed under adverse weather conditions (wet, snow, or ice) and highest under favorable (dry) conditions. For left-turn accidents, lowest involvement occurs under dry pavement conditions and highest under rainy conditions. Drivers may not able to cope with adverse roadway conditions when turning because their attentions are turned to the left-turning tasks.

Older drivers moving straight have a lower involvement ratio in rear-end accidents than other driver ages. They are also less likely to get involved in angle, rear-end or head-on accidents with a turning vehicle. However, they run a higher risk to become involved in the latter three types of accidents when their attention is consumed with the left-turning tasks. Involvement in head-on accidents when turning left is highest at locations with protected/permitted phasing.

Older drivers are less likely than other drivers to be involved in accidents where they are cited for speeding or following the leading vehicle too closely when they are moving straight. They have the highest overinvolvement in accidents where they are cited for improper lane use, improper turns and failure to yield. Citation patterns are consistent with problems older drivers recognize they have within the intersection environment. Older driver accident problem is exacerbated when turning left, and failure-to-yield citations are particularly prominent at permitted/protected locations, where right-of-way rules are the most complex among all left-turn phasing types.

Male drivers are underinvolved in total normal signal operations accidents, however, female drivers are underinvolved in turning accidents. Female drivers seem to be better able to handle more complex demands placed on the driver than their male counterparts.

5.5. CHAPTER SUMMARY

Approximately four-fifths of intersection accidents involve vehicles moving straight-through and occur during the daytime. Four-fifths of turning accidents are related to vehicles turning left and the remainder to vehicles turning right. Not surprisingly, permitted phasing violations account for a higher percentage of left-turn accidents than locations with protected phasing for all driver ages. As drivers age, the percentage of through accidents decreases while the percentage of turn accidents (both left and right turns) increases.

Older drivers are overinvolved in intersection accidents. Their overinvolvement in turning accidents is significantly more pronounced than that in accidents involving vehicles moving straight. Among turning accidents, involvement is highest for left turns and less pronounced for right turns. Older driver overinvolvement in left-turn accidents depends on approach left-turn control. The highest involvement is observed at permitted/protected and the lowest at protected locations.

Differences in older driver involvement ratios among intersection maneuvers can be explained based on intersection maneuver complexity. The simplest maneuver, driving straight through places minimal requirements on the driver, since the driver keeps driving in the same lane and only needs to monitor the leading vehicle and the through signal display. Through signal intervals have standard meanings and are easily interpreted. Thus, the through accident involvement ratio is lowest for older drivers. Drivers turning right may need to change lanes and monitor pedestrian traffic crossing the side street in addition to monitoring leading vehicles and signal indications. The higher complexity of this maneuver is reflected in higher older driver involvement ratios in right-turn accidents. Finally, the left-turn maneuver involves all tasks associated with right turns (with the difference that pedestrians crossing the cross street are further from the driver and thus harder to monitor) and the additional task of

monitoring opposing traffic in order to identify acceptable gaps. Older drivers have been demonstrated to have significant difficulty correctly judging speeds of oncoming traffic and/or acceptable gaps. Furthermore, the comprehension analysis indicated that older drivers have a particularly low comprehension of left-turn signal indications. The complexity of the left-turn maneuver is reflected in higher older driver involvement ratios in left-turn accidents.

Protected left-turns relieve the driver of the task of monitoring opposing traffic. In addition, the protected left-turn green arrow has a unique meaning. Thus, involvement ratios for protected left-turns are the lowest among alternative left-turn phase types. Left-turns under permitted phasing require the driver to monitor opposing traffic. The double use of permitted green balls as an indication granting the right-of-way to through traffic and an indication for permitted left-turns may also lead to driver confusion. The higher complexity of the tasks required under permitted phasing are reflected in higher involvement ratios for these locations. Finally, protected/permitted phasing provides the most complex left-turn maneuver since right-of-way rules change during the cycle and signal displays are often more complex with the presence of multiple illuminated sections. Thus, older driver involvement ratios under this phasing are the highest among all left-turn phasing types examined.

A number of signal, geometric, and accident variables were found to be related to older driver accident involvement. The most significant findings are summarized here.

Permitted phase duration was found to be directly related to left-turn accident involvement. Longer permitted phase durations are associated with a higher number of vehicular conflicts and more opportunity for accidents. Similar patterns were identified for protected phase duration at permitted/protected locations. Longer protected phases at such locations are associated with heavier left-turn demand (the protected interval is used to accommodate vehicles that did not have an opportunity to turn during the permitted phase). Thus, the protected phase duration is a likely surrogate for the real cause of accident overinvolvement, i.e., a heavy left-turn demand in the presence of the most complex right-of-way rules among all left-turn phasing strategies. Drivers are under pressure to complete left turns while continuously monitoring the left-turn signal for current right-of-way rules. The presence of an additional change interval (from protected to permitted or vice-versa) provides more opportunity for conflicts than any other phasing strategy. The complexity of the situation affects older drivers to a higher degree than their younger counterparts as explained previously. Therefore this finding can be explained in terms of opportunity of vehicular conflicts as well.

Simpler (stacked-three) left-turn signal face arrangements used at protected and protected/permitted locations are associated with lower accident involvement ratios than stacked-four displays. This finding is in agreement with comprehension analysis findings, where older drivers were found to comprehend simpler displays better.

Involvement ratios at locations with leading protected left-turn intervals were found to be lower than those at lagging intervals both under protected and protected/permitted phasing. Inferior lagging phase performance was attributed to opposing vehicles violating the change interval between the permitted and lagging protected phases.

Nighttime involvement ratios were lower for locations with flashing yellow balls than for those with flashing red balls. These findings correlate with comprehension analysis results indicating that serious error rates (see methodology for definition) among older drivers are lowest for flashing yellow balls and highest for flashing red balls. Locations with 24-hour full color operations have the highest nighttime involvement ratios. This is thought to be a direct consequence of the presence of higher volumes at such locations putting older drivers at a distinct disadvantage since they are more susceptible to glare and have longer glare recovery times than their younger counterparts, thus an

increase in opposing traffic volumes may have a disproportionately adverse effect on older driver performance.

The presence of left-turn lanes is associated with lower involvement in all daytime and left-turn accidents regardless of left-turn phase type. This is likely due to the effective elimination of interference between left and through traffic.

Left-turn signals placed closer to the driver were found to be associated with lower left-turn accident involvement ratios. A closer placement allows for more efficient scanning for, and identification of, the left-turn signal. This is particularly important for older drivers that have narrow peripheral vision: the larger the angle between the signal and the vehicle path, the higher the chances that they will not be able to simultaneously scan the left-turn signal as well as monitor leading and opposing vehicles and, thus, the higher the likelihood of accident involvement.

Although older drivers seem to be able to adequately compensate for adverse weather and roadway conditions when moving straight, they are overinvolved in accidents when turning left under adverse conditions. The tasks associated with left turns compared to those for going "through" consume a disproportionate share of drivers' attention, thus they tend to be more vulnerable to accidents.

Older drivers are overinvolved in rear-end, head-on, and angle accidents while turning left, regardless of approach left-turn control, than when moving straight. A possible explanation for these occurrences is that left-turning tasks detract from their ability to monitor leading vehicles and/or monitor signal indications.

Based on the literature, older drivers are aware of their major problems in the intersection environment such as the inability to locate signals, proper turn lane, and turning path, and have accurately reported them in personal surveys. However, they seem to be unable to compensate for these deficiencies as witnessed by a preponderance of citations for failure to yield, improper lane use, and improper turns.

Overinvolvement in accidents where such citations were issued is more prominent when turning left at locations with permitted phasing.

In summary, older drivers are generally better able to cope with driving tasks in simpler, rather than more complex situations. Although they seem to be aware of hazardous situations and effectively cope with certain adverse conditions (such as driving in bad weather) even better than other drivers, they are able to do so only when performing simpler tasks (e.g., driving straight). They appear to become overwhelmed as soon as the driving task becomes more complex-for example, turning left in bad weather when involvement becomes progressively higher for protected, permitted, and protected/permitted locations.

CHAPTER 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

6.1. INTRODUCTION

This research was an attempt to gain insights into the morphology and causes of older driver left-turn accident experience at signalized intersections. The basic hypothesis underlying this endeavor is that older driver accident overinvolvement is due to a reduced ability to make correct decisions in complex driving situations. The effect of various forms of driving environment complexity on older drivers was examined in two independent analyses:

i) A driver comprehension analysis based on laboratory data gathered during a previous study of left-turn signal displays sponsored by the FHWA and,

ii) An independent analysis of accident experience based on actual accident, signal, and geometric data specifically gathered for the present study.

The laboratory analysis was directed to measuring effects of left-turn signal display complexity using older driver comprehension as a measure of effectiveness. The field data analysis was also addressed to signal display complexity but was primarily concentrated on intersection maneuver complexity; disproportionate involvement in accidents by older drivers was used as a measure of effectiveness for this analysis. An effort was maintained throughout to examine "parallel" variables in the laboratory and field analyses and test the soundness of the hypothesis that signal display characteristics associated with reduced older driver comprehension measured in the laboratory may be related to disproportionately higher accident experience in the field.

In addition to variables pertaining to driving environment complexity, driver information variables included in the laboratory database, and signal, geometric and accident characteristics variables from the field database were analyzed.

6.2. COMPREHENSION ANALYSIS SUMMARY

The analysis of driver information variables collected as part of the comprehension database verified that trends of reduced miles driven per year as drivers age, identified in the National Personal Transportation Survey, were present in the subject sample. Thus, older subjects were found to drive less than any other age group and older female subjects were found to drive less than their male counterparts.

The database provided insights to driver-specific factors related to older driver comprehension of left-turn stimuli. Correct comprehension of left-turn signal displays was found to be related to miles driven per year--older drivers (that drive less than other age groups) are more likely to misinterpret such displays. Mitigating this finding is the observation that misinterpretations are more often than not associated with older drivers giving away their right of way (committing a minor error) rather than violating another driver's right of way (committing a serious error). Although serious errors are infrequent, older drivers commit significantly more such errors than other drivers; however, no significant differences exist between sexes. Interpretation of left-turn stimuli displays is related to number of years of driving experience: correct interpretation increases with experience to a point and then declines as detrimental aging effects appear to offset beneficial experience effects.

Inter-interval analysis

The driver comprehension analysis based on stimulus message showed that older driver left-turn signal misinterpretations leading to violations of other drivers' right of way are most likely when facing flashing and permitted left-turn displays, less likely when facing red displays, and least likely when facing change interval displays. Stimuli used exclusively to demand the most urgent driver reactions (such as preparation to stop for a change interval or red ball) are least likely to be misinterpreted; those requiring interpretation (such

as flashing nighttime red ball stimuli whose meaning depends on the simultaneous through indication) are most likely to be misinterpreted. Thus, higher complexity stimuli are related to a higher incidence of older driver serious errors.

Intra-interval analysis summary

The most important findings based on comparisons of alternative left-turn displays conveying similar messages (e.g., alternative displays used for permitted left-turns) are summarized in the following paragraphs.

Permitted interval

Older drivers were found to be less likely to violate other drivers' right of way due to misinterpretations of the permitted interval in situations where the lens illuminated on the left-turn display is not a green ball (i.e., the left-turn indication is a flashing yellow or red ball). The higher likelihood of older drivers violating other drivers' right of way when both the through and left-turn indications are green balls is attributed to confusion about the message of a green ball: the same signal indication grants the right of way to through drivers, while drivers turning left are expected to interpret the indication differently. Flashing yellow and red ball indications are automatically differentiated from through green balls and are always associated with a measure of caution, thus simplifying mental processing and improving the chance of correct interpretation (or at least decreasing the probability of drivers incorrectly presuming they have the right of way). It is important to note that older drivers were not found to be more likely than other age groups to incorrectly think they have the right of way under permitted phasing. However, older drivers are less likely than other age groups to correctly interpret permitted indications.

Protected interval

Since drivers have the right of way during the protected interval, misinterpretations of protected displays indicate that drivers incorrectly think they have to give up the right of way to other intersection movements. Older drivers are more likely than other ages to misinterpret the meaning of protected displays. Misinterpretations were found to be less likely in the presence of the sign "left-turn signal." The rate of misinterpretation was also found to be related to illuminated section configuration. Stimuli displaying green indications (i.e., green arrow alone or simultaneously with green ball) on the left-turn displays were found to be better comprehended than stimuli simultaneously displaying a green arrow and red ball. Better comprehension was found to be associated with a through red ball than a through green ball. These findings are consistent with the hypothesis of decreased comprehension for higher complexity stimuli: When lenses on the left-turn signal are green, the required interpretation is much less involved than that necessary when contradictory red ball and green arrow indications are present on the left-turn signal. Lower comprehension in the presence of a through green ball may be attributed to additional interpretation required to differentiate such displays from permitted displays: the driver needs to make the distinction between simultaneously illuminated through green ball and left-turn green arrow (protected) and through and left-turn green ball (permitted).

Red interval

Older drivers are more likely than other drivers to misinterpret a red left-turn indication. However, they are less likely to misinterpret red indications placed between the left-turn and the adjacent through lane than those placed along the left-turn lane centerline. Signal position affects the permitted green ball in an exactly opposite

direction: permitted displays placed in the straight-ahead position are less well comprehended than those placed between lanes. Both findings are interpreted as an effect of driver confusion about the dual meaning of green ball displays: green balls placed between lanes (closer to the through signal) lead left-turning drivers to believe that they have the right of way just like through drivers do. Permitted indications placed in the straight-ahead position (further from the through signal) are less likely to be confused with the through signal message and are therefore better comprehended. It is possible that a green ball carry-over effect may lead drivers facing a red ball on the left-turn signal to treat it differently than a through red ball when the signal is placed in the straight-ahead position (further from the through signal) than when it is placed between lanes (closer to the through signal).

Change interval

Older drivers are no more likely than other age groups to incorrectly think they have the right of way during a change interval (i.e., a yellow indication). However, older drivers are less likely than other age groups to correctly interpret change interval displays. Illuminated left-turn and through signal lens configuration were found to have a significant impact on correct stimulus interpretation. Comprehension is higher when a yellow arrow or ball is illuminated and lower when an additional red or green ball is illuminated. Red through indications enhance, and green indications have an adverse impact on comprehension.

Simple stimuli are better comprehended than more complex stimuli: a single illuminated yellow indication does not require extensive interpretation, since it has a unique meaning. When a different color lens is also illuminated, additional interpretation is required and confusion potential increases, thus comprehension deteriorates. A through red indication reinforces the message of a yellow left-turn indication, since both convey unique messages urging the driver to stop.

A through green ball may mislead drivers into thinking that the yellow left-turn indication will be followed by a permitted one, thus they need not necessarily stop.

Flashing operation

Older drivers are more likely to violate other drivers' right of way but not to a significant extent when facing signals under flashing operation. Older drivers are less likely to violate other drivers' right of way when facing flashing yellow left-turn indications than when facing red flashing indications. The lower performance under flashing red indications is directly related to the higher complexity of such displays: a flashing yellow left-turn ball is always associated with a permitted left-turn; the meaning of a flashing red ball can only be decided in conjunction with the through indication.

In summary, the comprehension analysis demonstrated that:

i) Older drivers have consistently lower comprehension scores than other drivers. Comprehension differences are more likely to be significant when measured in percent drivers correctly interpreting stimuli and less likely to be significant when measured in percent drivers incorrectly thinking they have the right of way when they don't.

ii) Stimulus complexity adversely impacts older driver comprehension regardless of stimulus message.

iii) Older driver stimulus comprehension depends on stimulus message. In terms of serious errors, change stimuli are best comprehended (fewer errors), followed by red, permitted and flashing operations stimuli (most errors). Most correct answers were associated with red interval stimuli followed by change, protected, permitted and flashing operations stimuli (least correct answers).

6.3. FIELD DATA ANALYSIS SUMMARY

The majority of intersection accidents involved vehicles moving straight through the intersection and occurred during daytime. Turning accidents most frequently involve vehicles turning left. Left-turn accidents occur more frequently at locations with permitted phasing than locations with protected phasing. As drivers age, involvement in through accidents decreases and a shift to turn accidents is observed.

Older drivers are overinvolved in intersection accidents, especially when turning. Overinvolvement is highest when executing left-turns and less pronounced for right-turns. Left-turn control was found to be related to older driver left-turn accident overinvolvement which is the highest at permitted/protected and the lowest at protected locations.

Maneuver analysis

A possible explanation for differences in older driver involvement ratios among intersection maneuvers can be found in intersection maneuver complexity. Simple maneuvers, such as driving straight through, place minimal requirements on the driver and are related to the lowest intersection accident involvement ratio. Turning right may require lane changes and monitoring pedestrian traffic in addition to tasks normally required for driving straight-through the intersection. The higher complexity of this maneuver is reflected in higher older driver involvement ratios in right-turn accidents.

Turning left requires all tasks associated with right turns (monitoring pedestrian traffic is, however, more difficult since pedestrian paths are further from the driver) with the additional task of monitoring opposing traffic in order to identify acceptable gaps in pedestrian and vehicular traffic. Furthermore, it was demonstrated that older drivers have a particularly low comprehension of left-turn signal indications. Thus, turning left is the most complex intersection task among the ones analyzed. This is reflected in older driver involvement

ratios which are the highest among the maneuvers examined in this study.

Left-turn accident analysis

Among left-turn phasing strategies, protected turns require simpler tasks than permitted or protected/permitted, since drivers do not need to monitor opposing traffic,and the green arrow associated with such turns has a unique meaning. Thus, involvement ratios for protected left-turns are the lowest among alternative left-turn phase types. Permitted phasing requires the driver to monitor opposing traffic, and the double use of permitted green balls as an indication granting the right of way to through traffic and an indication for permitted left-turns may lead to driver confusion. The higher task complexity under permitted phasing is reflected in higher involvement ratios at permitted locations. Finally, protected/permitted phasing requires more driver interpretation than any other phasing since right-of-way rules change during the cycle, and that, in the presence of more complex signal displays. Thus, older driver involvement ratios under this phasing are the highest among all left-turn phasing types examined in the present study.

Involvement related to signal, geometric, and accident attributes

A number of signal, geometric and accident variables were found to be related to older driver accident involvement. The most significant findings are summarized here.

Longer permitted phase durations were found to be associated with higher older driver involvement ratios, possibly due to more opportunity for vehicular conflicts during this phase. Protected phase duration at protected/permitted locations was also found to be directly related with left-turn involvement ratios. It was suggested that protected phase duration may be a surrogate for heavy left-turn demand during the permitted interval. Therefore it is possible that this finding can be explained in terms of opportunity of vehicular conflicts as well.

Simpler left-turn signal face arrangements (e.g., stacked-three) used at protected and protected/permitted locations are associated with lower accident involvement ratios than stacked-four displays. This finding is consistent with comprehension analysis findings, where older drivers were found to comprehend simpler displays better.

Leading protected left-turn intervals were associated with lower involvement ratios than lagging intervals both at locations with protected and protected/permitted phasing. Inferior lagging phase performance could be due to opposing vehicles violating the change interval between the permitted and lagging protected phases.

Flashing yellow balls are associated with lower nighttime accident involvement ratios than flashing red balls. These findings are in agreement with comprehension analysis results showing the lowest comprehension for flashing red balls and highest for flashing yellow balls. The highest nighttime involvement ratios were found at locations with twenty four-hour full color operations. It is possible that higher involvement ratios at such locations are due to higher opposing volumes causing disproportionately more serious glare problems for older drivers while simultaneously allowing fewer opportunities to turn (i.e., fewer acceptable gaps).

Lower involvement ratios were found at locations with exclusive left-turn lanes. Effective elimination of interference between left and through traffic is a possible explanation for this finding.

Lower left-turn accident involvement ratios were found where the left turn signal was placed closer to the driver. It is hypothesized that a closer placement allows for more efficient scanning of the left-turn signal while simultaneously monitoring other turning tasks.

Older drivers are not overinvolved in adverse weather and roadway conditions when moving straight, but are more vulnerable when turning left under such conditions. It is possible that left-turning tasks consume a disproportionate share of drivers' attention and older drivers

become overwhelmed with the additional difficulties of lower visibility and extra caution necessary to deal with adverse environmental conditions.

Rear-end, head-on and angle older driver accident overinvolvement is much more pronounced when turning left than when moving straight, possibly because left-turning tasks detract from the ability to monitor leading vehicles and through signal indications.

Older drivers involved in accidents are less likely to be cited for following too closely or speeding, but are more likely to be cited for failure to yield the right of way, improper lane use, and improper turns. The most common types of citations are most often issued at locations with permitted phasing.

Overall, older driver accident overinvolvement is less serious in situations requiring the performance of simpler tasks. Although older drivers seem to be aware of the dangers involved with certain adverse conditions (such as driving in bad weather) and cope with them even better than other drivers, they are only able to do so when performing simpler maneuvers (e.g., driving straight) under such conditions. However, they are likely to become overwhelmed as maneuver complexity, adverse environmental conditions, and signal display complexity increase.

6.4. CONCLUSIONS

The laboratory analysis of older driver comprehension of left-turn displays demonstrated that older drivers have lower left-turn display comprehension scores than other drivers. Laboratory results indicate that incorrect signal interpretations among all drivers are more likely to be related to a choice to yield when they have the right of way rather than violate other drivers' right of way. Although violations of other drivers' right of way are quite infrequent, significant differences exist between older and other drivers.

Incorrect interpretations of left-turn signal displays among older

drivers depend primarily on stimulus message and display complexity. Stimuli used to convey a single, simple message, and especially those conveying the most urgent messages (such as yellow ball or red ball conveying the messages prepare to stop and stop respectively) are better comprehended than those used to convey multiple messages (e.g., green ball, flashing operations left-turn red ball). Simpler stimuli using a single illuminated lens on the left-turn signal are better comprehended than those using two lenses.

Expectations that the presence of higher complexity displays associated with lower older driver comprehension would adversely affect older driver accident involvement were verified with field data. Indeed, older driver accident involvement was higher at locations with stacked four-section left-turn displays with two simultaneously illuminated sections than at locations with the better comprehended stacked three-section displays with a single illuminated section; flashing operation red ball indications with higher serious comprehension errors than flashing yellow ball indications were present at locations with higher left-turn accident involvement.

Intersection accident statistics roughly reflect the distribution of volumes among the through, left-, and right-turn maneuvers. Thus, almost four-fifths of at-fault drivers involved in intersection accidents are driving straight through with the remainder involving drivers turning left or right. A stratification of accidents according to approach left-turn control reveals that left-turn accident percentage differences exist based on the approach's left-turn control. As drivers age, the percentage of accidents involving a turning maneuver increases (percentage of through accidents decreases), especially for left-turns. Approaches with protected left-turn control have the lowest left-turn accident percentage, and those with permitted left-turn control the highest for each driver age group.

Older drivers are overinvolved in intersection accidents. The

degree of overinvolvement depends on intersection maneuver: it is lower for drivers moving straight through the intersection, higher for drivers attempting a right turn, and highest for drivers turning left. Increased overinvolvement correlates with additional tasks required for turning maneuvers compared to through movements (e.g., monitoring pedestrian traffic and/or opposing traffic).

Among left-turn accidents, overinvolvement is lowest under the simplest right of way rules, i.e., at locations with protected phasing, where drivers have the right of way over all other conflicting intersection movements. Left-turn accident involvement is highest at locations with permitted/protected phasing which is associated with the most complex right of way rules under which drivers have the right of way or have to yield to opposing traffic depending on the signal indication. Turning left under permitted/protected phasing is complicated by the need to continuously monitor the left-turn signal display and opposing traffic and correctly interpret the right-of-way rules at any instant.

Older driver susceptibility to environment complexity is also demonstrated by higher accident involvement in situations where opportunities for conflict with other vehicular movements are elevated (such as at approaches where no left-turn lanes are provided, or where permitted phase durations are longer), where more intense scanning is required in order to locate the left-turn signal (e.g., when the left-turn signal is located further from the driver), or where the difficulties of an already complicated driving task (such as turning left) are compounded by the presence of adverse meteorological conditions.

The older driver "profile" is one of a driver who drives fewer miles per year, avoids nighttime and adverse weather driving, does not exceed the speed limit, keeps adequate distances from leading vehicles and, when unsure about the meaning of a signal display, and is more

likely to grant the right of way to other drivers than violate their right of way. This finding based on laboratory results under simplified conditions in which older subjects could clearly see stimuli and had adequate time for mentally processing their messages are reversed in the field. Older drivers are more frequently cited for right of way violations when involved in accidents, perhaps, because they cannot clearly see left-turn displays and do not have adequate time to process signal information given that driving tasks in the field are far more complex than the laboratory environment.

Although older drivers seem to be able to correctly assess their risks under certain circumstances and effectively avoid being overinvolved in accidents (e.g., when driving straight during daytime, even in adverse weather conditions), they are unable to perform more complex tasks with the same efficiency and become overinvolved in accidents (e.g., turning left under adverse weather conditions).

Hypotheses based on older subject comprehension measured in the laboratory were generally verified using field data. Older driver poor performance measured in comprehension in the laboratory and accident experience in the field can be related to left-turn display and/or field parameter complexity.

6.5. RECOMMENDATIONS

The present research covered a broad spectrum of variables associated with older driver comprehension of left-turn displays and older driver involvement in left-turn accidents. However, not all variables investigated and found to be related to driver comprehension and/or accident involvement can be readily modified in the field in order to improve safety (e.g., longer permitted phases found to be related to higher older driver left-turn accident involvement cannot be altered at will). Thus, the following recommendations are necessarily limited to variables with a practical significance for the practitioner, that is, geometric and signal features variables that can

be reasonably expected to be amenable to adjustment in the field.

The safety benefits of simpler driving environments for older drivers have been demonstrated both in terms of better comprehension of left-turn signal displays and in terms of reduced accident involvement. The following recommendations based on the data analyzed herein are made with regard to left-turn signal displays:

Based on the comprehension analysis results:

i) The use of permitted left-turn green ball indications should be avoided in favor of indications using yellow or red flashing indications. Permitted left-turn green ball indications are less well comprehended and it is believed that driver confusion arises from the dual meaning of left-turn green ball sections that grant the right of way to through drivers but are expected to be interpreted differently from left-turning drivers. Better comprehension of the suggested alternative displays is believed to be due to their unique meanings and their differentiation from through signal indications that eliminate driver confusion to a significant extent.

Based on the accident analysis results:

i) Construction of a left-turn lane at approaches with permitted or protected/permitted left-turn control is recommended as a measure to reduce older driver overinvolvement in left-turn accidents.

ii) It is recommended that older drivers be made aware that they may not be able to correctly assess their vulnerability to left-turn accidents in adverse weather conditions and on roads that are wet or covered with snow. They should be advised to avoid driving under such conditions, but, should they have to, they should carefully choose alternate routes that will avoid left-turns as much as possible.

Based on both comprehension and accident analysis results:

i) Permitted displays be placed along the extension of the left-turn lane centerline instead of between the left-turn and the adjacent through lane. Placement in the straight-ahead position concurs with accident analysis results pointing out that older driver left-turn accident overinvolvement is lower at locations where the left-turn signal is placed closer to the driver. This recommendation could be implemented as a first, less expensive step in a permitted left-turn safety improvement program, before signal sections and controllers are equipped to operate under a flashing red or yellow permitted mode as recommended above.

ii) The use of stacked four-section displays with (fourth level) green arrow simultaneously illuminated with a green ball should be abandoned in favor of stacked three-section displays with a red ball, yellow ball and green arrow sections. A green arrow illuminated section should be used at approaches with protected left-turn phasing and green arrow/flashing red ball (for the protected and permitted phases respectively) should be used at approaches with protected/permitted phasing. These

recommendations are based both on the comprehension analysis (lower comprehension was found for stacked four-section displays) and the accident data analysis (higher involvement at approaches with four-section displays).

The following recommendations are based on **preliminary results;** further investigation is necessary before they can be adopted:

Based on the accident analysis:

i) Leading protected left-turn phasing be used at locations with protected or protected/permitted left-turn phasing. A lower performance of locations using lagging protected phasing was attributed to opposing through drivers violating the change interval preceding the protected phase. However, further research is recommended in order to identify the underlying causes for the observed differences in accident experience between leading and lagging protected phasing.

ii) It was found that older driver nighttime accident involvement was higher at locations with 24-hour full color operations. However, before a recommendation is made about using flashing operations during nighttime, it is recommended that additional data be collected and analyzed with regard to the merits of flashing versus 24-hour signal operation. This is because there were factors other than signal operation mode (e.g., glare recovery time that may disproportionately affect older drivers in the presence of higher nighttime traffic volumes) that may have a stronger influence on accident experience.

iii) It is recommended that further study of alternatives to making left-turns (e.g., turning right around the block) be conducted and their merits be compared to making left-turns before older drivers are advised about specific alternatives to making left turns.

The findings of the laboratory comprehension analysis pertaining to particular signal phases can be integrated with subsequent efforts dedicated to the study of driver behavior during particular signal phases in the field. Traffic conflict studies, for example, may reveal which phases and other signal characteristics are associated with the most dangerous and/or frequent violations of right of way rules, thus weights could be assigned to the importance of correctly comprehending each particular phase. Accident countermeasures could then be fine-tuned to address problems with particular phases.

A summary of the above recommendations is presented in table 6.1.

Table 6.1 Summary of recommendations

Recommendation	Based on	Data
Replace permitted green ball indications with flashing yellow or red indications.	Comprehension analysis	Adequate
Provide exclusive left-turn lanes at permitted and protected/permitted locations.	Accident analysis	Adequate
Educate older drivers about increased risk when turning left, especially under adverse weather conditions.	Accident analysis	Adequate
Place left-turn signals along the extension of the left-turn lane centerline.	Accident and comprehension analysis	Adequate
Replace stacked-four displays with stacked-three displays.	Accident and comprehension analysis	Adequate
Prefer leading protected left-turn phase where possible.	Accident analysis	Further research necessary
Eliminate 24-hour signal operation in favor of flashing operation during nighttime where possible.	Accident analysis	Further research necessary
Educate older drivers on preferred alternatives to turning left at intersections.	Accident analysis	Further research necessary

APPENDIX A

APPENDIX A

Comprehension analysis stimuli

Information in appendix A is based on the research project entitled "Signal Displays For Left Turn Control" (U.S. DOT Contract No. DTFH 61-85-C-00164). Details can be found in Task B report: "Driver Understanding of Signal Displays" prepared by Mark Freedman and David P. Gilfillan of KETRON, INC. for JHK & Associates in April, 1988.

The term "signal face arrangement" is used herein to indicate characteristics of signal heads (such as number and position of signals, traffic movements they address, signal face composition), and presence of left turn signs and left turn lanes. For a typical signal face arrangement refer to figure 3.2. The term "stimulus" is used to indicate a particular combination of illuminated signal lenses during a signal interval. The same signal face arrangement may be used for a number of stimuli (i.e., signal intervals).

Stimuli numbers used in the present appendix correspond to those used in the report mentioned above. In all 17 signal face arrangements used as a base for 81 stimuli are summarized in the following tables.

Information on number and position of left turn and through signal heads, presence of supplemental signs, and presence of exclusive left turn lane is shared by all stimuli based on a signal face arrangement. Each stimulus is represented by a schematic of one left-turn and one through signal face, where lens types/functions are indicated by the following abbreviations:

RB: Red Ball
RA: Red Arrow
FRB: Flashing Red Ball
FRA: Flashing Red Arrow
YB: Yellow Ball
YA: Yellow Arrow
FYB: Flashing Yellow Ball
FYA: Flashing Yellow Arrow
GB: Green Ball
GA: Green Arrow
FFGA: Fast Flashing Green Arrow
Blank: Lens Not Illuminated

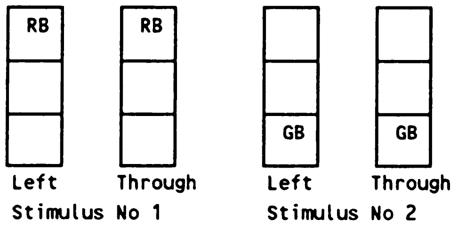
Both full color and flashing operations stimuli are present in the database and are identified as such. Certain flashing operations left-turn signal faces remain dark, thus no abbreviation is shown on the left-turn signal schematic for such stimuli.

Table A1 Permitted stimuli

Signal face arrangement No 1

Left turn signal characteristics	Through signal characteristics
Number of signal heads: 1 Vertical position: Pedestal Horizontal position: Far left curb Supplemental sign: None	Number of signal heads: 1 Vertical position: Pedestal Horizontal position: Far right curb **Special notes:** Single-lane approach

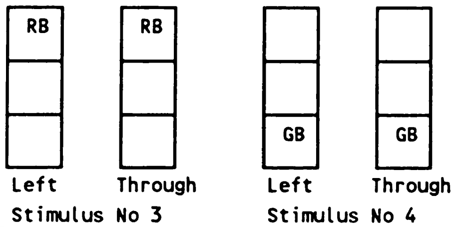
Full color operations



Signal face arrangement No 2

Left turn signal characteristics	Through signal characteristics
Number of signal heads: 1 Vertical position: Overhead Horizontal position: Between lanes Supplemental sign: None	Number of signal heads:1 Vertical position: Overhead **Horizontal position: Over through lanes** **Special notes:**Exclusive left turn lane

Full color operations



Flashing operations

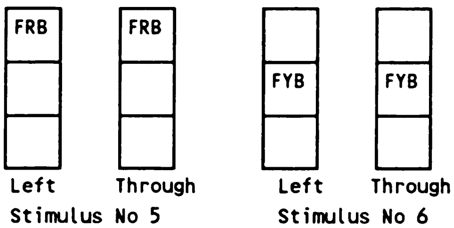
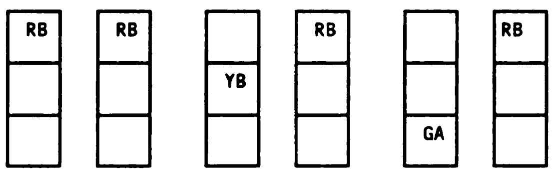


Table A2 Protected stimuli

Signal face arrangement No 3

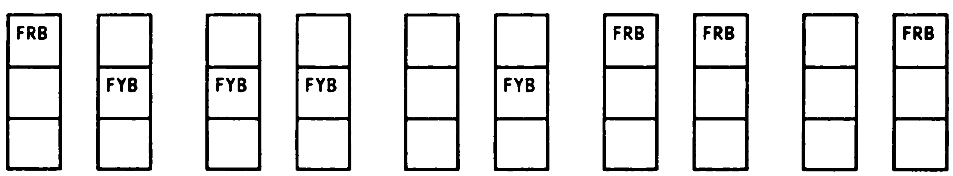
Left turn signal characteristics	Through signal characteristics
Number of signal heads: 1	Number of signal heads: 2
Vertical position: Overhead	Vertical position: Overhead
Horizontal position: Left-turn lane centerline	Horizontal position: Over through lanes
Supplemental sign: Left turn signal	Special notes: Exclusive left turn lane

Full color operations



Left Through — Stimulus No 7 | Left Through — Stimulus No 8 | Left Through — Stimulus No 9

Flashing operations

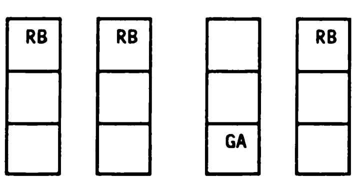


Left Through — Stimulus No 10 | Left Through — Stimulus No 11 | Left Through — Stimulus No 12 | Left Through — Stimulus No 13 | Left Through — Stimulus No 14

Signal face arrangement No 4

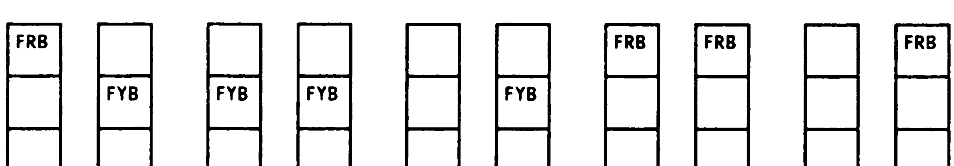
Left turn signal characteristics	Through signal characteristics
Number of signal heads: 1	Number of signal heads: 2
Vertical position: Pedestal	Vertical position: Overhead
Horizontal position: Far median between lanes	Horizontal position: Over through lanes
Supplemental sign: Left turn signal	Special notes: Exclusive left turn lane

Full color operations



Left Through — Stimulus No 15 | Left Through — Stimulus No 16

Flashing operations



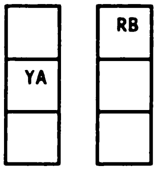
Left Through — Stimulus No 17 | Left Through — Stimulus No 18 | Left Through — Stimulus No 19 | Left Through — Stimulus No 20 | Left Through — Stimulus No 21

Table A2 (Cont'd).

Signal face arrangement No 5

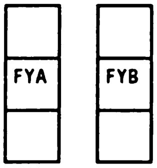
Left turn signal characteristics	Through signal characteristics
Number of signal heads: 1	Number of signal heads: 2
Vertical position: Overhead	Vertical position: Overhead
Horizontal position: Left-turn lane centerline	Horizontal position: Over through lanes
Supplemental sign: Left turn signal	Special notes: Exclusive left turn lane

Full color operations



Left Through
Stimulus No 22

Flashing operations

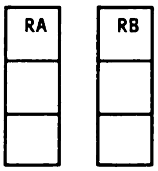


Left Through
Stimulus No 23

Signal face arrangement No 6

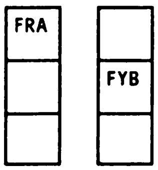
Left turn signal characteristics	Through signal characteristics
Number of signal heads: 1	Number of signal heads: 2
Vertical position: Overhead	Vertical position: Overhead
Horizontal position: Left-turn lane centerline	Horizontal position: Over through lanes
Supplemental sign: Left turn signal	Special notes: Exclusive left turn lane

Full color operations

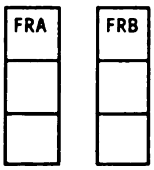


Left Through
Stimulus No 24

Flashing operations



Left Through
Stimulus No 25



Left Through
Stimulus No 26

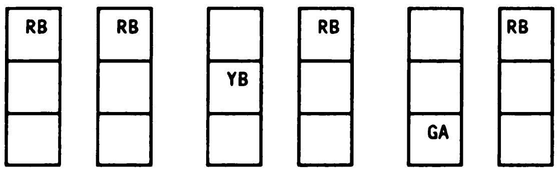
Table A2 (Cont'd).

Signal face arrangement No 7

Left turn signal characteristics
Number of signal heads: 1
Vertical position: Overhead
Horizontal position: Left-turn lane centerline
Supplemental sign: None

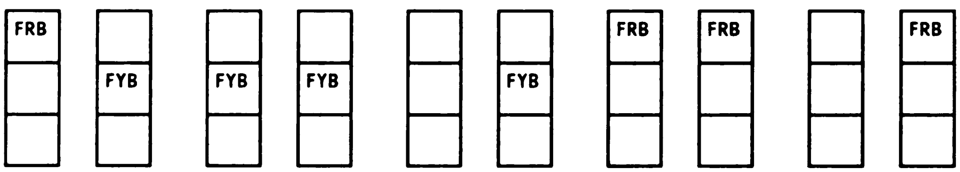
Through signal characteristics
Number of signal heads: 2
Vertical position: Overhead
Horizontal position: Over through lanes
Special notes: Exclusive left turn lane

Full color operations



Left Through Left Through Left Through
Stimulus No 27 Stimulus No 28 Stimulus No 29

Flashing operations



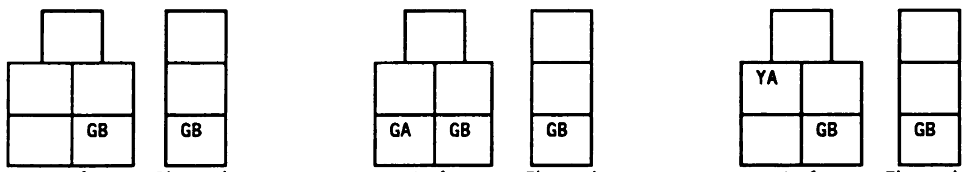
Left Through Left Through Left Through Left Through Left Through
Stimulus No 30 Stimulus No 31 Stimulus No 32 Stimulus No 33 Stimulus No 34

Table A3 Permitted/protected stimuli

Signal face arrangement No 8

Left turn signal characteristics	Through signal characteristics
Number of signal heads: 1	Number of signal heads: 1
Vertical position: Overhead	Vertical position: Overhead
Horizontal position: Between lanes	Horizontal position: Over through lanes
Supplemental sign: None	Special notes: Exclusive left turn lane

Full color operations

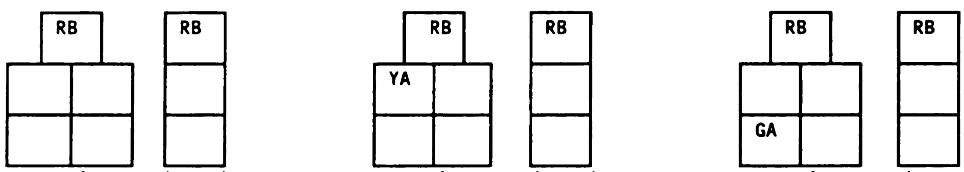


Left Through
Stimulus No 35

Left Through
Stimulus No 36

Left Through
Stimulus No 37

Full color operations

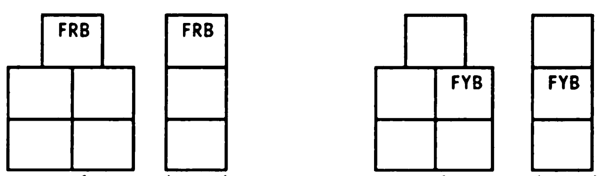


Left Through
Stimulus No 38

Left Through
Stimulus No 39

Left Through
Stimulus No 40

Flashing operations



Left Through
Stimulus No 41

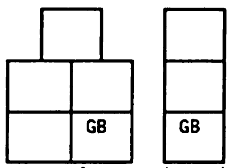
Left Through
Stimulus No 42

Table A3 (Cont'd).

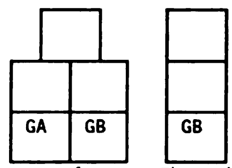
Signal face arrangement No 8

Left turn signal characteristics	Through signal characteristics
Number of signal heads: 1	Number of signal heads: 1
Vertical position: Overhead	Vertical position: Overhead
Horizontal position: Between lanes	Horizontal position: Over through lanes
Supplemental sign: Left turn yield on green ball	Special notes: Exclusive left turn lane

Full color operations



Left Through
Stimulus No 44

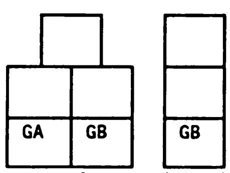


Left Through
Stimulus No 45

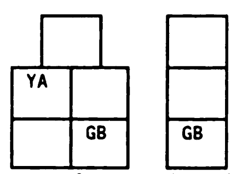
Signal face arrangement No 9

Left turn signal characteristics	Through signal characteristics
Number of signal heads: 1	Number of signal heads: 2
Vertical position: Overhead	Vertical position: Overhead
Horizontal position: Left turn lane centerline	Horizontal position: Over through lanes
Supplemental sign: None	Special notes: Exclusive left turn lane

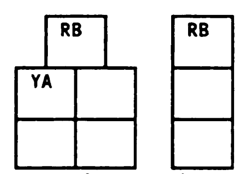
Full color operations



Left Through
Stimulus No 47

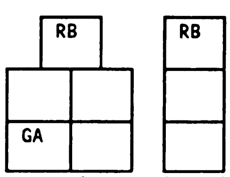


Left Through
Stimulus No 48

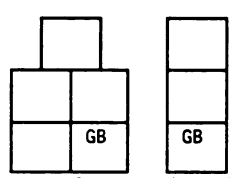


Left Through
Stimulus No 49

Full color operations



Left Through
Stimulus No 50



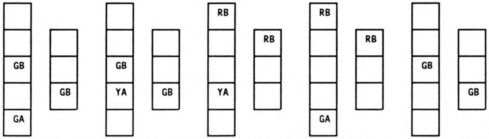
Left Through
Stimulus No 51

Table A3 (cont'd).

Signal face arrangement No 10

Left turn signal characteristics	Through signal characteristics
Number of signal heads: 1	Number of signal heads: 1
Vertical position: Overhead	Vertical position: Overhead
Horizontal position: Between lanes	Horizontal position: Over through lanes
Supplemental sign: None	**Special notes:** Exclusive left turn lane

Full color operations

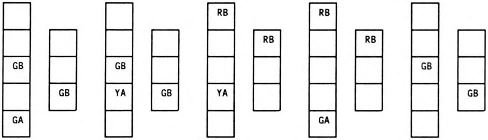


Left Through Left Through Left Through Left Through Left Through
Stimulus No 52 Stimulus No 53 Stimulus No 54 Stimulus No 55 Stimulus No 56

Signal face arrangement No 11

Left turn signal characteristics	Through signal characteristics
Number of signal heads: 1	Number of signal heads: 2
Vertical position: Pedestal	Vertical position: Overhead
Horizontal position: Far median between lanes	Horizontal position: Over through lanes
Supplemental sign: None	**Special notes:** Exclusive left turn lane

Full color operations



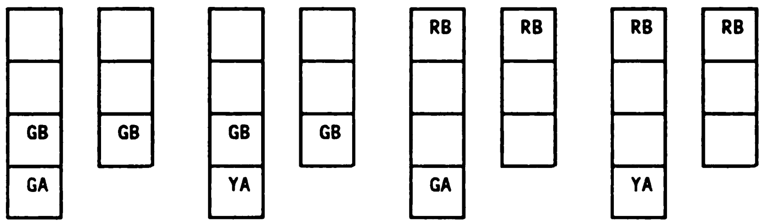
Left Through Left Through Left Through Left Through Left Through
Stimulus No 57 Stimulus No 58 Stimulus No 59 Stimulus No 60 Stimulus No 61

Table A3 (Cont'd).

Signal face arrangement No 12

Left turn signal characteristics	Through signal characteristics
Number of signal heads: 1	Number of signal heads: 1
Vertical position: Overhead	Vertical position: Overhead
Horizontal position: Between lanes	Horizontal position: Over through lanes
Supplemental sign: None	Special notes: Exclusive left turn lane

Full color operations

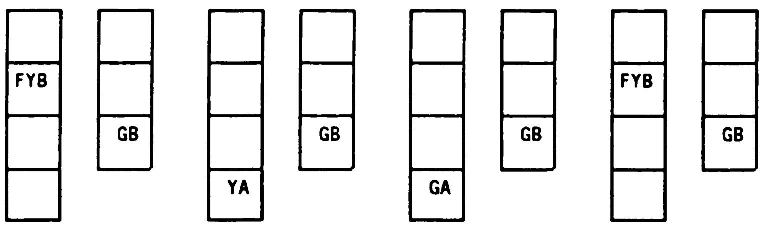


Left Through Left Through Left Through Left Through
Stimulus No 63 Stimulus No 64 Stimulus No 65 Stimulus No 66

Signal face arrangement No 13

Left turn signal characteristics	Through signal characteristics
Number of signal heads: 1	Number of signal heads: 2
Vertical position: Overhead	Vertical position: Overhead
Horizontal position: Left-turn lane centerline	Horizontal position: Over through lanes
Supplemental sign: Left-turn must yield on flashing yellow--only stimulus 70	Special notes: Exclusive left turn lane

Full color operations



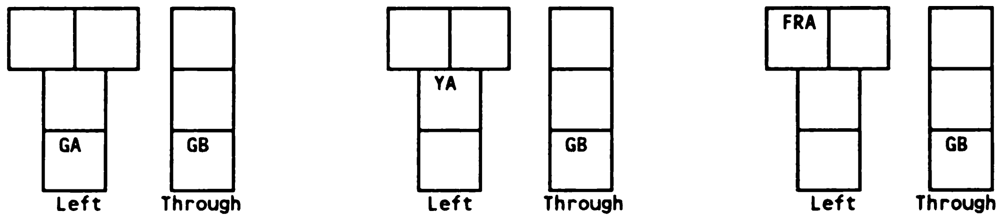
Left Through Left Through Left Through Left Through
Stimulus No 67 Stimulus No 68 Stimulus No 69 Stimulus No 70

Table A3 (Cont'd).

Signal face arrangement No 14

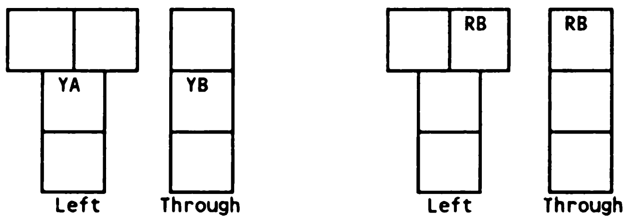
Left turn signal characteristics	Through signal characteristics
Number of signal heads: 1	Number of signal heads: 2
Vertical position: Overhead	Vertical position: Overhead
Horizontal position: Left-turn lane centerline	Horizontal position: Over through lanes
Supplemental sign: None	Special notes: Exclusive left turn lane Delaware DOT display

Full color operations



Stimulus No 71 Stimulus No 72 Stimulus No 73

Full color operations

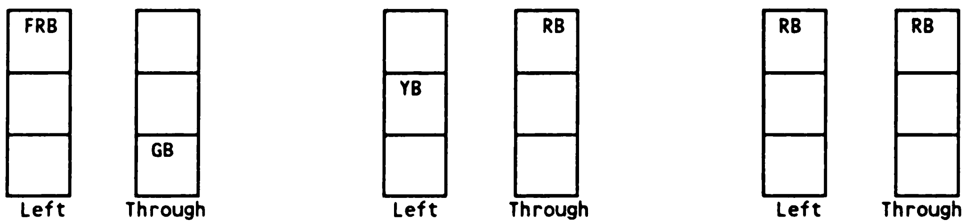


Stimulus No 74 Stimulus No 75

Signal face arrangement No 15

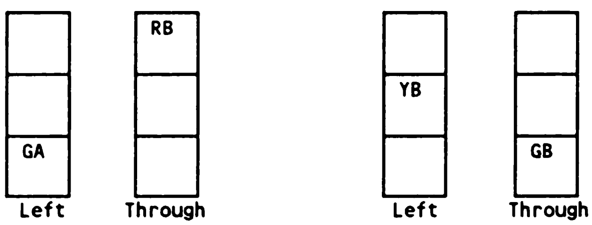
Left turn signal characteristics	Through signal characteristics
Number of signal heads: 1	Number of signal heads: 2
Vertical position: Overhead	Vertical position: Overhead
Horizontal position: Centerline of left-turn lane	Horizontal position: Over through lanes
Supplemental sign: None	Special notes: Exclusive left turn lane Michigan display

Full color operations



Stimulus No 76 Stimulus No 77 Stimulus No 78

Full color operations



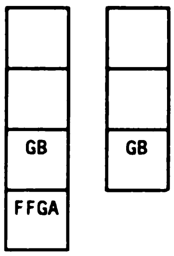
Stimulus No 79 Stimulus No 80

Table A3 (Cont'd).

Signal face arrangement No 16

Left turn signal characteristics	Through signal characteristics
Number of signal heads: 1	Number of signal heads: 1
Vertical position: Overhead	Vertical position: Overhead
Horizontal position: Left-turn lane centerline	Horizontal position: Over through lane
Supplemental sign: None	**Special notes:** Shared left turn lane Vancouver BC display

Full color operations



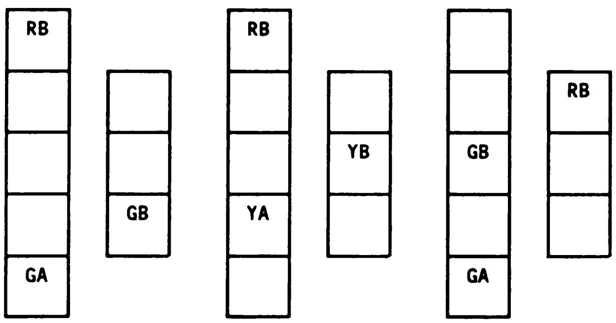
Left Through

Stimulus No 81

Signal face arrangement No 17

Left turn signal characteristics	Through signal characteristics
Number of signal heads: 1	Number of signal heads: 1
Vertical position: Overhead	Vertical position: Overhead
Horizontal position: Between lanes	Horizontal position: Over through lanes
Supplemental sign: Left turn signal	**Special notes:** Exclusive left turn lane Dallas TX display

Full color operations



Left Through Left Through Left Through

Stimulus No 82 Stimulus No 83 Stimulus No 84

APPENDIX B

APPENDIX B

Comprehension analysis results

Table B1 General comprehension analysis

Miles driven per year by subject age

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	3	1364906141	454968713.8	2.6185	.0525
WITHIN GROUPS	174	30232392631	173749382.9		
TOTAL	177	31597298772			

Miles driven per year by subject age and sex

ANALYSIS OF VARIANCE

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	2607596643	4	651899160.768	3.952	.004
AGE	1450877701	3	483625900.301	2.932	.035
SEX	1242690502	1	1242690501.66	7.534	.007
2-Way Interactions	947877278	3	315959092.728	1.915	.129
AGE SEX	947877278	3	315959092.728	1.915	.129
Explained	3555473921	7	507924845.894	3.079	.004
Residual	28041824851	170	164951910.887		
Total	31597298772	177	178515812.271		

191 cases were processed.
13 cases (6.8 pct) were missing.

Miles driven per year by subject age and sex

* * * M U L T I P L E   C L A S S I F I C A T I O N   A N A L Y S I S * * *

Grand Mean = 12080.93

Variable + Category	N	Unadjusted Dev'n	Eta	Adjusted for Independents Dev'n	Beta
AGE					
16 TO 30 YEARS OLD	47	-418.05		-653.73	
31 TO 45 YEARS OLD	48	1860.74		1805.56	
46 TO 60 YEARS OLD	43	2722.56		3051.55	
61 TO 75 YEARS OLD	40	-4668.43		-4678.96	
			.21		.21
SEX					
MALE	102	2200.45		2287.55	
FEMALE	76	-2953.23		-3070.13	
			.19		.20

Table B1 (cont'd).

Percent correct answers by miles driven per year

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	3	.6745	.2248	5.9903	.0007
WITHIN GROUPS	174	6.5309	.0375		
TOTAL	177	7.2054			

Percent serious error by miles driven per year

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	3	.0076	.0025	.8628	.4616
WITHIN GROUPS	174	.5132	.0029		
TOTAL	177	.5208			

Percent correct answers by subject age

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	3	1.1453	.3818	10.9486	.0000
WITHIN GROUPS	187	6.5204	.0349		
TOTAL	190	7.6657			

Percent serious errors by subject age

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	3	.0276	.0092	3.2611	.0227
WITHIN GROUPS	187	.5282	.0028		
TOTAL	190	.5558			

Table B1 (cont' d).

Percent correct answers by subject years of driving experience

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	3	.9370	.3123	8.7418	.0000
WITHIN GROUPS	176	6.2883	.0357		
TOTAL	179	7.2253			

Percent serious errors by subject years of driving experience

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	3	.0266	.0089	3.0794	.0289
WITHIN GROUPS	176	.5067	.0029		
TOTAL	179	.5333			

Percent correct answers by subject sex

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	1	.4124	.4124	10.7472	.0012
WITHIN GROUPS	189	7.2532	.0384		
TOTAL	190	7.6657			

Percent serious errors by subject sex

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	1	.0031	.0031	1.0713	.3020
WITHIN GROUPS	189	.5527	.0029		
TOTAL	190	.5558			

Table B2 Inter-interval comprehension analysis

Serious error rate: One-way analysis of variance by subject age

GROUP	COUNT	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN		
Age 15-30	50	.0527	.0716	.0101	.0000	.3333	.0323	TO	.0730
Age 31-45	51	.0569	.0640	.0090	.0000	.2273	.0389	TO	.0749
Age 46-60	48	.0801	.0862	.0124	.0000	.4161	.0551	TO	.1052
Age 60+	42	.0943	.0783	.0121	.0000	.2914	.0699	TO	.1187

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	.053	3	.018	3.151	.026
AGE	.053	3	.018	3.151	.026
Explained	.053	3	.018	3.151	.026
Residual	1.057	187	.006		
Total	1.111	190	.006		

Serious error rate: Multivariate analysis of variance, repeated measures, all age groups

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Permitted stimuli	.083	.150	186	.062	.105
Red stimuli	.037	.100	186	.023	.052
Nighttime stimuli	.126	.146	186	.105	.147
Change interval stimuli	.010	.032	186	.005	.015

Source of Variation	SS	DF	MS	F	Sig of F
AGE	.26	3	.09	5.65	.001
STIMULUS MEANING	1.47	3	.49	38.31	.000
AGE BY MEANING	.13	9	.01	1.11	.354

Serious error rate: Multivariate analysis of variance, repeated measures, older subjects

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Permitted stimuli	.125	.172	42	.071	.179
Red stimuli	.083	.142	42	.039	.127
Nighttime stimuli	.154	.146	42	.109	.200
Change interval stimuli	.014	.036	42	.003	.026

Source of Variation	SS	DF	MS	F	Sig of F
STIMULUS MEANING	.46	3	.15	9.73	.000

Table B2 (cont' d).

Correct answer rate: Multivariate analysis of variance, repeated measures, all age groups

	Mean	Std. Dev.	N	95 pct Conf.Interval	
Permitted stimuli	.558	.317	186	.513	.604
Protected stimuli	.642	.319	186	.596	.688
Red stimuli	.963	.100	186	.948	.977
Nighttime stimuli	.446	.259	186	.408	.483
Change interval stimuli	.740	.217	186	.709	.772

Source of Variation	SS	DF	MS	F	Sig of F
AGE	5.43	3	1.81	13.37	.000
STIMULUS MEANING	29.04	4	7.26	180.82	.000
AGE BY MEANING	1.17	12	.10	2.42	.004

Correct answer rate: Multivariate analysis of variance, repeated measures, older subjects

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Permitted stimuli	.384	.300	42	.290	.478
Protected stimuli	.488	.321	42	.388	.588
Red stimuli	.917	.142	42	.873	.961
Nighttime stimuli	.324	.206	42	.260	.388
Change stimuli	.629	.274	42	.544	.715

Source of Variation	SS	DF	MS	F	Sig of F
STIMULUS MEANING	9.37	4	2.34	47.38	.000

Table B3 Intra-interval comprehension analysis

PERMITTED STIMULI

Serious error rate: One-way analysis of variance by subject age

GROUP	COUNT	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN
Age 15-30	50	.0754	.2002	.0283	.0000	1.0000	.0185 TO .1323
Age 31-45	51	.0906	.1827	.0256	.0000	.8750	.0392 TO .1419
Age 46-60	47	.1120	.1851	.0270	.0000	.8000	.0577 TO .1664
Age 60+	42	.1250	.1721	.0266	.0000	.7000	.0713 TO .1786
TOTAL	190	.0995	.1853	.0134	.0000	1.0000	.0730 TO .1260

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	3	.0677	.0226	.6537	.5816
WITHIN GROUPS	186	6.4213	.0345		
TOTAL	189	6.4890			

Serious error rate: Multivariate analysis of variance repeated measures all subjects

AGREETH Left-turn signal concurrence/discordance with through signal

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Concurrent	.132	.240	187	.097	.167
Discordant	.014	.064	187	.005	.023

Source of Variation	SS	DF	MS	F	Sig of F
AGREETH	1.31	1	1.31	43.73	.000

Serious error rate: Multivariate analysis of variance repeated measures all subjects

NoTHRU: Number of through signal heads

	Mean	Std. Dev.	N	95 percent Conf. Interval	
1 Through signal	.104	.239	189	.069	.138
2 Through signals	.098	.167	189	.074	.122

Source of Variation	SS	DF	MS	F	Sig of F
NOTHRU	.00	1	.00	.22	.643

Table B3 (cont'd).

PERMITTED STIMULI

Serious error rate: Multivariate analysis of variance repeated measures all subjects

HPOSIT: Left-turn signal horizontal position

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Between lanes	.128	.253	188	.092	.165
Straight-ahead	.065	.135	188	.046	.085

Source of Variation	SS	DF	MS	F	Sig of F
HPOSIT	.37	1	.37	17.91	.000

Serious error rate: Multivariate analysis of variance repeated measures all subjects

AGE, AGREETH: Left-turn signal concurrence/discordance with through signal

Concurrent

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.080	.207	49	.021	.140
AGE	31 TO 45	.137	.276	50	.058	.215
AGE	46 TO 60	.140	.222	46	.075	.206
AGE	61 TO 75	.178	.249	42	.100	.255

Discordant

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.005	.036	49	-.005	.015
AGE	31 TO 45	.015	.060	50	-.002	.032
AGE	46 TO 60	.018	.070	46	-.003	.039
AGE	61 TO 75	.018	.085	42	-.009	.044

Source of Variation	SS	DF	MS	F	Sig of F
AGE	.15	3	.05	1.53	.207
AGREETH	1.33	1	1.33	44.61	.000
AGE BY AGREETH	.08	3	.03	.92	.431

Table B3 (cont' d).

PERMITTED STIMULI

Serious error rate: Multivariate analysis of variance repeated measures all subjects

AGE, NoTHRU: Number of through signal heads

1 Through signal

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.090	.239	50	.022	.158
AGE	31 TO 45	.118	.267	50	.042	.194
AGE	46 TO 60	.105	.234	47	.036	.174
AGE	61 TO 75	.102	.217	42	.034	.169

2 Through signals

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.063	.181	50	.012	.115
AGE	31 TO 45	.074	.146	50	.033	.115
AGE	46 TO 60	.116	.162	47	.068	.163
AGE	61 TO 75	.147	.171	42	.093	.200

Source of Variation	SS	DF	MS	F	Sig of F
AGE	.12	3	.04	.55	.652
NoTHRU	.00	1	.00	.08	.775
AGE BY NoTHRU	.11	3	.04	2.40	.069

Table B3 (Cont'd).

PERMITTED STIMULI

Serious error rate: Multivariate analysis of variance repeated measures all subjects

AGE, HPOSIT: Left-turn signal horizontal position

Between lanes

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.098	.246	50	.028	.168
AGE	31 TO 45	.117	.258	49	.043	.191
AGE	46 TO 60	.146	.252	47	.072	.220
AGE	61 TO 75	.158	.260	42	.077	.239

Straight-ahead

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.046	.163	50	.000	.092
AGE	31 TO 45	.053	.115	49	.020	.086
AGE	46 TO 60	.069	.116	47	.035	.103
AGE	61 TO 75	.099	.135	42	.057	.141

Source of Variation	SS	DF	MS	F	Sig of F
AGE	.17	3	.06	.93	.428
HPOSIT	.37	1	.37	17.63	.000
AGE BY HPOSIT	.01	3	.00	.13	.944

Serious error rate: Multivariate analysis of variance repeated measures older subjects

AGREETH: Left-turn signal concurrence/discordance with through signal

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Concurrent	.178	.249	42	.100	.255
Discordant	.018	.085	42	-.009	.044

Source of Variation	SS	DF	MS	F	Sig of F
AGREETH	.54	1	.54	15.23	.000

Serious error rate: Multivariate analysis of variance repeated measures older subjects

NoTHRU: Number of through signal heads

	Mean	Std. Dev.	N	95 percent Conf. Interval	
1 Through signal	.102	.217	42	.034	.169
2 Through signals	.147	.171	42	.093	.200

Source of Variation	SS	DF	MS	F	Sig of F
NOTHRU	.04	1	.04	2.56	.117

Table B3 (Cont'd).

PERMITTED STIMULI

Serious error rate: Multivariate analysis of variance repeated measures older subjects

HPOSIT: Left-turn signal horizontal position

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Between lanes	.158	.260	42	.077	.239
Straight-ahead	.099	.135	42	.057	.141

Source of Variation	SS	DF	MS	F	Sig of F
HPOSIT	.07	1	.07	2.81	.102

Correct answer rate: One-way analysis of variance by subject age

GROUP	COUNT	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN	
Age 15-30	50	.6573	.2878	.0407	.0000	1.0000	.5755 TO	.7391
Age 31-45	51	.6221	.3355	.0470	.0000	1.0000	.5278 TO	.7165
Age 46-60	47	.4983	.2971	.0433	.0000	1.0000	.4111 TO	.5856
Age 60+	42	.3840	.3004	.0464	.0000	1.0000	.2904 TO	.4776
TOTAL	190	.5481	.3218	.0233	.0000	1.0000	.5021 TO	.5942

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	3	2.1234	.7078	7.5446	.0001
WITHIN GROUPS	186	17.4497	.0938		
TOTAL	189	19.5731			

Correct answer rate: Multivariate analysis of variance repeated measures all subjects

AGREETH: Left-turn signal concurrence/discordance with through signal

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Concurrent	.566	.367	187	.513	.619
Discordant	.545	.340	187	.496	.594

Source of Variation	SS	DF	MS	F	Sig of F
AGREETH	.04	1	.04	.66	.416

Table B3 (Cont'd).

PERMITTED STIMULI

Correct answer rate: Multivariate analysis of variance repeated measures all subjects

NoTHRU: Number of through signal heads

	Mean	Std. Dev.	N	95 percent Conf. Interval	
1 Through signal	.562	.383	189	.507	.617
2 Through signals	.541	.315	189	.496	.586

Source of Variation	SS	DF	MS	F	Sig of F
NOTHRU	.04	1	.04	1.15	.286

Correct answer rate: Multivariate analysis of variance repeated measures all subjects

HPOSIT: Left-turn signal horizontal position

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Between lanes	.563	.382	188	.508	.618
Straight-ahead	.538	.320	188	.492	.584

Source of Variation	SS	DF	MS	F	Sig of F
HPOSIT	.06	1	.06	1.32	.252

Correct answer rate: Multivariate analysis of variance repeated measures all subjects

AGE, AGREETH: Left-turn signal concurrence/discordance with through signal

Concurrent

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.692	.341	49	.594	.790
AGE	31 TO 45	.672	.340	50	.575	.768
AGE	46 TO 60	.519	.345	46	.416	.621
AGE	61 TO 75	.346	.348	42	.238	.455

Discordant

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.643	.284	49	.561	.724
AGE	31 TO 45	.578	.365	50	.475	.682
AGE	46 TO 60	.495	.332	46	.396	.593
AGE	61 TO 75	.448	.352	42	.339	.558

AGE	4.04	3	1.35	7.95	.000
AGREETH	.02	1	.02	.41	.524
AGE BY AGREETH	.47	3	.16	2.60	.053

Table B3 (Cont'd).

PERMITTED STIMULI

Correct answer rate: Multivariate analysis of variance repeated measures all subjects

AGE, NoTHRU: Number of through signal heads

1 Through signal

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.659	.365	50	.555	.762
AGE	31 TO 45	.668	.350	50	.568	.768
AGE	46 TO 60	.529	.381	47	.417	.641
AGE	61 TO 75	.359	.368	42	.244	.474

2 Through signals

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.657	.269	50	.581	.734
AGE	31 TO 45	.608	.338	50	.512	.704
AGE	46 TO 60	.472	.286	47	.388	.556
AGE	61 TO 75	.401	.302	42	.307	.495

Source of Variation	SS	DF	MS	F	Sig of F
AGE	4.59	3	1.53	8.15	.000
NoTHRU	.03	1	.03	.94	.333
AGE BY NoTHRU	.16	3	.05	1.48	.221

Correct answer rate: Multivariate analysis of variance repeated measures older subjects

AGREETH: Left-turn signal concurrence/discordance with through signal

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Concurrent	.346	.348	42	.238	.455
Discordant	.448	.352	42	.339	.558

Source of Variation	SS	DF	MS	F	Sig of F
AGREETH	.22	1	.22	3.18	.082

Table B3 (Cont'd).

PERMITTED STIMULI

Correct answer rate: Multivariate analysis of variance repeated measures all subjects

AGE, HPOSIT: Left turn signal horizontal position

Between lanes

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.675	.369	50	.570	.780
AGE	31 TO 45	.685	.338	49	.588	.783
AGE	46 TO 60	.505	.367	47	.398	.613
AGE	61 TO 75	.351	.365	42	.238	.465

Straight-ahead

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.643	.273	50	.565	.720
AGE	31 TO 45	.599	.336	49	.502	.696
AGE	46 TO 60	.471	.310	47	.380	.562
AGE	61 TO 75	.418	.316	42	.319	.516

Source of Variation	SS	DF	MS	F	Sig of F
AGE	4.67	3	1.56	8.56	.000
HPOSIT	.04	1	.04	1.01	.316
AGE BY HPOSIT	.27	3	.09	2.12	.100

Table B3 (Cont'd).

PERMITTED STIMULI

Correct answer rate: Multivariate analysis of variance repeated measures older subjects

NoTHRU: Number of through signal heads

	Mean	Std. Dev.	N	95 percent Conf. Interval	
1 Through signal	.359	.368	42	.244	.474
2 Through signals	.401	.302	42	.307	.495

Source of Variation	SS	DF	MS	F	Sig of F
NOTHRU	.04	1	.04	.86	.360

Correct answer rate: Multivariate analysis of variance repeated measures older subjects

HPOSIT: Left-turn signal horizontal position

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Between lanes	.351	.365	42	.238	.465
Straight-ahead	.418	.316	42	.319	.516

Source of Variation	SS	DF	MS	F	Sig of F
HPOSIT	.09	1	.09	1.81	.186

Table B3 (Cont'd).

PROTECTED STIMULI

Minor error rate: One-way analysis of variance by subject age

GROUP	COUNT	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN
Age 15-30	50	.2430	.2787	.0394	.0000	1.0000	.1638 TO .3222
Age 31-45	51	.3666	.3363	.0471	.0000	1.0000	.2720 TO .4612
Age 46-60	48	.3891	.3226	.0466	.0000	1.0000	.2955 TO .4828
Age 60+	42	.5117	.3210	.0495	.0000	1.0000	.4117 TO .6117
TOTAL	191	.3718	.3264	.0236	.0000	1.0000	.3252 TO .4184

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	3	1.6673	.5558	5.5951	.0011
WITHIN GROUPS	187	18.5743	.0993		
TOTAL	190	20.2415			

Minor error rate: Multivariate analysis of variance repeated measures all subjects

SIGN: Left-turn supplemental sign

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Sign: "Left-turn signal"	.311	.336	189	.263	.360
No sign present	.378	.330	189	.331	.426

Source of Variation	SS	DF	MS	F	Sig of F
SIGN	.42	1	.42	22.17	.000

Minor error rate: Multivariate analysis of variance repeated measures all subjects

COLORS: Left-turn and through signal lens configuration

		Mean	Std. Dev.	N	95 percent Conf. Interval	
GA, GA+GB	Through: RB	.235	.355	188	.184	.286
GA+RB	Through: RB	.438	.393	188	.382	.495
GA, GA+GB	Through: GB	.311	.395	188	.254	.368
GA+RB	Through: GB	.534	.335	188	.486	.582

Source of Variation	SS	DF	MS	F	Sig of F
COLORS	9.94	3	3.31	69.72	.000

Table B3 (Cont'd).

PROTECTED STIMULI

Minor error rate: Multivariate analysis of variance repeated measures all subjects

AGE, SIGN: Left-turn supplemental sign

Sign: "Left-turn signal"

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.215	.307	50	.128	.302
AGE	31 TO 45	.295	.338	50	.199	.391
AGE	46 TO 60	.316	.328	48	.221	.411
AGE	61 TO 75	.443	.346	41	.334	.552

No sign present

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.250	.281	50	.170	.330
AGE	31 TO 45	.368	.337	50	.272	.464
AGE	46 TO 60	.408	.338	48	.310	.506
AGE	61 TO 75	.513	.317	41	.412	.613

Source of Variation	SS	DF	MS	F	Sig of F
AGE	2.76	3	.92	4.81	.003
SIGN	.43	1	.43	22.16	.000
AGE BY SIGN	.04	3	.01	.71	.545

Table B3 (Cont'd).

PROTECTED STIMULI

Minor error rate: Multivariate analysis of variance repeated measures all subjects

AGE, COLORS: Left-turn and through signal lens configuration

GA, GA+GB Through: RB

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.147	.305	50	.060	.234
AGE	31 TO 45	.212	.352	49	.111	.313
AGE	46 TO 60	.250	.351	48	.148	.352
AGE	61 TO 75	.353	.397	41	.227	.478

GA+RB Through: RB

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.256	.353	50	.156	.356
AGE	31 TO 45	.436	.401	49	.321	.551
AGE	46 TO 60	.503	.376	48	.394	.613
AGE	61 TO 75	.587	.375	41	.468	.705

Source of Variation	SS	DF	MS	F	Sig of F
AGE	6.31	3	2.10	5.55	.001
COLORS	10.04	3	3.35	70.50	.000
AGE BY COLORS	.47	9	.05	1.11	.352

Minor error rate: Multivariate analysis of variance repeated measures older subjects

SIGN: Left-turn supplemental sign

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Sign: "Left-turn signal"	.443	.346	41	.334	.552
No sign present	.513	.317	41	.412	.613

Source of Variation	SS	DF	MS	F	Sig of F
SIGN	.10	1	.10	5.82	.021

Minor error rate: Multivariate analysis of variance repeated measures older subjects

COLORS: Left-turn and through signal lens configuration

		Mean	Std. Dev.	N	95 percent Conf. Interval	
GA, GA+GB	Through: RB	.353	.397	41	.227	.478
GA+RB	Through: RB	.587	.375	41	.468	.705
GA, GA+GB	Through: GB	.426	.405	41	.298	.554
GA+RB	Through: GB	.699	.302	41	.604	.795

Source of Variation	SS	DF	MS	F	Sig of F
COLORS	3.01	3	1.00	17.93	.000

Table B3 (Cont'd).

RED STIMULI

Serious error rate: One-way analysis of variance by age

GROUP	COUNT	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN	
Age 15-30	49	.0136	.0432	.0062	.0000	.2222	.0012 TO	.0260
Age 31-45	51	.0212	.1074	.0150	.0000	.7500	-.0090 TO	.0514
Age 45-60	45	.0377	.0728	.0109	.0000	.3333	.0158 TO	.0595
Age 60+	42	.0833	.1416	.0219	.0000	.6250	.0392 TO	.1275
TOTAL	187	.0371	.0998	.0073	.0000	.7500	.0227 TO	.0515

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	3	.1297	.0432	4.5942	.0040
WITHIN GROUPS	183	1.7216	.0094		
TOTAL	186	1.8513			

Serious error rate: Multivariate analysis of variance repeated measures all subjects

HPOSIT: Left-turn signal horizontal position

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Straight-ahead	.031	.224	191	-.001	.063
Between lanes	.004	.174	191	-.021	.029

Source of Variation	SS	DF	MS	F	Sig of F
HPOSIT	.07	1	.07	6.44	.012

Serious error rate: Multivariate analysis of variance repeated measures all subjects

NoTHRU: Number of through signal heads

	Mean	Std. Dev.	N	95 percent Conf. Interval	
1 Through signal	.010	.244	191	-.024	.045
2 Through signals	.014	.181	191	-.012	.040

Source of Variation	SS	DF	MS	F	Sig of F
NOTHRU	.00	1	.00	.07	.794

Table B3 (Cont'd).

RED STIMULI

Serious error rate: Multivariate analysis of variance repeated measures all subjects

SIGN: Left-turn supplemental sign

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Sign: "Left turn signal"	.025	.227	191	-.007	.058
No sign	.008	.177	191	-.017	.034

Source of Variation	SS	DF	MS	F	Sig of F
SIGN	.03	1	.03	2.41	.122

Serious error rate: Multivariate analysis of variance repeated measures all subjects

AGE, HPOSIT: Left-turn signal horizontal position

Straight-ahead

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	-.013	.223	50	-.077	.050
AGE	31 TO 45	.033	.153	51	-.010	.076
AGE	46 TO 60	-.007	.288	48	-.090	.077
AGE	61 TO 75	.127	.191	42	.068	.186

Between lanes

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	-.013	.146	50	-.055	.028
AGE	31 TO 45	.013	.073	51	-.008	.034
AGE	46 TO 60	-.037	.261	48	-.113	.038
AGE	61 TO 75	.061	.154	42	.013	.109

Source of Variation	SS	DF	MS	F	Sig of F
AGE	.74	3	.25	3.73	.012
HPOSIT	.08	1	.08	7.24	.008
AGE BY HPOSIT	.05	3	.02	1.56	.200

Table B3 (Cont'd).

RED STIMULI

Serious error rate: Multivariate analysis of variance repeated measures all subjects

AGE, NoTHRU: Number of through signal heads

1 Through signal

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	-.007	.158	50	-.052	.038
AGE	31 TO 45	.026	.147	51	-.015	.067
AGE	46 TO 60	-.021	.287	48	-.104	.062
AGE	61 TO 75	.048	.350	42	-.061	.157

2 Through signals

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	-.007	.150	50	-.049	.036
AGE	31 TO 45	.020	.098	51	-.008	.047
AGE	46 TO 60	-.031	.263	48	-.108	.045
AGE	61 TO 75	.083	.158	42	.034	.133

Source of Variation	SS	DF	MS	F	Sig of F
AGE	.43	3	.14	1.92	.128
NOTHRU	.00	1	.00	.12	.728
AGE BY NOTHRU	.03	3	.01	.57	.636

Serious error rate: Multivariate analysis of variance repeated measures all subjects

AGE, SIGN: Left-turn supplemental sign

Sign: "Left turn signal"

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	-.013	.223	50	-.077	.050
AGE	31 TO 45	.033	.153	51	-.010	.076
AGE	46 TO 60	-.028	.274	48	-.107	.052
AGE	61 TO 75	.123	.224	42	.053	.193

No sign

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	-.013	.146	50	-.055	.028
AGE	31 TO 45	.016	.096	51	-.011	.043
AGE	46 TO 60	-.027	.270	48	-.105	.051
AGE	61 TO 75	.065	.141	42	.021	.109

Source of Variation	SS	DF	MS	F	Sig of F
AGE	.79	3	.26	3.82	.011
SIGN	.03	1	.03	2.85	.093
AGE BY SIGN	.05	3	.02	1.48	.222

Table B3 (Cont'd).

RED STIMULI

Serious error rate: Multivariate analysis of variance repeated measures older subjects

HPOSIT: Left-turn signal horizontal position

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Straight-ahead	.127	.191	42	.068	.186
Between lanes	.061	.154	42	.013	.109

Source of Variation	SS	DF	MS	F	Sig of F
HPOSIT	.09	1	.09	4.96	.031

Serious error rate: Multivariate analysis of variance repeated measures older subjects

NoTHRU: Number of through signal heads

	Mean	Std. Dev.	N	95 percent Conf. Interval	
1 Through signal	.048	.350	42	-.061	.157
2 Through signals	.083	.158	42	.034	.133

Source of Variation	SS	DF	MS	F	Sig of F
NOTHRU	.03	1	.03	.44	.509

Serious error rate: Multivariate analysis of variance repeated measures older subjects

SIGN: Left-turn supplemental sign

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Sign: "Left turn signal"	.123	.224	42	.053	.193
No sign	.065	.141	42	.021	.109

Source of Variation	SS	DF	MS	F	Sig of F
SIGN	.07	1	.07	3.61	.065

Table B3 (Cont'd).

CHANGE INTERVAL STIMULI

Serious error rate: One-way analysis of variance by age

GROUP	COUNT	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN
Age 15-30	49	.0262	.0828	.0118	.0000	.3750	.0025 TO .0500
Age 31-45	50	.0200	.0813	.0115	.0000	.3750	-.0031 TO .0431
Age 46-60	47	.0137	.0479	.0070	.0000	.2500	-.0004 TO .0277
Age 60+	42	.0304	.0721	.0111	.0000	.2500	.0079 TO .0528

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	3	.0072	.0024	.4574	.7124
WITHIN GROUPS	184	.9714	.0053		
TOTAL	187	.9787			

Table B3 (Cont'd).

CHANGE INTERVAL STIMULI

Correct answer rate: One-way analysis of variance by age

GROUP	COUNT	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN		
Age 15-30	49	.8027	.1893	.0270	.0000	1.0000	.7483	TO	.8571
Age 31-45	51	.7873	.1818	.0255	.0000	1.0000	.7361	TO	.8384
Age 46-60	47	.7163	.2117	.0309	.0000	1.0000	.6541	TO	.7785
Age 60+	42	.6293	.2739	.0423	.0000	1.0000	.5439	TO	.7147
TOTAL	189	.7385	.2231	.0162	.0000	1.0000	.7065	TO	.7705

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	3	.8471	.2824	6.1384	.0005
WITHIN GROUPS	185	8.5104	.0460		
TOTAL	188	9.3576			

Correct answer rate: Multivariate analysis of variance repeated measures all subjects

CHANGE: Change interval configuration

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Yellow ball or arrow	.883	.254	182	.846	.920
Yellow arrow + Red ball	.797	.274	182	.757	.837
Yellow arrow + Green ball	.519	.397	182	.461	.577

Source of Variation	SS	DF	MS	F	Sig of F
CHANGE	13.16	2	6.58	77.89	.000

Correct answer rate: Multivariate analysis of variance repeated measures all subjects

THRUCOL: Through signal indication

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Red ball	.823	.270	186	.784	.862
Green ball	.673	.255	186	.636	.710

Source of Variation	SS	DF	MS	F	Sig of F
THRUCOL	2.09	1	2.09	43.72	.000

Table B3 (Cont'd).

CHANGE INTERVAL STIMULI

Correct answer rate: Multivariate analysis of variance repeated measures all subjects

AGE, GHANGE: Change interval configuration

Yellow ball or arrow

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.911	.239	48	.842	.981
AGE	31 TO 45	.920	.239	48	.851	.989
AGE	46 TO 60	.924	.189	46	.868	.980
AGE	61 TO 75	.756	.315	40	.656	.857

Yellow arrow + Red ball

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.870	.217	48	.807	.933
AGE	31 TO 45	.829	.225	48	.764	.894
AGE	46 TO 60	.812	.244	46	.740	.885
AGE	61 TO 75	.654	.363	40	.538	.771

Yellow arrow + Green ball

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.547	.392	48	.433	.661
AGE	31 TO 45	.576	.383	48	.465	.688
AGE	46 TO 60	.433	.404	46	.313	.553
AGE	61 TO 75	.516	.411	40	.385	.648

Source of Variation	SS	DF	MS	F	Sig of F
AGE	1.53	3	.51	4.17	.007
CHANGE	12.77	2	6.38	76.77	.000
AGE BY CHANGE	.97	6	.16	1.94	.074

Table B3 (Cont'd).

CHANGE INTERVAL STIMULI

Correct answer rate: Multivariate analysis of variance repeated measures all subjects

AGE, THRUCOL: Through signal indication

Red ball

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.897	.217	49	.834	.959
AGE	31 TO 45	.873	.215	49	.811	.934
AGE	46 TO 60	.850	.219	46	.785	.916
AGE	61 TO 75	.647	.352	42	.537	.757

Green ball

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.718	.245	49	.648	.789
AGE	31 TO 45	.712	.228	49	.646	.777
AGE	46 TO 60	.635	.253	46	.560	.710
AGE	61 TO 75	.616	.286	42	.527	.705

Source of Variation	SS	DF	MS	F	Sig of F
AGE	1.68	3	.56	6.82	.000
THRUCOL	1.99	1	1.99	43.05	.000
AGE BY THRUCOL	.42	3	.14	3.02	.031

Correct answer rate: Multivariate analysis of variance repeated measures older subjects

CHANGE: Change interval configuration

	Mean	Std. Dev.	N	95 percent Conf. Interval		
Yellow ball or arrow		.756	.315	40	.656	.857
Yellow arrow + Red ball	.654	.363	40	.538	.771	
Yellow arrow + Green ball	.516	.411	40	.385	.648	

Source of Variation	SS	DF	MS	F	Sig of F
CHANGE	1.16	2	.58	5.36	.007

Correct answer rate: Multivariate analysis of variance repeated measures older subjects

THRUCOL: Through signal indication

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Red ball	.647	.352	42	.537	.757
Green ball	.616	.286	42	.527	.705

Source of Variation	SS	DF	MS	F	Sig of F
THRUCOL	.02	1	.02	.34	.562

Table B3 (Cont'd).

FLASHING INTERVAL STIMULI

Serious error rate: One-way analysis of variance by subject age

GROUP	COUNT	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN	
Age 15-30	50	.0989	.1364	.0193	.0000	.4545	.0601 TO	.1376
Age 31-45	51	.1074	.1543	.0216	.0000	.4545	.0640 TO	.1508
Age 46-60	48	.1445	.1496	.0216	.0000	.4706	.1011 TO	.1880
Age 60+	42	.1544	.1459	.0225	.0000	.4545	.1089 TO	.1999
TOTAL	191	.1248	.1474	.0107	.0000	.4706	.1038 TO	.1459

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	3	.1046	.0349	1.6202	.1862
WITHIN GROUPS	187	4.0260	.0215		
TOTAL	190	4.1306			

Serious error rate: Multivariate analysis of variance repeated measures all subjects

FLASH: Left-turn driver action during flashing signal operation

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Stop for both directions	.272	.332	188	.224	.319
Stop for opposing direction	.076	.164	188	.053	.100
Permitted	.010	.065	188	.001	.019

Source of Variation	SS	DF	MS	F	Sig of F
FLASH	6.96	2	3.48	83.74	.000

Serious error rate: Multivariate analysis of variance repeated measures all subjects

LFTFLSH: Left-turn signal indication during flashing signal operation

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Flash Red Ball	.206	.242	184	.171	.241
Flash Yellow Ball	.004	.034	184	-.001	.009
Dark left-turn signal	.124	.198	184	.095	.153

Source of Variation	SS	DF	MS	F	Sig of F
LFTFLSH	3.79	2	1.89	87.65	.000

Table B3 (Cont'd).

FLASHING INTERVAL STIMULI

Serious error rate: Multivariate analysis of variance repeated measures all subjects

THRUCOL: Through signal indication

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Flash Red Ball	.270	.331	189	.223	.318
Flash Yellow Ball	.185	.227	189	.153	.218

Source of Variation	SS	DF	MS	F	Sig of F
THRUCOL	.68	1	.68	109.70	.000

Serious error rate: Multivariate analysis of variance repeated measures all subjects

AGE, FLASH: Left-turn driver action during flashing signal operation

Stop for both directions

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.215	.318	49	.124	.307
AGE	31 TO 45	.241	.342	51	.144	.337
AGE	46 TO 60	.314	.322	47	.219	.408
AGE	61 TO 75	.330	.341	41	.222	.437

Stop for opposing direction

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.073	.171	49	.024	.122
AGE	31 TO 45	.060	.144	51	.020	.101
AGE	46 TO 60	.064	.142	47	.022	.106
AGE	61 TO 75	.114	.198	41	.051	.176

Permitted

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.005	.024	49	-.002	.012
AGE	31 TO 45	.000	.000	51	.000	.000
AGE	46 TO 60	.022	.103	47	-.009	.052
AGE	61 TO 75	.015	.080	41	-.010	.040

Source of Variation	SS	DF	MS	F	Sig of F
AGE	.29	3	.10	1.67	.175
FLASH	7.05	2	3.52	84.67	.000
AGE BY FLASH	.23	6	.04	.91	.485

Table B3 (Cont'd).

FLASHING INTERVAL STIMULI

Serious error rate: Multivariate analysis of variance repeated measures all subjects

AGE, LFTFLSH: Left-turn signal indication during flashing signal operation

Flash Red Ball

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.176	.239	47	.106	.247
AGE	31 TO 45	.187	.254	50	.115	.259
AGE	46 TO 60	.206	.223	45	.139	.273
AGE	61 TO 75	.262	.249	42	.185	.340

Flash Yellow Ball

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.000	.000	47	.000	.000
AGE	31 TO 45	.000	.000	50	.000	.000
AGE	46 TO 60	.017	.067	45	-.003	.038
AGE	61 TO 75	.000	.000	42	.000	.000

Dark left-turn signal

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.089	.177	47	.037	.141
AGE	31 TO 45	.108	.200	50	.051	.165
AGE	46 TO 60	.185	.226	45	.117	.253
AGE	61 TO 75	.117	.179	42	.061	.173

Source of Variation	SS	DF	MS	F	Sig of F
AGE	.21	3	.07	1.25	.292
LFTFLSH	3.84	2	1.92	89.90	.000
AGE BY LFTFLSH	.23	6	.04	1.80	.097

Table B3 (Cont'd).

FLASHING INTERVAL STIMULI

Serious error rate: Multivariate analysis of variance repeated measures all subjects

AGE, THRUCOL: Through signal indication

Flash Red Ball

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.215	.318	49	.124	.307
AGE	31 TO 45	.241	.342	51	.144	.337
AGE	46 TO 60	.314	.322	47	.219	.408
AGE	61 TO 75	.322	.341	42	.215	.428

Flash Yellow Ball

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.144	.210	49	.083	.204
AGE	31 TO 45	.165	.238	51	.098	.232
AGE	46 TO 60	.217	.223	47	.152	.283
AGE	61 TO 75	.223	.233	42	.150	.295

Source of Variation	SS	DF	MS	F	Sig of F
AGE	.59	3	.20	1.28	.283
THRUCOL	.69	1	.69	110.40	.000
AGE BY THRUCOL	.01	3	.00	.70	.551

Table B3 (Cont'd).

FLASHING INTERVAL STIMULI

Serious error rate: Multivariate analysis of variance repeated measures older subjects

FLASH: Left-turn driver action during flashing signal operation

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Stop for both directions	.330	.341	41	.222	.437
Stop for opposing direction	.114	.198	41	.051	.176
Permitted	.015	.080	41	-.010	.040

Source of Variation	SS	DF	MS	F	Sig of F
FLASH	2.12	2	1.06	19.97	.000

Serious error rate: Multivariate analysis of variance repeated measures older subjects

LFTFLSH: Left-turn signal indication during flasing signal operation

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Flash Red Ball	.262	.249	42	.185	.340
Flash Yellow Ball	.000	.000	42	.000	.000
Dark left-turn signal	.117	.179	42	.061	.173

Source of Variation	SS	DF	MS	F	Sig of F
LFTFLSH	1.45	2	.72	36.07	.000

Serious error rate: Multivariate analysis of variance repeated measures older subjects

THRUCOL: Through signal indication

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Flash Red Ball	.322	.341	42	.215	.428
Flash Yellow Ball	.223	.233	42	.150	.295

Source of Variation	SS	DF	MS	F	Sig of F
THRUCOL	.21	1	.21	29.26	.000

Table B3(Cont'd).

FLASHING INTERVAL STIMULI

Correct answer rate: One-way analysis of variance by age

GROUP	COUNT	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN
Age 15-30	50	.5517	.2546	.0360	.0000	1.0000	.4793 TO .6241
Age 31-45	51	.5022	.2746	.0385	.0000	1.0000	.4250 TO .5795
Age 46-60	48	.3779	.2416	.0349	.0000	.9524	.3078 TO .4481
Age 60+	42	.3239	.2056	.0317	.0000	.8182	.2599 TO .3880
TOTAL	191	.4447	.2615	.0189	.0000	1.0000	.4074 TO .4821

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	3	1.5680	.5227	8.5555	.0000
WITHIN GROUPS	187	11.4240	.0611		
TOTAL	190	12.9920			

Correct answer rate: Multivariate analysis of variance repeated measures all subjects

FLASH: Left-turn driver action during signal flahsing operation

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Stop for both directions	.577	.389	188	.521	.633
Stop for opposing direction	.369	.374	188	.315	.423
Permitted	.338	.373	188	.284	.392

Source of Variation	SS	DF	MS	F	Sig of F
FLASH	6.38	2	3.19	26.16	.000

Correct answer rate: Multivariate analysis of variance repeated measures all subjects

LFTFLSH: Left-turn signal indication during flashing signal operations

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Flash red ball	.514	.277	184	.473	.554
Flash yellow ball	.368	.415	184	.308	.428
Dark left-turn signal	.406	.333	184	.358	.455

Source of Variation	SS	DF	MS	F	Sig of F
LFTFLSH	2.10	2	1.05	15.14	.000

Table B3 (Cont'd).

FLASHING INTERVAL STIMULI

Correct answer rate: Multivariate analysis of variance repeated measures all subjects

THRUCOL: Through signal indication

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Flash Red Ball	.580	.390	189	.524	.635
Flash Yellow Ball	.343	.325	189	.296	.389

Source of Variation	SS	DF	MS	F	Sig of F
THRUCOL	5.30	1	5.30	43.96	.000

Correct answer rate: Multivariate analysis of variance repeated measures all subjects

AGE, FLASH: Left-turn driver action during signal flashing operation

Stop for both directions

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.698	.366	49	.593	.803
AGE	31 TO 45	.614	.405	51	.500	.728
AGE	46 TO 60	.537	.374	47	.427	.647
AGE	61 TO 75	.434	.374	41	.316	.552

Stop for opposing direction

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.350	.377	49	.242	.458
AGE	31 TO 45	.436	.410	51	.321	.552
AGE	46 TO 60	.314	.352	47	.211	.417
AGE	61 TO 75	.370	.348	41	.260	.480

Permitted

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.458	.409	49	.341	.575
AGE	31 TO 45	.420	.391	51	.310	.530
AGE	46 TO 60	.266	.326	47	.171	.362
AGE	61 TO 75	.174	.277	41	.087	.262

Source of Variation	SS	DF	MS	F	Sig of F
AGE	3.12	3	1.04	6.01	.001
FLASH	6.27	2	3.14	26.11	.000
AGE BY FLASH	1.37	6	.23	1.91	.079

Table B3 (Cont'd).

FLASHING INTERVAL STIMULI

Correct answer rate: Multivariate analysis of variance repeated measures all subjects

AGE, LFTFLSH: Left-turn signal indication during flashing signal operation

Flash Red Ball

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.576	.233	47	.508	.645
AGE	31 TO 45	.566	.289	50	.484	.648
AGE	46 TO 60	.476	.286	45	.390	.562
AGE	61 TO 75	.421	.275	42	.336	.507

Flash yellow ball

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.512	.442	47	.382	.642
AGE	31 TO 45	.468	.434	50	.345	.591
AGE	46 TO 60	.285	.370	45	.174	.396
AGE	61 TO 75	.177	.311	42	.081	.274

Dark left-turn signal

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.565	.341	47	.465	.666
AGE	31 TO 45	.438	.337	50	.342	.534
AGE	46 TO 60	.317	.288	45	.230	.404
AGE	61 TO 75	.286	.292	42	.195	.377

Source of Variation	SS	DF	MS	F	Sig of F
AGE	5.59	3	1.86	9.60	.000
LFTFLSH	2.19	2	1.09	15.94	.000
AGE BY LFTFLSH	.66	6	.11	1.61	.142

Table B3 (Cont'd).

FLASHING INTERVAL STIMULI

Correct answer rate: Multivariate analysis of variance repeated measures all subjects

AGE, THRUCOL: Through signal indication

Flash Red Ball

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.698	.366	49	.593	.803
AGE	31 TO 45	.614	.405	51	.500	.728
AGE	46 TO 60	.537	.374	47	.427	.647
AGE	61 TO 75	.447	.379	42	.329	.565

Flash Yellow Ball

FACTOR	CODE	Mean	Std. Dev.	N	95 percent Conf. Interval	
AGE	16 TO 30	.427	.348	49	.327	.527
AGE	31 TO 45	.416	.343	51	.320	.513
AGE	46 TO 60	.279	.296	47	.192	.366
AGE	61 TO 75	.227	.259	42	.146	.307

Source of Variation	SS	DF	MS	F	Sig of F
AGE	2.86	3	.95	7.72	.000
THRUCOL	5.27	1	5.27	43.20	.000
AGE BY THRUCOL	.08	3	.03	.23	.874

Correct answer rate: Multivariate analysis of variance repeated measures older subjects

FLASH: Left-turn driver action during flashing signal operation

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Stop for both directions	.434	.374	41	.316	.552
Stop for opposing direction	.370	.348	41	.260	.480
Permitted	.174	.277	41	.087	.262

Source of Variation	SS	DF	MS	F	Sig of F
FLASH	1.50	2	.75	6.94	.002

Correct answer rate: Multivariate analysis of variance repeated measures older subjects

LFTFLSH: Left-turn signal indication during flashing signal operation

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Flash Red Ball	.421	.275	42	.336	.507
Flash yellow ball	.177	.311	42	.081	.274
Dark left-turn signal	.286	.292	42	.195	.377

Source of Variation	SS	DF	MS	F	Sig of F
LFTFLSH	1.26	2	.63	9.51	.000

Table B3 (Cont'd).

FLASHING INTERVAL STIMULI

Correct answer rate: Multivariate analysis of variance repeated measures older subjects

THRUCOL: Through signal indication

	Mean	Std. Dev.	N	95 percent Conf. Interval	
Flash Red Ball	.447	.379	42	.329	.565
Flash Yellow Ball	.227	.259	42	.146	.307

Source of Variation	SS	DF	MS	F	Sig of F
THRUCOL	1.02	1	1.02	8.46	.006

LIST OF REFERENCES

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1. "A Time Progression Viewpoint of Accidents of Elderly Drivers", N. Stamatiadis, B.C. Lin, Transportation Research Board preprint paper No 920633, TRB Washington, D.C., 1992.

2. "Older Driver Resource Directory", Transportation Research Circular No 385, January 1992.

3. "Safety Issues Concerning Aged Drivers Response to Traffic Control Devices". T.R. Circular. TRB Annual Meeting 1988.

4. "Accident Characteristics of Elderly Drivers at Intersections", N.J. Garber, R. Srinivasan, Transportation Research Board preprint paper No 910609, TRB Washington, D.C., 1991.

5. Accidents Acts, 1976. National Safety Council, Chicago, Ill., 1976.

6. Agent, Kenneth R., "Development of Warrants for Left-Turn Lanes", Research Report 526, Kentucky Bureau of Highways, Lexington, Kentucky, 1979.

7. Allen, T.M. "Nighttime Legibility Distances of Highway Signs," HRB Bulletin, No. 191, 1958, pp. 33-40.

8. Ashton S.J. and G.M. Mackay. Benefits from Changes in Vehicle Exterior Design. In Pedestrian Impact Injury and Assessment, Society of Automotive Engineers, Detroit Michigan, March 1983, pp 225-264.

9. Awadallah F.I., "Guidelines for the Adequacy of Traffic Signs Retroreflectivity", ITE Compendium of Technical Papers, 1991.

10. Bailey, I.L. and J.E. Sheedy. "Vision Screening for Driver Licensure, "TRB Special Report 218, Vol 2, 1988, pp 294-324.

11. Bailey S.S., S.A. Jones, R.J. Stout, J.H. Bailey, S. Kass, B.B. Morgan Jr., "Issues on Elderly Pedestrians", 1991.

12. Ball, K., Beard, B., Roenker, D., Miller, R., & Griggs, D., "Age and visual search: Expanding the useful field of view", Journal of the Optical Society of America A, 5, 2210-2219, 1988.

13. Ball, K., Owsley, C. & Beard, B., "Clinical visual perimetry underestimates peripheral field problems in older adults", Clinical Vision Sciences, 5, 113-125, 1990.

14. Barrett G.V., W. Mihal, P.E. Panek, H.L. Sterns, and R. A. Alexander. Information Processing Skills Predictive of Accident Involvement for Younger and Older Commercial Drivers. Industrial Gerontology, Vol. 4, 1977, pp 173-182.

15. Bishu R.R., M. Tarawneh, P.T. McCoy, and B. Foster, "A Predictive Model for Elderly Drivers", Transportation Research Board preprint paper No 920712, TRB Washington, D.C., 1992.

16. Braune R. and C.D. Wickens. The Functional Age Profile: An Objective Decision Criterion for the Assessment of Pilot Performance Capacities and Capabilities. Human Factors, Vol. 27, No. 6, 1985, pp 681-693.

17. Brindle R.E., Some Aspects of Town Planning and Road Safety. Presented at New Zealand Roadway Symposium, Wellington, 1983.

18. Bull J. P. and G. M. Mackay. Some Characteristics of Collisions, the Population of Car Occupant Casualties and Their Relevance to Performance Testing. In Proceedings of the Fourth International Conference on Impact Trauma, International Research Committee on the Biokinetics of Impacts, Lyons, France, September 1978, pp.13-26.

19. Burden, D., "The older pedestrian: Special Problems and Needs", unpublished data, Talahassee, Florida, Florida Department of Transportation, 1991.

20. Burg A. Vision and Driving: A Report on Research. Human Factors, Vol. 13, No. 1, 1971, pp.79-87.

21. Burg A., Vision Test Scores and Driving Record: Additional Findings. Report 68-27. Department of Engineering, University of California, Los Angeles, 1968.

22. Burg A., The Relationship Between Vision Test Scores and Driving Record: General Findings. Report 67-24. Department of Engineering, University of California, Los Angeles, 1967.

23. Burg, A. Lateral visual field as related to age and sex. Journal of Applied Psychology, 52, 1968, pp. 10-15.

24. Cerrelli, E. Older Drivers, The Age Factor in Traffic Safety. Report DOT-HS-807-402. U.S. Department of Transportation, 1989.

25. Cottrell B.H., Jr. Guidelines for Protected/Permissive Left-Turn Signal Phasing. In transportation Research Record 1069, TRB, National Research Council, Washington, D.C., 1986, pp. 54-61.

26. Curry J.D. The Mechanical Consequences of Variation in the Mineral Content of Bone. Journal of Biomechanics, Vol 2, 1969, pp. 1-11.

27. Davis G.A., K. Koutsoukos, "A Statistical Method for Identifying Locations of High Crash Risk to Older Drivers", Transportation Research Board preprint paper No 920267, TRB Washington, D.C., 1992.

28. Davison P.A. Inter-relationship Between British Drivers' Visual Abilities, Age and Road Accident Histories. Ophthalmic and Physiological Optics, Vol. 5, 1985, pp 195-204.

29. Decina L.E., L.K. Staplin, A. Spiegel, "Correcting Unaware Vision Impaired Drivers", final report prepared by Ketron Inc. for PennDOT, Oct 1990.

30. "Effects of Supplemental Interchange Signing on Driver Control Behavior", Technical Report, FHWA, Washington D.C., March 1986.

31. Evans L. Fatal and Severe Crash Involvement Versus Driver

32. Age and Sex. GMR-5721. General Motors Research Laboratories, Warren, Michigan, 1987.

33. Evans L. Young Driver Involvement in Severe Car Crashes. Report GMR-5835. General Motors Research Laboratory, Warren, Michigan, 1987.

34. Evans L., "Older driver risks--to themselves and to other road users", Transportation Research Board preprint paper No 910490, TRB Washington, D.C., 1991.

35. Fatal Accident Reporting System: 1984. NHTSA, U.S.Department of Transportation, March 1985.

36. "The Federal Highway Administration's Action Plan for Older Persons", U.S. DOT, February 1989.

37. Fishman, G.A., Anderson, R.J., Simson, L., & Haque, A. (1981). Driving performance of retinitis pigmentosa patients. British Journal of Opthalmology, 65 122-126.

38. Forbes, T.W., K.Moscowitz, G.Morgan, and D.W. Loutzenheiser. "A Comparison of Lower Case and Capital Letters for Highway Signs," TAB Proceedings, Vol. 30, 1950, pp. 355-373.

39. Frisbie T., "Keeping Over-The-Hill Drivers in the Game", Traffic Safety, January/February, 1991 pp 10-13.

40. Grubb, M., "Driver behavior at intersections: An Analysis of Accident Related Variables", Proceedings of the Human Factors Society. Santa Monica, CA: Human Factors Society, 1986.

41. Guidelines for Major Street Design - A Recommended Practice. Institute of Transportation Engineers, Washington, D.C., 1984.

42. Harrington D. and R.McBride. Traffic Violations by Type, Age, Sex, and Marital Status. Accident Analysis and Prevention, Vol. 2, 1970, pp. 67-69.

43. Hawkins H.E., "A Comparison of Leading and Lagging Greens in Traffic Signal Sequence," 1963 Proceedings, Institute of Traffic Engineers, 33rd Annual Meeting, Toronto, Ontario, Canada, pp. 238-242.

44. Henderson R.L., A. Burg, and F.A. Brazelton, "Development of an Integrated Vision Testing Device: Phase I", Final Report, Systems Development Corporation Santa Monica, California, 1971.

45. Henderson, R. & Burg, A., "Vision and Audition in Driving", Technical Report No. TM(L)-5297/000/00, Washington D.C.: Department of Transportation, 1974.

46. Highway Statistics 1984. FHWA, U.S. Department of Transportation, October 1985.

47. Hills B. L. and A. Burg. A Reanalysis of California Driver Vision Data: General Findings. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1977.H. W. Hofstetter. Visual Acuity and Highway Accident. Journal of the American Optometric Association, Vol. 47, 1976, pp. 887-893.

48. Hills, B.L., & Burg, A., "A Re-analysis of California driver vision data: General findings", Report 768. Transport and Road Research Laboratory, Crowthorne, England, 1977.

49. Hostetter, R., McGee, H., Crowley, K., Sequin, E., and Dauber, G. (1986). Improved Perception-Reaction Time Information for Intersection Sight Distance. FHWA/ RD87/015. Washington, D.C.: Federal Highway Administration.

50. Hummer J.E., R.E. Montgomery, K.C. Sinha, "Guidelines for the Use of Leading and Lagging Left-Turn Signal Phasing", presentation TAB, January 1991.

51. Hunter-Zaworski, K., "The Performance of Drivers with Physical Limitations at T-Intersections", Covallis, OR: Doctoral dissertation, Department of Civil Engineering, Oregon State University, 1987.

52. IIHS Facts. Insurance Institute for Highway Safety, Arlington VA., 1988.

53. "Impact of Aging Driver Population and Impaired Drivers on Geometric Design", Transportation Research Circular No 317, June 1987.

54. "Implementation of Periodic Vision Screening to a Statewide Program", Task 5 Report, prepared by Ketron for PennDOT, January, 1990.

55. Johnson C.A. and J.L.Keltner. Incidence of Visual Field Loss in 20,000 Eyes and Its Relationship to Driving Performance. Archives of Opthalmology, Vol. 101, 1983, pp. 371-375.

56. Kausler D.H. Experimental Psychology and Human Aging. John Wiley, New York, 1982.

57. Khavanin N.R. and R.N. Schwab, "Traffic Sign Legibility and Conspicuity for the Older Drivers", ITE Compendium of Technical Papers, 1991.

58. Kikuchi S., J.R. Riegner, "A Methodology to Analyze the Driver Decision Environment at a Signal Change Interval: Application of Fuzzy Set Theory", presentation at the 70th Annual Meeting of the TAB, Dec 1990.

59. Kline, D.W., F.Schieber, L.A. Abusamara, and A.C. Coyne. "Age, the Eye and the Visual Channels: Contrast Sensitivity and Response Speed," Journal of Gerontology, Vol. 38, No. 2, 1983, pp. 211-216.

60. Koltonow P. G. Improving Safety and Mobility for Older People. TR News, September-October 1985, pp 20-23.

61. Korteling, J., "Perception-response speed and driving capabilities of brain-damaged and older drivers", Human factors, 32, 95-108, 1990.

62. Leibowitz, H. & Appelle, S., "The effect of a central task on luminance thresholds for peripherally presented stimuli", Human Factors, 11, 387-392, 1969.

63. Lerner N.D. and D.J. Ratte, "Problems in Freeway Use as Seen By Older Drivers", Transportation Research Board preprint paper No 910152, TAB Washington, D.C., 1991.

64. Lerner N.D., "Older Driver Perception-Reaction Time and Sight Distance Design Criteria", ITE Compendium of Technical Papers, 1991.

65. Lerner N.D., "Some Observations on Older Drivers", TAB, June 1988.

66. Lerner, N., Ratte, D., Huey, R., McGee, H., and Hussain, S., Literature Review: Older Driver Perception-Reaction Time. Working paper under contract DTFH 61-90-C-00038. Washington, D.C.: Federal Highway Administration, 1990.

67. Lin F.B., "Left-Turn Signal Phasing For Full-Actuated Signal Control", Transportation Research Board preprint paper No 910463, TAB Washington, D.C., 1991.

68. Lundgren-Linquist, B.; Aniansson, A.; & Rundgren, A. Functional studied in 79-year-olds. III. Walking performance and climbing ability. Scandinavian Journal of Rehabilitation Medicine, 15, p. 125-131.

69. Mace D.J., R. Gable, "Model Highway Visibility Minimum Required Visibility", Transportation Research Board reprint paper No 920709, TAB Washington, D.C., 1992.

70. Maleck T. and Hummer J. Driver Age and Highway Safety. In Transportation Research Record 1059, TAB, National Research Council, Washington, 1986, pp.6-12.

71. McCoy P.T., "Strategies for Improving the Safety of Elderly Drivers", ITE Compendium of Technical Papers, 1991.

72. McGee, H., Hooper, K., Jughes, W., and Benson, W. (1983). Highway Design and Operational Standards Affected by Driver Characteristics. FHWA/RD-83/015. Washington, D.C.: Federal Highway Administration.

73. McKelvey F.X. and Nikiforos Stamatiadis, "A Study of the Relationship Between Older Drivers and highway Safety in the State of Michigan", Final Report, CEE Department, MSU E. Lansing, Michigan.

74. McKelvey F.X. and Nikiforos Stamatiadis. Accidents and the older driver at signalized and non-signalized intersections. Division of Engineering Research, College of Engineering, Michigan State University, East Lansing Michigan.

75. McKelvey F.X., N. Stamatiadis, "Highway Accident Patterns in Michigan Related to Older Drivers", Transportation Research Board reprint paper 88-0374, Washington D.C. 1989.

76. McKelvey F.X., T.L. Maleck, N. Stamatiadis, P. Stamatiadis, "Relationship Between Driver Age and Highway Accidents", MSU, MOHSP, NHTSA, July 1987.

77. Moore R.L., I.P. Sedgley and B.E. Sabey. Ages of car drivers involved in accidents, with special reference to junctions. Transport and Road Research Laboratory, Department of the Environment, Department of Transport, Supplementary Report 718 Crowthorne, Berkshire, 1982.

78. National Highway Traffic Safety Administration. (1989a). Older Drivers. The Age Factor in Traffic Safety. (Report Number DOT HS 807 402) Washington. D.C.: U.S. Department of Transportation.

79. "The National Highway Traffic Safety Administration's Traffic Safety Plan for Older Persons", U.S. DOT, NHTSA, Sep. 1988.

80. Nationwide Personal Transportation Study 1983-84. FHWA, U.S. Department of Transportation, 1983.

81. "New Technology For Older Drivers", Traffic Safety, January/February, 1991 p 5.

82. Ng J.C.N., E. Hauer, and J.Lovel. Are Longer Signal Cycles Safer? In Proceedings, 12th Annual Meeting of the Institute of Transportation Engineers, District 7, Canada, Hamilton Ontario, Canada June 1987.

83. NHTSA Conference on Research and Development Needed to Improve Safety and Mobility of Older Drivers. Washington, D.C.: National Highway Traffic Safety Administration, 1990.

84. North R.V. The Relationship Between the Extent of Visual Field and Driving Performance - A Review. Ophthalmic and Physiological Optics, Vol. 5, 1985, pp 205-210.

85. "Older Driver Pilot Program", Federal Highway Administration, Office of Highway Safety, Report to Congress Apr87-Apr90, Washington D.C., 1990.

86. "Older drivers, The Age Factors in Traffic Safety", NHTSA, February 1989.

87. Olson, P., Cleveland, D., Fancher, P., Kostyniuk,L., and Schneider, L., "Parameters Affecting Stopping Sight Distance:, NCHRP Report 270. Washington, D.C.: Transportation Research Board, 1984.

88. "Operation, Safety, And Maintenance of Transportation Facilities", Transportation Research Circular No 370, May 1991.

89. "Operational Effects of Geometrics and Geometric Design", Transportation Research Circular No 349, TAB/NRC, April 1989.

90. Owsley C., K. Ball, M. Sloane, D. Roenker, J. Bruni, "Visual Perceptual/Cognitive Correlates of Vehicle Accidents in Older Drivers", Transportation Research Board reprint paper No 910368, TAB Washington, D.C., 1991.

91. Owsley C., K. Ball, M.E. Sloane, D.L. Roenker, J.R. Bruni, "Visual/Cognitive Correlates of Vehicle Accidents in Older Drivers", Psychology and Aging,

92. Owsley. C., & Sloane M.E., "Vision and aging", In F. Boller & J. Grafman (Eds.) Handbook of Neuropsychology, Volume 4 (pp229-249). the Netherlands: Elsevier, 1990.

93. Papacostas C.S., N.H. Kasamoto, "The Intergreen Interval Controversy: Toward a Common Framework",

94. Parker, M. and C.V. Zegeer, "Traffic Conflict Techniques for Safety and Operations", Engineer's Guide, FHWA-IP-88-026, FHWA, McLean, Virginia, 1988.

95. Partyka S. C. Traffic Victim Age and Gender Distribution. NHTSA, U.S. Department of Transportation, July 1984.

96. Partyka S. Comparison by Age of Drivers in Two-Car Fatal Crashes. NHTSA, U.S. Department of Transportation, 1983.

97. Perchonok K., P.M. Hurst, "Effect of Lane-Closure Signals Upon Driver Decision Making and Traffic Flow", Journal of Applied Pshychology Vol 52, No. 5, 410-413, 1968.

98. Personal Travel in the U.S. In 1983-1984 Nationwide Personal Transportation Study, Vol. 1, FHWA, U.S. Department of Transportation, 1986.

99. Planek T.W. and R.C. Fowler. Traffic Accident Problems and Exposure Characteristics of the Aging Driver. Journal of Gerontology, Vol.26, No.2, 1971, pp. 224-230.

100. "A Policy on Geometric Design for Highways and Streets". American Association of State Highway and Transportation Officials, Washington, D.C., 1984.

101. "A Policy on Geometric Design of Highways and Streets". American Association of State Highway and Transportation Officials, Washington, D.C. 1990.

102. Ponds R.W.H.M., W. H. Brouwer, and P.C. van Wolffelaar. Age Differences in Divided Attention in a Simulated Driving Task. Journal of Gerontology: Psychological Sciences, Vol.43, No. 6, 1988, pp. 151-156.

103. Principles for Urban Planning with Respect to Road Safety. SCANT, Sweden, 1968.

104. Prospective Trends in the Size and Structure of the Elderly Population, Impact of Mortality Trends, and Some Implications. Current Population Reports, Special Studies, Series P-23, No.78. Bureau of Census, U.S. Department of Commerce, 1978.

105. Rabbit, P.M.A., "An age/decrement in the ability to ignore irrelevant information", Journal of Gerontology, vol 20, 1965, pp. 233-238.

106. Race L., "Traffic Signals", Transportation and Traffic Engineering Handbook, 2nd Edition, Institute of Transportation Engineers, Washington, D. C. 1982, pp 737-782.

107. Rainey T.A. and N.H. Pulling, "Performance Differences on Driving and Laboratory Tasks Between Drivers of Different Ages", Transportation Research Record 1281, January, 1990.

108. Recommended Guidelines for Subdivision Streets - A Recommended Practice, Institute of Transportation Engineers, Washington, D.C., 1984.

109. Retching, S., Co, J., Fox, M., and Irwin, L., "Performance-based measurements among elderly drivers and nondrivers", Journal of the American Geriatrics Society, 36, 813-819, 1988.

110. Rys M., E. Russell, D. Harwood and A. Rys, "Development of a Headlight Measurement System", Transportation Research Board reprint paper No 920778, TAB Washington, D.C., 1992.

111. Rys M., E. Russell, D. Harwood and A. Rys, "Field Studies with a Headlight Measurement System" Transportation Research Board reprint paper No 920777, TAB Washington, D.C., 1992.

112. Salthouse T. A. Adult Cognition: An Experimental Psychology of Human Aging. Springer-Verlag, New York, 1982.

113. Saremi A.R., "Identification of the Color of Highway Signs Under a Combination of Vehicle Headlamp and High Intensity Discharge Light Sources", ITE Compendium of Technical Papers, 1991.

114. Scialfa, C.T., Kline, D.W., & Lyman, B.J., "Age differences in target identification as a function of retinal location and noise level: an examination of the useful field of view", Psychology and Aging, 2, 14-19, 1987.

115. Sekuler, R., Ball, K., "Visual Localization: Age and Practice", Journal of the Optical Society of America A, 3, 864-867.

116. Senior Driver Facts. California Department of Motor Vehicles, Sacramento, January 1982.

117. Shapiro, P., Upchurch, J., Loewen, J., and Siaurusaitis, V., "Identification of needed traffic control device research", Transportation Research Record 1114, 11-20, 1987.

118. Sharpe, J. A. & Sylverster, T. O., "Effects of aging on horizontal smooth pursuit", Investigative Opthalmology and Visual Science, 17, 1978, pp. 465-468.

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

120. Shinar, D., "Driver Visual Limitations: Diagnosis and Treatment", (Contract DOT-HS-5-1275) Washington D.C.: Department of Transportation, 1977.

121. Shotton M. A. Belt Up-If You Can. Applied Ergonomics, June 1985, pp. 127-133.

122. "Signal Displays For Left Turn Control", Final Report, FHWA, U.S. Department of Transportation, 1988.

123. Sivak, M., P.L. Olson and L.A. Pastalan, "Effect of Driver and Age on Nighttime Legibility of Highway Signs," Human Factors, Vol 23, No.1, 1981, pp. 59-64.

124. Solomon D. The Older Drive an Highway Design. In Needs and Problems of Older Drivers: Survey Results and Recommendations (J. L. Malfette, ed.), AAA Foundation for Traffic Safety, Falls Church, Va, February 1985.

125. Stamatiadis Nikiforos, "Relationship Between Accidents of Elderly Drivers and Intersection Traffic Control Devices", Ph.D. Dissertation, Michigan State University, E. Lansing, Michigan, 1990.

126. Staplin L. and R.W. Lyles, "Specific Traffic Maneuver problems for older drivers", August 1990.

127. Staplin L. K., M. Breton, S. Haimo, E. Sarber, and A. M. Byrnes, "Age-Related Diminished Capabilities and Driver Performance", Working Paper, FHWA, U.S. Department of Transportation, 1987.

128. Staplin L., "Age-related Differences in Sensory, Cognitive, and Psychomotor Test Performance with Implications for Traffic Control Device Design", Transportation Research Board Annual Meeting, Washington D.C., Jan. 1988.

129. Staplin L., M. Drapcho, "Assessing Age Differences in Human Information Processing Capabilities Underlying Traffic Control Device Usage", L. Staplin, M. Drapcho, Transportation Research Board Annual Meeting, Jan., 1988.

130. Staplin L., M. Drapcho, K. Lococo, J. Sim, "Age Differences in a Visual Information Processing Capability Underlying Traffic Control Device Usage", Transportation Research Board Annual Meeting, Jan., 1988.

131. Staplin L.K. "Age-Related Diminished Capabilities and Driver Performance", Working paper submitted by Ketron, Inc. FHWA Contract DTFH 61-86-C-00044. Federal Highway Administration. 1990.

132. Staplin L.K. Age-Related Diminished Capabilities and Driver Performance. Working Paper. FHWA, U.S. Department of Transportation, January 1985.

133. States J.D. Musculoskeletal System Impairment Related to Safety and Comfort of Drivers 55+. In Drivers 55+, J.L. Malfetti (ed). AAA Foundation for Traffic Safety, Falls Church, Virginia, 1985.

134. Stein, S.K., "Risk factors of sober and drunk drivers by time of day", Alcohol, Drugs, and Driving, 5(3), 215-227, 1985.

135. Szlyck, J.P., Fishman, G.A., Mater, S., & Alexander, K.R., (1990) Visual field screening for driving in retinitis pigmentosa patients. Investigative Opthalmology and Visual Science (Supplement), 31, 416.

136. Tan C.H., "Increasing Highway Sign Legibility for Older Drivers", Transportation Research Board reprint paper No 920711, TAB Washington, D.C., 1992.

137. "Teen and Senior Drivers", State of California Department of Motor Vehicles, Oct. 1990.

138. "Traffic Control Design Elements for Accommodating Drivers With Diminished Capacity", Technical Report, Volume II, FHWA, Washington D.C., May 1990.

139. "Transportation in an aging society",TAB Special Report 218.

140. U.S. Congress. Senate. Special Commission on Aging. Aging America: Trends and Projections. 1985.

141. U.S. Department of Transportation. (1985). Survey data tabulations, 1983-1984 Nationwide Personal Transportation Study. (DOT-P36-85-1). Washington D.C.: Author.

142. Untermann R.K. Accommodating the Pedestrian - Adapting Towns and Neighbourhoods for Walking and Bicycling. Van Nostrand Reinhold Company, New York, 1984.

143. Upchurch J., "A Comparison of Left Turn Accident Rates for Different Types of Left Turn Phasing",

144. Van der Zwagg D.C. Induced Exposure as a Tool to Determine Passenger Car and Truck Involvement in Accidents. HIT LAB Reports, University of Michigan, 1971.

145. Viano, D.C., Culver, C.C., Evans, L., Frick, M.C. and Scott, R. (1990). "Involvement of older drivers in multivehicle side-impact crashes. Accident Analysis and Prevention, 22, 177-199.

146. Walker J., C.A. Sedney, T.M. Mast, "Older Drivers and Useful Field of View in a Part-Task Simulator", Transportation Research Board reprint paper No 920702, TAB Washington, D.C., 1992.

147. Waller J.A. Medical Limitations and the Elderly Driver. In Proceedings of the National Conference on the Aging Driver, American Association of Motor Vehicle Administrators, Washington, D.C., 1974, pp.71-84.

148. Waller J.A. Medical Conditions-What Role in Crashes? New England Journal of Medicine, Vol. 233, 1974, pp. 429-430.

149. Waller P.F., E. G. House, and J.R. Stewart. An analysis of Accidents by Age. University of North Carolina Highway Safety Research Center, Chapel Hill, 1977.

150. Waller P.F., E.G. House, and J.R. Stewart. An Analysis of Accidents by Age. Presented at 56th Annual Meeting of the Transportation Research Board, Washington, D.C., 1977.

151. Welford A.T. changes of Performance With Age: An Overview. In Aging and Human Performance (N.Charness, ed.) Wiley, Chichester, England, 1985.

152. Willis S.L.. Cognitive Training and Everyday Competence. In Annual Review of Gerontology and Geriatrics (k.W. Schaieand C. Eisdorfer, eds.) Vol. 7, 1987, pp 159-188.

153. Wisconsin DOT monograph "Wisconsin's Aging Population and Their Impact on Transportation", 1986.

154. "Workshop on Roadway Improvements for the Mobility and Safety of Older Drivers and Pedestrians", summary of discussions and recommendations sponsored by the Highway Users Federation, the Automotive Safety Foundation and FHWA, October 19-20, Arlington VA,1989.

155. Yanik A. J. What Accident Data Reveal About Elderly Drivers. Paper 851688. Society of Automotive Engineers, Dearborn, Michigan, September 1985.

156. Zacks J.L. and R.T. Zacks, "Visual Search Times Assessed without Reaction Times: Changes with Aging", Michigan State University,

157. Zwahlen H.T., M. Sunkara, D. Kellmeyer, S. Sundarram, "Legibility and Conspicuity Performance of Dry and Wet Beads on Paint and Reflective Sheeting License Plates under Low beam Illumination at Night", Transportation Research Board reprint paper No 920865, TAB Washington, D.C., 1992.

158. Zwahlen H.T., U.D. Vel, "Conspicuity in Terms of Peripheral Visual Detection and Recognition of Fluorescent Color Targets vs. Non-Fluorescent Color Targets Against Different Backgrounds During Daytime", Transportation Research Board reprint paper No 920880, TAB Washington, D.C., 1992.