T-Intersection Simulator Performance of Drivers with Physical Limitations

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The effect of restricted head and neck movement on driving performance was measured by decision time at simulated T-intersections. Little traffic safety and human factors literature concerning the performance of drivers with physical limitations was found. Most accidents involving drivers with diminished capacities occur at intersections; therefore, simulated T-intersections were selected for study. A laboratory study using a driving simulator was selected to provide better experimental control, safety, and repeatability. A fixed-base driving simulator that incorporated videorecordings of intersections to provide a 180-degree field of view was used. Eighteen intersections with various levels of traffic volume and sight distance were studied. The 72 test subjects were either between the ages of 30 and 50 or between 60 and 80, and half in each group had a restricted range of neck movement. The subjects' task was to depress the brake pedal, watch the video presentations of the T-intersections on three screens, and release the brake pedal when it was safe to make a left turn. The decision time was a measure of driving performance. The following hypotheses were confirmed: (a) decision time increases with age, and age effects dominated the other factors studied; (b) decision time increases with age and level of impairment, indicating that younger drivers are able to compensate for their impairments, but older drivers both with and without impairments are unable to make compensations in their driving performance; and (c) skewed intersections are hazardous for drivers with neck impairments. Further laboratory and field studies are recommended to validate the study results and to examine the problem of skewed intersections.

A study of the performance of drivers with physical limitations was undertaken at the Turner Fairbank Highway Research Center of FHWA, U.S. Department of Transportation, in McLean, Virginia, as part of the graduate research fellowship program. A review of the current transportation literature showed that little is known about the relationship of biomechanics and driving performance. A driving simulator was used to examine the relationship between head and neck mobility and decision time at simulated T-intersections.

BACKGROUND

Accident rate statistics document the increase in accident rates of older drivers and drivers with diminished capacities on a miles-driven basis and indicate the need to study the performance of these drivers (*1*). The population demographics predict a dramatic increase in the percentage of older people in the total population by the year 2000 and beyond (*2*). The majority of accidents involving the older driver occur at intersections, during lane changing and turning maneuvers (*3*). These facts indicated the need to study the performance of drivers with physical limitations at intersections.

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The problems of drivers with diminished capacities need to be understood to determine safer road design standards and operational and control strategies. A better understanding of these drivers' characteristics will facilitate the design of education programs to help these drivers compensate for their limitations. Human factors, vehicle characteristics, and road geometric requirements form the basis of most of the standards used for the design of highways and streets. The study of drivers with diminished capacities at intersections covers a broad spectrum of fields, from human factors, gerontology, ophthalmology, and ergonomics to traffic engineering. Significant studies that examine the psychological and cognitive aspects of drivers with diminished capacities have been undertaken. These studies are complementary to studies of physical limitations (*4*).

The transportation and human factors literature indicated that little is known about the relationship between physical limitations and driving performance; therefore, this relationship was selected for study. Most of the human factors literature relating to older drivers has focused on the visual and cognitive aspects of driver behavior and performance. The gerontology and human factors literature (*5–7*) has clearly documented the changes in visual acuity and accommodation with age. Drivers with diminished capacities have different sensory, cognitive, and physical thresholds than other members of the driving public (*8*). These drivers require more stimuli for perception, or extra time to react, as a result of physical limitations. Several reports (*9,10*) have shown that a physically challenged individual's driving performance, as judged by accident statistics, is normally average or above average. However, the performance of drivers who are marginally physically impaired, either permanently or temporarily, has not been studied.

Intersections require drivers to make decisions about turning or crossing and present conflicting traffic flows and changing roadway geometrics, which increase driver workload. Increased accident rates at intersections appear to be related to the implementation of new traffic control devices, high traffic volumes, and low sight distance (*11–13*). Polus (*14*) points out that more restrictive signalization does not necessarily result in a decrease in accidents or unsafe movements.

RESEARCH OBJECTIVES

A better understanding of the effects of physical limitations on driving behavior and decision-making ability was sought.

The behavior of drivers at simulated T-intersections was investigated to determine the relationships between the range of movement of the head and neck, the visual field, and the decision time for a simulated traffic maneuver.

EXPERIMENTAL DESIGN

A driving simulator in a laboratory environment was used, because of the hazards and lack of experimental control of a field study. Three rear projection screens were used to provide a 180-degree field of view in the driving simulator. This method of providing the drivers' perspective of the roadway was more realistic than the other methods of intersection simulation. The performance times of drivers with physical limitations at simulated unsignalized T-intersections were examined to determine the relationship between physical limitations of the neck and decision time. Each intersection presented different geometrics and traffic volumes.

The experiment was a 2 (age) × 2 (impairment) × 3 (sight distance) × 2 (volume) factorial design, with repeated measures on sight distance and volume. The subjects were partitioned according to age and impairment, and two levels of traffic volume and three levels of restricted sight distance were established. The independent variables were the age and impairment of subjects.

The subjects were divided as follows:

- 30 to 50 years, impaired: 15 subjects;
- 30 to 50 years, unimpaired: 15 subjects;
- 60 to 80 years, impaired: 15 subjects; and
- 60 to 80 years, unimpaired: 15 subjects.

Figure 1 is a histogram of the distribution of ages in the two groups (*15*). The median age for the 30- to 50-year age group was 40 years, and the median age for the 60- to 80-year age group was 67. For this research, impairment was defined by a combined static range of movement of the head and visual field of less than 285 degrees. A range from 285 to 360 degrees was defined as no impairment. No definitive definition of impairment was found in the literature, so the choice of 285 degrees was based on the functional requirements for driving.

The 18 intersections had variations in traffic volume and sight distance. The two levels of traffic volumes were measured in terms of average gap length (*g*). The videotaping was done during morning rush hour for some of the intersections and at midday for the others. The gap lengths in the cross-stream traffic on the videotapes were measured to determine the traffic volume for each intersection. Light traffic volumes consisted of gap lengths of 8 sec or longer on both traffic streams. Moderate traffic volume had gaps of less than 8 sec in both traffic streams. Nine intersections had low traffic volumes, and nine had moderate traffic volumes. Of the sight distances for the 18 intersections, six were below standard, six were approximately at standard, and six were longer than standard. The sight distance standard was defined by AASHTO's *Policy on Geometric Design of Highways and Streets* (*16*). The intersections were all within a 5-mi radius of the Turner Fairbank Highway Research Center in McLean, Virginia. The terrain is rolling, so few of the intersections were level. All but one were 90-degree intersections. All intersections were filmed in daylight, when the pavement was dry.

The independent variables were age, impairment level, traffic volume level, and intersection sight distance. The measured or dependent variables were as follows:

1. Response time, which was determined by measuring the time between the tone indicating that an intersection pres-

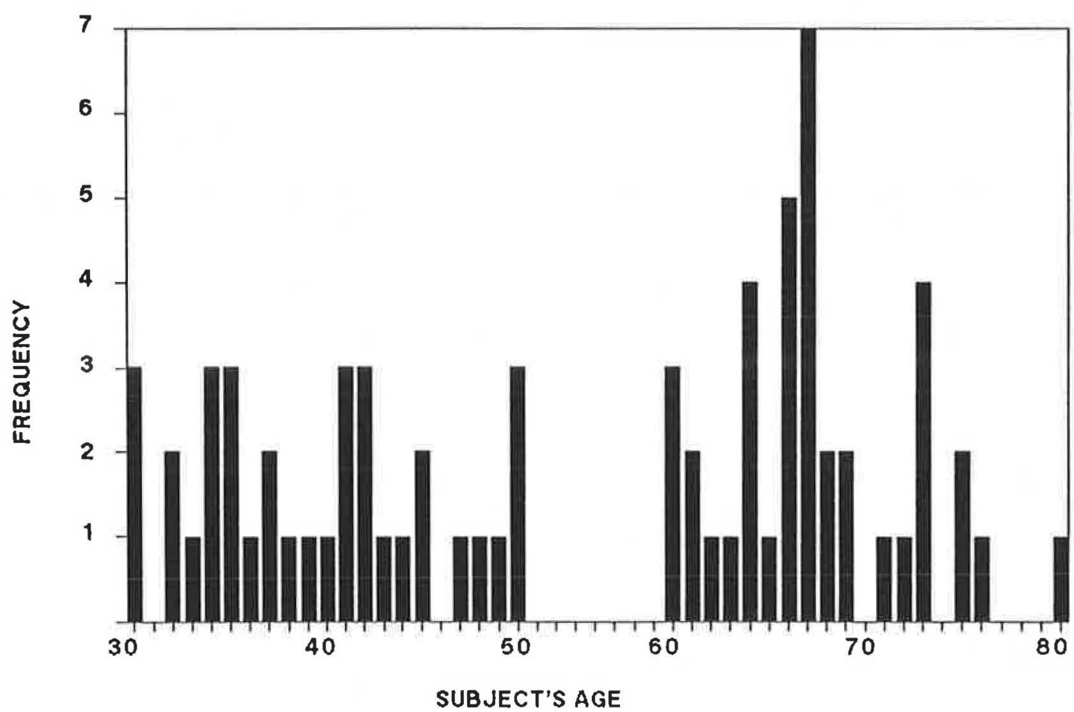

FIGURE 1 Histogram of subjects' ages.

entation had begun and the moment the brake pedal was released in preparation for a left turn;

2. Static range of motion (the principal measure of impairment), which was the maximum head turn angle of each subject as measured by the goniometer before testing; and

3. Visual field, which was the maximum field-of-vision width of each subject, measured on the ortho rater before testing.

Response time was the principal dependent variable for the research.

Subjects

Participants between the ages of 30 and 50, or 60 and 80, were involved. Approximately one-half the subjects in each age group had some degree of physical limitation, which restricted the range of movement of their heads and necks but was not severe enough to require major vehicle modifications, such as additional mirrors. Subjects were recruited as paid participants through local advertisements and through contacts with local agencies, such as the Arthritis Foundation and the American Association of Retired Persons. Each participant was compensated $25.00 for involvement in the study. All participants were required to have a valid driver's license and to drive an average of at least 10 mi/week.

The subjects exhibited a wide variety of driving behavior and physical skills. Many subjects who thought that they were not impaired had less than a 105-degree static range of neck movement, and others who had arthritis and thought they were impaired showed no impairment in range of neck movement. Many of the subjects with arthritis were taking anti-inflammatory medication and participated regularly in exercise programs sponsored by the Arthritis Foundation. In the 60- to 80-year age group, nearly all the subjects showed limited neck mobility. Driving skills in this age group also varied greatly. Some of the variability could be explained by the type of vehicle regularly driven, lifestyle, and attitude. In general, the female subjects in both groups were much more cautious and required many more practice intersections before they felt confidence to proceed with the 18 test intersections. Videotapes of two extra intersections were used for practice. The practice intersections had moderate traffic volumes and mixed sight distance. Most of the male subjects only required two practice intersections. Twelve of the subjects missed four or more intersections; therefore, the final statistical analysis was performed using the data from 60 subjects. A missed intersection resulted from the subject removing his or her foot from the brake before the sound of the tone marking the beginning of the measure of response time. As a result, no data were collected for that subject at that intersection.

Experimental Procedure

The participants were screened over the telephone to determine whether or not they met the criteria for participation, as well as to explain the general nature of the research and their participation. At the beginning of the experiment, the general purpose of the research was outlined in the instruction sheets, and each participant was asked to sign an informed consent form. The informed consent form is standard policy at the Turner Fairbank Highway Research Center. After the introduction, the following information was collected as part of the experimental design: participant's age, sex, description of physical impairment for the subjects in the impaired group, whether they wear glasses for driving, static range of head and neck movement, and visual field.

The questioning was followed by a range-of-movement test of the neck and head, and a visual field test. The initial procedures took approximately 30 min to complete. Afterwards, the participants were allowed a short break. The participants were then introduced to the simulator equipment and permitted a few minutes to become accustomed to the equipment. Participants were also given instructions for the test and permitted to ask any questions concerning the test procedures or equipment.

The subjects' task was to watch video presentations of the intersections on the three rear projection screens. Before each intersection was presented, the intersection was announced and the subject depressed the brake pedal. A few seconds of run-in of the scene followed, then the audible beep signalled the subject that decision timing was beginning. The subjects watched the scene. When they felt it was safe, they would indicate that they were ready to make a left turn by releasing the brake pedal. The release of the brake pedal would signal the end of that intersection's presentation, and a pause of 1 to 2 min would take place before the presentation of the next intersection. The videotapes covered half of the visual range; therefore, the test subjects had to mentally fill in the visual image between the screens. The test subjects had to judge when there were acceptable gaps in both the left and right traffic streams. In general, the traffic volumes were low in one or both traffic streams.

Two trial intersections were presented for practice, often repeatedly. Then 18 test intersections were presented, sequentially and without repetition, to each participant. For some participants, subjective responses to each intersection were made during a short period after the presentation of each intersection. Response information was recorded on a data sheet and on a data acquisition system for analysis at a later time. The data acquisition system recorded the response time and the degree of head movement. After the presentation of the final intersection, each participant was debriefed and paid.

EXPERIMENTAL RESULTS

The experimental results were split into two segments: totals (across all subjects and all intersections) and individual intersection summaries (across all subjects). The statistical results of the intersection summaries were similar to the statistical results for the totals of all subjects at all intersections. More error was introduced into the totals, because the decision time was averaged only over the correctly answered intersections for each subject, and each intersection had a different time interval depending on traffic volume and geometrics. Many of the older subjects did not follow instructions correctly and misjudged several intersections. As a result, the data could not be used for those intersections, and the intersections were judged to be incorrect. Therefore, the totals results only

represent the correct intersections driven by each subject. This process introduces bias, because some intersections were more consistently incorrect than others. Individual intersection statistics were examined to eliminate errors resulting from different intersection time intervals, sight distance, volumes, and geometrics.

The totals summary statistics give a general impression of the significant relationships. Subjects' ages were coded into two groups; subjects 30 to 50 years old were in Group 1, and subjects 60 to 80 years old were in Group 2. The ANOVA for the relationship of average decision time versus age was significant at the 4 percent level. The means and standard deviations of average decision time versus age are presented in Table 1. A smaller left-turn decision time indicates better driving performance, because the driver has more of the gap time to accelerate to speed and will not affect the uniform speed of the traffic stream. The older drivers took 2 sec longer to decide to turn at T-intersections than the younger drivers. The standard deviations for the older drivers are 0.43 sec higher than those of younger drivers, which indicates greater inconsistency in this segment of the population.

The ANOVA indicates that the relationship between average decision time and functional level is significant at the 8 percent level. The definition of functional level is a combination of age and impairment level:

- Functional Level 1 = 30 to 50 years old with no impairment,
- Functional Level 2 = 30 to 50 years old with impairment,
- Functional Level 3 = 60 to 80 years old with no impairment, and
- Functional Level 4 = 60 to 80 years old with impairment.

The means and standard deviations of average decision time versus functional level are presented in Table 2.

The mean decision time increases with functional level, and the increase in decision time between the younger and older age groups is approximately 2 sec. The 1.25-sec increase in standard deviation with impairment can be explained by the wide diversity of impairment level and the less consistent driving behavior in this subject group. The implication of these results is that the younger impaired drivers were able to compensate for their impairment in their driving behavior but the older drivers, either impaired or unimpaired, were unable to make the necessary compensations. The older drivers took longer to make a decision and were more inconsistent in their decision making than the younger drivers. The larger standard deviation is a measure of the inconsistency in driver behavior. Both the longer decision time and the inconsistency of the older drivers support the hypothesis that reaction times are influenced by age. These conclusions are also suggested in the literature and highway accident data (*1,17,18*).

TABLE 1 AVERAGE DECISION TIME IN SECONDS VERSUS AGE (p = 0.04, COEFFICIENT OF VARIATION = 29.88)

AGE	MEAN	STD.DEV
30-50	11.3	3.45
60-80	13.3	3.88

TABLE 2 AVERAGE DECISION TIME IN SECONDS VERSUS FUNCTIONAL LEVEL (p = 0.08, COEFFICIENT OF VARIATION = 29.66)

FUNCTIONAL LEVEL	MEAN	STD.DEV.
1 30-50, UNIMPAIRED	11.3	2.87
2 30-50, IMPAIRED	11.4	4.09
3 60-80, UNIMPAIRED	12.1	3.08
4 60-80, IMPAIRED	14.4	4.35

EXPERIMENTAL OBSERVATIONS

The experimental observations contained qualitative information gathered during conversations with the subjects, as well as observations made during the data collection phase. The observations give further insight into the problems of drivers with diminished capacities at T-intersections.

Several bad intersections are near the Turner Fairbank Highway Research Center, prompting many of the subjects to comment on intersection design in general. Several of the older subjects mentioned that they had problems with skewed intersections (not 90 degrees), because they were forced to turn their heads and look over their shoulders, which was painful or not possible. Some of these participants mentioned that they would drive out of their way to avoid skewed intersections, because they could not turn their head enough to judge gap length and approaching vehicle speed. These people were asked if they had any problems with merging on freeways and highways. The most frequent response was that they could always look ahead, and use their rear view mirrors or side mirrors when they were in the merge lane. The skewed intersection presents a greater problem because the vehicle is stopped and a greater gap length is needed for acceleration to speed. Skewed intersections are often complicated by poor sight distance conditions associated with the terrain or foliage. Hauer (*13*) discusses the problems of intersection angles of 75 degrees or less and states, "The need of extensive head movement is in itself a problem for the older segment of the driving population, which may not have been taken into account in AASHTO's geometric design policy." These comments support the observations made by the test subjects.

Subjects from both age groups mentioned that they often felt that they had problems with gap length judgment and sight distance because of obstructions such as utility poles, street signs, or foliage. These comments are consistent with the literature (*13,19*).

CONCLUSIONS AND RECOMMENDATIONS

In general, older impaired drivers require more time to perceive and react to traffic conditions at T-intersections. The major specific conclusions of the study are as follows:

1. Older drivers take longer to decide to make left turns at simulated T-intersections, and their driving behavior is much more inconsistent than that of younger drivers.
2. The relationship between decision time and functional level, which is a combination of age and impairment, shows

that younger drivers with impairments are able to compensate for their impairments in their driving behavior. Older drivers, either with or without impairments, are not able to make the same compensations in their driving behavior.

The conclusion that older drivers require more time to perceive and react to traffic conditions at T-intersections has two main traffic safety implications:

1. Older drivers need to change their driving behavior to account for the changes in their reaction time. Special driver education courses exist to help mature drivers learn more about their own driving needs, as well as to account for changes in traffic and roadway design. Better incentives for mature driver education, such as lower insurance rates and easier license renewal procedures, would encourage more older drivers to participate in driver improvement programs.
2. Traffic engineers need to account for drivers with diminished capacities in the design of intersections and roadways. The perception reaction time factor in the sight distance calculation should be increased, particularly at complex intersections.

An increase in average decision time with age, and also with age and impairment level, has been shown. These findings are based on a laboratory study; however, further studies in the laboratory and the field are required to validate the results. The experimental observations indicated skewed intersections present a significant problem to drivers with limited neck movement and should be studied further.

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