# CHAPTER 5.  RESULTS AND DISCUSSION

Data Extraction

Data were collected using a combination of video footage and in-vehicle instrumentation. Graphs showing individual driving behaviors were created for each subject (see Appendix K). These graphs capture five seconds of behavior prior to the rear end conflict as well as subject behavior during the conflict until they reached a full stop.

Data obtained from steering sensors contained noise.  This was removed by using a low pass filter on the data.  The steering data were also slightly offset and so five seconds of data were averaged to obtain a new zero value.  Subsequently, steering deviations from this average were assessed.

Steering criteria.  A steering response is defined here as an initiation of a steering avoidance response by the subject in reaction to the stopped vehicle. Each data set had to fulfill predefined criteria to be classed as an intentional steering response.

Two steering criteria were developed, based on field data collected by the experimenter to differentiate between "steering" and "non-steering responses."  In order to develop these criteria, the experimenter drove the instrumented vehicle on the Smart Road and made steering maneuvers to avoid a real Ford Taurus parked in the same position as the surrogate had been throughout the experiment.  The approach speed was 25mph.  The steering response began each time at the mean distance from the surrogate that subjects exhibited their first movement. Twenty steering passes were made consisting of ten steering movements to the right and ten to the left of the stopped vehicle.

An average steering response was calculated.  Once an average was calculated, the maximum steering deviation from that average was calculated for each pass at the Taurus. The lowest maximum steering deviation required to pass the vehicle was used as the first criterion (13 degrees).

As subjects may have initiated an incomplete steering response without reaching the predefined maximum angle, a second criterion was developed which addressed these cases. For each pass made by the experimenter, the steering rate was calculated for the first second of the steering response. The maximum steering rate for this time period was then compared with other steering maneuvers made by the experimenter. The lowest maximum steering rate (34 degrees per second) was then used as the second steering criterion.

Analysis of Objective Data

Non-parametric data analyses were performed on important frequency data. These analyses were performed to determine two issues:

1) Whether there was a significant difference between subjects' first response (i.e., steering maneuver as first response compared to braking maneuver as first response) between the strobe and no strobe conditions.

2) To compare numbers of subjects who did or did not steer (in addition to braking) for each condition.

Parametric data analyses were also performed, including both descriptive and inferential statistics. Means tables were collated for each dependent measure and can be found in Appendix L. Following calculation of means, an Analysis of Variance (ANOVA) was conducted on all dependent measures collected during the experiment. For results of the ANOVA tests to be significant an alpha level of 0.1 was chosen. This level was chosen due to the exploratory nature of the study. This level would increase the likelihood of detecting any difference between conditions. This is also important in safety-related research to give a potential safety improvement the greatest reasonable chance of success. The ANOVA tables depicting the results are presented in Appendix M. If significant findings were present for certain variables, means tables were included in the main body of the report. A simple effects test was also performed on any significant results. The summary tables for these can be found in Appendix N.

Nonparametric analyses comparing driver behavior. Although all 33 subjects initiated a braking maneuver, the frequency of people who did or did not steer as part of this avoidance maneuver for each condition was calculated. These frequencies can be found in Table 5.1.

**TABLE 5.1. Frequency table: People who did or did not steer as part of braking avoidance maneuver.**

| | Strobe Condition | No Strobe Condition |
|---|---|---|
| Steer | 9 | 8 |
| No Steer (brake only) | 7 | 9 |

A Chi-Square test was performed on these results to determine whether the strobe or no strobe conditions affected driver behavior. The Chi Square test showed that there was no significant difference between the strobe and no strobe conditions ($X^2 = 0.60$, $p = 0.44$). This suggests that the strobe signal did not influence subjects driving behavior (i.e., subject's decision to steer in addition to braking to avoid the rear end conflict, as opposed to braking only).

Next, subjects' first behavior was assessed. On perceiving the stopped vehicle (with or without the strobe light), drivers first had one of two responses (either steering response or brake response). These frequencies can be found in Table 5.2.

**TABLE 5.2. Frequency table: People who initiated steering or brake response as first response during perception response time.**

| | Strobe Condition | No Strobe Condition |
|---|---|---|
| Steering Response | 2 | 0 |
| Brake Response | 14 | 17 |

To determine whether the strobe or no strobe conditions influenced these behaviors, a Fisher's Exact Test was performed. This was chosen over a Chi Square because assumptions were violated (i.e., the smallest expected frequency was below five). The results showed that there was no significant difference between the two conditions ($p = 0.23$).

Time To Collision (TTC). Time to collision (TTC) is defined as "the time it will take to reach an obstacle" (see equation 1) and is a crucial predictor in brake regulation. This variable was analyzed to ensure that subjects in all conditions were consistently presented with the stopped vehicle/obstacle at the same point in time and therefore had the same amount of time to perceive and react. A means table for this dependent variable can be found in Appendix L, Table L-1. Overall, subjects were given an average 2.99 seconds from the time that the surrogate first appeared to perceive and respond to the stopped vehicle. As discussed in the method section, a TTC of 3.15 seconds was the goal. Taking into account the variation in time associated with vehicle speed and the position at which the operator of the lead vehicle changed lanes, a consistent time to collision was a positive result. Even more encouraging were ANOVA results (see Appendix M, Table M-1), which found no significant differences between the mean TTC of the strobe (3.05 seconds) and the no strobe (2.94 seconds) conditions. There were no significant main or interaction effects between treatment condition and age range. This suggests that all subjects were presented with a consistent scenario, thus ensuring the reliability of the data collected.

Velocity. As TTC was dependent upon velocity and the distance between the subject's vehicle and the surrogate vehicle, it was important that a consistent speed of 25mph was maintained. Maintaining this speed helped ensure that subjects had ample time to avoid the stopped surrogate vehicle. Subjects' velocities at the time the surrogate first appeared to the camera were collected and collated to form a means table which can be found in Appendix L, Table L-2. Overall, subjects were travelling at an average of 26.29 mph at the time the surrogate first appeared. The ANOVA (see Appendix M, Table M-2) found no significant differences between the mean velocity of the strobe (26.52 mph) and the no strobe (26.07 mph) conditions. There were no significant main or interaction effects between treatment condition and age range. This finding is not surprising, as there were no significant differences in the subjects' TTC. This further suggests that the methodology of using a lead vehicle to maintain the subjects' speed was effective. Consequently, this contributed to a consistent TTC and a consistent scenario ensuring the reliability of the data collected.

<u>Perception time.</u> Perception time was operationally defined as the transition time elapsed from the appearance of the stimulus (to the camera) to the instant that the driver initiated their first movement (i.e., brake press or accelerator release). The means for perception time can be found in Table 5.3.

**TABLE 5.3. Means Table showing perception times (seconds)**

| | Strobe | No Strobe | Age Range Mean |
|---|---|---|---|
| Younger | 0.51 (n=8) | 0.66 (n=9) | 0.59 (n=17) |
| Older | 0.59 (n=8) | 0.46 (n=8) | 0.53 (n=16) |
| Condition Mean | 0.55 (n=16) | 0.56 (n=17) | Grand Mean |
| | | | 0.56 (n=33) |

An ANOVA showed a significant two-way interaction between age range and condition ($F_{1,29}$ = 5.11, p = 0.03). Figure 5.1 shows this interaction graphically. The ANOVA table can be found in Appendix M, Table M-3.

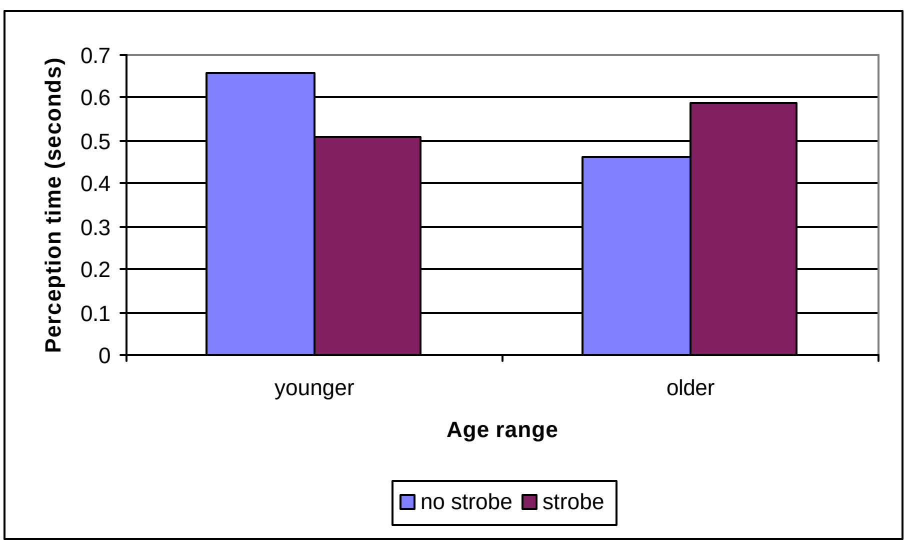


**Figure 5.1. Perception Time: Two-way interaction between condition and age range.**

A simple effects test was then performed (see Appendix N). As seen in Appendix N, Table N-1, there was a significant difference between younger subjects in the no strobe and strobe conditions. The tests and the graph showed that younger subjects had a significantly shorter perception time when exposed to the strobe than when no strobe was presented ($F_{1,29}$ = 3.00, p = 0.09). Older subjects, however, showed no significant difference in perception time between strobe conditions.

There was also a significant difference between older and younger subjects in the no strobe condition (Appendix N, Table N-2). The table and Figure 5.1 show that older subjects had a significantly quicker perception time than younger subjects in the no strobe condition ( $F_{1,29}$ = 5.46, p = 0.03), but there was no significant difference between younger and older subjects' perception time when the strobe was presented.

The strobe may have been more effective for younger subjects than older subjects because the strobe was not as conspicuous to older subjects due to degraded brightness contrast caused by increased opacity of the lens of the eye. A more plausible explanation is that global changes in perceptual performance, due to general slowing of neural responses, were responsible for this lack of difference in perception time. Older subjects have difficulty with briefly presented stimuli (Hoyer and Plude, 1980), slower reaction times to stimulus onset (Stern, Oster and Newport, 1980), and have difficulty in identifying stimuli arriving in a rapid sequence (Birren, Woods, and Williams, 1980). When the perceptual tasks become more complex, slowing perceptual processing becomes even more apparent (Cerella, Poon, and Williams, 1980; Cunningham, 1980). The flashing strobe light, the headway display that had to be monitored, and a potentially dangerous situation created a scenario that would slow perception (in terms of detection, identification, decision, and response) of the hazard presented to the older drivers.

Further impacting the perceptual process is the distribution of attention to perceptual tasks. Older people seem to have more difficulty dividing their attention between various stimuli (Craik and Simon, 1980). This finding has also become evident in the driving environment where older drivers have shown reduced performance compared to younger drivers during the operation of secondary automotive tasks (Monty, 1984; Dingus, Antin, Hulse, and Wierwille, 1989). A study performed by Ponds et al. (1988) suggested that this degradation of dual task performance is restricted to persons over 60 years of age.

Another factor to consider when assessing these results is that in the original experimental protocol, it was anticipated that roughly 50% of subjects would be visually distracted and looking away from the roadway as the surrogate appeared. However, only four subjects were looking away from the road prior to detecting the stimulus. This was a difficult variable to control. Events took place so quickly that asking subjects to read the display and getting an immediate response at exactly the right moment was very difficult to accomplish. However, subjects who were looking at the roadway prior to detection of the surrogate vehicle were observed as being cognitively distracted. Even though the van changed lanes and revealed the stopped surrogate vehicle in full view, subjects often continued to perform the distraction task without recognizing the obstruction ahead of them despite looking directly at the obstacle. It is possible that, had subjects been looking away from the road for a longer period of time, the impact of the strobe signal on perception times would have been measured more effectively, and that overall perception times would have been longer.

Age related differences between perception times in the no strobe condition provide further explanation of the impact of strobe signal on driving behavior. Reduced ability to divide attention during dual task performance, as observed by the experimenter and demonstrated in the literature (Ponds et al., 1988), could have contributed to better vigilance by older subjects prior to the presentation of the surrogate vehicle. In addition, it has also been hypothesized that younger drivers take more time than older drivers to evaluate hazardous situations before responding, to ensure a more effective, controlled response (Lerner, 1993, Lerner, Huey, McGee, and Sullivan, 1995).

First response time. This is defined as the transition time between subjects' perception time (subjects first movement: accelerator release or brake press initiation) and the time to initiate first response (i.e., steering or braking response). The means table for this dependent variable can be found in Appendix L, Table L-3. Overall, subjects had an average first response time of 0.21 seconds. The ANOVA (see Appendix M, Table M-4) found no significant differences between the mean first response time in the strobe condition (0.20 seconds) and the no strobe condition (0.22 seconds). There were no significant main or interaction effects between treatment condition and age range.

Perception response time (PRT). Perception response time was operationally defined as the time from the appearance of the surrogate vehicle to the initiation of first response by the subject (i.e., brake response or steering response). A mean of 0.73 seconds was obtained for both strobe and no strobe conditions. The complete means table for this dependent variable can be found in Appendix L, Table L-4. An ANOVA was performed to determine whether there was any significance between factors, and no significant interactions or main effects were found (Appendix M, Table M-5).

In summary, the strobe light had no effect on the perception response times of subjects. As discussed previously, an interaction was observed for perception time. The lack of significant findings for PRT could be a result of the speed of subjects' first responses. In other words, subjects made up for differences in perception times, as those with quicker perception times took longer to respond, while those with longer perception times were quicker to respond (see previous discussion of perception times). This longer braking response offset shorter perception times resulting in non-significant differences in PRT.

Time to brake press. Time to brake press is defined as the time from when the surrogate first appears to the time that a subject initiates a brake press. The means for strobe and no strobe conditions were similar to perception response times, with a mean of 0.74 for the strobe condition and 0.73 for the no strobe condition. Appendix L, Table L-5, summarizes the means for this dependent variable. The ANOVA calculations showed no significant effects of condition or age range (Appendix M, Table M-6).

Brake response time (BRT). Brake response times are defined as the time from when subjects release the accelerator to the time that a brake press is initiated. As five subjects already had their foot over or on the brake pedal instead of the accelerator prior to their first movement, these subjects had no brake response time. Consequently, 28 data points were used in the statistical calculations. The mean brake response times for strobe and no strobe conditions are presented in Table 5.4.

**TABLE 5.4. Means Table showing brake response times (seconds)**

| | Strobe | No Strobe | Age Range Mean |
|---|---|---|---|
| Younger | 0.21 (n=8) | 0.15 (n=6) | 0.19 (n=14) |
| Older | 0.19 (n=7) | 0.27 (n=7) | 0.23 (n=14) |
| Condition Mean | 0.20 (n=15) | 0.22 (n=13) | Grand Mean |
| | | | 0.21 (n=28) |

An ANOVA was also performed on the data (Appendix M, Table M-7). A significant two-way interaction between condition and age range ($F_{1,24} = 4.03$, $p = 0.06$) was found. Figure 5.2 illustrates this interaction graphically.

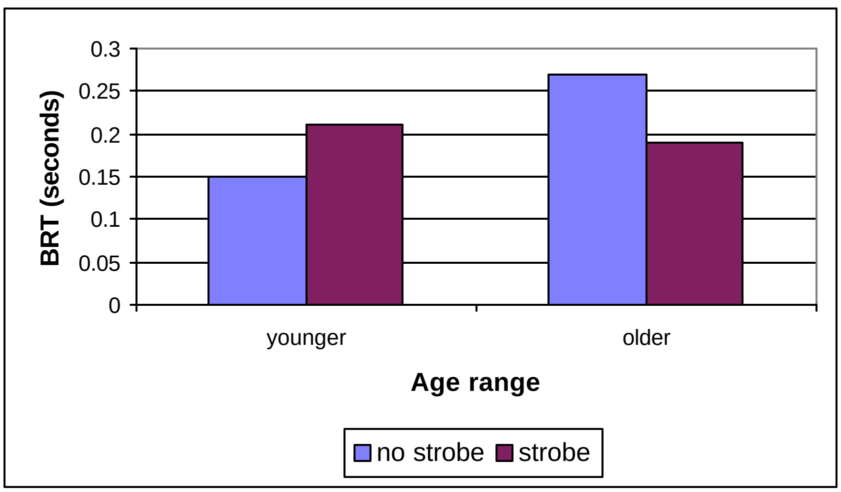


**Figure 5.2. Brake Response Time: Two-way interaction between age range and condition.**

A simple effects test was performed on the data to assess this interaction in more detail. The LS means summary table can be found in Appendix N. As seen in Appendix N, Table N-3, the simple effects test, found no significant difference for brake response time in younger subjects between strobe and no strobe conditions. However, older subjects' brake response times between strobe and no strobe conditions approached significance ($F_{1, 24} = 2.73$, $p = 0.11$). The direction of the effect is shown in Figure 5.2, as older subjects showed an improvement in brake response times as a result of strobe presentation.

As seen in Appendix N, Table N-4, the simple effects test found a significant difference in the no strobe condition between younger and older subjects ($F_{1, 24} = 5.04$, $p = 0.03$). Figure 5.2 shows the direction of the effect in that younger subjects had faster brake response times than older subjects when no strobe signal was used. No significant difference was found between younger and older subjects' brake response times in the strobe condition.

In summary, for the no strobe condition, younger subjects were significantly better at initiating a brake response than older subjects. This could be related to findings associated with perception times. Recall that younger subjects' perception times were significantly longer than older subjects' perception times in the no strobe condition. Due to the longer perception time required to evaluate the situation, younger subjects then needed to initiate braking more rapidly. Although older subjects may have initiated an accelerator response earlier, Lerner (1993) suggests that older drivers respond to surprise braking situations in more reflexive stereotyped ways than younger drivers to compensate for degradation in neural processes. Since older drivers' perception times were faster than those of younger subjects, older subjects had more time to respond, and therefore did not need to respond as quickly as younger subjects to avoid the surrogate vehicle.

Brake Movement Time (BMT). BMT has been previously defined as the time from when the subject initiates a brake press to the moment the brake is fully depressed. This variable therefore examines the speed of the brake response.

A mean of 0.49 seconds was obtained for the strobe condition and 0.58 seconds for the no strobe condition. The complete means table for this dependent variable can be found in Appendix L, Table L-6. An ANOVA was performed to determine whether there was any significance between factors (Appendix M, Table M-8). No significant interactions or main effects were found. In summary, the speed at which subjects depressed the brake pedal to its maximum position was not different regardless of whether they were presented with a strobe signal.

Time to Steer. Time to steer was defined as from when the surrogate first appeared to the time that the subject initiated a steering response. In essence, this dependent variable sums the perception time with the steering response time. However, not all subjects used steering as part of their avoidance maneuver and as a result the statistical analyses were performed on only 17 data points. Mean time to steer values for the strobe and no strobe conditions are presented in Appendix L, Table L-7.

An ANOVA was performed on this dependent variable (Appendix M, Table M-9), and showed no significant main effects or interactions. In summary, for those who steered as part of their avoidance maneuver, the strobe warning did not have any significant effect on the time it took to perceive and initiate a steering response.

Steering Response Time (SRT). SRT is defined as the time taken to initiate a steering response following first movement (i.e., brake press or accelerator release). This dependent variable looked more specifically at the time to decide on a steering response after perception. Not all subjects used steering as part of their avoidance maneuver, and as a result, statistical analyses were performed on 17 data points. Mean steering response times for the strobe and no strobe conditions are presented in Appendix L, Table L-8. An ANOVA performed on this dependent variable (Appendix M, Table M-10) showed no significant main effects or interactions.

In summary, for those who steered as part of their avoidance maneuver, the strobe warning did not have any significant effect on the time is took to initiate and decide upon a steering response.

Steering movement time. Steering movement time is the time from the initiation of a steering response to the time that the steering deviation is at a maximum angle. Steering movement can provide an indication of the urgency with which people steered in response to the strobe. Not all subjects used steering as part of their avoidance maneuver, so as a result statistical analyses were performed on 17 data points.

A mean steering movement time of 1.83 seconds was obtained for the strobe condition and 1.71 seconds for the no strobe condition. The complete means table for this dependent variable can be found in Appendix L, Table L-9. An ANOVA was performed on this dependent variable (Appendix M, Table M-11). This showed no significant main effects or interactions. In summary, no differences were found to indicate that subjects in the strobe condition had a more rapid steering movement than those in the no strobe condition.

Maximum brake press. Maximum brake press is defined as the maximum normalized brake pressure subjects had used to stop the vehicle. In other words, this shows how hard subjects were braking.

A mean brake pressure of 61% was obtained for both the strobe and the no strobe conditions. The complete means table for this dependent variable can be found in Appendix L, Table L-10. An ANOVA was performed to determine whether there was any significance between factors. The ANOVA summary table can be found in Appendix M, Table M-12. No significant interactions or main effects of condition or age range were found.

Maximum steering deviation. Maximum steer refers to the maximum steering angle/deviation subjects reached during their steering avoidance maneuver. This value was calculated from data adjusted for noise. The maximum steering deviation provides information on the severity of subjects' steering response in each condition. Not all subjects used steering as part of their avoidance maneuver, so as a result, statistical analyses were performed on 17 data points.

A mean maximum steering deviation of 47.57 degrees was obtained for the strobe condition and 31 degrees for the no strobe condition. The complete means table for this dependent variable can be found in Appendix L, Table L-11.

An ANOVA was performed on this dependent variable (Appendix M, Table M-13) and showed no significant main effects or interactions. A quick scan of the variances showed that this dependent variable in particular did not meet the guidelines set for assumptions of homogeneity of variance needed for an ANOVA to provide useful results (as suggested by Howell, 1992). Howell specifies that the difference between smallest and largest variances should not exceed a magnitude of four. This was not the case as the differences between smallest and largest variances for steering deviation did exceed this criteria (variances were different by a magnitude of 5.5). To check these findings a Bartlett test was conducted to determine heterogeneity of variance. This test found that variances between the strobe and no strobe conditions were significantly different from one another ($X^2 = 4.36$, $p = 0.04$). As a result, a median test was conducted to determine whether there was a difference between the strobe and no strobe conditions. This test found no significant differences between conditions ($Z = 0.22$, prob>|Z| = 0.8241).

Rate of steering. This dependent measure isolates the severity of each participant's steer by comparing each participant's steering rate per second for the first second of the steering response. This also provides an indication of the severity of the steering maneuver. Not all subjects used steering as part of their avoidance maneuver, resulting in 17 data points.

A mean steering rate of 87.21 degrees per second was obtained for the strobe condition and 36.53 degrees per second for the no strobe condition. The complete means table for this dependent variable can be found below in Table 5.5.

**TABLE 5.5. Rate of steering (degrees per second)**

| | Strobe | No Strobe | Age Range Mean |
|---|---|---|---|
| Younger | 66.83 (n=3) | 38.2 (n=3) | 52.52 (n=6) |
| Older | 97.40 (n=6) | 35.52 (n=5) | 69.28 (n=11) |
| Condition Mean | 87.21 (n=9) | 36.53 (n=8) | Grand Mean |
| | | | 63.36 (n=17) |

An ANOVA was performed on this dependent variable (Appendix M, Table M-14). This showed no significant main effects or interactions. However, due to the noticeable difference between the means, a quick scan of the variances showed that this dependent variable also did not meet the guidelines set for assumptions of homogeneity of variance needed for an ANOVA to provide valid results (Howell, 1992). Howell specifies that the difference between smallest and largest variances should not exceed a magnitude of four. This was not the case here. The difference in magnitude between the strobe and no strobe variances for this dependent measure was approximately 14. A Bartlett test was conducted on this dependent variable to determine heterogeneity of variance, and found that variances between the strobe and no strobe conditions were significantly different ($X^2 = 9.17$, $p = 0.0025$). As a result, a median test was conducted to determine whether there was a difference between strobe and no strobe conditions. This found a significant difference between conditions ($Z = 1.77$, $prob>|Z| = 0.07$).

In summary, this result suggests that subjects who were exposed to the strobe initiated a significantly faster steering response than those who were not exposed to the strobe light. The fact that this measure was significant but maximum deviation was not could be explained by the variations involved with the amount of steering required to avoid the surrogate. Subjects' positions varied somewhat with respect to the surrogate vehicle. For example, some subjects were further to the left and so any steering deviation to the left to avoid the obstacle would be much smaller than if he had steered to the right in the same situation. Hence, rate of steering provides a more accurate indication of the severity with which subjects viewed the rear end conflict when a warning was provided to them.

The increased severity of subjects steering rate when exposed to the strobe suggests that the warning conveyed a sense of urgency to subjects as they viewed the rear end conflict. This resulted in a more decisive initiation of steering.

Time to full stop. Time to full stop is defined as the time from when the surrogate vehicle appears to the time the subject vehicle comes to a full stop. Only data from those who did not steer and used a predominantly braking response were included in this statistical analysis (16 data points). This variable also provided information on the urgency with which people stopped when they were exposed to a warning signal.

A mean time to full stop of 4.4 seconds was obtained for the strobe condition and 4.75 seconds for the no strobe condition. The complete means table for this dependent variable can be found in Appendix L, Table L-12. An ANOVA was performed on this dependent variable (Appendix M, Table M-15). This showed no significant main effects or interactions. In summary, regardless of whether or not a signal was presented, subjects did not exhibit differences in the speed with which they stopped their vehicle.

Subjects' final stopping distance. Subjects' final stopping distance was calculated from the output of the radar sensor (these distances were also measured when possible to verify distance measures). Only data for subjects who had used a braking response only were included (16 data points in total). A means table showing the mean distances that subjects stopped in front of the surrogate vehicle can be found in Appendix L, Table L-13. Mean distances that subjects stopped away from the surrogate were 28.67 feet in the strobe condition compared to a mean of 17.56 feet in the no strobe condition. ANOVA results show no significant differences for any group of subjects (see Appendix M, Table M-16).

In summary, although subjects perceived the obstacle at different times, there were no differences in the time it took subjects (who used a predominantly braking avoidance maneuver) to stop their vehicle.

## Individual Differences in Driving Behavior

The data collected during this experiment demonstrated noticeable differences in individual subject behavior in response to the surrogate vehicle. As a result, these differences, in combination with low numbers of subjects may have decreased the power of the analyses presented. It is possible that lack of power may have been responsible for the lack of significance found for the majority of the dependent measures. The two way interactions found during the experiment for perception time and brake response time may also have showed greater significance as these particular dependent measures were clustered around the mean and showed little variation. A more detailed description of these variations is given below.

Overall, driver behavior was split evenly concerning combination steering and braking responses (17 out of 33 subjects) as opposed to braking only responses (16 out of 33 subjects). A variation of emergency avoidance behavior was therefore evident in this sample of drivers. Although statistical tests produced statistically significant differences for only two of the many dependent variables measured, behavioral differences were still present in the 33 subjects under test.

The data from subject 53 in Appendix K, Figure K-10 provides a typical order of responses for those that steered and braked to avoid the surrogate and represents a combination avoidance procedure. Fifteen out of the 17 who steered and braked in combination released the accelerator first, followed by a brake press then a steering response. A full brake press was normally initiated before steering was at a maximum angle. Of the other two subjects who initiated a steering response, one (Appendix K, K-8) steered first followed by a brake press and the other (Appendix K, K-11) had their foot on the brake pedal prior to their perception of the surrogate vehicle. Sixteen other drivers did not combine the two avoidance responses and simply braked to avoid the surrogate vehicle. Subject 58, Appendix K, Figure K-4 shows a representative order of responses for those who only braked. Subjects who did not steer would typically release the accelerator prior to initiating a sharp braking movement.

These two examples represent extreme differences between avoidance strategies that did not appear to be associated with the presence of the strobe. Age did seem to impact the type of avoidance procedure used, as 11 out of the 17 subjects who steered and braked in combination to avoid the vehicle were between 60-70 years old and fell in the older age range. The numbers who steered were distributed fairly evenly between conditions (six out of nine who steered in the strobe condition were older and five out of the eight in the no strobe condition were older). This would suggest that older subjects have a tendency to steer and brake to avoid a roadway obstruction rather than to only brake. All subjects varied widely in terms of the brake pressure used to stop the subject vehicle (between 40-98%, with a standard deviation (SD) of 12%). Older subjects exhibited a wide variation in brake pressure ranging from 42-79% (SD = 10.7%), but this range was narrower than for younger subjects who varied between 40-98% (SD = 13.4%). As a higher frequency of older subjects steered, it is likely that less brake pressure was required to avoid the vehicle while employing a concurrent steering response. Appendix K,

Figure K-2 illustrates a hard brake press compared to Appendix K, Figure K-30, where less brake pressure was employed during the avoidance maneuver. Maximum steering deviations ranged from small to very severe (between 13 and 107 degrees for all subjects, SD = 27.2 degrees). Subjects' steering rates were also highly variable, ranging from 17 to 269 degrees per second (SD = 61.1 degrees). Other dependent measures of interest, such as perception time, perception–response time, brake response time, response time, and steering response time had scores that were clustered around the mean.

Other more subtle differences in driving behavior were found for those that steered. Ten of the 17 who steered did so to the right (as indicated by positive numbers), four steered to the left, and three subjects drove to the right and left prior to stopping ahead of the surrogate vehicle. These behaviors are shown in Appendix K, Figures K-10, K-11, and K-14 respectively. As stated earlier, most subjects released the accelerator prior to braking or steering responses. Five subjects however had their foot over the brake pedal in preparation to slow down prior to their perception of the surrogate vehicle and as a result braking was their first movement, not accelerator release. One of these subjects used a combination of steering and braking (Appendix K, Figure K-11) compared to four who braked only. (see Appendix K, Figures K-18, K-22, K-17, and K-25 ).

Analysis of Subjective Opinion

Sample questionnaires presented to participants in the no strobe and strobe conditions can be found in Appendices B and C. The aim of the questionnaire was to target data that could not be objectively collected through instrumentation and to investigate several main areas of inquiry. These areas of inquiry were: effectiveness of the method, effectiveness of the warning, participants' perception of the strobe light, participant opinion of the strobe as a warning and participants' suggestions for warning redesign. The responses are summarized below and have been separated out into each of these areas.

Effectiveness of the methodology.

*Safety.* A major concern throughout the design of this experiment was the safety of the participants. Most participants in the study (24 out of 33 total participants) ranked their feelings of endangerment as "E. I felt no danger at all throughout the experiment." Figure 5.3 shows the numbers of participants and their ratings of endangerment.

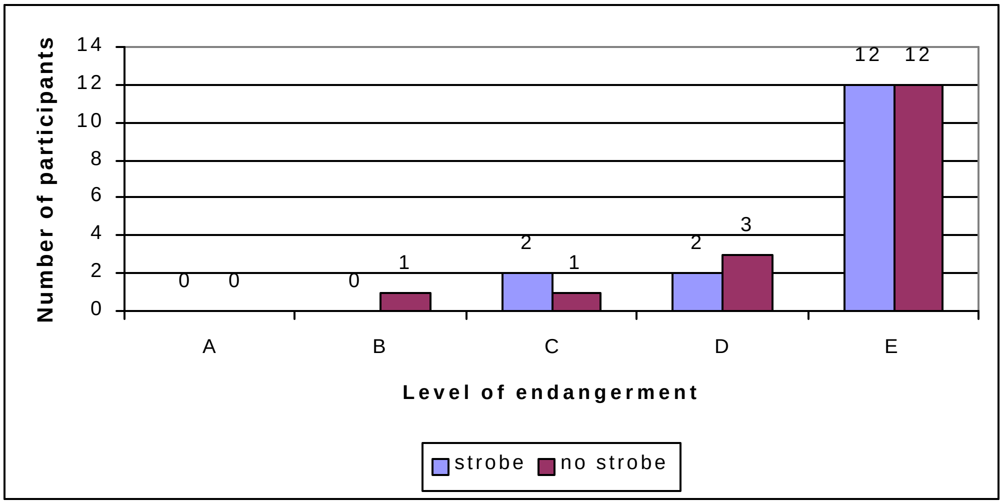


**Figure 5.3. Ratings of endangerment by all participants (n = 33)**

Where:

A. I felt very endangered throughout the experiment

B. I felt very endangered at certain points in the experiment

C. I felt slight endangerment throughout the experiment

D. I felt slight endangerment at certain points in the experiment

E. I felt no endangerment at all throughout the experiment

Those who stated they felt no danger constituted 73% of participants. This percentage was split equally between the no strobe and strobe conditions. This suggests that the TTC chosen allowed enough time to make an evasive maneuver for both conditions. Had the TTC been closer, then the response to this question would perhaps have been very different.

Six of the other nine participants who may have felt slight danger during the experiment provided additional comments. Three of the six comments referred to the following distance of 24 feet as uncomfortable. All three of these comments were made by older participants, two of whom were older women. This following distance did seem to be a problem for older women in general during the study. Many older women were observed to have problems with this distance and they would often comment on the difficulty of concentrating on the distracter task while following so closely to the vehicle ahead. Three older women had to be excluded from the study because they drove too far to the right in an effort to see around the van, and thus spotted the surrogate vehicle too early.

*Realism*. All 33 participants (100%) rated the realism of the experiment as "Very realistic" (9 out of 33 participants) or “Extremely realistic” (24 out of 33 participants). Those participants who rated the study as "very realistic" were split equally between the no strobe and strobe conditions (See Appendix O, Figure O-1). In some cases participants also supported their ratings with explanations of their rankings (see Appendix P). Most expressed their reaction as "automatic" and that they “would have reacted in the same manner in a real situation." The only comments concerning unrealistic response were that the participants did not feel the need to check the rear view mirror during the experiment.

Another way of assessing realism involved asking more indirect questions about the study to verify subjects’ subjective opinion of realism. Subjects were asked what had first alerted them to the stopped vehicle (see Appendix Q). This was to identify whether the van swerving or any other unforeseen factors had unduly alerted subjects to the stopped vehicle, thus compromising realism and validity. Only one of the subjects in the "no strobe" condition had suggested that the van moving had alerted them. All other subjects were not aware of the stopped vehicle until it was revealed to them with or without the flashing strobe. This was further substantiated by subjects responses concerning their level of surprise at seeing the stopped vehicle (see Appendix O, Figure O-2). Participants in both conditions gave a median ranking of 5 "Extremely surprised" (the mean ranking for the strobe condition was 4.75 and the mean ranking for the no strobe condition was 4.71).

These results suggest that the method was valid, as it was considered very realistic by the participants. Participants explained that their responses were “automatic” and that they had no prior knowledge or warning of the stopped vehicle's presence in the road. These data suggest that all response times collected for this study were realistic and valid for the overall population of drivers in those age groups.

*Distraction*. Simulating a distracted driver was another challenge that had to be addressed. Participants were asked to rate their level of distraction prior to the presentation of the stopped vehicle (see Appendix O, Figure O-3). The distraction levels experienced in strobe and no strobe conditions appear to be similar. Participants in both conditions gave a median rating of 3 (moderately distracted) with an average rating of 2.5 for the no strobe and 2.87 for the strobe conditions. The participants also gave their opinion concerning the source of their distraction (see Appendix R). This question was asked to determine the effectiveness of the distracter task in creating a typically distracted driver. It appears that the distracter task performed very well in keeping the driver distracted. However, heightened discomfort associated with maintaining a constant 24 feet seemed to influence participants' behavior towards using the headway display. Participants who felt the most discomfort tended to watch the back of the van and estimate their distance, only checking the gauge every so often.

In instances where subjects appeared to be experiencing less discomfort, questionnaire results and observations suggest that the monotony of driving became a contributory factor for distraction. As participants were not paying as much attention to the driving environment, a real life driver was simulated in many respects. All participants, however, became used to observing the lead vehicle change lanes at various points in the road prior to the rear end conflict. Therefore, subjects were not attentive to this maneuver regardless of their comfort at using the headway display.

Effectiveness of a strobe warning signal. Subjects also rated the effectiveness of the strobe (see Appendix O, Figure O-4). The average rating was "very effective," as the mean rating was 4.4 (median rating of 4.5). To further verify this response to the conspicuity of the strobe light as a way of alerting subjects, subjects were also asked what first alerted them to the stopped vehicle (see Appendix Q). Of the 16 who were in the strobe condition, 11 (69%) responded that the blinking/flashing light was the first thing they noticed once the lead vehicle had swerved. The other 4 (31%) subjects suggested that they were unsure whether they saw the light first.

Those in the no strobe condition were asked whether some kind of warning alerting them to the presence of the stopped vehicle would have changed their reaction (see Appendix S). All participants except one responded that a signal of some kind would have changed the way they reacted or that they would have responded sooner.

As the implementation of a strobe is a concept at this point, it was beneficial to ascertain how drivers currently respond to strobe lights in other traffic applications. First, subjects were asked to discuss their familiarity with strobe lights in normal traffic applications (see Appendix O, Figure O-5). Subjects indicated that they only saw strobes infrequently, a few times per month. When strobe signals were seen, results suggest that two general traffic applications were more commonly noticed: strobes in traffic lights and strobes on emergency vehicles. Seventeen responses mentioned seeing strobe lights in traffic lights, and 12 responses mentioned emergency vehicles (see Appendix T). Other responses included construction zones, bikes, and school buses. Only six subjects tested could not recall, or were not familiar with strobe lights in transportation. Subjects were asked more specifically for a description of the message that strobe signals convey to them (see Appendix U). The most common descriptions of the meaning of strobes were "warning," "be alert," and "danger." Overall, subjects' responses to this question were that strobe lights are a good way of getting a driver's attention to a point of immediate interest.

These findings suggest that the majority of drivers are familiar with strobe lights as a device used to raise awareness to a possible danger. This is further supported by the subject responses when asked whether they had perceived the strobe as it was intended, as an alert to the hazard they approached (see Appendix V). Twelve of the 16 subjects (75%) responded positively, three subjects (19%) were unsure, and one did not respond (6%).

These results suggest that real life application of the strobe as a rear end imminent warning signal would elicit correct interpretation of its meaning and hence appropriate hazard avoidance responses.

Finally, subjects were questioned concerning the design of the strobe. One initial fear was that the strobe would elicit a startle effect on its recipients. To determine whether this was indeed the case, subjects in the strobe condition were asked to describe their reaction on first seeing the light, using one word (see Appendix W). Of the total 16 subjects, only two participants (12.5%) used the word "panic." The majority (31% or 5 out of 33 participants) used the word "surprise." Other words such as "stop," "emergency," "whoa," and "yikes" were used to indicate a sense of imminence. One subject indicated that his response was more due to the presence of the vehicle and not the light. These responses suggest that the light evoked a sense of urgency more than a sense of panic on approach.

All subjects were also asked their opinion on what the strobe should look like concerning overall flash rate, brightness, size, color, and placement of the light. Participants in the strobe condition, who had already seen the strobe light, thought that the flash rate was "ok," or else they did not comment. Two of the 16 participants (12.5%) suggested that the flash rate be faster. Participants in the strobe condition did not reach consensus regarding the brightness/intensity of the strobe. Of the five subjects who responded to this question, two subjects stated the intensity was acceptable as it was. One subject stated that the light was too bright and one subject stated the light was not bright enough. One subject suggested a high intensity and was not sure whether this was currently the case. Comments concerning the size of the strobe were equally varied. Only seven participants had comments about the strobe's size. Two of these stated that the size of the current strobe was "ok." One subject stated the signal was too large, whereas one subject stated the signal was too small. Two subjects had suggestions concerning the shape of the signal: one suggested an X, whereas the other suggested a bar strobing from side to side. One subject was unsure but thought the strobe could be smaller if necessary. Eight of the 16 subjects exposed to the strobe light had comments on the color of the signal. Four participants preferred red, two participants preferred yellow, and three participants liked white. Seven of the 16 participants had comments on positioning of the strobe. Two thought the positioning was "ok" where it was, four of the subjects preferred the trunk/bumper area. Most general comments about the use of the strobe were positive and only one participant showed concern about the novelty factor of implementation (i.e., over a period of time, strobes would become less effective).