AN INVESTIGATION OF ATTENTIONAL DEMAND IN A SIMULATED DRIVING ENVIRONMENT

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The primary objective of this simulator study was to examine how attentional demand during automobile driving changes as a function of vehicle speed, road curvature and lane width. Attentional demand was estimated quantitatively using self-paced visual occlusion during driving and was calculated as the percent of the time that the visual occlusion spectacles were open. The results revealed that, in accordance with earlier related studies in the literature, attentional demand increases as speed increases and as lane width decreases, and is also greater for curved as compared to straight road segments. Implications of the findings both for further research and practical road design are discussed.

INTRODUCTION

The task of driving an automobile is comprise of a variety of aspects of information processing, chief among which is that of dynamic allocation of attention. Under most circumstances, drivers are very good at allocating an appropriate amount of attention to the appropriate elements of the road environment in order to meet situational demands (Shinar, 1978). Nevertheless, in order to design traffic environments which impose attentional demands that are compatible with drivers' capabilities, it is important to develop suitable models of driver attentional allocation which take into account both driver internal state and the external environment.

In 1967, Senders, Kristofferson, Levison, Dietrich & Ward introduced the concept of (self-paced) visual occlusion as an experimental technique to measure driver attentional demand. They used a pneumatically driven visor mounted on a football helmet, to provide drivers with a half second glance at the road whenever they felt it was necessary. They found that, in accordance with their uncertainty model, as the velocity of the vehicle increased, so did the attentional demand, as estimated by the frequency of requested glances. Following up on Senders et al.'s original research, Milgram, Godthelp, and Blaauw performed an extensive set of on-the-road baseline visual occlusion experiments in the 1980's (Milgram et al., 1982). Their principal conclusion was that drivers appear to adopt a criterion of constant redundancy when driving; that is, they tend to request more information than is strictly speaking necessary from an information theoretic point of view, but the relative amount of uncertainty tolerated before requesting a new sample of the roadway remains constant relative to the maximum possible uncertainty predicted by their model. Mourant & Ge (1997) performed a similar experiment in a driving simulator and found that greater attentional demand was required for curved as opposed to straight roads and for traffic versus no traffic scenarios. In an even more recent visual occlusion experiment, it was found that the visual demand imposed by road curvature is inversely related to radius of curvature and that, while driving in curved sections, there is a tendency to fixate on one edge of the road (Fitzpatrick, Wooldridge, Tsimhoni, Collins, Green, Bauer, Parma, Koppa, Harwood, Anderson, Krammes, & Poggioli, 1999).

The objectives of the visual occlusion experiments reported here were twofold: to estimate the attentional demand of drivers under a variety of simulated driving conditions, and to determine whether doing so in a relatively simple driving simulator would generate results which were consistent with earlier on-the-road studies in the literature. Specifically, the investigators examined how speed, curvature of the road and road width affect the level of attentional demand, as estimated through the frequency of look requests. It was hypothesised that, in accordance with earlier models and data, as speed increased so would attentional demand and that this demand would be greater for curved roads as compared to straight road sections. Although no earlier published studies were found regarding quantitative measures of attention as a function of lane width, it was expected that, as lane width increased, attentional demand would decrease.

METHOD[1]

Subjects

Ten subjects, five males and five females, participated in this experiment. All were in their twenties and had held a valid driver's license for a minimum of two years. Subjects were paid Cdn $37 for their participation.

Apparatus

Subjects were required to drive a variety of pre-programmed driving scenarios using a Systems Technology Inc. (STI) driving simulator (Allen, Rosenthal & Aponso, 1998). The STI simulator is run by a minicomputer and comprises three seventeen inch monitors to display the driving scene, a steering wheel, accelerator pedal, brake pedal and driving chair.

In addition to the simulator, a pair of PLATO liquid crystal shuttering spectacles (Milgram, 1987) provided by

[1] Further details of the experiment are reported in (Courage, 2000)

Translucent Technologies Inc. were used. The opening and closing times of the spectacle lenses were rated at 1 ms and 3-5 ms respectively. These spectacles were programmed, using the ToTaLcontrol software (Translucent Technologies Inc.), for the lenses to open and allow for a 0.5s view of the roadway scene each time the subjects activated the switch. The switch was incorporated into the simulator's turn signal activator, located beneath the left side of the steering wheel.

Experimental Design

A 2x2x2x4, mixed factorial design was carried out, with the factors being gender, speed, road curvature and lane width. With the exception of gender, all variables were within subjects. The two genders (male and female), two speeds (60 and 100 km/h), two road curvatures (straight and curved, with radius of curvature = 1520 m), and four lane widths (2.7 m, 3.0 m, 3.4 m, 3.7 m) (i.e., 9, 10, 11 and 12 feet respectively) yielded a total of 32 treatments.

Procedure

Subjects underwent two hours of training prior to data collection to become familiar with the simulator and with driving with the visual occlusion spectacles. Subjects were instructed to drive safely and to look at the road (i.e., request that the spectacles open) as often as they felt necessary. It was also emphasised to subjects that this was not an experiment in risk-taking. The subjects drove 8 scenarios in a randomised order. Each scenario comprised only one speed which was set at a constant and one lane width, but included both straight and curved road segments.

RESULTS

A repeated measures ANOVA was performed on the percent of time with glasses open (PTO) data. Four significant main effects were found ($p<.05$).

First of all, a main effect was found for the variable *speed* ($f(1,8)=35.98$, $p<.05$). Specifically, as hypothesised, the percent of time with the glasses open was significantly larger for the 100 km/h scenarios (mean = 73%) when compared to the 60 km/h scenarios (mean = 59%). Figure 1 presents these results.

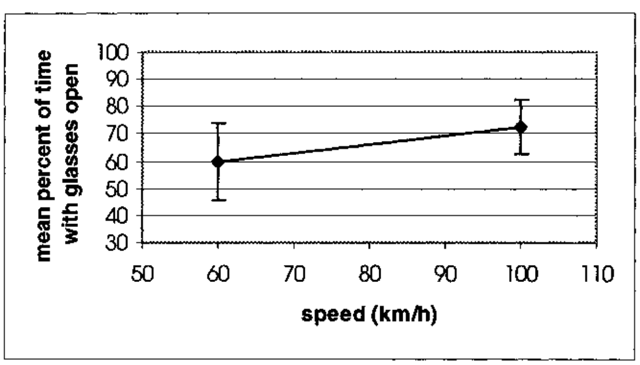

Figure 1. Mean percent of time with glasses open, PTO, (± standard deviation) for the 60 and 100 km/h scenarios (n=10).

A second main effect was found for the variable *curvature* ($f=234.75$, $p<.05$). Specifically, as hypothesised, the mean PTO was significantly larger for the curved portions of the runs (mean = 67%) when compared to the straight portions (mean = 57%). Figure 2 presents these results.

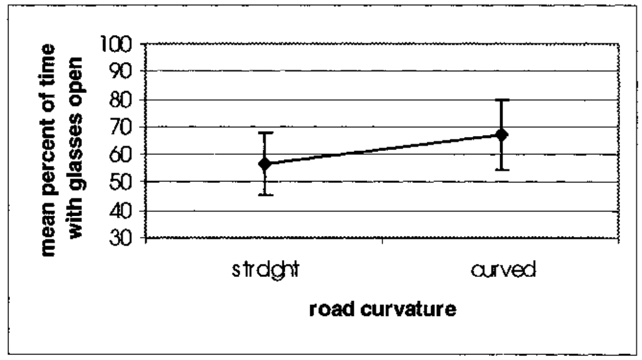

Figure 2. Mean percent of time with the glasses open, PTO, (+/- standard deviation) for the curved and straight road sections (n=10).

Thirdly, a significant main effect was also found for the variable *lane width* ($f(3,24)=6.68$, $p<.01$). Specifically, as hypothesised, the mean PTO was larger for the smaller lane widths. Figure 3 presents these results.

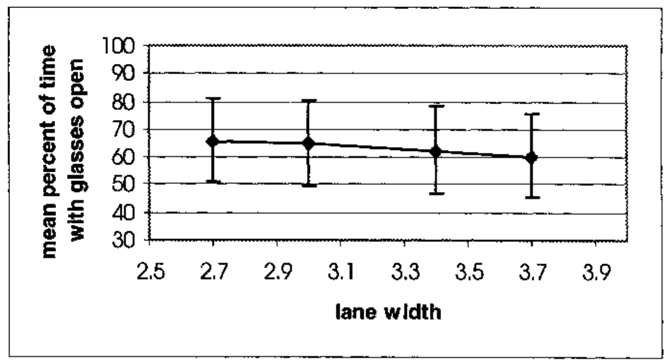

Figure 3. Mean percent of time with the glasses open, PTO, (+/- the standard deviation) for each lane width (2.7, 3.0, 3.4, 3.7 m) (i.e. 9, 10, 11, 12 feet) (n=10).

Planned comparisons revealed a number of significant differences between the various lane widths. Specifically, as the lane width became larger, the subjects had the glasses open for a significantly smaller portion of the time. A significant difference was not found between the PTO's for the two narrowest lane widths (2.7 and 3.0m) however.

Finally, a fourth significant main effect was found for the variable, *gender*. Specifically it was found that the PTO was significantly shorter for males (mean = 57%) as compared to females (mean = 69%) ($f(1,8)=7.26$, $p<.05$). Figure 4 illustrates these results.

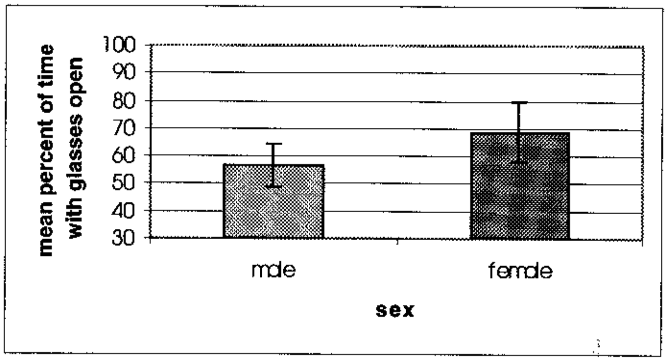

Figure 4. Mean percent of time with the glasses open, PTO, (+/- the standard deviation) for males and females (n=10).

DISCUSSION

The primary objective of this experiment was to investigate how speed, curvature of the road and lane width affect the level of attentional demand in a simulated driving environment. For this purpose, the dependent variable presented here, mean percent of time with the glasses opened (PTO), was assumed to be an index of driver *attentional demand*. That is, it was assumed that, as demand increased, the percentage of time that subjects felt it necessary to sample the roadway would also increase, and they would thus sample more often. (Another experimental dependent variable, mean time between glances, reported in (Courage, 2000) but omitted from the present paper, yielded comparable results.)

Two speeds were examined (60 and 100 km/h). As in previous studies (Milgram et al., 1982; Senders et al., 1967), and as hypothesised, it was found that, as speed increased, so did PTO. Specifically, there was a 15% increase in attentional demand from 60 to 100km/h.

In addition to speed, curvature of the road was also examined. Based on previous findings, it was hypothesised that greater attentional demand would be required for the curved sections of road as compared to the straight segments (Mourant & Ge, 1997; Fitzpatrick et al., 1999). This hypothesis was supported by the fact that the mean PTO was significantly greater for the curved road, as compared to the straight sections. Specifically, the attentional demand required on the curved segments of the road (radius of curvature = 1520m) was 10% greater than that required on the straight segments of road.

A third variable, lane width, was also investigated. Specifically, the attentional demand across 2.7, 3.0, 3.4, and 3.7 m lanes were examined. It was hypothesised that, as lane width decreased, the required attentional demand would increase. This hypothesis was supported. With the exception of the comparisons between the 2.7and 3.0m lanes (discussed below) it was found that, as lane width increased, the time between looks at the road increased and the percentage of time with the glasses open (PTO) decreased. In other words, as lane width decreases, attentional demand increases. Specifically, a 6% increase in attentional demand was found as the lane width decreased from 3.7 to 2.7 m (12 feet to 9 feet).

These findings are of potentially great importance for road design, especially given that we have found no published studies thus far which have examined the relationship between lane width and attentional demand. Often, to help cope with increasing traffic volume, highway designers reduce lane widths so that additional lanes can be added to existing roads (Heimbach, Cribbins, & Chang, 1983). The findings of the current study demonstrate, however, that lane width apparently has a significant potential impact on the information processing load imposed upon the driver, in the sense that, by narrowing lane widths, the driver's attentional demand is likely to become significantly greater. Presumably, increased attentional demand increases the possibility of attentional overload, which can in turn result in driving errors or accidents. It has already been shown that roads with narrower lane widths have a relatively higher percentage of accidents (Zegeer, Huang, Stewart, & Williams, 1998); the present study illustrates why this may be the case.

As mentioned above, one unexpected finding regarding lane widths occurred. Specifically, it was found that significant differences did not exist between the 2.7 and 3.0 m lane widths for the dependent variables measured. However, it is believed that the absence of significant differences in this case does not in fact imply that the attentional loads for the 2.7 and 3.0 m lane widths were equal. Rather, if we take into account that the actual times between spectacle openings for both the 2.7 and 3.0 m lane widths were very small, with a mean of approximately 0.8 s, when the (constant) duration of time that the glasses were open, 0.5s, is subtracted from that mean, we are left with a mean time of approximately 0.3 s between the end of one glance and the beginning of the request for the next.

Based on this magnitude, which is comparable to a simple human reaction time, it is probable that subjects were opening the spectacles essentially as fast they were physically and mentally able for these lane widths, given the particular control lever, thus accounting for the absence of significant differences between the 2.7 and 3.0 m lane widths. That is, to open the spectacles subjects were required to activate the left turn signal, and it is quite conceivable that it took them on the order of 0.3 s to accomplish this. Furthermore, despite the fact that in theory the spectacle control lever could be operated mechanically at a faster rate to allow the drivers to look more often (up to 100% of the time if they had actually initiated subsequent look requests while current look periods were still underway), such 100% looking behaviour was not observed.

One explanation for this is that possibly fatigue could have resulted from continually opening the glasses at a very rapid rate for relatively long durations of time. Observations made during testing also support this. It was observed that, when subjects were driving scenarios which contained the 2.7 and 3.0 m lane widths, they were rapidly initiating look requests through the left turn signal throughout the duration of the drive. It would thus be of interest to rerun this experiment and examine the attentional demand produced by these lane widths once again. This would require implementation of a method to open the glasses which is not as physically demanding or time consuming as the method used in the present study. If this were done, it would likely be seen that the attentional demand imposed by the 2.7 m (9 ft) lane width is greater than that of the 3.0 m (10 ft) lane width.

The fourth variable which was examined was the between subjects variable, gender. Although this variable was not the focus of the present study, it was felt while designing the experiment that it was important to examine gender, because significant differences between males and females in driving behaviour have already been shown elsewhere to exist (Mourant & Rockwell, 1972; Shinar, 1978). Nevertheless, the significant male-female differences found in this experiment were somewhat unexpected.. In particular, it was found that, for females, the time between glass openings was smaller and the PTO was (12%) larger when compared to males. (12% greater). Although the looking behaviour differed, males and females had similar lane keeping performance, indicating that both performed the task as required. One possible explanation for the attentional demand difference is simply that females tend to sample the road scene more often because they subjectively prefer relatively higher levels of information redundancy, which can be of information acquired from the driving scene by sampling the roadway more often.

CONCLUSION

There are a number of important issues worth discussing which arose from the present study. One is the value of the method of visual occlusion as a means of estimating attentional demand. As discussed above, it was found that attentional demand varies with speed and road curvature. These findings are not new; authors such as Senders et al. (1967), Milgram et al. (1982) and Mourant and Ge (1996) have made similar findings. Replication of such results using visual occlusion is nevertheless of great importance because it provides further support for the *reliability* of this method for assessing attentional demand. Additional support for the method in the present study came from the *sensitivity* and *diagnosticity* that it provided. The sensitivity, diagnosticity and reliability that visual occlusion provides make it an excellent tool for assessing attentional demand, also beyond the realm of automobile driving.

Another important finding of the present study pertains to how drivers dynamically allocate their attention to meet different demands of the driving situation. The findings reported here confirm that drivers do indeed allocate resources dynamically in response to changing demands. In this study the elements: speed, road curvature and lane width were all found to have an impact. Specifically, it was found that, as speed increased, so did estimated attentional demand. Attentional demand also was found to vary directly with road curvature; that is, drivers allocated significantly more attention to the road when it was curved as opposed to straight. Finally, it was found that, as lane width decreased, drivers were again forced to pay more attention to the road.

In summary, an understanding of the attentional demands imposed upon drivers by different driving conditions has very important implications for human factors professionals and highway designers. Specifically, such an understanding can help these professionals ensure that roadways which exceed drivers' capabilities are not created.

Finally, in the present experiment the attentional demand of fairly simplistic driving conditions was examined using the simple but effective technique of self-paced visual occlusion. In future experiments it would be of great interest to examine the attentional demand imposed by more complex driving circumstances, such as conditions involving multiple lanes, vehicular traffic, and/or pedestrians. It would also be of interest to examine conditions in which the driver is dividing his/her attention between the driving task and in-vehicle technology, for example, driving while operating a cell phone or navigation device. The additional attentional demand introduced by such devices could in the first instance be easily assessed simply by comparing measures such as PTO during operation of such devices to baseline measures of attentional demand such as those reported in the present study.

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