The Effect of In-Vehicle Warning Systems on Speed Compliance in Work Zones

James Whitmire II[1], J.F. Morgan[2], Tal Oron-Gilad[3], and P.A. Hancock[1]

[1]University of Central Florida,
[2]Virginia Tech Transportation Institute,
and
[3]Ben-Gurion University of the Negev

The purpose of this research was to evaluate the effectiveness of augmented in-vehicle information on driver behavior in work zones. In-vehicle information systems (IVISs) can increase driver awareness to an oncoming change in traffic flow and provide specific guidelines for driving speed requirements, for example. Three variations of IVISs were examined as the drivers entered a work zone in a simulated driving environment. The first was a control condition, which used only traditional signage and no IVIS. The second condition had the addition of visual in-vehicle warnings and the final condition the addition of auditory in-vehicle warnings. Results indicated that adding in-vehicle warnings did affect driver compliance to the work zone speed limit. Further, participants in the audio warning condition responded more quickly to the warning than in the visual condition. These were each respectively different from the drivers in the control condition. Conclusions and implications are discussed.

INTRODUCTION

Highway work zones present one of the most hazardous of all roadway conditions. The increased risk affects not only drivers in transit through the work zone but also those whose job it is to work within them (Mohan & Zech, 2005). Operations within the work zone produce serious highway safety problems by affecting the normal traffic flow and generating unexpected conditions and the potential for serious traffic conflicts (Morgan, Duley, & Hancock, 2010). Work zones on highways have been shown by quantitative analysis to be significantly more dangerous than comparable pre-work zone roadways in the same areas (Khattak, Khattak & Council, 2002).

Clearly, speed has a main contributory role in work zone crashes. In fact, a specific study by the Minnesota Department of Transportation (MnDOT) identified the major cause of accidents in work zones as being related to drivers exceeding the posted speed limits (Stackhouse & Tan, 1998). This recognition of overt behavioral change is also recognized by the drivers themselves. For example, Benekohal, Hashmi and Orloski (1993) surveyed drivers in order to examine whether they made behavioral adjustments while passing through work zones. They found that the majority (77.5%) paid more attention to work zone signage and thought speed limits were posted correctly (97.0%). Unfortunately, their study did not report whether the people who felt the speed limit was correct for the work zone, then went on to actually comply with the limit.

In-vehicle technologies are becoming increasingly common in the modern vehicle. These systems could be used to convey specific operational information for the driver, especially in such difficult and demanding conditions (Vashitz, Shinar, & Blum, 2008). Recently, Warner and Åberg (2008) investigated the long term effects of a first generation intelligent speed adaptation device and found an initial decrease in the time spent over the speed limit. Unfortunately, this compliance attenuated with time. Nonetheless, in-vehicle information devices can increase driver awareness to a coming change in traffic flow and provide specific guidelines for the driver in terms of speed requirements, lane merging strategies, or unexpected changes in the roadway (e.g., detours, lane shifts, etc). While research efforts have provided evidence that in-vehicle information technologies can positively affect driver compliance and improve safety, particularly with regard to driving speed (Brookhuis & De Waard, 1999), the targeted application of such systems to work zones is an area that has yet to be fully addressed, especially through comparative experimental procedures.

The particular concern of the present study was in the investigation of the effectiveness of in-vehicle information to influence driver speed compliance behavior in work zones.

METHOD

Experimental Participants

Sixty participants (27 males and 33 females) between 20 and 63 years of age were recruited from the population of a large university. The mean age of the groups was 33 years, with a standard deviation of 12 years. All participants were required to have a valid driver's license with at least three years of driving experience. Participants had on average 21 years of driving experience. All participants reported having normal hearing and had normal or corrected to normal vision.

Experimental Materials and Apparatus

The experiment was conducted in a fixed-base driving simulator manufactured by I-Sim (Patrol Sim with software version 4.0.85). The simulator consists of three visual channels providing an approximate 150° field of view at a distance of approximately 1.0 m from the driver. The dashboard and seat were from a Ford Crown Victoria. In conjunction with the driving simulator, a dedicated LabVIEW software program was integrated with the simulator for the purpose of recording driver responses such as steering movement, speed, and triggering the audio and visual in-vehicle warning messages. The visual messages were presented to the participants via an HP IPaq Pocket PC (600x800 VGA resolution) mounted in the location of the OEM radio. The audio messages were delivered via a small speaker set mounted just below the screen. The audio warning messages were verbal recordings in a male's voice and their content was identical to the text that appeared in the visual messages. Auditory warnings were presented at 60dbC (conversation level).

The warning messages consisted of black text on an orange background (visual condition) or a male's spoken voice (auditory condition) announcing that the driver was approaching a work zone ("Work Zone Ahead"), that the driver had entered the work zone ("Begin Work Zone"), and a warning presented if the driver exceeded the posted speed limit ("Slow Down"). The "Slow Down" message was triggered if the participant exceeded the posted speed limit by more than 5 kph.

Experimental Design and Procedures

The experiment was a between participant study where the between-participant factor consisted of audio, visual and control groups. Individually, the participants were required to ride through a simulated drive that included a work zone with the total simulation lasting an average of 7 minutes in duration. All participants started at the same location within the simulation. The control group received regular road signage, while the audio group received regular road signage plus audio warning messages. The visual group received regular road signage plus in-vehicle visual warning messages. Within the drive there was a stop sign, a Work Zone Ahead sign, and a Begin Work Zone sign. Once in the work zone if the driver traveled over 45 kph he or she would receive a continuous visual or audio warning message until their speed limit was reduced to or below 45 kph. The end of the experiment was signaled by a final stop sign and after exiting the work zone participants were asked to pull over to the right of the roadway. Driving related data collection began upon entrance to the work zone and continued throughout the driving session and finally concluded when the driver turned the ignition to the off position. Data was collected on acceleration, braking, lane position, and steering as well as the prime dependent variable of interest which was speed at a rate of 60 Hz.

RESULTS

Compliance to Work Zone Speed limit

Driver's compliance to the warning messages was measured by the time spent in violation of the speed limit and the speed range of the episode of violation. The sub-measures were as follows: Total Time in Violation within the Work Zone, Total Time of each Violation, Mean Total Time of each Violation, Mean Speed of each Violation, and Mean Speed of all Violations.

Total Time in Work Zone

This measure indicates on average how long the drivers spent within the work zone and reflects the speed of transit in each respective between-participant condition. The audio group spent the longest time in the work zone (M = 186.8 s, SD = 11.5), followed by the visual group (M = 180.1 s, SD = 25.7) and finally the control group (M = 159.2 s, SD = 32.4). Analysis of variance revealed a significant effect for total time in work zone $F(2, 57) = 3.35$, $p = .08$. Post-hoc analysis using Tukey's HSD procedure revealed significant differences between the control condition and the other two experimental conditions but no significant differences between the latter two audio and the visual groups.

Number of Violations

The number of violations occurring in each group was examined. The Control group had an average of 4.30 (SD = 2.18) violations, while the visual (M = 3.22, SD = 2.18) and audio (M = 3.50, SD = 2.09) groups both had a lesser number. The number of violations in each group was compared using an ANOVA, that indicated that the groups were equivalent in the number of speed violations occurring within the work zone, $F(2, 57) = 1.31$, $p = .27$.

Duration of Violations

The duration of speed violations across the groups was examined. The control group had the greatest average violation duration, while the audio and visual groups had a much smaller average violation duration (Figure 1).

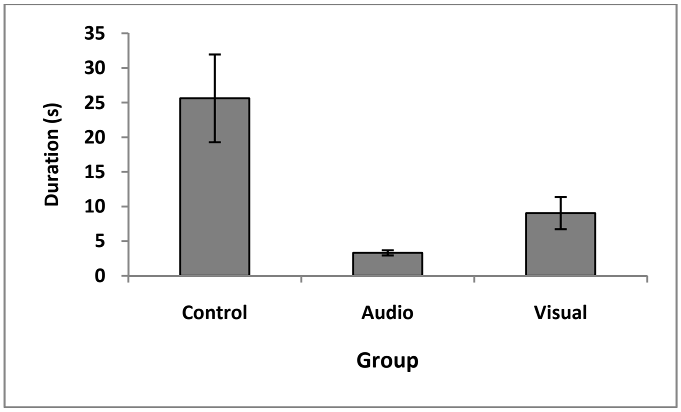

Figure 1. Average duration of violations, by group. Error bars represent standard error.

An ANOVA was conducted, comparing the violation duration across groups in consideration of the number of violations within each group. The ANOVA was significant, $F(2, 59) = 8.81$, $p = .0005$. The average violation duration for the control group was significantly greater than those for either the audio or visual groups. There was not a significant difference between audio and control groups.

Total Time in Violation

This measure provides the amount of time within a drive that participants spent above 45 kph while within the work zone. This measure is presented as a percentage value being relative to the total time spent in the work zone. In the control conditions participants spent on average 70.6 s (*SD* = 42.6), or 44% of the time, violating this threshold. In the audio condition participants spent on average 12.6 s (*SD* = 10.7), or 7% of the time, violating the speed limit and in the visual condition participants spent 32.3 s (*SD* = 39.2), or 18% of the time. The results for Total Time in Violation were statistically significant, $F(2, 57) = 5.05$, $p < .01$. Post-hoc analysis (Tukey-HSD) revealed significant differences between the control and the other two conditions but again no significant differences between the audio and the visual groups.

A MANOVA was conducted examining approach speed at 32, 24, 16, and 8 seconds, and the post-work zone speed at 8, 16, 24, and 32 seconds. Using Wilk's criteria, the MANOVA was significant, $F(16, 100) = 1.95$, $p = .020$. Based on this, follow-up ANOVAs were conducted examining the effect of group on speed. There were no differences in pre-work zone speed ($p > .05$ in all comparisons). There was a significant effect of group on the 24 second post-work zone speed, $F(2, 57) = 7.17$, $p = 0.0017$. Bonferroni corrected *t*-tests show that the control group had a significantly greater mean speed (*M* = 57.1 kph, *SD* = 16.4) as compared to either visual (*M* = 47.9 kph, *SD* = 16.3) or audio (*M* = 40.9 kph, *SD* = 4.89) groups. There was no difference between visual and audio groups. Likewise, there was a significant effect of group on the 32 second post-entrance to work zone speed, $F(2, 57) = 9.54$, $p = 0.0003$. Bonferroni corrected t-tests show that the control group had a significantly greater mean speed (M = 54.6 kph, *SD* = 14.5) as compared to either visual (*M* = 43.6 kph, *SD* = 10.6) or audio (*M* = 40.2 kph, *SD* =5.5) groups. There was no significant difference between visual and audio groups (Figure 2).

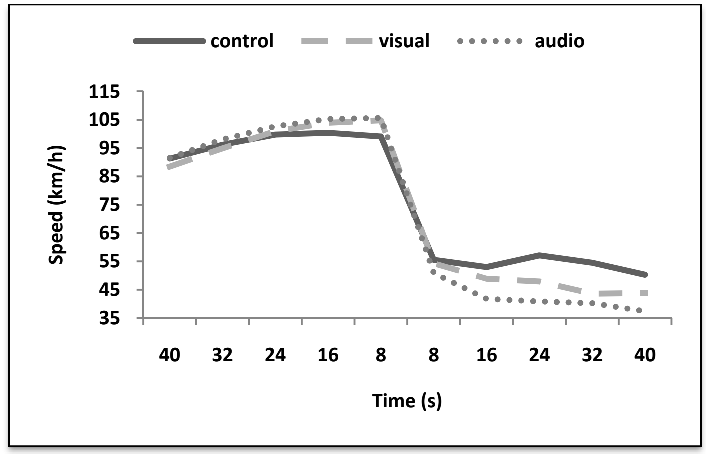

Figure 2: The entrance to the work zone is between the 8 second tick marks. Please notice the stimulus-response differences after the entrance to the work zone.

DISCUSSION

One primary assumption of any transportation system is that the operators' primary task is the safe control of the vehicle. In the multi-tasking environment of driving, it is of the assumption that the driver intuitively holds driving above all other tasks as the one preeminent concern (Wickens & Gosney, 2003). In situations where the driver is required to perform sudden and unexpected maneuvers, where rapid and often ill-defined task shifts are required, this prioritization may be challenged by the context of the driving task in itself. In-vehicle messages, in different sensory modalities, could potentially act to improve drivers' compliance to desired work zone transit speed. Always remembering the speed in itself has been implicated as the main factor in work zone collision rate increase. Such in-vehicle information sources are viewed as a supplement to traditional methods of providing drivers with information regarding upcoming road hazards. These traditional approaches include static and variable message signs. Informing the driver of upcoming high risk sections of roadways, such as the work zones used in this study, hold the possibility of reducing the risk such areas present. Further, multimodal presentation of these types of messages should allow the message to be clearly received by the driver with only a minimal cost in terms of increased cognitive workload.

The driving scenarios examined in this study should be considered the most basic configuration of work zone. This is partly due to the lack of other dynamic elements in the simulation as the driver traveled through the environment. Although in any typical work zone additional visual demand would be present due to the movement of workers, machinery, and other vehicles, this was not examined in this study. However, the presence of an effect for signaling (especially the ability to provide multimodal messaging, reducing the burden on any one sensory channel) in the absence of additional visual loading is of particular interest. In theory, this strengthens the findings that the audio modality is a much better channel through which to cue the driver during critical event.

Drivers, regardless of message modality, traveled at approximately the same speed through the work zone (and both traveled at a lower speed than the control group). This serves as indication of message comprehension. Similarly, no differences between message modality were observed for the amount of time drivers spent in violation of the work zone speed limit (again, both were in violation for a smaller amount of time than the control group). Although no significant differences were present between auditory and visual conditions in terms of overall speed compliance, some significant differences were present in measures of drivers' response time to warnings. While drivers in the audio condition took six seconds to respond, their counterparts in the visual condition took twenty-two seconds to respond. The final outcome of both message modalities was the same (speed compliance). However the longer time to compliance, and the associated increases in risk which accompany it, suggests the dominance of the auditory channel for this type of information. Additionally, our findings demonstrate interesting differences in the violations observed in work zones, as well as a difference in the effect of modality on driver responses to messages. Drivers with multimodal warnings most frequently violated the safe speed upon entering the work zone. However, once they were alerted to this state they typically did not have additional speed violations. Drivers without a system to provide warnings to unsafe speeds did not display such a pattern. Although higher initial entry speeds are apparently universal among this study's population, the drivers did respond very well to target warnings regarding safety behavior compliance.

While these findings present a clear starting point for future research, the atypical nature of work zones must be considered. There are definite standards for the configuration of highway work zones; however these are not always implemented on the roadway. The driver traveling through two different rural 105 kph divided highways with an upcoming work zone may not experience the same spatial organization of pre-work zone information and in-work zone channeling. This is not necessarily due to inattention on the part of maintenance workers: it is an adaptation to the demands of the specific environment. However, the driver is typically ill-informed and given little information in these multiple configurations of work zones. Such situations require different levels of demand on the visual system. With this in mind, the visual demand may fluctuate across work zones that, according to regulations, should be identical. The results suggest there is indeed a better way to cue the driver to his or her speed within a work zone as compared to regular road signage.

The idea of interference in the transmission of a message is not a new concept by any means (Shannon & Weaver, 1949). In the case of the driving environment interference in the message may come from a myriad of sources, ranging from telephones and entertainment systems, to advertisements and other roadway users. The cost of these distracters is often negligible, until a rapid and accurate response is required from the driver. Occasionally, driving shifts from a low level control and monitoring task to a true continuous control task. It is at these points where providing better and more efficient information to the driver may prove beneficial.

As one would predict, based on multiple resource theory (Wickens, 2002), the findings of this study suggest the necessity of redundant signal modalities in driver messaging systems. The practical implications of these findings, specifically in respect to the increasing implementation of in-vehicle communication devices, are wide. Specifically, in order to achieve the best compliance with messages presented to the driver, those messages through consist of a specific temporal sequence of modalities. The ideal driver message should begin with a brief auditory and visual messages (of a duration no greater than 6.0 seconds), followed by a visual warning message only which remains visible until compliance or acknowledgment. In closing, further research is called for in the specific auditory and visual characteristics of such messages. The density of auditory and visual information, as well as the formatting of text-based messages on in-vehicle displays, remains a largely unknown contributor to the speed and accuracy of a busy driver's interpretation of the information.

REFERENCES

Benekohal, R., Hashmi, A., Orloski, R., 1993. Drivers' opinion on work zone traffic control. TransportationQuarterly 47 (1), ENO Foundation, pp. 19–38.

Brookhuis, K. & Waard, D. (1999). *Limiting Speed, towards an intelligent speed adapter* (ISA). Centre for Environmental Traffic Psychology COV, University of Groningen, Grote Kruisstraat.

Khattak, A. J., Khattak, A. J., & Council, F. M. (2002). *Accident Analysis and Prevention, 34, 19-29.*

Mohan, S., & Zech, W.C. (2005). Characteristics of worker accidents on NYSDOT construction projects. *Journal of Safety Research, 36*, 353-360.

Morgan, J.F., Duley, A.D., & Hancock, P.A. (2010). Driver responses to differing urban work zone configurations. *Accident Analysis & Prevention, in press.*

Shannon, C. E. & Weaver, W. (1949). *The Mathematical Theory of Communication*. University of Illinois Press, Urbana.

Stackhouse, S. & Tan, A. (1998). *Effective Speed Reduction in Work Zones.* University of Minnesota, Human Factors Research Laboratory, Minneapolis, Minnesota.

Vashitz, G., Shinar, D., & Blum, Y. (2008). In-Vehicle information systems to improve traffic safety in roads tunnels. *Transportation Part F, 11*, 61-74.

Warner, W.W., & Aberg, L. (2008). The long-term effects of an ISA speed-warning device on drivers' speeding behaviour. *Transportation Part F, 11,* 96-107.

Wickens, C.D. (2002). Multiple resources and performance prediction. *Theoretical Issues In Ergonomics Science, 3*(2), 159-177.

Wickens, C. D., & Gosney, J.L. (2003). Redundancy, modality, priority and instructions in dual task interference between simulated vehicle control and in-vehicle technology. *Techinical Report AHFD-03-18/GM-03-3.* General Motors Corporation, Warren, MI. Contract GM TCS16231 WIC.