

EFFECTIVENESS OF BIMODAL VERSUS UNIMODAL ALERTS FOR DISTRACTED DRIVERS

Bridget A. Lewis, B. N. Penaranda, Daniel M. Roberts & Carryl L. Baldwin
George Mason University
Fairfax, Virginia, USA
Email: bridget.ann.lewis@gmail.com

Summary: Twenty-two participants drove a simulated vehicle while engaged in a low or high working memory load task and responded to signals presented in auditory, visual and tactile modalities or their bimodal combinations by pressing on the brake. Signals were designed to be of low or high urgency in both unimodal and bimodal combinations. High urgency and bimodal signals were responded to faster than their low urgency and unimodal counterparts. Fewer bimodal signals were missed overall. This bimodal advantage was particularly significant relative to unimodal signals of low urgency in the high working memory load condition. Together these results indicate that hazard mapping can most effectively be obtained by designing with both the perceived urgency level of the signal and modal plurality in mind.

INTRODUCTION

Advances in automotive technology have led to the capability of providing more information to the driver than he or she could ever process. In-vehicle displays can provide critical safety information such as advanced notification of potential collision situations, lane deviations, and hazardous road conditions, as well as a range of less urgent notifications (e.g., speed alerts, traffic updates and weather alerts, and infotainment notifications). This proliferation of information has the potential to both aid and distract the driver. In order to ensure their safe and effective implementation, in-vehicle signals must be appropriately matched to the hazard level of the situation or information they are intended to represent (Hellier & Edworthy, 1999; Wogalter & Silver, 1990, 1995). This urgency mapping is essential for ensuring that safety critical alerts are detected even when the driver is experiencing heavy perceptual or cognitive workload or is distracted. Additionally, it ensures that non-critical signals do not pre-empt safe operation of the vehicle. Making use of parameters that convey a range of perceived urgency and using multiple modalities are two key methods of conveying time criticality in alerts and warnings.

There has been increased attention regarding the potential benefit of using two modalities to convey time critical information. Bimodal alerts may lead to faster response times than unimodal. In basic laboratory search tasks, presenting stimuli in two modalities frequently yields faster response times than stimuli presented in a single modality – a phenomenon known as the redundant target effect (RTE; Miller, 1982; Miller, 1991). Currently, there is little evidence regarding whether the RTE applies in more complex tasks like driving. In one of the few existing investigations, Levy and Pashler (2008) observed faster brake response times in a driving simulation when a visual alert (a light) was paired with either a tactor signal or an auditory icon (screeching brakes) in comparison to when the light was presented in isolation. The redundant signals also made it more likely that participants appropriately prioritized braking over a less important secondary task. However, a tactor-only or auditory icon-only condition was not

included and therefore it is not known whether or not the redundant condition led to faster response times than would have been observed for either the unimodal auditory or tactile signals.

Recently, Lees et al. (2012) compared unimodal and bimodal cues in the context of a driving simulator. They found that an auditory-only cue and any bimodal combination that included an auditory signal resulted in the fastest response times, but found no direct support for the RTE. Additionally, responses were to a visual target discrimination task and were not directly related to driving. It seems bimodal signals may benefit drivers in reorienting their attention when they are engaged in a concurrent perceptually demanding task.

While both unimodal and bimodal alerts are capable of attracting attention in undistracted conditions, bimodal alerts show increased benefit during tasks that induce high perceptual load (Botta et al., 2011; Chan & Chan, 2006; Ho, Reed, & Spence, 2007; Ho, Santangelo, & Spence, 2009; Santangelo & Spence, 2007). For example, Santangelo and Spence (2007) found that when participants were engaged in a perceptually demanding central rapid serial visual presentation task, bimodal cues aided detection of peripheral visual targets more than unimodal signals. Though unexamined in these investigations, signal urgency may have also played a role.

Though considerable work has established the predictive power of subjective ratings for determining the perceived urgency of auditory and visual signals (Edworthy, 1998; Hellier & Edworthy, 2002; Stanton & Edworthy, 1999; Wogalter & Silver, 1995), much less is currently known regarding vibrotactile signals (but, see Baldwin et al., 2012). Further, there is a scarcity of research examining the connection between perceptions of urgency and actual responses, particularly within a vehicle. Results are equivocal from the limited existing research. For example, Suied, Susini, and McAdams (2008) and Haas and Casali (1995) both found negative correlations between perceived urgency and response time. Suied et al. also found that response time decreased as the time between auditory pulses decreased, though they caution that the underlying mechanisms involved may be unrelated. Conversely, Burt, Bartolome, Burdette, and Comstock (1995) found no relationship between urgency ratings and reaction times, though they also point out that their alerts may have been somewhat hard to distinguish as they used relatively small ranges of sound parameters. Further, Baldwin and May (2010) found that alerts on either extreme of the urgency scale (very low or very high) were less effective in reducing crashes than medium urgency (for example a loudly spoken "Notice" or a quietly spoken "Danger") when used in a crash warning system.

The Present Study

In the present study we sought to determine whether bimodal signals might be more effective than unimodal signals at orienting attention when the driver of a simulated vehicle was engaged in a task requiring high working memory (a 3-back n-back task, for reviews see Conway et al., 2005 and Kane & Engle, 2002), rather than perceptual load. Further, we sought to examine whether presenting signals at high unimodal urgency levels would be as effective as bimodal signals, and if the combination of bimodal signals at high urgency might be particularly beneficial at getting attention when drivers were engaged in a high working memory load task.

We hypothesized that both high signal urgency and the use of bimodal signals would result in faster responses to target signals in comparison to unimodal signals of low urgency. We expected these differences to be particularly evident when drivers were engaged in a task requiring a high versus low level of working memory resources.

METHODS

Participants

Twenty-two undergraduate and graduate students (4 male, average age = 25.5 years), recruited through the George Mason University subject pool, participated in this study. Participants received a small amount of research participation credit that could be applied to their classes. All were right-handed, reported normal or corrected-to-normal vision and hearing and were licensed drivers.

Stimuli

Stimuli used for the alerts consisted of unimodal and bimodal, “high” and “low” urgency alerts (as rated in previous experiments; see Lewis & Baldwin, 2012). Unimodal stimuli consisted of auditory alerts played through loudspeakers and tactile alerts presented via a C-2 tactor (Engineering Acoustics, Inc.) attached to a custom amplifier built in-house. All alerts had a total duration of around 2500 ms (when alerts ended with a silence interval, alerts finished a little early so that participants weren’t listening to silence). Pulse durations lasted for 200 ms with variable length inter-pulse intervals (IPI). “Low” urgency alerts had IPI of 475 ms and “high” urgency alerts had IPI of 9 ms. Visual alerts did not pulse and remained visible for the full 2500 ms. Visual alerts consisted of a colored box with the word “Warning” in bold, all-uppercase type. “Low” urgency visual alerts consisted of a green (0R, 1.0G, 0B) colored box (calculated as 510 nm) and “high” urgency stimuli consisted of a red (1.0R, 0G, 0B) colored box (calculated as 645 nm). The signal word was presented in black on the green background and white on the red background based on Laughery (2006).

Bimodal stimuli were made up of combinations of unimodal stimuli. Audiovisual and visuotactile “low” urgency stimuli consisted of a combination of 475 ms IPI auditory pulses paired with a green “Warning” box while “high” audiovisual and visuotactile stimuli consisted of a 9 ms IPI auditory pulse paired with a red “Warning” box. Audiotactile pulses were synchronized.

Apparatus and Procedure

The experiment was run in a sound attenuated lab room. Participants were seated at a table equipped with a Logitech Driving Force steering wheel and pedals. After giving written informed consent participants completed a brief demographic survey. Next, a C2 tactor was placed on the back of the participants left wrist and secured with an elastic wrist band, similar to methods used by (Ferris & Sarter, 2008). Participants then completed multiple practice sessions, including driving only, performing the n-back only at the 0-back and 3-back load levels and then performing both tasks at the same time. The n-back task allowed 2 seconds to respond and had a

30% target probability. The third practice block was comprised of an experimental task practice set. Participants were required to drive (maintaining 55 mph and their lane position) while completing the 0-back task. Additionally participants were informed that they would receive various auditory alerts (these alerts were separate from those used in the actual experimental conditions). Participants were asked to respond “promptly” to any alerts they heard by pressing the brakes.

RESULTS

Space limitations prevent a complete depiction of all results. The main hypotheses could be examined for the present purposes by averaging all unimodal signals and all bimodal combinations into their respective low and high urgency conditions. Analyses of these averaged signal combinations are reported here. A 2 (modality: unimodal or bimodal) × 2 (urgency level: low or high) × 2 (load: low or high) repeated measures design was used to analyze the dependent measure brake response time (RT). As shown in Figures 1a and 1b, there were significant main effects of both modality, $F(1, 21) = 34.93, p < .001$, where bimodal alerts resulted in faster RTs than unimodal, and urgency, $F(1, 21) = 7.37, p = .013$, where high urgency alerts resulted in faster RT than low urgency alerts. There was no significant main effect of load ($p = .486$).

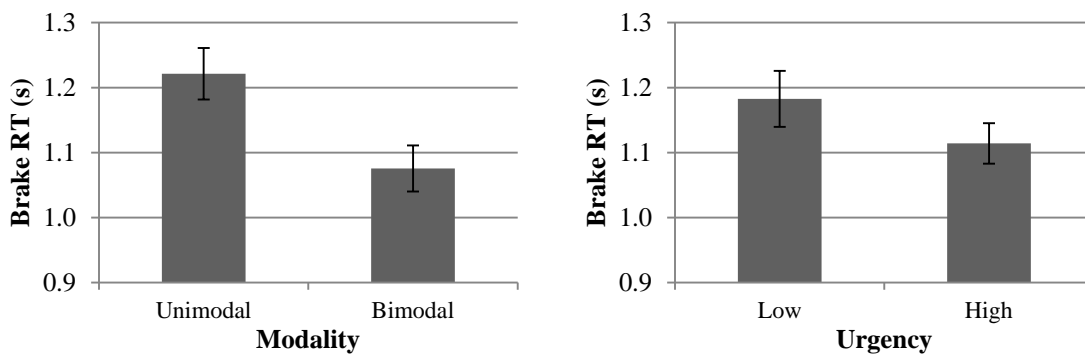


Figure 1a and 1b. The effect of modality on response time and the effect of urgency on response time. Error bars indicate standard error

A significant interaction of urgency and load (see Figure 2), $F(1, 21) = 5.48, p = .029$, was observed. This interaction indicated that in the low load condition participants were able to more readily distinguish between low and high urgency alerts, responding significantly faster to high urgency alerts than low. When task load was high, a paired samples t -test revealed that people’s response time to the alerts did not differ between the high and low urgency alerts. No significant interaction or trend was observed for modality and load.

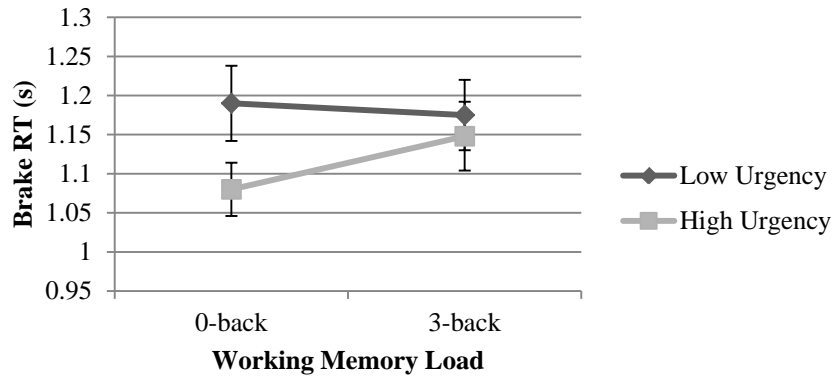


Figure 2. The interaction between urgency and load level. Error bars indicate standard error

Misses

Additionally, another 2 modality × 2 urgency × 2 load repeated measures design was used to analyze misses in all conditions. Responses longer than 5 seconds were considered misses. We observed a significant main effect for modality, $F(1, 21) = 7.50, p < .001$, where there were more misses in the unimodal condition.

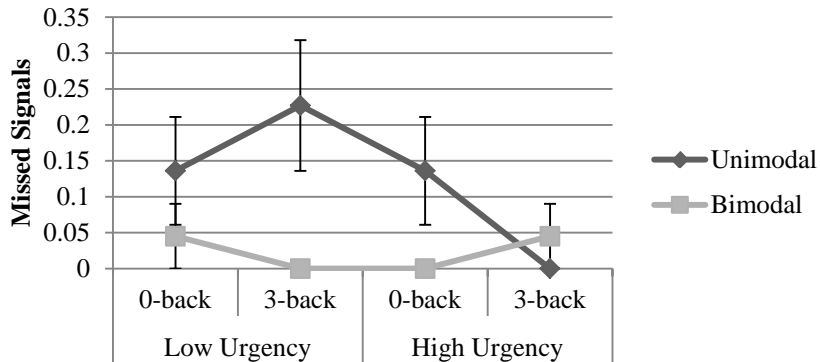


Figure 3. Modality by urgency by load interaction for misses. Error bars indicate standard error

As illustrated in Figure 3, we observed a significant modality by urgency by load interaction effect, $F(5, 105) = 1.184, p = .053$. This effect is primarily indicative of participants being more likely to miss alerts in the unimodal condition if they were low urgency signals and they were engaged in the high working memory load task.

Load Manipulation

All participants performed the 0-back task extremely accurately with (Mean correct response rate of 97.5%). As expected, the 3-back task was more difficult and resulted in a mean correct response rate of 77.4%. These results confirmed that our manipulation of working memory load was successful. Note that all participants were required to obtain a criterion score of 60% or better on the 3-back task in single task conditions in order to be included in the study. (Signal probability was 30%, so a 60% correct detection rate was significantly above chance performance.)

Driving Performance

All alerts were presented in random order while participants were simultaneously driving and performing one of the two working memory load tasks. A paired samples *t*-test showed that participants drove significantly faster $t(19) = -3.54$, $p = .002$, in the high working memory load condition (a mean speed of 52.23 mph in the 3-back condition and a mean speed of 50.91 mph in the 0-back condition) and had greater variability, $t(18) = -3.25$, $p = .004$, in the high working memory load condition (with a mean of 4.95 mph in the 3-back condition and a mean of 3.96 mph in the 0-back condition). We observed no significant difference in lane-keeping ability.

DISCUSSION

The current investigation indicates that the use of bimodal signals conveys some advantage in obtaining faster brake response times from drivers and that bimodal signals may be particularly beneficial in avoiding missed signals. At the same time, providing signals that vary along parameters known to affect perceived urgency also conveys a general response time advantage for high- relative to low-urgency signals. The current results indicate that making the distinction between whether or not a signal is of high or low urgency is much clearer when working memory demands are low. Providing high urgency signals resulted in fewer overall missed signals. As indicated by the three-way interaction, participants missed the most when low urgency, unimodal signals were presented in the high working memory load condition. Together, these results indicate that both signal urgency and the use of multiple modality combinations can potentially be used to effectively direct attention when drivers are distracted. The current study did include some limitations that should be taken into consideration. The sample had relatively few males due to the nature of the undergraduate participant pool. Further, for similar reasons, the sample was relatively young and it is possible that working memory load may prove more distracting to older adults than to younger adults. We did not find an effect of working memory load on responses. This may be due to participants' adherence to our instructions that they focus on completing the *n*-back task to the best of their ability thus compromising their responding to alerts. More research is warranted to examine further the nature of the relationship between urgency, modality and load and their applicability in more ecologically valid driving situations.

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