The Effects of Modality, Urgency and Message Content on Responses to Multimodal Driver Displays

Ioannis Politis
Glasgow Interactive Systems Group
School of Computing Science
University of Glasgow
Glasgow, G12 8QQ, UK
I.Politis.1@research.gla.ac.uk

Supervisor 1: Stephen Brewster
Glasgow Interactive Systems Group
School of Computing Science
University of Glasgow
Glasgow, G12 8QQ, UK
Stephen.Brewster@glasgow.ac.uk

Supervisor 2: Frank Pollick
School of Psychology
University of Glasgow
Glasgow, G12 8QB, UK
Frank.Pollick@glasgow.ac.uk

ABSTRACT

This work investigates the design and use of multimodal displays for the car. Driver cues that vary in urgency as well as message content and use the audio, tactile and visual modalities in all their unimodal and multimodal combinations have been designed and evaluated. The goal is to investigate how such displays can effectively alert drivers without distracting. This will form the basis for creating an algorithm using multimodal displays to inform drivers, based on warning design and characteristics of the driving task. A set of experiments conducted and planned in order to better understand this subject are described in this paper.

Author Keywords
Multimodal interaction, warnings, audio, visual, tactile, perceived urgency, perceived annoyance, perceived alerting effectiveness, situational urgency, recognition time, response time, simulator.

ACM Classification Keywords
H.5.2 [Information interfaces and presentation]: User Interfaces. - Auditory (non-speech) feedback; Haptic I/O; Voice I/O.

INTRODUCTION

The increasing use of multimodal displays in the car provides an opportunity for richer interaction. It also introduces a challenge on how to effectively inform drivers about events of varying urgency without distracting. Automotive manufacturers have started exploring the use of audio, visual and tactile modalities in vehicles. Thus, there is potential in presenting a set of guidelines for designing multimodal displays, without overloading drivers with unnecessary information and increasing risk.

Current research has identified ways to use the audio [11], visual [17] and tactile [13] modalities and some of their combinations [10], in order to achieve quick driver responses and low levels of distraction to the main driving task. The signified events are not always equally urgent, so research has also looked at how to design audio [6], visual [15] or tactile [23] signals conveying different levels of urgency. However, investigating the use of all combinations of these cues along with a primary simulated driving task is still an open topic [2]. Further the cues using audio, visual or tactile modalities are often not informative [13], or need some prior learning [5], requiring higher driver attention and leaving space for additional warnings designs. To address the above, this work investigates the use of multimodal warnings for drivers, taking into account the urgency of the situation, the content of the message, as well as parameters related to the driving task. An algorithm deciding which modalities are best and when, based on empirical data gathered will be created as a result.

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RELATED WORK

Several studies highlight the usefulness of multimodal displays to provide information related to the driving task. Ho & Spence [11] showed the effectiveness of naturalistic audio cues (car horn sounds) and speech warnings, when coming from the direction of a rapidly approaching vehicle. Ho, Tan & Spence [13] used directional vibrotactile cues to indicate an approaching danger and decreased drivers' reaction times during a simulated driving task, compared to cues presented from the opposite direction. Utilizing bimodal signals, Ho, Reed & Spence [10] achieved improved reaction times when using audiotactile presentation in front-to-rear-end collision warnings, through vibration on the torso and a car horn sound.

Investigating cues with a stronger semantic association to the signified events, Sullivan & Buonarosa [25] observed faster reaction times and higher recognition rates of car horn and tire sounds compared to abstract pulses. McKeown & Isherwood [19] compared abstract sounds, environmental sounds unrelated to driving (e.g. footsteps), environmental sounds related to driving (e.g. car speeding past) and speech messages. They found that abstract sounds had the highest response times and were the most difficult to identify. Speech and environmental sounds created the quickest responses and were identified best.

In the previous studies, the urgency conveyed through the warnings was not varied, resulting mostly in messages of high designed urgency. This can be a limitation for warnings design, since there are often less urgent events to be signified. Cao *et al.* [5] present an example where this was addressed, by investigating the audio and tactile cues conveying four different urgency levels. Using parameters like pitch, intensity and interpulse interval, a trend of higher urgency cues leading to faster responses was found. Lewis *et al.* [16] present another similar example, where they observed quicker response times in bimodal audio, visual and tactile cues compared to unimodal ones and in high urgency warnings compared to low urgency ones. However, not all combinations of modalities were used in the above studies, while messages were relatively simple in terms of semantic content. Therefore, there is still space in exploring more complex cues in the driving task, both in terms of content as well as modality combinations.

To provide guidelines for designing urgency in auditory warnings, several studies have investigated how signal parameters relate to perceived urgency. Edworthy, Loxley & Dennis [6] used higher fundamental frequency, higher speed and larger pitch range to increase the perceived urgency ratings of auditory warnings. Marshall, Lee & Austria [18] used parameters like lower pulse duration and lower interpulse interval to increase ratings of urgency of audio. Baldwin [1] reported that stimulus intensity influenced the ratings of perceived urgency and response times. Baldwin & Lewis [3] investigated the tactile modality, and found that pulse rate positively influenced perceived urgency, having less impact on perceived annoyance. Baldwin *et al.* [2], Lewis & Baldwin [15] and Pratt *et al.* [23] extended this investigation to audio, tactile and visual modalities and suggested pulse rate as a means to vary urgency across these three modalities. Although very useful, the above guidelines were mostly applied outside of the driving task and where there was such a task present, the multimodal combinations used were not exhaustive. The cues evaluated were largely repeated tones, leaving space for the evaluation of richer display designs.

In terms of designing urgency in speech messages, Baldwin & Moore [4] investigated the influence of signal words in collision avoidance messages. *"Danger"* was perceived as the most urgent, *"Warning"* and *"Caution"* as intermediate, and *"Notice"* as the least urgent. Hellier *et al.* [9] observed how acoustics and speaking style influenced the ratings of urgency. Urgent utterance of signal words increased ratings of urgency. Ratings of the word *"Danger"* were also highest in this study. Additionally, the potential for transferring some speech features into vibration has also been explored. Salminen *et al.* [24] used audiotactile messages, with the vibration mimicking speech and Tuuri, Eerola & Pirhonen [26] delivered pure tones either through audio or through vibration using intonation and rhythm of speech. The above studies are examples of using speech information in warnings, however in the case of audio signals there was no other modality investigated in combination with speech. This would enrich the interaction and enhance responses. In the case of the tactile equivalents to speech, none of the studies varied urgency in the tactile messages or used them in a driving context.

Regarding the nature of the simulated driving task, Horberry *et al.* [14] evaluated the use of billboards, buildings, vehicles and other highway furniture. It was found that they had a negative effect on driving performance. However, this study did not investigate the use of warnings in driving. Additionally, a systematic way to deliver such warnings based on the driving environment and the urgency of the events and the cues would advance available knowledge and aid responses. Previous studies have developed algorithms for prioritizing driver messages, e.g. [16,17] and modeling the driving task, e.g. [4,28]. However, the development of an algorithm delivering multimodal warnings based on environmental characteristics, urgency and message content is unexplored in the driving context.

In summary, there have been studies investigating the use of multimodal warnings in the car. There are also guidelines on how to design warnings of different urgency in this context. However, there is less work using all combinations of audio, tactile and visual messages to evaluate the available guidelines and present new insights on what modality combinations work best in which cases. Additionally, studies use either abstract warnings or speech warnings, but a comparison of abstract and speech warnings across all modalities has not been presented. Further, transferring rich information related to speech through vibration has never been investigated in the car. Therefore, this work addresses the above by investigating multimodal warnings for drivers across all unimodal, bimodal and trimodal combinations of the audio, tactile and visual modalities. All signals are evaluated along different urgency levels, depending on how critical is the signified event. New and richer cues along all modalities are investigated, while informative audio, visual and tactile cues are compared to abstract ones. Finally, parameters related to situational urgency (e.g. simulated environment, automated vehicle control) are taken into account. An algorithm deciding which modalities are best and when, based on the above information will be eventually designed, addressing the lack of such work.

RESEARCH APPROACH

This work will investigate through a series of experiments good ways to display multimodal information to drivers without causing distraction. With the empirical results acquired, an algorithm will be designed, which based on urgency, message content and characteristics of the driving task, will prescribe the appropriate cues. The main research questions of this work, along with the experiments designed to address them are presented below (see also Table 1 for a brief description of the experiments):

- How do abstract multimodal driver warnings perform in terms of subjective and objective measures? (Experiments 1and 2 – 1st year, completed)
- How does situational urgency influence responses to abstract multimodal driver warnings? (Experiment 3 – 2nd year, completed)
- How do informative multimodal driver warnings perform in terms of subjective and objective measures? (Experiments 4 and 5 – 2nd year, completed)

- How do abstract and informative multimodal driver warnings compare to each other in terms of subjective measures? (Experiments 6 and 7 – 2nd year, completed)
- How do more variations of situational urgency (e.g. simulated environment, automated vehicle control) influence responses to abstract and informative multimodal driver warnings? (Experiment 8 – 3rd year, planned)
- How does an algorithm prescribing modality, urgency and content of multimodal driver warnings based on situational urgency perform against a random delivery of warnings? (Experiment 9 – 3rd year, planned)

METHODOLOGY AND RESULTS

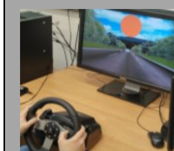
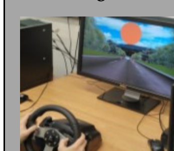
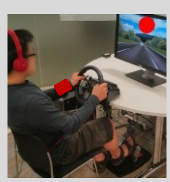
This research is based on a set of experiments in a driving simulator, gathering empirical results to inform the design of multimodal warnings. A brief description of the experiments conducted so far with the results gathered, as well as the experiments planned will be provided below. The factors studied in all experiments conducted so far, as well as pictures of the setup used can be found on Table 1.

Experiments 1 and **2** [21] evaluated the influence of modality and designed urgency of a set of abstract multimodal cues to subjective responses of perceived urgency and annoyance. Objective measures of recognition time and accuracy were also investigated. A set of unimodal, bimodal and trimodal messages with all combinations of Audio, Visual and Tactile modalities was used. This set was designed to convey three urgency levels, high, medium and low, by varying signal properties according to known guidelines, e.g. [6]. Strong evidence on the influence of number of modalities to the responses to multimodal warnings was found. More modalities created quicker recognition of the cues and higher ratings of urgency and annoyance. Cues of high designed urgency created quicker responses. Additionally, cues including the visual modality were perceived as more urgent, while cues including the tactile modality as more annoying.

Experiment 3 [20] evaluated the influence of situational urgency, i.e. the presence or absence of a critical driving event, to response times to warnings and driving metrics. The cues designed in [21] were evaluated in terms of reaction times. Additionally, situational urgency was varied, simulated as a car in front of the driver braking or not braking when the warnings were presented.

Results showed that reactions to warnings were quicker when presented along with a car braking and also when their designed urgency was high. Trimodal warnings induced quicker reactions compared to unimodal and bimodal ones. There was a limitation of the visual modality, observed as slower responses to warnings including visuals when there was a car braking and as poorer lane keeping behavior when the car braking event was present.

Table 1: Description of the experiments conducted so far.

Experiment	Independent Variables	Dependent Variables
1 	Modality Designed Urgency	Perceived Urgency Perceived Annoyance
2 	Modality Designed Urgency	Recognition Time Recognition Accuracy
3 	Modality Designed Urgency Situational Urgency	Response Time Lateral Deviation Steering Angle
4  	Message Modality Design	Perceived Urgency Perceived Annoyance Perceived Alerting Effectiveness
5 	Message Design	Recognition Accuracy
6 	Modality Information Designed Urgency	Recognition Time Recognition Accuracy
7 	Modality Information Designed Urgency	Recognition Time Recognition Accuracy Response Time Lateral Deviation Steering Angle

Experiments 4 and **5** [22] investigated subjective responses to informative auditory (A), tactile (T) and audio-tactile (AT) warnings for drivers, and recognition accuracy of the T warnings. A set of speech warnings across three urgency levels, high medium and low was designed according to known guidelines, e.g. [9]. Additionally, a set of new T warnings was designed, the Speech Tactons. These were derived from speech and retained its rhythmic parameters. The Speech Tactons were presented either alone or along with speech. All these warnings were evaluated for perceived urgency, annoyance and alerting effectiveness in Experiment 4. It was found that AT messages were rated as more urgent, annoying and effective compared to A and T ones. Perceived urgency and perceived alerting effectiveness was found to decrease along with the designed urgency of the messages. Further, perceived annoyance was higher for messages of lowest and highest designed urgency and ratings of urgency, annoyance and effectiveness did not vary significantly for the tactile modality. Experiment 5 investigated the recognition rates for Speech Tactons when they were not accompanied by Audio and found satisfactory results (50% - 80%).

Experiments 6 and **7** investigated responses to both informative (speech-related) and abstract cues so as to compare how well they perform against each other. Previous experiments have evaluated the performance of informative versus abstract audio [7, 11, 19] or tactile cues [8]. However, this investigation has never looked into all multimodal combinations of audio, visual and tactile warnings. Recognition time of abstract versus informative warnings during a low criticality task (i.e. recognizing the warnings' urgency) was investigated. Further, response time to warnings during a high criticality task (i.e. responding to high urgency warnings along with a car braking event) was assessed. Results showed an advantage of abstract cues and cues including visuals in the low criticality task. Cues including audio performed better while abstract and informative warnings performed similarly in the high criticality task. Driving behavior slightly worsened when responding to highly urgent warnings and a critical event. It was unaffected when exposed to warnings of medium and low urgency without a response task and without such an event.

Experiment 8, planned for 3rd year, will use a subset of the above modalities to evaluate their performance under different road situations. Having the same motivation as Experiment 3, this experiment will investigate more environmental parameters related to the driving task, as well as the influence of partially automating the vehicle control, so as to vary situational urgency.

Following the above experiments, there will be a set of results for different cues and situations. This will allow the creation of an algorithm, which based on these results will provide the appropriate signal (one or more of the above cues) at the appropriate time (depending on the situation) and in the appropriate way (with the appropriate modality). This will be evaluated in **Experiment 9**, planned for 3rd year, by providing a cue prescribed, versus a random cue.

CONCLUSION

This work will inform the design of multimodal displays for drivers and highlight a set of strengths and limitations of using these displays across varying contexts of urgency. Knowledge on the influence of warning design and situational urgency on the reaction to these displays will also be extended. The results will provide guidelines on delivering multimodal displays in the described contexts. The exhaustive study of all multimodal combinations in the cues, the design of richer informative multimodal cues and comparison with the abstract ones, the study of the cue performance in different driving situations and the delivery of an algorithm to prescribe the cues based on empirical results are the main contributions of this work.

QUESTIONS AND ISSUES

I am keen to discuss the following at the colloquium:

- The Algorithm to be designed will use empirical results to assign weights to multimodal cues, based on their performance. This will result to a set of lookup tables to choose the cues from, which are not presented here due to limited space. What is the best way to use these tables so that they are scalable for other cases, such as new cues, more environmental characteristics or driver characteristics such as age or workload?
- Speech Tactons presented good results when used in combination with audio messages in [22]. They also had acceptable recognition accuracy when used alone and after prior training. Can they be a recommended solution to be used alone in car warnings or do they need to be always tied to speech?
- What are some good metrics to use when measuring driving behavior during curves, in presence of repeated warnings triggered by simulated events?
- How can one assess good driving behavior during traffic? How does the number of cars play a role to this?

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REFERENCES

[1] Baldwin, C.L. 2011. Verbal collision avoidance messages during simulated driving: perceived urgency, alerting effectiveness and annoyance. *Ergonomics*. 54, 4 (Apr. 2011), 328–337.

[2] Baldwin, C.L., Eisert, J.L. and Garcia, A. 2012. Multimodal urgency coding: auditory, visual, and tactile parameters and their impact on perceived urgency. *Work*. 41, (2012), 3586–3591.

[3] Baldwin, C.L. and Lewis, B.A. 2013. Perceived urgency mapping across modalities within a driving context. *Applied Ergonomics*. (2013), 1–8.

[4] Baldwin, C.L. and Moore, C. 2002. Perceived Urgency, Alerting Effectiveness and Annoyance of Verbal Collision Avoidance System Messages. *HFES Annual Meeting*. 46, 22 (2002), 1848–1852.

[5] Cao, Y., van der Sluis, F., Theune, M., op den Akker, R. and Nijholt, A. 2010. Evaluating informative auditory and tactile cues for in-vehicle information systems. *AutomotiveUI '10* (New York, New York, USA, 2010), 102 – 109.

[6] Edworthy, J., Loxley, S. and Dennis, I. 1991. Improving auditory warning design: Relationship between warning sound parameters and perceived urgency. *Human Factors*. 33, 2 (1991), 205 –231.

[7] Edworthy, J., Walters, K., Hellier, E. and Weedon, B. 2000. Comparing Speech and Nonspeech Warnings. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*. 44, 22 (Jul. 2000), 746–749.

[8] Gray, R., Ho, C. and Spence, C. 2014. A comparison of different informative vibrotactile forward collision warnings: does the warning need to be linked to the collision event? *PloS one*. 9, 1 (Jan. 2014), e87070.

[9] Hellier, E., Edworthy, J., Weedon, B., Walters, K. and Adams, A. 2002. The Perceived Urgency of Speech Warnings: Semantics versus Acoustics. *Human Factors*. 44, 1 (Jan. 2002), 1–17.

[10] Ho, C., Reed, N. and Spence, C. 2007. Multisensory In-Car Warning Signals for Collision Avoidance. *Human Factors*. 49, 6 (2007), 1107–1114.

[11] Ho, C. and Spence, C. 2005. Assessing the effectiveness of various auditory cues in capturing a driver's visual attention. *Journal of experimental psychology. Applied*. 11, 3 (Sep. 2005), 157–74.

[12] Ho, C. and Spence, C. 2008. *Multisensory Driver*. Ashgate.

[13] Ho, C., Tan, H.Z. and Spence, C. 2005. Using spatial vibrotactile cues to direct visual attention in driving scenes. *Traffic Psychology and Behaviour*. 8, 6 (Nov. 2005), 397–412.

[14] Horberry, T., Anderson, J., Regan, M. a, Triggs, T.J. and Brown, J. 2006. Driver distraction: the effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident; analysis and prevention*. 38, 1 (Jan. 2006), 185 – 191.

[15] Lewis, B.A. and Baldwin, C.L. 2012. Equating Perceived Urgency Across Auditory, Visual, and Tactile Signals. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*. 56, 1 (Oct. 2012), 1307–1311.

[16] Lewis, B.A., Penaranda, B.N., Roberts, D.M. and Baldwin, C.L. 2013. Effectiveness of Bimodal Versus Unimodal Alerts for Distracted Drivers. *Human Factors in Driver Assessment, Training and Vehicle Design* (2013), 376–382.

[17] Lindgren, A., Angelelli, A., Mendoza, P.A. and Chen, F. 2009. Driver behaviour when using an integrated advisory warning display for advanced driver assistance systems. *IET Intelligent Transport Systems*. 3, 4 (2009), 390–399.

[18] Marshall, D.C., Lee, J.D. and Austria, P.A. 2007. Alerts for In-Vehicle Information Systems: Annoyance, Urgency, and Appropriateness. *Human Factors*. 49, 1 (Feb. 2007), 145–157.

[19] McKeown, D. and Isherwood, S. 2007. Mapping Candidate Within-Vehicle Auditory Displays to Their Referents. *Human Factors*. 49, 3 (2007), 417–428.

[20] Politis, I., Brewster, S. and Pollick, F. 2014. Evaluating multimodal driver displays under varying situational urgency. *CHI 2014* (New York, New York, USA, 2014), 4067 – 4076.

[21] Politis, I., Brewster, S.A. and Pollick, F. 2013. Evaluating Multimodal Driver Displays of Varying Urgency. *Automotive UI 2013* (2013), 92 – 99.

[22] Politis, I., Brewster, S.A. and Pollick, F. 2014. Speech Tactons Improve Speech Warnings for Drivers. *Automotive UI 2014* (2014).

[23] Pratt, S.M., Lewis, B.A., Penaranda, B.N., Roberts, D.M., Gonzalez, C. and Baldwin, C.L. 2012. Perceived Urgency Scaling in Tactile Alerts. *HFES Annual Meeting*. 56, 1 (Oct. 2012), 1303–1306.

[24] Salminen, K., Surakka, V., Lylykangas, J., Rantala, J., Ahmaniemi, T., Raisamo, R., Trendafilov, D. and Kildal, J. 2012. Tactile Modulation of Emotional Speech Samples. *Advances in Human-Computer Interaction*. 2012, (2012), 1–13.

[25] Sullivan, J.M. and Buonarosa, M.L. 2009. Acquisition, response, and error rates with three suites of collision warning sounds. *Proceedings of the Fifth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design* (2009), 284–290.

[26] Tuuri, K., Eerola, T. and Pirhonen, A. 2010. Leaping across modalities: Speed regulation messages in audio and tactile domains. *Haptic and Audio Interaction Design* (2010), 10 – 19.