A Beep, a Flash, a Rumble? Evaluating Multimodal Displays for Drivers

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

Abstract
Multimodal displays should alert drivers in effective ways without distracting. They have a great potential for improving the driving task and even preventing injuries that can result from critical events. This work investigates the design and use of such displays to alert drivers about events of varying importance. The goal is to assess responses based on urgency, situation on the road, driver workload, as well as driver characteristics. This will form the basis for designing an algorithm that will utilize multimodal displays to inform drivers.

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Multimodal interaction; warnings; audio; visual; tactile; perceived urgency; perceived annoyance; situational urgency; recognition time; response time; simulator.

Research Situation
I am in the second year of a 3.5 year PhD program in the University of Glasgow, School of Computing Science. I have completed my first-year evaluation and I anticipate finishing my doctoral work in late 2015. I identify myself as a usability specialist, with background in Computer Science.

My research topic is in the field of Multimodal Displays for Drivers. I am investigating the influence of urgency, type of information, simulated environment, driver workload and age on the responses to such displays. My end goal is to design an algorithm that will deliver the appropriate type of display to the driver based on these factors. So far I have evaluated the influence of designed and situational urgency in these displays, by completing a set of experiments in a driving simulator.

Experiment 1

Independent Variables	Dependent Variables
Modality	Perceived Urgency
Designed Urgency	Perceived Annoyance

Experiment 2

Independent Variables	Dependent Variables
Modality	Recognition Time
Designed Urgency	Recognition Accuracy

Experiment 3

Independent Variables	Dependent Variables
Modality	Response Time
Designed Urgency	Lateral Deviation
Situational Urgency	Steering Angle

Figure 1: Description of the experiments completed so far.

With this Doctoral Consortium, I intend to share some of the results that have emerged from my research so far, as well as discuss my plans on how to proceed.

Context and Motivation

The use of multimodal displays in cars introduces the challenge of how to effectively alert the driver without distracting the primary task of driving. Such new ways of providing information involving the audio, visual and tactile modalities are being considered by automotive manufacturers. Therefore, it is essential to create guidelines on designing warnings that will use these modalities to help drivers, without overloading them with information and increasing risk.

Background and Related Work

Current research has identified good ways to use the audio [5], visual [10] and tactile [7] modalities, as well as some of their combinations [4], in order to achieve quick driver responses and low levels of distraction. Since the events signified by the displays are not always equally urgent, research has also looked at how to design audio [3], visual [9] or tactile [13] signals that can convey different levels of urgency, depending on the relevance of these events.

However, investigating the use of all combinations of these cues along with a primary driving task is still an open topic [1]. Additionally, the ecological validity of the primary driving task used in existing studies is often low, leaving space for creating richer simulated tasks to ensure the effectiveness of the warnings in this context [6]. The cues using the audio, visual or tactile modalities are often not informative [7], or not informative enough [2], requiring high driver attention and prior learning. The effect of drivers' characteristics such as age, are also parameters that are not thoroughly investigated, when multimodal displays are used in the vehicle [8].

Therefore, this work will investigate multimodal warnings for drivers, taking into account the urgency of the situation, as well as parameters related to the environment and the driver, and create an algorithm that will decide which modalities are best and when, based on the above information.

Statement of Thesis or Problem

Complex information presentation is a growing trend in vehicle displays and could lead to information overload and driver distraction, compromising safety. Therefore, presenting the right information at the right time and in the right manner is critical. This work will investigate ways to display multimodal information while minimizing driver distraction. The delivery method will be decided based on urgency, driver responses and characteristics of the driver and the driving context.

Research Goals and Methods

The research will be based on a set of experiments in a driving simulator, investigating the influence of various parameters to the driving task and the responses to multimodal warnings. Three of these experiments have been conducted and four more are planned. The results will be used to design the aforementioned algorithm for delivering multimodal warnings. The experiments are listed below (see also Figures 1 and 2):

- Experiment 1 evaluated the influence of modality and designed urgency of the cues to subjective responses of perceived urgency and annoyance.

Experiment 1

Experiment 2

Experiment 3

Figure 2: Setup of the experiments completed so far.

- Experiment 2 evaluated the influence of the same factors to objective measures of recognition time and accuracy.
- Experiment 3 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.
- Experiment 4 will use informative speech and new tactile cues to construct the multimodal messages. The tactile cues will use prosodic features of speech to create vibrational messages. As in the previous experiments, both subjective and objective responses to these modalities will be acquired.
- Experiment 5 will use a subset of the above modalities to evaluate their performance under richer road situations such as varying weather conditions, road curvature or traffic.
- Experiment 6 will investigate the influence of increased driver workload when responding to the cues, by introducing a cognitive task while driving, for example interacting with a mobile device.
- Finally, experiment 7 will investigate how results of the above studies generalize for older drivers.

These results will inform the design of an algorithm for delivering multimodal warnings. The algorithm will be designed by placing weights on the factors investigated and using empirical findings to manipulate these weights, in order to decide the most appropriate display for every context. For example, a display that created long response times when situational urgency was high might receive a higher weight in this context and thus be less preferred by the algorithm. The algorithm will ideally be tested against a random selection of modalities and the results of driving metrics acquired will be compared so as to evaluate its effectiveness.

Dissertation Status

The chapters of my thesis related to Experiments 1, 2 and 3 are written. An outline of the thesis is also constructed to accommodate the content related to the experiments still to be performed.

Experiments 1 and 2 [11] found strong evidence on the influence of number of modalities to the responses to multimodal warnings. More modalities lead to quicker recognition of the cues and to 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 [12] also detected quicker reactions to trimodal as opposed to unimodal and bimodal warnings. When both situational urgency and designed urgency were high reactions were quicker. Visual warnings did not elicit as quick responses in the presence of a critical driving event as in the absence of the event. Finally, lane keeping and steering behavior was improved with the presence of warnings. However, when a car braking event was added this improvement was not present.

These results demonstrated how multimodal warnings of varying designed urgency can be recognized as such and also induce quicker responses as designed urgency and situational urgency increase. They also highlighted the potential of using multiple modalities to alert drivers. Finally the limitations of using the visual modality under critical situations simulated by a visual event and

the tactile modality when aiming to achieve quick recognition of the cues were identified.

The next set of experiments is expected to be covered in the next two years, so as to gather empirical results that will formulate the design of the algorithm.

Expected Contributions

With this work I 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. I also wish to extend knowledge on the influence of warning design, environment and driver characteristics on the reaction to these displays. The results will provide guidelines on delivering multimodal driver displays in the described contexts.

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