Multimodal Driver Displays: Potential and Limitations

Ioannis Politis
About me (http://yannispolitis.info/hci/)

● Background:
  – B.Sc. Informatics & Telecommunications – University of Athens
  – M.Sc. Advanced Information Systems – University of Piraeus
  – P.D.Eng. User-System Interaction – Eindhoven University of Technology
  – Usability Engineer – Philips Design Healthcare

● Currently a PhD student at Multimodal Interaction Group, University of Glasgow

● Supervisors:
  – Prof Stephen Brewster – Department of Computing Science (http://www.dcs.gla.ac.uk/~stephen/)
  – Prof Frank Pollick – Department of Psychology (http://www.psy.gla.ac.uk/~frank/)
  – Co-funded by Freescale Semiconductor Inc. (http://www.freescale.com/)

● Group research interests:
  – Multimodal human-computer interaction (HCI)
  – 3D sound and Earcons in human-computer interfaces
  – Novel multimodal interfaces for mobile devices
  – The use of force-feedback devices, tactile displays, thermal feedback, pressure input and Tactons
  – Sonification / Perceptualisation of data
  – Design of haptic medical simulators
  – Interaction design for older users and users with visual disabilities, homecare systems
  – Smell-based user interfaces
Introduction

- Multimodal warnings for drivers are increasingly used by car manufacturers.
- Excessive use of warnings may hinder the driving task.
- Available results reveal benefits of providing audio, visual and tactile warnings in isolation or in combination.
- However, there is still work needed on:
  - How to warn the driver without distracting the driving task.
  - How to effectively convey urgency in the cues.
  - How to deliver all combinations of multimodal warnings of varying urgency.
  - The influence of situational urgency, i.e. what actually happens in the driving task.
Pro-active collision avoidance systems

Automatic Distance Control (ADC) - Volkswagen

Lane Assist - Volkswagen

Collision warning systems

Lane Departure Warning - Ford

Blind Spot Detection - Ford

http://www.volkswagen.co.uk/technology/proximity-sensing/adc
http://www.volkswagen.co.uk/technology/proximity-sensing/lane-assist
http://media.ford.com/images/10031/BLIS.pdf
Available research (1/2)

- Spatially predictive as well as non-predictive vibrotactile cues, presented from the same direction as the approaching threat can decrease drivers reaction times during a simulated driving task (Ho, Tan & Spence, 2005).
- Audiotactile presentation (vibration on the torso and car horn) of front-to-rear-end collision warnings can lead to faster reactions in a simulated driving task compared to the unimodal presentation of the warnings (Ho, Reed & Spence, 2007).
- Tactile warnings on the seat belt can induce shorter reaction times during a critical situation compared to audio sounds and visual warnings (Scott & Gray, 2008).
Available research (2/2)

- Multimodal information presentation including speech and vibration on the steering wheel can lead to increased performance and user acceptance in a navigational task (Kern et al., 2009).

- Providing action suggestions through speech can provide benefits in performance and acceptance in a driving task, when avoiding collision with not-yet-visible obstacles. Moreover, the use of speech may not be the best candidate for critical warnings (Cao et al., 2010a).

- The use of looming auditory warnings (increasing in intensity as the vehicles approach) can lead to shorter break reaction times for drivers, compared to constant, pulsed or ramped audio warnings as well a car horn (Gray, 2011).
Five load conditions

Objective measures:
- Tracking error on a visual task
- Cue detection failure
- Cue identification accuracy
- Response time

Subjective measures:
- Ease of cue identification
- Modality preference
- Physical comfort
- Features used to detect the cues.

Main findings:
- "General trend" of higher priority, faster response
- More accurate identification for vibration
- Lower response times for sound (except when radio was present)
- More identification errors occurred along adjacent levels of priority, where the cues resembled each other
- Higher tracking error in the high load condition
- Higher tracking error for the higher two priority levels
- Sound rated as more intuitive and comfortable

Priority: Cao et al. (2010b)
“In future research […] it would be of interest to determine if low urgency alerts would result in both appropriate response and acceptability for low urgency situations (i.e. low fuel) relative to pairings of high urgency alerts with high urgency situations (i.e., collision situations of various types). […] Further, there is little if any information regarding the impact of multiple modality presentation on perceptions of urgency and annoyance.”
Standards for message priorities

- **ISO/TS 16951:2004: Road vehicles - Ergonomic aspects of transport information and control systems (TICS) - Procedures for determining priority of on-board messages presented to drivers:**
  - Recommends priorities of information, including navigation, warnings, systems status and telephone messages.

- **SAE J2395 (2007) : ITS In-Vehicle Message Priority:**
  - Describes the method for prioritizing in-vehicle messages and/or displayed information. A prioritization rule is used to determine the priority in which simultaneous or overlapping, in-vehicle messages are presented to the driver.
Our work: Motivation

- How does the **designed urgency** of the cues affect responses?
- How does the **amount of information** conveyed by the cues affect the results?
- How do parameters of the **environment** and the **driver** affect the use of multimodal displays?
- How do the cues perform when tested in situations of **high driver workload**?
- How do multimodal cues perform when tested in the context of a **driving simulator**?
### Warning Design

<table>
<thead>
<tr>
<th>Level 1 – High Urgency</th>
<th>Level 2 – Medium Urgency</th>
<th>Level 3 – Low Urgency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audio (A)</td>
<td>Audio (A)</td>
<td>Audio (A)</td>
</tr>
<tr>
<td>Visual (V)</td>
<td>Visual (V)</td>
<td>Visual (V)</td>
</tr>
<tr>
<td>Tactile (T)</td>
<td>Tactile (T)</td>
<td>Tactile (T)</td>
</tr>
<tr>
<td>Audio – Tactile (AT)</td>
<td>Audio – Tactile (AT)</td>
<td>Audio – Tactile (AT)</td>
</tr>
<tr>
<td>Tactile – Visual (TV)</td>
<td>Tactile – Visual (TV)</td>
<td>Tactile – Visual (TV)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Common level features</th>
<th>Audio</th>
<th>Tactile</th>
<th>Visual</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulses/sec: 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of pulses: 8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single pulse duration: 0.1 sec</td>
<td>Frequency: 1000 Hz</td>
<td>Frequency: 250 Hz</td>
<td>Color: Red, RGB(255,0,0)</td>
</tr>
<tr>
<td>Stimulus duration: 1.5 sec</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| **Level 2**           |       |         |        |
| Pulses/sec: 3         |       |         |        |
| Number of pulses: 5   |       |         |        |
| Single pulse duration: 0.17 sec | Frequency: 700 Hz | Frequency: 250 Hz | Color: Orange, RGB(255,127,0) |
| Stimulus duration: 1.5 sec |

| **Level 3**           |       |         |        |
| Pulses/sec: 1         |       |         |        |
| Number of pulses: 2   |       |         |        |
| Single pulse duration: 0.5 sec | Frequency: 400 Hz | Frequency: 250 Hz | Color: Yellow, RGB(255,255,0) |
| Stimulus duration: 1.5 sec |
### Experiment 1

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Dependent Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modality</td>
<td>Perceived Urgency</td>
</tr>
<tr>
<td>Designed Urgency</td>
<td>Perceived Annoyance</td>
</tr>
<tr>
<td>Context</td>
<td></td>
</tr>
</tbody>
</table>

- **Lead car doesn’t brake, no driving task.**
- **No simulator running**

- **Urgency of each stimulus**
- **Annoyance of each stimulus**
Results

● More urgent warnings were perceived as such.
● More urgent warnings were also perceived as more annoying, but this effect was not as strong.
● Warnings including the visual modality were perceived as more urgent, in all unimodal bimodal and trimodal signals.
● Warnings including the tactile modality were perceived as more annoying.
### Experiment 2

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Dependent Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modality</td>
<td>Recognition Time</td>
</tr>
<tr>
<td>Designed Urgency</td>
<td>Recognition Accuracy</td>
</tr>
<tr>
<td>Context</td>
<td></td>
</tr>
</tbody>
</table>

- **No simulator running**
- **Lead car doesn’t brake, only wheel operated.**

The experiment setup includes a steering wheel and a computer display, with labels indicating recognition time and accuracy.
Results

- More urgent warnings were recognized the quickest.
- More urgent warnings created less mistakes in recognition.
- Warnings including the tactile modality were recognized the slowest.
- Warnings were perceived as more urgent and more annoying when the number of modalities increased. The effect of annoyance was lower compared to urgency.
- Warnings including more modalities induced quicker responses.
## Experiment 3

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Dependent Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modality</td>
<td>Perceived Urgency</td>
</tr>
<tr>
<td>Designed Urgency</td>
<td>Perceived Annoyance</td>
</tr>
<tr>
<td>Situational Urgency</td>
<td></td>
</tr>
</tbody>
</table>

- **Lead car brakes, stimulus is presented**
- **Lead car brakes, stimulus is not presented**
- **Lead car doesn’t brake, stimulus is presented**

- **Lateral Deviation**
- **Steering Angle**
- **Response time**
Results

- Reactions to warnings were quicker when they were presented along with a car braking.
- Reactions to warnings with two or three modalities were quicker, as opposed to warnings with only one.
- Reactions to warnings including the visual modality was slower when they were presented along with a car braking.
- Although warnings created better steering and lane keeping behaviour, when a car braking event was added, this improvement was not present.
Conclusions

- More urgent warnings can be recognized and reacted to as such.
- There is benefit on using more modalities to convey a message when requiring quicker and more accurate responses.
- The advantage of visual warnings in terms of reaction times can be limited during critical situations, providing evidence of increased visual load.
- Tactile warnings can be perceived as more annoying and recognized slower compared to audio and visual ones.
- The presence of a critical event can create quicker responses compared to their presentation in the absence of such an event.
- Although lane keeping and steering behavior improves with the presentation of warnings, this improvement is limited in critical situations.
See also


- ISO/TS 16951:2004: Road vehicles - Ergonomic aspects of transport information and control systems (TICS) - Procedures for determining priority of on-board messages presented to drivers:


Thank you!
Appendix 1: Results of Experiment 1

More urgent warnings were perceived as such
More urgent warnings were also perceived as more annoying, but this effect was not as strong.

Warnings including the visual modality were perceived as more urgent, in all unimodal bimodal and trimodal signals.

Warnings including the tactile modality were perceived as more annoying.

* Significant result
More urgent warnings were recognized the quickest.

More urgent warnings created less mistakes in recognition.

Warnings including the tactile modality were recognized the slowest.

* Significant result
Significant result

Warnings were perceived as more urgent and more annoying when the number of modalities increased. The effect of annoyance was lower compared to urgency. People reacted quicker to warnings including more modalities.

Appendix 3: Results of Experiment 2 (2/2)

![Graph showing mean ratings and recognition time with significant results indicated.](image)

* Significant result
People reacted quicker to warnings when they were presented along with a car braking.

People reacted quicker to warnings with two or three modalities, as opposed to only one.

People reacted slower to warnings including the visual modality when they were presented along with a car braking.

Although warnings created better steering and lane keeping behavior, when a car braking event was added, this improvement was not present.

* Significant result