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Perceived urgency mapping across modalities within a driving context

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Hazard mapping is essential to effective driver-vehicle interface (DVI) design. Determining which modality to use for situations of different criticality requires an understanding of the relative impact of signal parameters within each modality on perceptions of urgency and annoyance. Towards this goal we obtained psychometric functions for visual, auditory and tactile interpulse interval (IPI), visual color, signal word, and auditory fundamental frequency on perceptions of urgency, annoyance, and acceptability. Results indicate that manipulation of IPI in the tactile modality, relative to visual and auditory, has greater utility (greater impact on urgency than annoyance). Manipulations of color were generally rated as less annoying and more acceptable than auditory and tactile stimuli; but they were also rated as lower in urgency relative to other modality manipulations. Manipulation of auditory fundamental frequency resulted in high ratings of both urgency and annoyance. Results of the current investigation can be used to guide DVI design and evaluation.

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1. Introduction

Modern automobiles, like many other advanced technological systems, utilize increasingly sophisticated displays capable of presenting information to the driver in a variety of ways. New components continue to be introduced into the driver-vehicle interface (DVI) increasing both its potential usefulness and complexity. One of the many advances that have taken place recently is the use of vibrotactile signals in addition to the more common auditory and visual displays. Vibrotactile signals show promise for improving a driver's response to potential collision situations, particularly under distracted conditions (Fitch et al., 2011) and when presented in combination with signals in other sensory modalities (Ho et al., 2009; Lee et al., 2006).

Determining the relative merit of providing information to drivers in one modality versus another is a challenging task. The choice of which modality to use will depend on many factors including the context in which the signal is likely to occur (e.g., daylight driving in dense traffic in relatively noisy conditions versus nighttime driving in quiet surroundings), driver characteristics (e.g., driver's age and sensory/cognitive capabilities), as well as the driver's state (e.g., alert versus fatigued) and habits (e.g., likely to be engaged in multiple tasks and distractions) and experience level (expert versus novice drivers). Also critical is the situation that the cue is designed to represent. Current and future driver DVIs will provide signals to drivers that are designed to represent a considerable range of situations that vary in criticality and importance. For example, current systems such as SYNC for MyFord Touch®100 or MyLincoln Touch®122 support hands free interactions with incoming calls and texts and navigation assistance while also interacting with driver safety systems such as blind spot indicators and collision avoidance technologies. It is critical to effective design that signals are appropriately mapped to the situations they are designed to represent (Dingus et al., 1998; Edworthy, 1998; Edworthy et al., 1991; Edworthy and Stanton, 1995).

1.1. Perceived urgency mapping

Mapping the perceived urgency of a signal to the hazard level which it is designed to represent has been recognized as an important aspect of warning design since at least as far back as the 1980's (Chapanis, 1994; Edworthy et al., 1991; Hollander and Wogalter, 2000; Patterson, 1982, 1990; Wogalter and Silver, 1990, 1995). When signals are too prevalent, intense, abrasive, startling, or simply too numerous they cause annoyance and distraction (Baldwin, 2011; Edworthy et al., 1991; Marshall et al., 2007; Wiese and Lee, 2004), have little or no performance benefit (Baldwin & May, 2011), reduce trust in the system (Lees and Lee, 2007) and can even lead to impaired reactions to subsequent critical events (Fagerlonn, 2011). As the number of displays and alerts in the DVI proliferate it will be increasingly important to ensure that the signals, alerts and warnings presented convey appropriate levels of urgency.

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The relationship between changes in several key physical stimulus parameters and perceived urgency in visual and auditory modalities has been documented. For example, as the fundamental frequency of a sound increases, and/or as the time interval between pulses of sound decreases, it is perceived as increasingly urgent (Edworthy et al., 1991; Hellier and Edworthy, 1999; Hellier et al., 1993). Likewise, as the wavelength of visible light increases (hue or perceived color changing from green to yellow to red) it is perceived as more urgent (Chapanis, 1994; Wogalter et al., 2002, 1998). In general, there is a direct relationship between perceived urgency and annoyance, such that as a signal becomes more urgent it is also perceived as more annoying (Baldwin, 2011; Marshall et al., 2007). However, the context in which the signal is presented influences this relationship (Wiese and Lee, 2004). More urgent signals are perceived as less annoying in conjunction with situations where the high urgency seems appropriate (collision warnings) relative to situations where it is less appropriate to receive a very urgent signal (e.g., navigation command or email alert) (Marshall et al., 2007). Further research is needed to elucidate the impact of different types of context on the relationship between perceived urgency and annoyance and the potential impact that signal modality may play in this relationship. Choosing an effective modality and parameter level is particularly important for time critical situations represented by collision warnings.

1.2. Collision avoidance systems

Several research investigations have compared the time drivers take to respond to collision warnings presented in one modality versus another (Kramer et al., 2007; Mohebbi et al., 2009; Scott and Gray, 2008). For example, Scott and Gray (2008) compared brake response times to visual, auditory, and tactile collision warnings and concluded that tactile warnings resulted in the fastest responses. Mohebbi et al. (2009) compared auditory versus tactile warnings when drivers were engaged in simple versus complex simulated cell phone conversations. Participants in their study exhibited faster response times to tactile warnings relative to auditory warnings while engaged in both simple and complex conversations. However, despite careful consideration of the type of auditory and tactile signals to present (gleaned from existing guidelines and the available literature), it remains possible that in both of these investigations the signals presented in the different modalities may not have been equally salient to drivers. That is, driver response times may have differed significantly from those observed had they used different types of auditory or tactile signals (e.g., different intensity, frequency, or temporal pulse patterns).

In fact, drivers may fail to even notice some visual warnings (Curry et al., 2009). This is of practical significance since an undetected alert is of little use. However, it is also possible that visual signals that are perceived as more urgent or that are more salient are more likely to capture attention and subsequently be more effective. For example, a flashing red alert that is perceived as highly urgent may be more effective than a low frequency, low intensity, long burst of sound. However, without first equating the two signals for perceived urgency it would be misleading to suggest that modality alone was driving differences in signal effectiveness. The primary rationale for the current study was to compare stimuli across visual, auditory, and tactile modalities for perceived urgency in order to facilitate future examinations of the effectiveness of modality across equivalent urgency levels.

A wide variety of different auditory, visual, and tactile signals have been compared. Visual signals frequently consist of an array of light emitting diodes (LEDs) in various colors (e.g., red, amber, yellow or green) that may or may not flash and may be located in a variety of head-up and head-down positions (Kramer et al., 2007; Neale et al., 2007; Scott and Gray, 2008) modeled after those examined in the Crash Avoidance Metric Partnership (CAMP) program (Kiefer et al., 1999). The CAMP program was designed to provide guidance on collision alert timing and modality requirements. Based in large part on that research, many subsequent investigations of auditory signals have examined various nonspeech tones. In the CAMP project, Keifer et al. (1999) compared the crash warning capabilities of a tone with a peak at 2500 Hz and the spoken signal word, such as “Warning” repeated. Both the speech and nonspeech auditory signals were set to play from the car speakers at 67.4 dBA. Kiefer et al. (1999) concluded that the nonspeech tone had superior crash warning alert capabilities relative to the speech warning. This result corroborated Tan and Lerner’s (1995) multiattribute evaluation findings that the auditory sounds most likely to be effective as primary collision avoidance warnings were also nonverbal sounds. Many subsequent DVI researchers have tended to avoid speech warnings and concentrate instead on nonverbal tones. For example, Wiese and Lee (2004) compared two nonverbal sounds thought to convey different levels of urgency and Scott and Gray utilized a 2000 Hz tone.

It is of note that in the Kiefer et al. investigation, speech warnings were initially rated as the most favorable on key attributes, such as noticeability, and urgency. Despite this only one speech warning was examined and it was always presented in combination with a head down visual display. On average brake responses were slower to the speech warning relative to the nonspeech warning. It is possible that the lower fundamental frequency of the speech or its relative ability to penetrate through the ambient background noise resulted in a fundamental difference in detectability and perceived urgency that could have significantly impacted the results. Various subsequent studies have found that acoustic factors interact with semantic factors (e.g., signal word) (see Baldwin & May, 2011 and Edworthy et al., 2003) and that this interaction can impact both perceived urgency and collision avoidance response (Baldwin, 2011).

Haptic or Tactile alerts vary, but in the CAMP report they consisted of a “vehicle jerk” that simulated the feeling of a brake pulse (Kiefer et al., 1999). Other researchers have examined vibrotactile signals presented in various places – the seat pan (Fitch et al., 2011) or a waist belt (Ho et al., 2007; Ho et al., 2009; Mohebbi et al., 2009) at a variety of temporal rates. For example, Fitch et al. (2011) used an interpulse interval (IPI) of 50 ms in a collision avoidance signal context; Van Erp and Van Veen (2004) examined IPI rates ranging from 270 ms to 10 ms. Research for DVIs will need to determine the most effective parameters within each modality or combination of modalities for these imminent crash warnings while also examining efficient methods of cueing the driver’s attention appropriately to less critical situations. Equating signals for urgency across differing modalities and modes will be essential to appropriate hazard mapping for both critical and noncritical alerts.

1.3. Noncritical alerts

Not all signals presented to drivers should connote high urgency. For example drivers may be alerted to incoming phone messages and emails, receive information regarding future and near turn route guidance, as well as weather, traffic, and road conditions. Future DVIs will have the capability of providing even more information to the driver making it critical to appropriately match the urgency conveyed with the importance and time criticality of the situation it represents. For example, in one investigation of driver acceptance of simulated distraction mitigation alerts both middle-aged and older drivers reported significantly higher acceptance of these non-time critical alerts when they were presented in a visual rather than auditory modality (Donmez et al.,

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