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The effectiveness of auditory forward collision warning alerts

Xingwei Wu [a], Linda Ng Boyle [a,*], Dawn Marshall [b], West O'Brien [a]

[a] University of Washington, Seattle, WA 98195, United States
[b] University of Iowa, Iowa City, IA 52242, United States

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ABSTRACT

The objective of this study is to evaluate the effects of auditory warning characteristics from a forward collision alert system on drivers' avoidance behavior. A driving simulator study was designed and conducted with a pre-collision scenario that included a lead vehicle decelerating. This scenario is used to examine whether any casual relationship exists between the auditory alert characteristics and collision avoidance. The study included 192 participants across the U.S. The auditory characteristics, including fundamental frequency and duty cycle, were examined at three urgency levels. The data from the study was analyzed using Partial Least Squares (PLS) path modeling. The collision avoidance behavior was measured using two reaction times (throttle release, brake) and three response intensities (maximum brake pedal force, maximum lane deviation and response type). All tested warning alerts resulted in reduced collision rates, shorter reaction times, larger maximum brake pedal force, and larger maximum lane deviation when compared to the baseline condition without a warning. Participants were also more likely to simultaneously brake and steer when given an alert. The models illustrate that the auditory warning information has both a direct and indirect effect on occurrence of collisions, with the indirect effect playing a more important role on collision avoidance than the direct effect. The findings also showed that the low urgency level of duty cycle and high urgency level of fundamental frequency are not recommended for collision warning alerts.

1. Introduction

Rear-end collisions, in which a vehicle collides with the rear of a slower moving or stopped preceding vehicle, are among the most common of vehicle-related accidents. In 2014, there were nearly 2 million police-reported rear-end collisions, which represents over 30% of all police-reported crashes (Cicchino, 2017). Each year, rear-end collisions kill approximately 17,000 people and injure over 500,000 people (Helsey, 2015). With the introduction of smart phones and new in-vehicle technologies, drivers today are more easily distracted in vehicles. According to a National Highway Traffic Safety Administration (NHTSA) report, up to 87% of rear-end crashes are related to driver distraction (NHTSA, 2007).

A Forward Collision Warnings System (FCWS) uses sensors (radars or lasers) and cameras to detect vehicles and other obstacles in front of the vehicle. If an obstacle is detected and the collision risk exceeds a certain safety threshold, an alert is issued. FCWS can effectively draw a driver's attention to critical roadway incidents and has the potential to reduce both the severity and occurrence rate of rear-end collisions. Jermakian (2011) estimated that FCWS along with Autonomous Emergency Braking System (AEBS) can potentially prevent or mitigate up to 70% of rear-end collisions and 20% of all

* Corresponding author.
E-mail address: linda@uw.edu (L.N. Boyle).

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passenger vehicle collisions. The Highway Loss Data Institute, who performed a series of studies analyzing U.S. insurance claim rates, found that FCWS alone was associated with 7–22% reductions in rates of property damage liability claims and 4–25% reductions in rates of bodily injury liability claims.

There are three commonly used alert modalities for collision warning systems in passenger vehicles: auditory warnings, visual warnings, and tactile (or haptic) warnings. Visual warnings alert drivers by displaying warning information on the instrument cluster or in a heads-up display (Wege, Will, & Victor, 2013). However, when presented alone, visual warnings may go unnoticed by drivers whose attention is away from the location of the visual icon (Curry, Blommer, Greenberg, & Tijerina, 2009). Additionally, a visual alert may allocate a driver's attention toward visual icons rather than toward the roadway, which can increase the driver's workload and the likelihood of a crash (Baumann, Keinath, Krems, & Bengler, 2004). Tactile or haptic alerts provide a vibration cue to drivers in a location where they have direct contact such as the seat, steering wheel or pedal (Haas & Erp, 2014). Drivers may also miss haptic or tactile warnings if the driver is not in direct contact with the specific portion of the vehicle when the alert is issued (Verbunt & Bartneck, 2009). Auditory warnings provide alerts to the drivers using representational sounds that can include omni bearing sound signals to ensure that drivers receive the warning regardless of where he or she is looking at.

An effective auditory alert for collision warning systems should be noticeable, catch the driver's attention, depict significant urgency, and deliver correct information to drivers. Previous studies noted that drivers respond faster to alerts that sound more urgent within an acceptable range (Burt, Bartolome, Burdette, & Comstock, 1995; Edworthy, Hellier, Walters, Weedon, & Adams, 2000; Haas & Casali, 1995). The urgency of measures can be manipulated by changing the physical characteristics (e.g., frequency, inter-pulse interval) of an auditory alert. Many researchers have demonstrated how different characteristics of auditory alerts are associated with different perceived urgency levels. For example, alert tones with higher fundamental frequency, shorter inter-pulse, and higher intensity (loudness) are perceived as more urgent (Haas & Casali, 1995; Hellier, Edworthy, & Dennis, 1993; Marshall, Lee, & Austria, 2007). Lerner et al. (2015) conducted a series of experiments to identify the ranges of auditory characteristics where sounds would be classified by drivers as highly urgent collision alerts and provide mean value for each individual characteristic of those highly urgent alerts: base frequency (931.71 Hz), tempo or inter-burst interval (330 ms), pulse duration (460 ms), and pulses per burst (2.73).

Previous studies showed that an auditory characteristic at high urgency levels can accurately convey meaning for urgent situations (Baldwin & Lewis, 2014; Edworthy, Loxley, & Dennis, 1991). However, auditory alerts with too high a level of perceived urgency may startle or produce other negative effects on drivers responses (Blumenthal, 1996). Moreover, highly urgent alerts may increase annoyance and workload (Wiese & Lee, 2004). Thus, it is important to identify the range of each single auditory characteristic that would span the transition point between effective alerts and ineffective alerts (Lee, McGehee, Brown, & Marshall, 2006). While numerous studies have been conducted to measure and investigate the influence of FCW on drivers' performance (i.e. reaction times and collision abatement), the detailed characteristics of avoidance behavior with FCWS still need be understood comprehensively. Particularly, few studies were found investigating the causal relationship between alert characteristics, human factors, collision avoidance behavior, and collision abatement.

The goal of this study is to examine the effectiveness of the auditory FCW alerts given different urgency levels. The research hypothesis is that drivers' behavior and ability to avoid a crash will differ given the type of urgency level provided in their in-vehicle auditory alert system. Five warning alerts are generated from two different auditory characteristics at three urgency levels to provide a better understanding of the relationship between changes in a characteristic and perceived urgency.

2. Method

2.1. Participants

The participants were recruited from four different data collection sites: Iowa City, IA, Seattle, WA, Clemson, SC, and Austin, TX. The combination of these sites provides geographic variety that includes bi-coastal, southern, and mid-west regions of the United States, a range of population densities and socioeconomic factors from which to draw a representative sample.

There were 192 men and women, aged 25–55 years old, who successfully completed the study. They had no known health issues based on a pre-screening tool. The age and gender groups are comparable to previous related studies. For example, the Crash Warning Interface Metrics (CWIM) project used a similar age group of 25–59 to investigate peoples comprehension of message content for visual status displays of advanced collision warning systems (Lerner et al., 2011). They were required to have a valid US drivers license for at least two years and drive at least 3500 miles/year. Although the proposed sample of participants may not represent the general driving population, these participants do represent those drivers who are most likely to use a Collision Warning (CW) system (Najm, Stearns, Howarth, Koopmann, & Hitz, 2006).

2.2. Apparatus

All data collection sites used one-quarter cab, miniSim driving simulators with 42″ 720p plasma displays. The simulator includes three screens (3.0′ [wide] by 1.7′ [tall] each) positioned four feet away from the drivers eye point. They also had the same version of the miniSim software, comparable cab interface boards, steering loaders and sound cards to ensure the same data collection apparatus at each site.