Attention Enhancement During Steering Through Auditory Warning Signals

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Abstract
Nowadays modern cars integrate advanced driving assistance systems which range up to fully automated driving modes. Since fully automated driving modes have not come into everyday practice yet, operators are currently making use of assistance systems. While still being in control of the vehicle, alerts signal possible collision dangers when, for example, parking. The reason for the necessity of such warnings is the fact that humans have limited resources. A critical event can stay unnoticed simply because the attention was focused elsewhere. This raises the question: What is an effective alert in a steering environment? Auditory warning signals have been shown to efficiently direct attention. In the context of traffic, they can prevent collisions by heightening the driver's situational awareness to potential accidents.

Author Keywords
Attention; driving assistance systems; auditory warning signals; situational awareness; looming; multitasking

ACM Classification Keywords
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Introduction

Controlling a vehicle without assistance is a complex task. Task-critical information during driving is mostly vision-based. To account for different visual inputs, we need to divide our attention, switch between different visual tasks, and attend selectively between, for instance, pedestrians and vehicles surrounding us. In addition, an operator has to be aware and judge not only the speed and distance, but also estimate the risk of a situation and react appropriately upon it. When driving in a new town, for example, we might be focused on the GPS' commands and fail to notice a pedestrian that is about to cross the street. Assistant systems have been developed to enhance situational awareness in driving environments. By using onboard sensors such as real-time cameras, they detect collision candidates and strive to capture a driver's attention effectively with the correct use of alerts. By doing so, the mental processing time for the otherwise neglected event is sped up and hastens the execution of appropriate behavioral responses.

Attention in the context of driving

One of the most common road traffic accident causes can be interpreted as being of the "looked, but failed to see" type (Hills, 1980). This failure to notice can be ascribed to limits of visibility (visual object size, luminance, proximity), an object's conspicuity (depends on the environment), but also to higher-order problems such as a driver's state (fatigue, stress), expectancy, and availability of attentional resources. This phenomenon of inattentional blindness when focused on a task suggests that our attentional resources are limited. It challenges the traditional view that individual sensory modalities process information independently (multiple resource theory; Wickens 2008). Multiple resource theory might suggest, for example, that auditory information is processed independently from visual information, perhaps to the extent that talking on the phone while driving would not interfere with the steering task. Studies and everyday life have proven otherwise: Talking, with passengers or on the phone, while driving can increase the risk of collision significantly (McEvoy, Stevenson, & Woodward, 2007; Redelmeier & Tibshirani, 1997) as well as induce a neglect of road signs, pedestrians, and other vehicles (Strayer & Drew, 2004). Therefore, it would appear that sensory information is integrated from multiple streams under certain circumstances, in which attentional bottlenecks constrain performance at either a modality-specific or at a higher, crossmodal level of attention (Lavie, 1995). In other words, an overload of information can occur when we have to process too much visual information (perceptual level) but also when information is coming from different modalities at a cognitive level. Therefore, it is useful that we are able to actively focus our attention on a certain task and, in doing so, ignore irrelevant information that might only serve to interfere with the primary task objectives (Hillyard & Münte, 1984; Posner, 1980). In the context of driving this would mean that we are primarily focused on the steering task, including speed control and lane maintenance as well as navigation, but ignore other information as a consequence. Being engaged in non-driving activities such as conversations or entertainment systems can lead to compromised safety. Given this, complementary and artificial warning signals can be used to capture and direct a driver's attention to the crucial place at the right time.

Different types of auditory warnings

This raises the question: What is an effective alert in a steering environment? Behavioral studies have shown that auditory cues can direct visual attention compellingly, while preventing a visual overload. Nevertheless, there are many different auditory signals that could be used and the question remains which auditory cue is suitable. Speech warnings would be very intuitive auditory warnings. However, they are not ideal for several reasons. Even though speech warnings require minimal to no learning, in an emergency situation they could take longer to process than tonal cues (Ho & Spence, 2012). The problem rises with speech warnings being longer than two single-syllables. In emergency situations, operators are compelled to act before the message is finished and, hence, might not understand the warning correctly. Additionally, the speech warning could be masked by distractors such as the instructions of a navigation device, a conversation, or the radio. Another option for an auditory alert is an iconic sound (e.g., car horn). Although this could be an intuitive and highly effective warning, it comes with the drawback of evoking significantly more false alarms than other tonal cues (Gray, 2011). The reason being, that the car horn can easily be confused with real occurrences from the extrapersonal space (outside the car). Another road user could be honking for various reasons and motivations, i.e., another driver, bicyclist, or pedestrian. To avoid false alarms through confusion with sounds from the environment, artificial yet meaningful cues need to be employed. Hence, ecologically valid signals that resemble the real-world collisions serve as a strong candidate (Brewer, 2000). These ecologically valid sounds could tap into our intuitive tendency to orient towards threat (Bach et al., 2008). In the real world, a moving object that approaches an observer would be perceived with increasing intensity. Such a looming sound could be characterized by its intensity and frequency profile, which conveys its estimated time-to-contact. Conversely, a receding sound corresponds to the reversed profile that characterizes a departing object.

Previous studies on looming sounds

Previous studies have evaluated the effectiveness of looming and receding sounds and have consistently demonstrated preferential processing of a looming alert. To begin, behavioral studies showed a strong attentional preference for looming sounds, meaning that subjects oriented more or responded faster to the rising sound profile (Ghazanfar, Neuhoff, & Logothetis, 2002; Maier, Neuhoff, Logothetis, & Ghazanfar, 2004; Cappe, Thut, Romei, & Murray, 2009). So what about the neural representation of these dynamic signals? Brain imaging studies with looming and receding stimuli have investigated these neural underpinnings for the preferable processing of rising sounds. Results showed a greater cortical activity for looming compared to receding sounds (Maier & Ghazanfar, 2007) as well as greater functional interactions between auditory and visual cortices (Maier, Chandrasekaran, & Ghazanfar, 2008; Tyll et al., 2013). Furthermore, a greater activation of the amygdala and the superior temporal sulcus has been demonstrated, suggesting that looming cues are associated with an evaluation of threat and induce a stronger percept of object motion (Seifritz et al., 2002; Bach et al., 2008; Maier et al., 2008). Cappe, Thelen, Romei, Thut, & Murray (2012) were able to combine behavioral and the neurophysiological studies by showing direct links between faster reaction times and earlier mental processing for multisensory looming stimuli.

In the context of steering, Gray (2011) investigated the utility of different auditory alerts in simulated front-to-rear collisions. He found that auditory looming alerts elicited the fastest braking responses, if their intensity increased in relation to an impending collision with an oncoming car in a driving simulator. This finding was shown in comparison to other auditory alerts, such as constant tones, linearly rising tones, oscillating tones, or recognizable sounds (e.g., car horns). More importantly, Gray (2011) designed the looming auditory alert to have a rising intensity profile that denotes the estimated time-to-contact of a colliding object. In doing so, he demonstrated that braking response times corresponded with the estimated time-to-contact, and not merely the rising intensity profile.

Even though auditory warning signals have been in use, for instance, in parking assistance systems, it seems to be worthwhile to consider the implementation of ecologically valid warnings. Most of these former alerts deal with stationary dangers. But what about approaching vehicles that one is about to collide with? This is where ecologically rising sounds with a time-to-contact profile could be very convenient. They can convey the time until collision through their physical properties and hence convey the urgency to react. Given the previous findings, these intuitively interpretable cues could enable us to start processing critical information earlier which in turn quickens a behavioral reaction, such as breaking. This could save critical time when braking to avoid an approaching collision. To date, it remains to be shown how looming cues work for spatial cueing in a steering environment.

Conclusion

The key to understand how drivers operate and how their behavior can be improved in multitasking situation such as steering/navigation and hazard detection is to study the state and allocation of attention. Auditory warning signals can capture and direct operators' attention to draw attention to a secondary task so that the driver can evaluate and react accordingly to avoid a possible accident. Given previous studies, looming sounds with an ecologically valid intensity profile are desirable sounds because they would trigger the intuitive threat system that urges the human to avoid collisions. At the same time, one would not have to compromise on the primary steering performance when using these looming signals.

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