Original Research Paper

Assessment of driver compliance on roadside safety signs with auditory warning sounds generated from pavement surface–a driving simulator study

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HIGHLIGHTS

- A low-cost, engineering countermeasure, called auditory warning sound (AWS), was proposed.
- The effects of AWS were assessed with driving simulator experiments.
- Results showed AWS improved driver compliance to roadside safety signs effectively.
- AWS would be effective where drowsy driving crashes are an issue.

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ABSTRACT

A variety of word messages are used in highways in different forms to inform drivers of traffic safety information or to influence positively drivers' behavior. These include direct word messages for a particular event (such as road work) or general safety messages that warn drivers of risky driving behaviors (such as distracted driving and speeding). However, it is often observed that many drivers even do not recognize the safety messages despite being displayed on roadside signs in a fairly good visibility condition. The present study focused on an engineering method, namely auditory warning sound (AWS), which calls driver's attention on driving tasks and helps them comply with roadside safety signs. A driving simulator experiment was conducted to assess effects of AWS on driver compliance to roadside safety signs. AWS was implemented into driving simulator scenarios as a parameter to generate a certain level of growling warning sounds when subject vehicles are entering within a legibility distance of a roadside safety sign. The present study described laboratory setup and data for the driving simulator experiment, and drew conclusions on driver compliance to roadside safety signs with and without presence of AWS. The experiment results show that drivers are more compliant to roadside safety signs when AWS is used. It is expected that AWS will greatly help drivers comply with roadside safety signs where a specific safety concern is raised, such as a work-zone or a drowsy driving advisory zone.

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1.   Introduction

Various word or picture messages are used in highways in different forms to inform drivers of traffic safety information or to influence positively drivers' behavior. These include direct messages for a particular event (such as road work, incident, and weather information) or general safety messages that warn drivers of risky driving behaviors, such as distracted driving and speeding (Zhong et al., 2003). However, it is often observed that many drivers do not recognize the safety messages despite being displayed on roadside signs in a relatively good visibility condition (Dewar and Olson, 2007; Shinar, 1978). Many factors are associated with this sign recognition issue, including limitations of human beings on information processing, driver distractions, weather, and complexity of traffic, roadway, and roadside conditions (Loy and Barnes, 2004).

The present study focused on a low-cost, engineering countermeasure, namely auditory warning sounds (AWS) with a treated pavement surface, which helps drivers keep eyes on the road and comply with roadside safety signs. The safety treatment was selected as it would be effective in alerting drivers as well as help them recognize objects on roads or roadsides where a specific safety concern is raised, such as a work-zone or a drowsy driving advisory zone (Kang et al., 2015; Kozak et al., 2006; Royal, 2002).

Many studies explored an auditory alarm device as part of an in-vehicle driver assistant system to see its effectiveness on assisting complex driving tasks (Fagerlonn, 2010; Fagerlonn et al., 2012; Lin et al., 2009). However, their scope is limited to vehicles having such a technology. A road surface treatment generating AWS, however, is an engineering application for all road users as anyone can hear tire-pavement noise when traveling on it. The objective of the present study is to evaluate the effectiveness of the safety countermeasure on driver compliance to roadside safety signs. To attain the objective, a driving simulator was used to i) build a typical rural freeway track, ii) develop various driving scenarios, and iii) analyze driver behavior with and without presence of AWS. A similar study was conducted by Lee and Abdel-Aty (2008), using a driving simulator, to examine driver behavior with response to variable message sign (VMS) warning of downstream speed changes implemented via variable speed limits (VSL) control. The study showed that driver compliance to the downstream speed is significantly affected by presence of VMS and type of message displayed on the sign. It is important to note however that this study could have results that are more reasonable if it considered a possibility that drivers may not recognize traffic signage and VLS displays during a driving task, which is commonly observed in real-world. All participants in the study were asked to drive only a short (i.e., 5 miles) section of a freeway track where VMS and VLS were present. Thus, a relatively high driver compliance rate could be obtained with a short period of a driving task given. To realistically represent possible driver distraction in real-world, the present study developed a 42.5-mile-long roadway track, and each participant was asked to drive 24 miles of the track in different locations. Specific roadway sections where a series of events are implemented for analyzing driver behavior ("analysis section" in this paper) were provided after 5—7 miles of a normal freeway section.

Another similar study was conducted by Lin et al. (2009), using a virtual reality driving experiment, to see the effect of auditory warning signals on drivers' attention. In the study, driver response was tested using different audio stimulus under several conditions (e.g., 500, 1750, and 3000 Hz continuous warning tones). The study showed that auditory warning signals increase drivers' attention and improve driving safety. The study however was for warning signals embedded in an in-vehicle driver assistant system, not for a low-cost infrastructure countermeasure which can be implemented in the field.

This paper is organized as follows. After the introduction, Section 2 describes AWS used in the present study. Section 3 briefly introduces a driving simulator used in the study. Laboratory setup (i.e., roadway tracks and scenarios design) and core data collected from driving simulator experiments are discussed in Section 4. Section 5 describes how the experiments proceeded. In Section 6, data inclusion criteria for analyzing driver behavior data are discussed. Data analysis and findings, through a logistic regression analysis and a two-way repeated measure ANOVA test, are discussed in Section 7. Section 8 concludes the summary and limitations of the present study.

2.   Auditory warning sounds

In the present study, a software algorithm was developed and implemented into driving simulator scenarios as a parameter to generate a certain level of growling warning sounds (i.e., AWS) when subject vehicles are entering within a legibility distance of a roadside safety sign. Note that AWS is not an in-vehicle information system popularly used in-vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communication technologies (Fagerlonn, 2010; Fagerlonn et al., 2012; Koegel et al., 2010). It is a noise generated from a tire-pavement interface when vehicles are traveling on a treated road surface. AWS with a treated surface is a low-cost engineering counter-measure to improve vehicular safety and guidance. It can break the monotony of the common road noise generated by the same type of pavement surface. It is important to note that AWS is to help drivers' eyes on the road against distraction, without (or minimally) affecting vehicle speed reduction (Rimini-Doering et al., 2005). Thus, a treated road surface for AWS should be distinguished from transverse rumble strips typically used in intersection approaches or freeway ramps and tollbooths for reducing vehicle speeds (Lee et al., 2013; Srinivasan, 2010). In driving simulator scenarios of the present study, we set vehicle speeds not to be automatically changed unless intended by subject drivers. Note that surface texture with characteristic length less than 10 mm tends to reduce noise and vibration according to Bernhard et al. (2005).

A typical noise level inside a normal passenger car, running at 50 mph or higher in a light traffic condition, is about 60 dB (Johnson and Saunders, 1968; Lee et al., 2013). Rumble strips can increase the noise level inside the car by 10—15 dB according to a recent study by Haron et al. (2012). A recording of a rumble strip sound from the field was implemented into