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Efficacy of haptic blind spot warnings applied through a steering wheel or a seatbelt ☆

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ABSTRACT

This study evaluates the efficacy of haptic feedback for the Blind Spot Warnings (BSWs) that are delivered to a driver through a steering wheel or a seatbelt. To this end, we developed a virtual driving simulator that implemented potential side collision scenarios. Haptic BSWs were issued as a vibrotactile alert during lane changes if a car in the target lane approached from the participant's blind spot at a faster speed. The two haptic warning types were assessed through a human factors experiment with participants of two age groups: younger (30–40 years) and older (50–60 years). No warning condition was also included as the control condition. As performance measures, the Collision Prevention Rate (CPR) and the Minimum Distance by which a collision was Avoided (MDA) were collected. As preference measures, the participants' perception of usefulness of the haptic warnings and their overall satisfaction were used. Experimental results showed that the highest CPR, the longest MDA, and the highest preference were achieved when BSWs were delivered through the steering wheel. For the seatbelt BSW, the CPR and MDA did not increase with statistical significance than those of the no-warning condition, but the participants felt that the haptic seatbelt was useful with high satisfaction. Interestingly, the scores of perceived usefulness and satisfaction were higher with the older group, suggesting that older drivers can be more willing to accept these new types of warning. In addition, the experiment suggested several factors that need to be studied to further improve the performance and preference of haptic BSW, such as warning issue timing and vibration intensity.

1. Introduction

Driving is a complicated sensorimotor task that requires a very high visual workload; 95% of information is identified by vision (Shinar & Schieber, 1991). Furthermore, drivers' visual workload is increasing as the road environment (e.g., traffic, pedestrians, roadside obstacles, and street vendors) becomes more complex (Horberry, Anderson, Regan, Triggs, & Brown, 2006). To cope with this complexity, drivers must shift their visual attention continually within a driving environment while performing other tasks such as decision making and body control (Salvucci & Liu, 2002). These competitive tasks do not allow drivers to always concentrate on information sources that are critical for safe driving. When drivers' attention is occupied, they can even commit a cognitive failure called "*looked but failed to see*," in which they miss clearly visible objects (Herslund & Jørgensen, 2003).

☆ Relevance to Industry: To enhance road safety, the present study evaluates several haptic feedback methods that warn a driver of potential blind spot collisions. A virtual driving simulator was developed for a user experiment. The experimental scenarios and specifications of the haptic warnings used in the experiment are specified in the paper.

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In this regard, lane changes are one of the most notoriously hazardous situations, especially for novice drivers. About 5% of reported car accidents occur during lane changes (Svenson, Gawron, & Brown, 2005). For safe lane changes, a driver must scan a large area around the car, including the front and back of both the current and target lane. This requirement of divided visual attention can cause the driver to miss objects that appear briefly on a side mirror. This problem is exacerbated by the presence of blind spots in which objects are invisible to the driver (Wang & Knipling, 1994). Various methods have been proposed to reduce blind spots. These include the use of wide-view room mirrors, convex mirrors attached on the side mirror, and progressive multifocal mirrors (Fig. 1). In spite of their effectiveness, collision risks are still present if the driver's visual attention is away from those mirrors.

To improve this situation, research direction has been shifted toward developing effective Blind Spot Warning (BSW) systems, which can direct the driver's attention to the locations of potential hazards. For this purpose, vision and audition have been the major sensory modalities. For example, visual BSW often uses signal lights that blink or flash on the side mirrors or A-pillars, and auditory BSW commonly use beepers. Nevertheless, visual warnings impose an additional visual burden on the drivers who are already exposed to a great amount of visual workload, while sound alarms can be masked by ambient noise or loud music (Ryu, Chun, Park, Choi, & Han, 2010).

To find a remedy for these drawbacks, the automobile industry has begun to apply haptics technology. Haptic display is an effective, reliable, and direct way of delivering information for in-car controls (Burnett & Mark Porter, 2001) and offers an alternative way for providing information to the driver under heavy visual workload (Van Erp & van Veen, 2004). In particular, haptic signals are effective in conveying simple and intuitive meanings when adequately associated with the egocentric orientation of events (Choi & Kuchenbecker, 2013; Jones & Sarter, 2008). As such, haptic warnings in the form of vibrotactile stimuli have been tested for various purposes, including forward collision warning (Green, 2008; Ho, Reed, & Spence, 2007; Lee, Hoffman, & Hayes, 2004), BSW related to lane change warnings (Campbell, Richard, Brown, & McCallum, 2007; Kochhar & Tijerina, 2006), curve speed warning (Green, 2008), lane departure warning (Griffiths & Gillespie, 2005), speeding warning (Adell, Várhelyi, & Hjälmdahl, 2008), and road departure crash warning (Campbell et al., 2007).

By compiling the test results of such studies and expert judgments, NHTSA (National Highway Traffic Safety Administration) summarized the efficacy of several haptic warning types for BSW—brake pulse, accelerator counter-force, accelerator vibration, steering wheel torque, non-directional steering wheel vibration, and seat vibration (Campbell et al., 2007). In this report, haptic warnings in the form of seat vibration and steering wheel torque were rated as '*Fair*' and '*Good*'. The other haptic warning types, including *non-directional* steering wheel vibration, were all rated as '*Poor*,' which means that those haptic warning types are unable to deliver warnings against blind spot collisions intuitively and instantaneously.

In the present study, we consider two more types of haptic BSWs that have not been tested before: a haptic steering wheel that presents *directional* vibrotactile feedback to the hands and a haptic seatbelt that provides *tangential* vibrotactile feedback to the chest. In the directional vibrotactile feedback, the direction of a potential collision is informed by the position at which a vibration is produced (left or right half of the steering wheel). The haptic seatbelt is a new commercial system that can deliver collision warnings and secure the driver at the same time. The seatbelt vibrates along its length direction upon the driver's chest when warnings are issued. We evaluated the efficacy of the two haptic warning systems through a human subjects experiment with two groups of participants in different age bands (30–40 and 50–60 years). Details of the investigation are presented in the rest of this paper.

2. Driving simulator

2.1. Hardware

The driving simulation system used in our experiment is shown in Fig. 2. The simulator consisted of a high-performance computer, a steering wheel with an accelerator and a brake pedal (G25 Racing Wheel; Logitech, USA), a driving seat, a vibrotactile feedback seatbelt (Pre-safe Seatbelt; Hyundai Motor Company, Korea), and three visual displays (Fig. 3). The seat,

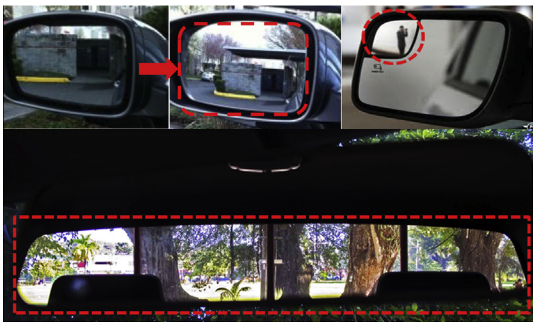

Fig. 1. Examples of blind spot reduction methods.