

Evaluating the effectiveness of haptic feedback on a steering wheel for FCW

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ABSTRACT: The effectiveness of a haptic warning on a steering wheel in an automobile was evaluated in terms of forward collision warning (FCW). An effective warning system is critical for safe driving, especially when the driver is not paying attention to the road. Haptic feedback warning systems have attracted interest because they do not require any extra visual load; warnings are transmitted to the driver using tactile sensation and are not interfered by ambient noise around the vehicle. Twenty-four subjects participated in the study. Experiment was conducted in a virtual reality environment that simulated collision situations involving FCWs. Performance measures that were evaluated in the FCW experiment included the driver's reaction time to the warning signal. The results show that a haptic FCW on the steering wheel can play a supportive role in preventing a collision. We conclude that haptic warning on a steering wheel could be useful for FCWs.

Keywords: haptic feedback system, forward collision warning, blind spot warning.

1 INTRODUCTION

Constant visual attention on the road is important for safe driving. However, a driver's attention is often distracted by audio, navigation, and driver information systems. The additional visual load incurred while using such systems can increase the risk of collision (Ranney et al. 2000).

Issuing a warning signal via a visual display can be problematic as this can simply serve as an additional visual distraction. Audio is commonly used in warning signals; however, warnings issued in this way cannot be transferred effectively when the driver is surrounded by ambient noise (Ryu et al. 2010). Moreover, when audio signals are already in use in the vehicle, the meaning of the warning signal can be confusing in an urgent situation.

A warning signal that utilizes haptic feedback can offer an effective alternative. Via direct contact, haptic feedback can deliver information effectively and in a manner that the driver can respond to intuitively. In addition, the information is transmitted only to the driver; the passengers remain unaware of the warning.

Recently, the automobile industry has begun using haptic feedback in warning systems. Examples include warning drivers of a potential forward collision, as well as blind spots and lane departure. In most instances, the haptic feedback is transmitted

via the steering wheel, seat or pedals. Researchers have evaluated the effectiveness of haptic warning signals in various situations such as FCW, LDW (Lane Departure Warning), and BSW (Blind spot warning) (Lerner et al. 1997, Lee et al. 2004, Griffiths et al. 2005, Navarro et al. 2007). Campbell et al. (2007) summarized the results of existing studies and empirically evaluated the effectiveness of various proposed warning systems. However, some combinations of warning location and warning situation have not yet been fully examined (Table 1). We do not know whether it is effective to provide a signal on the steering wheel for FCW and BSW.

In our study, we assessed haptic feedback on the steering wheel in FCW situation.

Table 1. Results of evaluation of haptic feedbacks on collision warning systems

	FCW	LDW	BSW
Seat	GOOD	FAIR	FAIR
Steering Wheel	-	GOOD	-

Haptic feedback on pedals was excluded due to the potential disturbance that might occur while manipulating the pedals (Campbell et al. 2007). An additional problem with haptic feedback on pedals is that the amplitude of the signal can be seriously affected by the thickness and material of the sole of the driver's shoe. By evaluating the effectiveness of a combination of haptic feedbacks in warning situations not previously stu-

died, the effectiveness of warning signals can be compared qualitatively.

2 METHODS

2.1 Apparatus

A driving simulator was developed to represent events surrounding FCW in a virtual environment. A 50-inch monitor and two 23-inch monitors were used to ensure a seamless representation of the driving environment. A 7-inch touch screen was used for a secondary task (Fig. 1).

Six vibration actuators (3 on the left, 3 on the right) were embedded in the steering wheel to deliver sufficient amplitude of haptic feedback (Fig. 2). All 6 vibration actuators were activated at the same time (frequency 100Hz; amplitude, 0.025 mm; and periodic envelope with 0.4 sec on-time and 0.1sec off-time). Pilot tests were conducted to determine the specification of the vibration feedback.

Participants wore headphones that played white noise to prevent sound cues being generated from haptic feedback. The actual size and layout of the seat and steering wheel were considered when designing the seating buck. The distance between the seating buck and steering wheel was adjustable to reduce driver discomfort.



Figure 1. Example of secondary task device

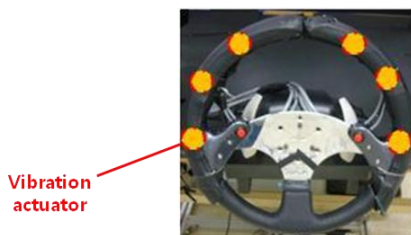


Figure 2. Haptic steering wheel (Circles are locations of vibration actuators for haptic warning)

2.2 Participants

Briefly, two different age groups, 30–40 yrs and 50–60 yrs, were assessed in each warning system. Since the ability to detect haptic sensations reduces with age (Verrillo et al. 2002), we aimed to determine the effect of age on driver effectiveness in the FCW experiment. For the age group of 30–40yrs, the participants consisted of 12 males, with an average age of

39.3. The average age of the older group was 56.0 (12 male participants).

2.3 Experiment design and scenario for FCW

The independent variables were haptic warning and age group. Dependent variables evaluated were performance and preference measures.

The performance measures were the rate of collision prevented and reaction time. We divided the number of successful decelerations (without collision) by the total number of collision events to calculate the rate of collision prevented. The reaction time was defined as the time that elapsed between deceleration of a preceding vehicle (with a brake light on) and manipulation of the brake pedal.

The preference measures examined were usefulness of the proposed warning signal and overall driver satisfaction. The participants were also asked to consider the inconvenience of the proposed haptic warning when evaluating overall driver satisfaction.

In the experiment, a dual-task paradigm was used to distract participants while driving. As a primary task, the participants were asked to follow a car that maintained a speed of 80 km/sec. In the secondary task, they were required to continuously enter 7 digits that appeared on a touch screen (Fig. 1). From pilot test, we found that the participants were distracted for about 10 sec while completing the secondary task. Whenever a participant makes consecutive errors while entering digits, we determined that the participant was not concentrating and hence excluded the data.

While conducting the secondary task, the vehicle in front randomly started to decelerate and the participants were instructed to manipulate the brake pedal to avoid possible collision. Each participant repeated the FCW event 20 times. The warning signal was transmitted 4 sec prior to collision. Once the warning signal was transmitted, it maintained until TTC (Time To Collision) exceeded 4sec.

3 RESULTS & DISCUSSION

The initial speed of participants' vehicles and the average distance between vehicles did not show a significant difference based on independent variables. Therefore, the forward collision events can be assumed to have occurred under similar driving conditions.

In the 30–40 yrs age group, the reaction time was significantly shorter in the presence of the haptic warning. Similar results were observed in the older age group (Fig. 3). When the haptic warning was present, participants were more quickly able to recognize that the car in front was decelerating. A shorter reaction time was associated with a decrease

in the braking distance (7.36 m, 30–40 yrs; 4.89 m on average, 50–60 yrs).

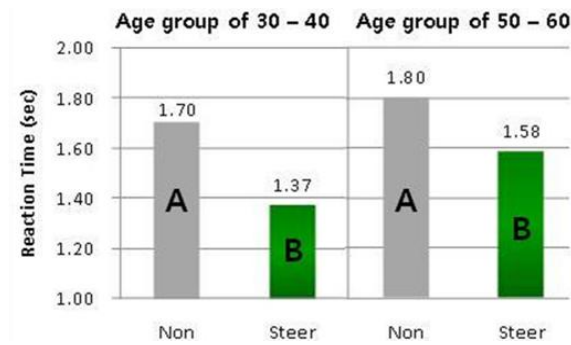


Figure 3. Reaction time

The number of collisions significantly decreased with haptic warning (Fig. 4). However, the effectiveness of the haptic warning was relatively small in the older age group. Generally, the absolute threshold of haptic sensation increased with age. Overall, this resulted in a lower detectability of haptic warning in the older age group.

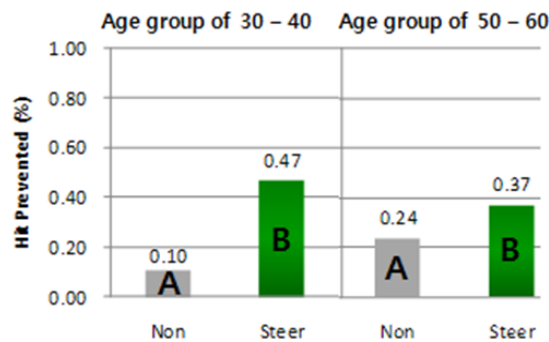


Figure 4. The rate of hit prevented

The results of preference evaluation showed that participants found the haptic warning useful and satisfactory (Fig. 5).

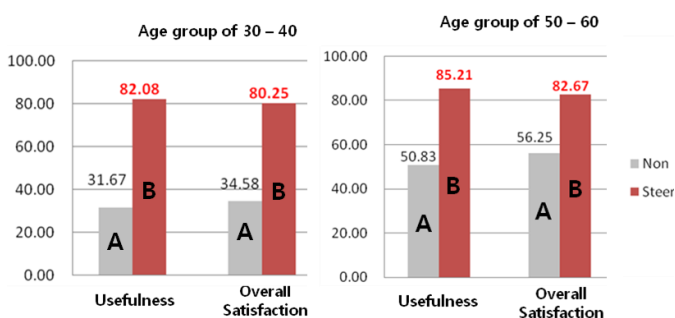


Figure 5. Results of evaluation of preference measures (FCW)

Participants in the younger group favored haptic feedback more than the older group (the score of preference measures greatly increased when haptic warning is given). Some participants commented that although they found haptic feedback strange at first, they soon became familiar with the stimuli.

4 CONCLUSION

In this paper, we evaluated haptic warnings on the steering wheel for FCW, which has been studied in previous studies. The risk of collision was significantly decreased in the presence of the haptic warning, and the effectiveness of the warning was consistent across the entire age band evaluated in this study. Moreover, participants felt the warning useful and were satisfied with its performance. The performance of the younger group in particular was better when haptic warnings were given.

Based on our results, we conclude that haptic feedback can be effectively used in FCW. The methods proposed in this study could be used to evaluate other types of warnings for FCW. Further study is needed to find a robust specification of haptic feedback suitable for older age groups. We plan to conduct additional research on the value of haptic feedback on BSW. Also, we will consider other driving situations such as heavy or speeding traffic.

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