Evaluating the Effectiveness of Haptic Feedback on a Steering Wheel for BSW

*Jaemin Chun[1], Gunhyuk Park[2], Seunghwan Oh[1], Jongman Seo[2], In lee[2], Seungmoon Choi[2], Sung H. Han[1]**

[1]Department of Industrial & Management Engineering, POSTECH, South Korea
[2]Department of Industrial & Management Engineering, POSTECH, South Korea
*shan@postech.edu

ABSTRACT

Driver's inattention to blind spots is one of the main causes of lane change-related car accidents. Efforts have been made to eliminate such blind spots but there still exist some areas around the vehicle that cannot be directly observed by the driver. Also, drivers cannot always focus on the rear-view mirror or side mirrors that help them to monitor other vehicles near blind spots. So, for this study, we used a collision warning system based on a different modality to find out whether it can enhance drivers' awareness of other vehicles in blind spots. A haptic feedback was applied on a steering wheel for BSW (Blind Spot Warning). Haptic feedbacks are known to have several advantages over other modalities. First, they do not require any extra visual load which is already heavily placed upon drivers while driving in general cases. Second, haptic warnings are transmitted to the driver in a private way so other passengers are not disturbed by warnings like flashing lights or loud alarms. Third, haptic feedbacks are free from ambient noises that are generated by various sources around the driver. In this study, the effectiveness of haptic feedback was evaluated by comparing the performance and preference measures of the haptic condition with the non-haptic condition. For the performance measure, the collision prevention rate was analyzed as well as the minimum distance between the vehicles after collision events were carried out. As for the preference measure, the participants were asked to score the perceived usefulness and the overall satisfaction of the provided collision warning. For this experiment, a total number of twenty-four males in two different age groups (30-40 yrs and 50-60 yrs) were recruited to define the age effect. A virtual driving simulator with a software program and devices was developed and collision scenarios were provided to the participants. In the experimental scenario, participants were to perform as drivers and were asked to follow a preceding car which changes lanes from time to time. A haptic warning signal was presented on the steering wheel when a vehicle approached from the driver's blind spot while the participant moved into the other lane to follow the preceding car. Haptic feedbacks were generated in separated locations (left and right) of the steering wheel corresponding to the direction of the possible collision event. The warning was provided to the participants 4 seconds before an expected collision. To isolate the vibration of each haptic feedback and prevent them transferring from one side to the other, the rim of the steering was sawed-off. As shown in the evaluation result, the effect of haptic BSW was valid to the participants. They avoided possible collision situations better with the help of haptic BSW. Also, when the participants successfully avoided the collision event, the mean minimum distance between their vehicle and the other vehicle increased, indicating the decreased possibilities of an accident. In terms of age, the younger group has shown better performance than the older group due to their superior detectability of haptic stimuli and motor skills. As for preference measures, the participants felt haptic BSWs as useful and were highly. The older participants in particular have shown higher level of perceived usefulness and satisfaction with haptic BSWs. From the result of our study, we conclude that the haptic BSW on a steering wheel could be helpful for safe driving.

Keywords: haptic, collision warning, blind spot

1 INTRODUCTION

Blind spots on the sides of a vehicle are closely related to drivers' safety when changing a lane (Svenson et al., 2005). Drivers are frequently unaware of the other vehicle's approach due to blind spots. Several monitoring techniques were introduced to minimize blind spots and help drivers to obtain a better vision of them (Becker et al., 2005, Krips et al., 2003). However, even when blind spots are effectively removed, drivers can still meet problematic situations when they fail to observe the side mirrors at the appropriate time. As the most important and essential task of drivers is to monitor the situation of the road ahead, drivers should be aware of the movement of the preceding car even when they are making a lane change. This means that drivers should constantly shift their visual attention between the road and side mirrors. As a result, from time to time, drivers unintentionally lose their visual attention from side mirrors at critical moments during a lane change. This is especially true for novice drivers who experience greater difficulty when switching their attention from road to side mirrors. Thus, an effective warning is needed to direct driver's attention to side mirrors when necessary.

Several attention-gathering techniques using visual and auditory cues were developed by automobile manufacturers. However, even with visual BSWs such as flashing lights, drivers still have some chances of missing the warning signal because they cannot identify the warning when their attention is focused on the road. Also, a BSW with an auditory alarm can be blocked by ambient noises surrounding the driver (Ryu et al, 2010). Recently, to overcome these limitations of visual and auditory warnings, haptic feedback has been introduced. Haptic feedback is suggested as an effective warning signal in terms of reaction time (Carlander et al., 2007) and in effectively providing the warning signal solely to the driver through a direct contact (Chun et al., 2010). Based on empirical data and expert review, Campbell et al. (2007) evaluated the effectiveness of various haptic warning systems (brake pulse, accelerator counter pulse, seat shaker and etc.) applied on diverse warning situations. However, compared to other types of haptic warning systems, relatively limited evaluation was conducted on the haptic steering wheel. So, in our study, we evaluated the effectiveness of the haptic steering wheel as a BSW through an experiment.

2 METHODS

2.1 Apparatus

A driving simulator with a software program and devices was developed to present a virtual driving environment and the possible collision events to the participants. Also, an adjustable sitting buck of the actual size and layout of a vehicle was arranged. A 50-inch and two 23-inch LCD monitors were used to provide frontal view and side views (Figure.1) and these displays were calibrated to enable a seamless surrounding view for the driver.

Figure 1 Driver's vision in virtual simulator

To generate haptic BSW, three off-the-shelf vibration motors were attached on each side (left and right) of the steering wheel (Figure.2) and the specification of the vibration feedback (frequency:120 Hz; amplitude: 0.014 mm; periodic envelope: 0.2 seconds on-time and 0.1 seconds off-time) was determined through a pilot test. To isolate the vibration feedback from each side of the steering wheel, the rim of the steering wheel was physically disconnected by sawing. Participants were asked to wear ear plugs and headphones (with white noise played) to block the sound cues being generated from the vibration actuators.

Figure 2 Haptic steering wheel (Yellow circles are locations of vibration actuators)

2.2 Participants

As human sensitivity to haptic stimuli degrades with age, we considered two age groups (30-40yrs and 50-60yrs) and recruited 12 participants for each group. The average age of the younger group was 39.5 while it was 54.0 for the older group.

2.3 Experiment design and scenario

For each age group, two warning conditions were evaluated: non-haptic and haptic. In non-haptic condition, the participants had to detect the collision risk only by observing side mirrors, which is a general case. When the haptic BSW was provided, the participants identified the collision risks with the help of a vibration feedback. To evaluate the effectiveness of warning conditions, several performance and preference measures were used. For performance measures, the collision prevention rate and the minimum distance were collected. The minimum distance was defined as the distance between the participants' vehicle and the other vehicle at a time when the participants successfully avoided the collision event. After the experiment, the participants were asked to give scores to the preference measures including the perceived usefulness and the overall satisfaction. When grading the overall satisfaction of each warning type, we asked the participants to also consider the inconvenience brought about by the proposed warning type.

In the experiment, the participants' task was to follow a car running at a speed of 80km/h and changing lanes occasionally. When they move into the other lane to follow the preceding car, a possible collision scenario plays out; a high speed vehicle from the blind spot suddenly approaches the participants' vehicle. To avoid any possible crash, participants were asked to manipulate the brake pedal and the steering wheel. The possible collision events were provided to each participant for

20 times and a haptic BSW was activated 4 s econds before a collision. The participants' behavior was video-taped to observe any interesting reactions.

3 Results and Discussions

A t-test was conducted to define the statistical significance of warning conditions on performance and preference measures. Regardless of the age group, participants showed a significantly higher collision prevention rate with haptic BSW ($t(477) = 3.09$, $p < 0.0021$ for the younger group and $t(472) = 2.71$, $p < 0.0070$ for the older group) (Figure.3). The collision prevention rate increased from 0.34 to 0.48 for the younger group and from 0.24 to 0.35 for the older group.

While changing lanes to follow the preceding car, the participants had to switch their visual attention frequently between the side mirror and the road and they instantly lost their visual attention on the side mirror during the process. By providing the haptic BSW on the steering wheel, drivers were able to refocus their distracted visual attention to the side mirrors and this resulted in a decreased collision rate. In general, the younger participants were able to perform better with haptic BSW due to their superior cognitive ability of visual and tactile sensation.

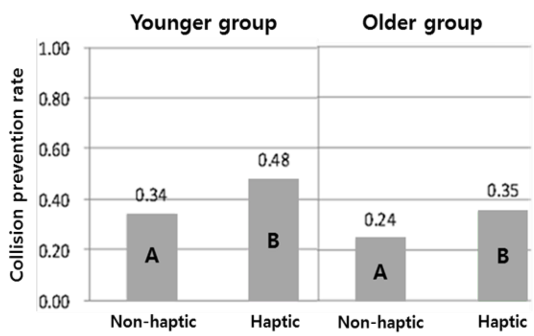

Figure 3 Collision prevention rate

Similarly, when the haptic BSW was provided, the average minimum distance increased significantly for both age groups; $t(458) = -3.26$, $p < 0.0012$ for the younger group and $t(454) = -2.50$, $p < 0.0127$ for the older group (Figure.4). The minimum distance increased from 0.10 m to 0.15 m for the younger group, and 0.06 m to 0.10 m for the older group.

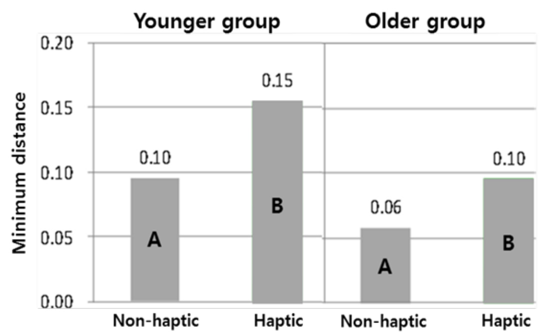

Figure.4 Minimum distance

Not only were the participants of both age groups able to avoid the collision successfully, their minimum distance increased significantly with the haptic steering wheel. This indicates that it is better to have the BSW with 4 seconds of TTC; participants were able to identify the collision risks when there was less than 4 seconds before the crash. If we set the BSW's TTC above 4 seconds, we can reduce the collision risk by increasing the minimum distance. However, care should be taken when determining the warning timing since an earlier warning can increase the rate of false alarm at the same time.

Participants' preference measures were significantly affected by the warning condition. They felt that the haptic steering wheel was useful ($t(22) = -5.45$, $p < 0.0001$ for the younger group and $t(22) = -5.71$, $p < 0.0001$ for the older group) and were satisfied with the haptic BSW ($t(22) = -5.23$, $p < 0.0001$ for the younger group and $t(22) = -5.22$, $p < 0.0001$ for the older group) even though they felt some discomforts with the unfamiliar warning type. Judging from the score difference between the warning conditions (younger group's usefulness score rose from 41.25 to 79.16 and satisfaction score from 37.50 to 77.92 while those measures increased from 54.58 to 82.92 and from 56.25 to 86.25 respectively in the older group), younger group felt greater advantage with the haptic BSW than the older group (Figure.5).

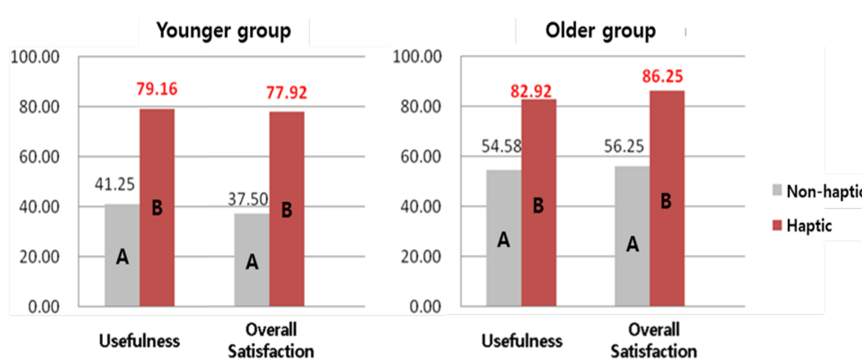

Figure.5 Perceived usefulness and Overall satisfaction

As what we have identified from the video analysis, conservative and safety-oriented driving habits of older drivers (Green, 2009) have resulted in relatively smaller score gap between the warning conditions among the older group than the younger group. Also, the score difference between the preference measures (the perceived usefulness and the overall satisfaction) show that both age groups' level of discomfort experienced by the haptic BSW is not significant. Although the provided haptic BSW was new to participants, according to the participants comments after the experiment, the level of discomfort greatly decreased after experiencing it for several times.

4 CONCLUSIONS

In this study, we empirically evaluated the effectiveness of the haptic steering wheel by comparing the haptic BSW condition with the non-haptic condition. The participants were able to detect the collision risk better and more successfully avoid a possible crash with the haptic BSW. Also, distance between the participants' car and the other car increased when they successfully stopped the vehicle after receiving the haptic BSW at possible collision event. The effectiveness of the proposed haptic BSW was valid for participants of all age groups tested in this study. Participants considered the haptic BSW useful and were satisfied with the way warnings were provided. Also, they quickly became familiar with the haptic stimuli even though they newly experienced it. As shown in our experimental results, we conclude that the haptic BSW on a steering wheel can be used effectively. The simulator and experimental program can also be used to evaluate other haptic feedbacks such as the car seat, seatbelt and so on. In the following works, softer and smoother haptic stimuli with an equally effective specification should be identified so that it can deliver effective warnings as well as satisfy the emotional aspect of drivers. Also, further study is needed to find a more efficient warning timing that can enhance the warning performance without increasing the false alarm rate.

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