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Enhanced performance for in-vehicle display placed around back mirror by means of tactile warning

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ABSTRACT

In-vehicle displays have been found more effective in terms of reaction time, accuracy and subjective visibility rating when the size of such displays was moderate and placed around a steering wheel. To date, however, little data has been reported on the safety and efficiency of replacing side mirrors with in-vehicle displays placed around a back or room mirror. Although back mirror displays save space for installing other display features, it is expected that they would be inferior to in-vehicle displays placed around side mirrors, around the driver's center position, or around a steering wheel in accuracy and reaction time, because back mirror displays require drivers to execute more vertical eye movement than other in-vehicle displays or side mirrors, and eventually the perceptual and recognition time of hazard becomes longer. The primary purpose of this study was to improve the reaction time and accuracy of in-vehicle displays placed around a back mirror with the support of a tactile warning system. First, participants were instructed to engage in a primary, simulated driving task. Simultaneously with the primary task, participants were required to undertake a secondary, discrimination task. The secondary task involved the discrimination of a pre-specified vehicle displayed on either a side mirror or an in-vehicle liquid crystal display (LCD) placed around a back mirror or steering wheel. Second, reaction time and accuracy of in-vehicle displays placed around a back mirror were examined to determine whether they could be improved with the addition of a tactile warning to the displays. Participants were directed to carry out a driving task (run a straight second lane of three-lane highway) similar to that performed in the first experiment. As expected, in-vehicle displays placed around a back mirror produced inferior accuracy as compared to in-vehicle displays placed around a steering wheel. The tactile warning effectively compensated for the shortcomings of the 4.3-in. in-vehicle displays placed around a back mirror, and it further improved both reaction time and accuracy.

1. Introduction

Drivers often must simultaneously perform two or more tasks requiring shared attention. Shared attention may slow reactions to a warned situation or increase deviations of one's own vehicle, possibly causing fatal or non-fatal motor vehicle crashes (Stanton & Young, 2005). As visual and cognitive workload increases while driving, driver-vehicle interaction

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becomes increasingly complicated (Castro, 2009; Dukic, Hanson, & Falkmer, 2006; Gkikas, 2013; Lee, Caven, Haake, & Brown, 2001). Drivers cannot help being distracted by a variety of secondary tasks, such as the operation of switches for a CD player or air conditioner (Regan, Lee, & Young, 2009). The result is an increased risk of inattentive driving.

There is a tendency to replace rear-view or side mirrors with a camera-monitor system (CMS) for indirect vision (Fitch, Blanco, & Hanowski, 2009; Schmidt et al., 2015). Regulation No. 46 of the United Nations Economic Commission for Europe (UNECE) defines CMS as a device which represents the field of view obtained by means of a camera-monitor combination (Matthias, 2016). In-vehicle CMS usually provides a driver with rear views. The World Forum for Harmonization of Vehicle Regulations (WP29) now permits replacing side mirrors with cameras and in-vehicle LCD. The rule further allows vehicles without a side mirror to drive on public roads provided that the field of view of the CMS is equal to that of the side mirror.

CMS has both advantages and disadvantages. Replacing a side mirror with a CMS (Beck, Lee, & Park, 2017; Large, Crundall, Burnett, Harvey, & Konstantopoulos, 2016; Mohamed & Fatin, 2014; Schmidt et al., 2015) restrains air resistance and thus improves fuel efficiency. This technology also eliminates the blind spot and improves the field of view at night, thereby enhancing safety. Once a CMS malfunctions, the driver no longer can receive all of the necessary information. As a practical matter, a CMS costs more than a conventional side mirror.

In a crowded traffic situation, a driver must be able to operate the vehicle without substantially moving his or her head to the left or the right. This need can be better accommodated with an in-vehicle display appropriately placed in an automotive cockpit than it can when a side rear-view mirror is utilized. The CMS gradually is being recognized as a more effective replacement for exterior mirrors in enhancing traffic safety. A CMS enables drivers to reduce the frequency of looking aside and consequently allows them to concentrate on the main driving task. Moreover, the CMS is expected to reduce blind spot-related crashes, such as improper lane changes and crossing into the path of another vehicle (Camden, Fitch, Blanco, & Hanowski, 2011; Wierwille, Schaudt, Gupta, et al., 2008; Wierwille, Schaudt, Spaulding, et al., 2008).

Many studies have attempted to develop an appropriate and effective CMS (Fitch et al., 2011; Fitch, Blanco, Camden, & Hanowski, 2011; Jenness, Llaneras, & Huey, 2008; Schaudt, Wierwille, & Hanowski, 2008; Wierwille, Schaudt, Blanco, Alden, & Hanowski, 2011). However, the CMS has not been proven an effective replacement for an in-vehicle rear-view mirror. Little data has been reported on the safety and efficiency of such a replacement system. Schmidt et al. (2015) stated that a CMS can be used in vehicles to display the driver's rear view on a monitor mounted inside the vehicle. This may offer a better alternative to the conventional exterior mirror. However, UN-R 46 designates exterior mirrors as safety-relevant vehicle parts for securing a driver's indirect rear view. This provision raises the question as to whether a CMS can provide an equivalent substitute for exterior mirrors.

CMS and conventional exterior mirrors (Schaudt et al., 2008; Wierwille et al., 2011) were compared in real-world test drives and static tests under different external conditions. Tests showed that it was possible for a CMS to sufficiently display the indirect rear view to the driver. The detailed design of the CMS further made it possible to receive more information on the rear-view space than was provided by side mirrors. However, the tests suggested that changing the driver's system for indirect view from mirrors to CMS would require a certain period of familiarization with the new technology.

What has not been explored is how the location and size of the LCD connected to the CMS might impact the effectiveness of a CMS replacement for a side mirror. Most drivers might find it challenging to change their practice of using side mirrors by replacing them with in-vehicle LCDs. In the long-term, however, drivers using in-vehicle LCDs placed around a foveal vision benefit from shortened reaction time and less-frequent looking aside.

Murata and Kohno (2018) relied on previous studies that explored the safety and efficiency of replacing side mirrors with in-vehicle LCDs (Beck et al., 2017; Large et al., 2016) to support the necessity of making the change. The experimental factors were the size of the LCDs, the location of the display (in-vehicle LCDs and side mirror), and which side of the driver (left or right). The safety and efficiency evaluation measures for the conventional side mirror and the replacement system were compared to verify the effectiveness of the change.

Murata and Kohno (2018), however, did not examine the effectiveness of an in-vehicle display located around a back mirror (for detail, see Figs. 3(b) and 5). At present, little data has been reported on the safety and efficiency of replacing side mirrors with in-vehicle displays around a back mirror (room mirror). While back mirror displays can save space for installing other display features, it is expected that they would be inferior to in-vehicle displays placed around side mirrors, around the driver's center position, or around a steering wheel in both accuracy and reaction time.

Lee, McGehee, Brown, and Marshall (2006) examined the effectiveness of various warning modalities in making distracted drivers more attentive during severe braking situations that exceeded adaptive cruise control (ACC) capability. Denworth (2015) and Linden (2015) suggested the power of touch via tactile sense. The potential application of the tactile sense to automotive warning systems has drawn increasing attention to efforts seeking to enhance driving safety. Jones and Sarter (2008) studied the sense of touch as a medium for information representation. The results suggested that sense of touch represented a promising means of communication in human-vehicle systems.

Cross-modal information processing and design tendencies also have emerged as a potentially viable design for automotive warning systems (Driver, 2001; Driver & Spence, 1998; Jones, Gray, Spence, & Tan, 2008; Spence & Driver, 1994, 1997a, 1997b, 2004). Transmitting information through multiple modalities such as vision, audition and touch is promising for enhancing safety. A better understanding of spatial and temporal cross-modal links is essential for better applications of these properties to automotive warning design. Ferris and Sarter (2008) found significant asymmetric performance effects of cross-modal spatial links. They showed that auditory cues shortened response latencies for collocated visual targets, but not for visual cues. It also was confirmed that responses to contra-lateral targets were faster for tactually-cued auditory