Transportation Research Part F 24 (2014) 158–168

Contents lists available at ScienceDirect

Transportation Research Part F

journal homepage: www.elsevier.com/locate/trf

Behavioural adaptation and effectiveness of a Forward Collision Warning System depending on a secondary cognitive task

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ARTICLE INFO

Article history:
Received 27 June 2013
Received in revised form 28 January 2014
Accepted 14 April 2014

Keywords:
Driving simulator
Forward Collision Warning System
Behavioural adaptation
Distraction
Cognitive load
Attentional resources

ABSTRACT

Forward Collision Warning Systems (FCWS) have been designed to enhance road safety by reducing the number of rear-end collisions. Nevertheless, little is known about how drivers adapt their behaviour over time when using this kind of system. In addition, these systems are expected to aid particularly distracted drivers. However, previous research has suggested that the effectiveness of the system could depend on the difficulty level of the secondary task. The objective of this study on driving simulator was twofold. Firstly, it consisted in evaluating the behavioural adaptation to an FCWS as well as analysing the possible consequences of driving without the system after a short period of adaptation. Secondly, it was to evaluate the effectiveness of the system according to two different difficulty levels of a cognitive secondary task. The results showed that drivers adapted their behaviour positively when the system was introduced. Nevertheless, both the effectiveness and the behavioural adaptation in the short term were dependent on the cognitive load induced by the secondary task. These findings suggest that the warning needs some attentional resources to be processed. Finally, no negative or transfer effect was observed following the removal of the system after a short period of adaptation.

1. Introduction

The increasing development of Advance Driver Assistance Systems (ADAS) and In-Vehicle Information Systems (IVIS), as well as the progressive availability of equipped vehicles, are having an impact on driving safety. These systems are expected to induce positive and safer behaviours in driving, especially when providing assistance to drivers in critical situations. But even if these systems are designed to facilitate the driving task, they could also modify drivers' behaviour negatively. Some examples concerning expected and unexpected behavioural changes related to the use of ADAS are found in the literature. For example, the use of an Intelligent Speed Adaptation system in a simulator study resulted in positive effects since drivers reduced their maximum speed in low speed limit areas compared to participants driving without the system (Comte, 2000). Nevertheless, more risky behaviour was also associated with the presence of this system, such as accepting smaller gaps when merging onto a road with approaching traffic and spending more time at short headways. Concerning the Lane

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http://dx.doi.org/10.1016/j.trf.2014.04.012
1369-8478/

Departure Warning, it seems that both accurate and less accurate systems could improve lane-keeping performance compared to a control group receiving no warning. However, those participants who initially drove with the accurate system kept a high rate of trust in the system even when it became inaccurate (Rudin-Brown & Noy, 2002). These are only a few examples of the positive and negative behavioural changes associated with the use of some ADAS. But literature has often showed contradictory results regarding the same system type (for review, see Saad et al., 2004) which could be due, among other factors, to different methodologies (driving simulator, on-road tests, etc.). This underlines the need for more research on this topic.

This study is focused on the behavioural adaptation to a particular assistance system, the Forward Collision Warning System (FCWS). Such a system has been designed to reduce and/or to avoid rear-end collisions by warning drivers when forward obstacles are detected.

Certainly, behavioural changes could appear during the first contacts with the system (learning phase) when drivers are learning how the system works, but also after a longer period of exposure (integration phase) once drivers have acquired a higher level of experience with the system (Saad et al., 2004). In general, the results concerning FCWS have been obtained after a brief exposure to the system in short-term studies. These studies have shown the positive value of the FCWS reflected, for example, by a reduction of the number of collisions (Lee, McGehee, Brown, & Reyes, 2002), by faster braking reaction times following the detection of critical situations (Abe & Richardson, 2006), by the adoption of longer and safer headways (Ben-Yaacov, Maltz, & Shinar, 2002), and by returning attention to the critical direction when necessary (Ho & Spence, 2009). These results provide evidence of the positive impact of the system during the learning phase. However, most of the past experimental studies counterbalanced periods with and without the system. Therefore, it is not possible to fully understand the effect of introducing the system for the first time. In addition, some authors insist on the fact that these systems also have longer-term effects on drivers' behaviours. However, with regard to the FCWS, there is a gap in knowledge concerning the behavioural adaptation effects in the integration phase. Another important issue is to observe how drivers could react if the system is switched off (for example, because of a malfunctioning of the system) after a short or longer use. If drivers become dependent on the aid of the system, then they could be very vulnerable in the case of potential hazards if the system is no longer available. However, if drivers consider the system as an assistant and not as a surrogate driver, then they could transfer the positive effect of the system even if it is no longer available.

This issue of potential transfer effects of an FCWS in the short term and in the long term were examined in the Ben-Yaacov et al. (2002) study, conducted in a field operation test. In this study, participants had to drive in real traffic conditions, firstly without (1st trial) and afterwards with the FCWS (2nd trial). In addition, the authors investigated the immediate effects of switching off the system in a third trial as well as the long-term effects of switching off the system in a fourth trial conducted six months later. The results showed that participants adopted safer headways when they were driving with the system (2nd trial) and that they were able to transfer this positive effect when the warning assistance was no longer available (3rd trial). Interestingly, this effect was also observed six months later (4th trial). To our knowledge, the work of Ben-Yaacov et al. (2002) is the only study examining the behavioural effects of switching off an FCWS over time.

FCWS are expected to be of benefit to distracted drivers in particular. In general, the studies comparing the effectiveness of the system between undistracted and distracted drivers showed that undistracted drivers benefited as much as distracted drivers (see for example, Ho & Spence, 2009; Kramer, Cassavaugh, Horrey, Becic, & Mayhugh, 2007; Lee et al., 2002). However, among these studies, the focus is mainly put on the effectiveness of the system when drivers were visually distracted. It could be possible that the system may have different effects according to the modality of the distraction task. For example, Mohebbi, Gray, and Tan (2009) found that when participants were involved in complex conversations (mental calculation and categorisation questions), only a tactile warning was effective but not an auditory warning. In addition, previous experiments on a simplified simulator (Bueno, Fabrigoule, Deleurence, Ndiaye, & Fort, 2012; Bueno et al., 2013) showed that an FCWS (auditory warning) was not able to compensate for the negative effects of a cognitive secondary task on brake RT. From this result, it was hypothesised that the warning signal may need some attentional resources to be processed. In order to test this hypothesis in this study, the effect of the cognitive secondary task load was analysed. In a broader sense, it is known that the amount of attentional resources available is considerably reduced by the presence of a competitive task (Baddeley, 1996; Wickens, 1980). Moreover, if the primary or the secondary task (or both tasks) are highly demanding, participants might not have enough attentional resources to treat them. Thus, in a driving context, dealing with a demanding cognitive secondary task may result in a deterioration of the driving behaviour. In this regard, Harbluk, Noy, Trbovich, and Eizenman (2007) investigated the effects of different difficulty levels of a cognitive secondary task while participants drove in an on-road experiment. Their results showed that the driving behaviour was negatively affected, as the secondary task difficulty increased: participants spent more time looking towards the central areas of the road, less time looking at the peripheral areas and mirrors, and more hard braking trials occurred. Similarly, Jamson and Merat (2005) found in a simulator study that, as the demands of both a visual and a cognitive secondary task increased, the safety margins were gradually reduced and participants reduced the driving speed. Concerning the effect of an FCWS, if the warning signal needs attentional resources to be treated, it would be expected that high demanding secondary tasks could reduce the effectiveness of the system.

The objective of this study was twofold. Firstly, this work aimed at evaluating the behavioural adaptation to an auditory FCWS on the first uses, after a short-term period, and when driving without the system after this short period of adaptation. Secondly, the effectiveness of the FCWS was analysed according to different difficulty levels of a cognitive secondary task. We hypothesised that the system would only be effective when the secondary task was less cognitively demanding.