Accident Analysis and Prevention 42 (2010) 904–912

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

Objective and subjective evaluation of motor priming and warning systems applied to lateral control assistance

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ARTICLE INFO

Article history:
Received 31 July 2008
Received in revised form 24 April 2009
Accepted 14 July 2009

Keywords:
Human–machine cooperation
Lane departure
Steering control
Acceptance
Car driving

ABSTRACT

Previous research has shown that a device called "motor priming" (MP) was more effective than other lane departure warning systems. MP prompts drivers to take action by means of small asymmetric oscillations of the steering wheel. The first objective of this experiment was to provide a deeper understanding of MP mechanisms through a series of comparisons with other haptic and auditory systems. The results suggest that much of the improvement in recovery manoeuvres observed with MP is due to the motor cue (proprioceptive pre-activation of the gesture). Other factors, such as delivering the signal directly to the hands (stimulation of response effectors) or using the tactile modality rather than auditory warning, play a lesser role. This supports the hypothesis that MP devices directly intervene at the motor level, in contrast to more traditional warning systems, which only improve situation diagnosis. The second objective was to assess drivers' acceptance of the assistance devices. A dissociation between efficiency and acceptance of the devices was observed: drivers globally preferred auditory warning to MP. The combination of auditory warning and motor priming appeared to be a good compromise to achieve both effectiveness and acceptance. This experiment illustrates the relevance of simulator studies when dangerous situations are the main targets of the investigation.

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1. Introduction

Najm et al. (2007) have estimated that accidents that follow an unintended lane departure represent more than 27% of all single vehicle crashes. For this reason, helping drivers to keep their vehicle on the road has become a challenge for car manufacturers. A consequence of this situation is the development of ESP (electronic stability program), which targets loss of control crashes by acting on the vehicle dynamics when skidding has already started. Although such a last-second intervention can be beneficial in some cases, efforts have also been made to improve the driver's behaviour before the car enters in such a critical situation. The evaluation of devices designed to intervene in dangerous situations is a classic example of simulator use, where scenario and traffic context controllability is very high. It allows placing participants in critical or near-to-critical situations without putting them at harmful risks.

Hoc et al. (2009) put forward a four-level classification system in order to categorize driving assistance devices within the framework of human–machine cooperation (Hoc, 2001). First, perceptive mode devices provide uninterpreted information in order to enhance the drivers' perception (e.g. speedometer). The mutual control mode includes devices that either provide a criticism on driver behaviour (e.g. collision warning) or act on the vehicle commands without actually taking control (e.g. resistance in the accelerator pedal). Function delegation mode devices are in use when the drivers decide to delegate part of the driving functions for a while (e.g. cruise control). Finally, in fully automatic mode, the driver would become the supervisor of automation which carries out the whole driving task. Fig. 1 summarizes this classification with its application to lateral control.

All the devices assessed in this study belong to the "mutual control" category. For lateral control, they can be split into two subcategories: lane departure warning systems (LDWS) and lane keeping assistance systems (LKAS). LKAS actively intervene on the steering wheel. For instance, torque may be continuously applied to the steering wheel in order to help drivers remain close to the lane centre. This is truly shared control, where the actions of the automation device should blend into the driver's sensorimotor control loop (Griffiths and Gillespie, 2005). Contrary to LKAS, LDWS do not directly influence steering at the action level. They warn that the lateral position in the lane is unsafe, thus improving the situation diagnosis made by the driver.

Navarro et al. (2007) proposed a new type of assistance device called "motor priming". The rationale for this device was to take the best of both LDWS and LKAS categories: to act at the action

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0001-4575/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.aap.2009.07.008

level, with anticipated gains in effectiveness, but with minimal direct action on steering control. Intervention at a motor level, without intruding into vehicle control, is performed through asymmetric oscillations of the steering wheel when the car is about to cross one of the lane edge lines. More precisely, the device delivers small alternating movements to the steering wheel (Fig. 3). The first movement is directed toward the road centre. This movement and subsequent movements in the same direction are characterized by a torque applied to the steering wheel that is stronger than the movements in the opposite direction (the side of lane departure). It gives the sensation of gentle pushes on the steering wheel in the direction of the expected response. The aim is to pre-activate the corrective gesture at the proprioceptive level, without actually performing it on the driver's behalf. The motor priming (MP) device was compared to more traditional warning devices, such as a simple steering wheel vibration or a sound indicating the side of lane departure. The benefits of all assistance devices were measured during lane departures that were generated by occluding the driving scene at specific locations. Results showed that all driving assistance devices improved recovery manoeuvres in comparison to a condition without assistance. The drivers spent less time in a dangerous lateral position. The benefits were significantly larger when MP was delivered, either alone or in combination with auditory warning. The results reported by Navarro et al. (2007) support the idea that MP not only improves situation diagnosis, in the same way as LDWS, but also provides a motor cue to the effectors of the corrective manoeuvre, i.e. the hands.

Within this context, the first objective of the current experiment was to further investigate the determinants of benefits associated with the MP approach. For this, a progressive method was used which compared assistance devices that were increasingly different from MP. The aim was to assess the relative contribution made by the different characteristics which define the MP mode to the observed benefits on recovery manoeuvres. The first step was to compare the MP to a lateralized vibratory warning on the steering wheel. Both devices were identical (i.e. they both provided directional information to the hands by means of the haptic modality), with the exception of the motor prompt which characterizes motor priming. This comparison will isolate the specific role of the motor cue in the improvement of recovery manoeuvre. Improved responses from the driver may also be achieved because the warning signal is delivered directly to the hands, which are the effectors of the manoeuvre. To determine the proper effect of the localization of the stimulus, a comparison was made between the lateralized vibratory warning on the steering wheel and a lateralized vibratory warning on the seat. Both devices gave directional information via the haptic modality, but at different locations. Finally, the use of the haptic modality rather than a more traditional auditory signal may explain some of the benefits associated with motor priming (Sklar and Starter, 1999; van Erp and van Veen, 2004). In an attempt to isolate this factor, the lateralized vibratory warning on the seat was compared to a lateralized warning sound.

Beyond effectiveness, the assistance devices need to be designed in such a way that drivers actually wish to use them. Indeed, well-accepted devices have the tendency to be used more often. For example, Young and Regan (2007) found that drivers used cruise control devices more frequently when they had a more positive attitude towards them. Even if an assistance device can objectively be proven to be effective, the driver may choose to switch it off if, for instance, it is judged too intrusive. Therefore acceptance is a key element in the global assessment of MP. An example of this is given by Young and Regan (2007), who noted that cruise control and speed alerting devices, supposed to help avoid excessive speeding, are typically set up to 15 km above the speed limit. At the same time, participants had a positive attitude towards the systems and felt that these devices were generally effective in helping them to control their speed. Similarly, Ho et al. (2006) found that drivers preferred distinctive alarms for different warning systems, even though the results showed that objective performance was the same whether a single master alarm or multiple alarms were used. Therefore two devices with the same level of effectiveness could result in very different levels of acceptance. Ideally, the design of assistance devices should be directed by an objective to optimize both effectiveness and acceptance.

The secondary objective of the experiment was to assess drivers' acceptance of all driving assistance devices in parallel with their objective effects on steering behaviour. According to Nielsen (1993, p. 24), system acceptability can broadly be defined as "the question of whether the system is good enough to satisfy all the needs and requirements of the users". In this study, the subjective satisfaction dimension, defined as "how pleasant it is to use the system", has been more specifically targeted. Various methods are traditionally used to evaluate acceptance. The main evaluation techniques are focus groups (interviews on small groups to perform qualitative evaluation of the object), simulated or field trials with acceptability questionnaires (e.g. van der Laan et al., 1997), attitudinal surveys and stated preference techniques (Comte et al., 2000). In the current experiment, drivers were asked to rank the different devices in terms of preference. Focus group non-directive interviews were conducted as a complement to the stated preference technique in order to gain insight into the cognitive, affective and sensorial dimensions of drivers' acceptance (Cahour, 2008). Of particular interest was the subjective assessment of MP, since this intervenes at the action level. Some studies on cruise control have revealed that, if drivers were not feeling in control of the car, they tended to stop using the device (Young and Regan, 2007) or perceive the device as less acceptable (Comte et al., 2000). In addition, drivers' judgements may not favour an automation device which acts on the steering wheel, even if it does not interfere with their control of the vehicle (Lefeuvre et al., 2004). It is hypothesized that, because of its action on the steering wheel (i.e. the car's main mean of control) and the motor prompt it provides, MP would be less acceptable than other devices. Conversely, an auditory warning device that mimics the familiar sound of rumble strips can be expected to be

Human-machine cooperation mode	Perception mode	Mutual control mode		Delegation function mode	Fully automatic mode
Example for lateral control assistance device	Road edges enhancement	Lane departure warning systems (LDWS)	Lane keeping assistance systems (LKAS)	Automatic steering	Automatic pilot

Fig. 1. Classification of human–machine cooperation modes proposed by Hoc et al. (2009). Bottom row: examples of lateral control devices for each mode.

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