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Effectiveness of a Forward Collision Warning System in simple and in dual task from an electrophysiological perspective

Mercedes Bueno[a,b,c,*], Alexandra Fort[a,b], Mathilde Francois[b], Daniel Ndiaye[d], Philippe Deleurence[a,b], Colette Fabrigoule[c]

[a] IFSTTAR-LESCOT, F-69675 Bron, France
[b] University of Lyon, F-69622 Lyon, France
[c] University Bordeaux Segalen, USR CNRS 3413 SANPSY, F-33076 Bordeaux, France
[d] University of Paris-Est, IFSTTAR, IM, LEPSIS, F-75732 Paris, France

HIGHLIGHTS

- The effectiveness of the FCWS was assessed in undistracted and distracted drivers.
- Behavioural and electrophysiological data (ERP) was recorded in a simulator study.
- In undistracted drivers, the FCWS accelerated the detection of a potential obstacle.
- And it improved the anticipation (CNV) and the cognitive process of the target (P3).
- However, the effectiveness of the FCWS in distracted drivers was limited.

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ABSTRACT

Forward Collision Warning Systems (FCWS) are expected to assist drivers; however, it is not completely clear whether these systems are of benefit to distracted drivers as much as they are to undistracted drivers. This study aims at investigating further the analysis of the effectiveness of a surrogate FCWS according to the attentional state of participants. In this experiment electrophysiological and behavioural data were recording while participants were required to drive in a simple car simulator and to react to the braking of the lead vehicle which could be announced by a warning system. The effectiveness of this warning system was evaluated when drivers were distracted or not by a secondary cognitive task. In a previous study, the warning signal was not completely effective likely due to the presence of another predictor of the forthcoming braking which competes with the warning. By eliminating this secondary predictor in the present study, the results confirmed the negative effect of the secondary task and revealed the expected effectiveness of the warning system at behavioural and electrophysiological levels.

1. Introduction

Forward Collision Warning Systems (FCWS) have been introduced in the motor industry to assist drivers in preventing potential collisions. It is well known that the effectiveness of the system can strongly depend on different technical parameters. For example, the timing of the warning, the reliability of the system and/or the modality of the warning signal are some important elements to be considered when investigating FCWS [1,4,15]. Moreover, driver distraction could also have an impact on the effectiveness of the system. Indeed, driver distraction has been identified as the main contributing factor for rear-end collisions [16]. Thus, it could be expected that these systems are of benefit to distracted drivers in particular, mitigating the negative effect of the competitive tasks by redirecting attention to the road and/or by promoting a response to avoid a potential collision [18]. Most research has showed positive effects of FCWS when drivers are undistracted [e.g., 13]. In the case of distraction, the system also seems to be effective [e.g., 20]; however, the impact of the distraction has not been systematically assessed by a control group, therefore it is not currently completely clear whether the warning system is of more benefit to distracted drivers.

At a more fundamental level, warning signals have also been demonstrated to be effective in reducing reaction time [25]. Moreover, it has been discussed that warning signals affect response

* Corresponding author at: IFSTTAR-LESCOT, 25 avenue François Mitterrand, F-69675 BRON, France. Tel.: +33 472142433; fax: +33 472376837.
E-mail address: mercedes.bueno-garcia@ifsttar.fr (M. Bueno).

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selection and cognitive processes rather than sensory or motor processes [12,25]. The fact that dual tasks impair performance has been largely investigated [3,29]; however, whether warning signals are effective in reducing this negative effect and, if this had been true, at which stages of processing, remains less studied to our knowledge. To answer this question, techniques like electroencephalography (EEG) and the associated Event Related Potential (ERP) can be very valuable. Indeed, they enable to make a distinction among the different stages of information processing like anticipation processes (Contingent Negative Variation, CNV), sensory analysis of the stimulus (N1 component), and higher cognitive processing (P3 component).

ERPs have been used in order to examine the dual task costs in non-driving studies. For example, Guerri and Eimer [11] found that when participants had to perform a visual detection task at the same time that they had to listen to a story to posteriorly answer some questions, the amplitude of the N1, N2, and P3 components were reduced in comparison to when participants only had to perform the visual detection task [see also 10]. In the driving domain, ERP studies have been used mainly to examine the fatigue effects and vigilance while driving. There are only a few ERP driving simulator studies showing the disrupting effect of performing a concurrent cognitive secondary task [see, for example, 6, 24]. and this technique has only been implemented recently in the study of advanced driver assistance systems and, specifically, in the study of FCWS [7].

The present study completes a series of experiments from our laboratory investigating the effectiveness of a warning signal by recording both behavioural and electrophysiological data. In a non-driving study performed on a computer, Fort et al. [10] analysed the effect of an auditory warning signal on the detection of a simple visual target according to the attentional state of the participants, distracted or not by a secondary cognitive task. The warning could precede the target either in 100% of the cases (perfect condition) or in only 70% of the cases (imperfect condition). The negative effect of the secondary task was evident through behavioural data and ERP data at the level of the CNV, the amplitude of the N1, and the amplitude and latency of the P3. In addition, faster reaction times when the warning (perfect and imperfect conditions) was available were observed. This result was confirmed by ERP data at the level of the CNV, the amplitude and latency of the N1, and the latency of the P3.

Afterwards, in a "driving" study, Bueno et al. [7] used a similar protocol adapted on a simplified driving simulator to investigate the effect of a surrogate FCWS in a driving context. Participants were required to drive and to react by decelerating when the brake light (target) of the lead motorcycle was illuminated. The reliability of a warning system (perfect, imperfect or no system) in predicting the brake light and the drivers' attentional state (undistracted or distracted by a secondary cognitive task) were manipulated. The results showed a negative effect of the secondary task at behavioural and ERP levels (CNV, N1, and P3 amplitude). However, unexpectedly and contrary to the previous non-driving study, the results only showed an effect of the warning signal at the level of the P3 latency. A possible explanation could come from the experimental design. Indeed, an initial deceleration of the motorcycle occurred systematically before braking in all trials, with or without the occurrence of the warning signal. Thus, participants may have used this motorcycle deceleration as a better predictor of the brake light occurrence than the warning signal which was not always reliable.

Therefore, the current study aims at eliminating the predictive value of this motorcycle deceleration for the forthcoming brake light in order to better evaluate the impact of an FCWS according to the drivers' attentional state. For this, simple deceleration trials that were not followed by the brake light were added in a similar protocol than the one used in Bueno et al. [7]. This change in the experimental design should increase the predictive value of the warning signal and, consequently, its effectiveness. Moreover, this would provide a more realistic context as, in real driving conditions, vehicles can also decelerate only by releasing the accelerator and without pressing the brake.

2. Methods

2.1. Participants

12 right-handed men (mean age: 28.9 years, SD: 3.8) took part in the experiment. All participants had at least six years of driving experience and they drove at least 3000 km per year (mean: 9792 km). None suffered from any neurological disorders and none reported any kind of experience with FCWS. Written informed consent was obtained from each participant and they were financially compensated for their participation.

2.2. Materials/apparatus

This experiment was conducted in a simplified driving simulator composed of a PC, a 24 in. screen, steering wheel, and pedals. The stimulus presentation and response gathering on the traffic simulation were controlled with the IFSTTAR simulator software architecture, ArchiSim.

The electrophysiological data was recorded with Biosemi ActiveTwo system (http://www.biosemi.com/). A cap containing 32 active electrodes placed according to the International 10-20 System and two additional electrodes placed on the Ma1 and Ma2 (left and right mastoids respectively) were used. Electrooculography activity (EOG) was recorded from the outer canthus of the right eye. An electrode placed near the corner of the mouth enabled to identify verbal responses during the secondary task. The reference electrode was located on the nose. For EEG and EOG, signals were acquired using ActiveTwo® Ad box, 24 bit ADC per channel sampled at 1024 Hz. Offline, ERPs were extracted from EEG signals separately for the two warning conditions in simple and in dual task using ELAN software [2].

2.3. Procedure

Before the task began, all participants were given a 5 min practice session to familiarise themselves with the driving task on the simulator and with the secondary cognitive task, separately. Afterwards, the electrodes were positioned and the experimental phase started.

Participants were required to drive actively on the simulator following a lead motorcycle located 40 m ahead. They were instructed to press the accelerator pedal to its maximum which corresponded to a speed of 90 km/h. This instruction enabled to identify the reaction time (RT) more easily. Foggy and no-traffic conditions were chosen specifically to reduce saccadic movements and to justify, to a certain extent, the frequent decelerations of the motorcycle (lasting between 2 and 3 s.) presented randomly from 4 to 7 s. Participants had to remove their right foot from the accelerator pedal as fast as possible in response to the motorcycle's brake light (target). An auditory warning could forewarn participants that the motorcycle was going to brake soon. This warning was 500 ms long and consisted of five pulses at 2000 Hz frequency for 80 ms each one with a shorter pause (20 ms) between them. These parameters were chosen to increase the perceived urgency [8]. The warning was presented randomly ranging from 1500 to 2300 ms (mean 1900 ms) in