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# An electrophysiological study of the impact of a Forward Collision Warning System in a simulator driving task

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ABSTRACT

Driver distraction has been identified as the most important contributing factor in rear-end collisions. In this context, Forward Collision Warning Systems (FCWS) have been developed specifically to warn drivers of potential rear-end collisions. The main objective of this work is to evaluate the impact of a surrogate FCWS and of its reliability according to the driver's attentional state by recording both behavioral and electrophysiological data. Participants drove following a lead motorcycle in a simplified simulator with or without a warning system which gave forewarning of the preceding vehicle braking. Participants had to perform this driving task either alone (simple task) or simultaneously with a secondary cognitive task (dual task). Behavioral and electrophysiological data contributed to revealing a positive effect of the warning system. Participants were faster in detecting the brake light when the system was perfect or imperfect, and the time and attentional resources allocation required for processing the target at higher cognitive level were reduced when the system was completely reliable. When both tasks were performed simultaneously, warning effectiveness was considerably affected at both performance and neural levels; however, the analysis of the brain activity revealed fewer differences between distracted and undistracted drivers when using the warning system. These results show that electrophysiological data could be a valuable tool to complement behavioral data and to have a better understanding of how these systems impact the driver.

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## 1. Introduction

According to the National Highway Traffic Safety Administration (2009), rear-end collisions represent approximately 30% of all crashes. Although the proportion of fatalities as a result of these collisions is relatively low (5.4%), these crashes are one of the most frequent types of collisions, disturbing traffic flow and representing an important economic cost for society.

There are three factors that contribute to rear-end collisions. According to the sources, the environment (e.g. poor visibility, slick roads) has been identified as a crash

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contributing factor in 5–11% and the vehicle (e.g. brake system) in 12–20% of the cases. However, the factor that most frequently contributes to rear-end collisions (from 75% to 93%) is the driver (Knipling et al., 1993; Kuge et al., 1995; Vogel and Bester, 2005). Specifically, driver distraction is the main reason (60%) for these accidents. In this context, Forward Collision Warning Systems (FCWS) have been developed to warn drivers of potential rear-end collisions. This kind of system provides a warning signal (e.g. visual, auditory, and/or tactile) when there is a risk of collision. In general, the moment for triggering a warning is calculated as a function of either the time to collision between two vehicles traveling at their current speed, or the minimum distance required to stop the vehicle safely (Bella and Russo, 2011). The benefits of these systems for drivers are clear and it has been demonstrated that a warning system is more effective than no warning at all. For example, the impact of the systems on safety can be visible by reducing the number of collisions (Lee et al., 2002; Zhu, 2001), by returning attention to the critical direction if necessary (Ho and Spence, 2009), by faster braking reaction times in detecting critical situations (Abe and Richardson, 2006), and/or, by longer and safer headways (Ben-Yaacov et al., 2002).

Given its implication in road safety, driver distraction has been the central issue in numerous scientific reports (e.g. Regan et al., 2008). Regan et al. (2011, p. 1780) define driver inattention as “insufficient or no attention to activities critical for safe driving” whereas driver distraction or driver-diverted attention is a type of driver inattention where the attention to activities critical for safe driving is threatened by the diversion towards another competing activity. Most of the studies showed a clear benefit from the FCWS when drivers are undistracted. For instance, Maltz and Shinar (2004) found that participants driving in a simulator equipped with an FCWS adopted longer headways than non-equipped drivers. Ho et al. (2006) also reported safer headways together with faster reaction times in detecting potential rear-end collisions when the warning system was available. Nevertheless, even if it is known that the majority of these collisions are due to distraction, relatively few studies have focused on the impact of the FCWS on both undistracted and distracted drivers. The existing data showed that distracted drivers are those who most benefited from the warning systems and, in some cases, the system even completely dissipated the negative effect of being distracted (Ho and Spence, 2009; Lee et al., 2002). However, the results could vary depending on the warning modality and the kind of secondary task carried out (different modalities or mental workload). For example, Mohebbi et al. (2009) studied the effectiveness of an auditory and tactile warning in avoiding collisions with the lead vehicle when participants were distracted by having a simple conversation (demographic and personal questions) or a complex conversation (mental calculation and categorization questions). Their results showed that when participants were engaged in a complex conversation, only the tactile warning was effective, whereas when engaged in a simple conversation, both warnings were useful. However, in this case, only the tactile one completely eliminated the disruptive effect of the secondary task.

The FCWS is designed to provide assistance and to avoid accidents or at least mitigate their consequences. However, these systems are not completely reliable and cannot replace the driver. It is known that the warning may malfunction, producing false alarms and/or misses of critical events. False alarms refer to the situations in which an alert is issued in the absence of any potential collision. Misses occur when an alert is not triggered despite the situation requiring it. Differences in acceptance of the system and, consequently on driver performance, could be noticed depending on the missed or false alarm rate given by the system (Sullivan et al., 2007). Drivers could consider the system as ineffective if the number of false alarms is too high. Usually, false alarms are irritating and distracting when unnecessary (Maltz and Shinar, 2004). Thereby, if false alarms are frequent, users might ignore the system or might react inadequately to valid warnings (Lerner et al., 1996). Similarly, drivers could consider the system as ineffective if the threshold for triggering the warning is too strict. Nevertheless, misses could be seen in this context as more “practical” and helpful than false alarms. Indeed, if a system almost never fails to detect a collision, drivers may over-rely on it and become vulnerable or not react adequately, when, for example, driving an unequipped vehicle (Parasuraman et al., 1997). But assessing which level of false alarms/misses is acceptable is complicated, given that the probability of experiencing a rear-end collision during a lifetime is very low, and the efforts for finding out the cut-off point have not been very conclusive as yet (Kiefer et al., 1999; Lerner et al., 1996).

Other studies have investigated the reliability of the system focusing on the percentage of true alarms without specifying the amount of false alarms or misses. In general, higher levels of reliability result in better performance, but the point where the system becomes useless remains unclear. Bliss and Acton (2003) noted that participants responded more frequently to the warning and maneuvered more appropriately in avoiding collisions when the warning was 100% reliable. Nevertheless, Maltz and Shinar (2004) and Ben-Yaacov et al. (2002) did not find differences between systems reliable at 60%, 80–85% and 90–95%. Subsequently, Wickens and Dixon (2007), after analyzing a total of 22 studies, concluded that 70% should be the threshold for considering a system as reliable.

Simulators have proved to be an excellent tool for the study of the FCWS, where different scenarios as well as the severity of collisions can be easily manipulated. Behavioral parameters are the measure used most frequently by researchers in driving simulator studies, as they are certainly a strong reflection of drivers' performance, but other techniques can also be used to obtain additional information that is not visible through drivers' performance. For example, the electroencephalography and the associated Event Related Potential (ERP) are effective tools that enable to dissociate the different stages of the information processing. Through these measures, it is possible to obtain information on anticipation/orienting, sensory and cognitive processes. Specifically, before the stimulus is presented, processes related to movement preparation and sensory anticipation (Bender et al., 2004) can be detected through the Contingent Negative Variation (CNV). Once the stimulus appears, the sensorial analysis of the stimulus can be reflected by components like the N1. This component is sensitive to the physical properties

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