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How does a collision warning system shape driver's brake response time? The influence of expectancy and automation complacency on real-life emergency braking

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ABSTRACT

Brake Reaction Time (BRT) is an important parameter for road safety. Previous research has shown that drivers' expectations can impact RT when facing hazardous situations, but driving with advanced driver assistance systems, can change the way BRT are considered. The interaction with a collision warning system can help faster more efficient responses, but at the same time can require a monitoring task and evaluation process that may lead to automation complacency. The aims of the present study are to test in a real-life setting whether automation compliancy can be generated by a collision warning system and what component of expectancy can impact the different tasks involved in an assisted BRT process. More specifically four component of expectancy were investigated: presence/absence of anticipatory information, previous direct experience, reliability of the device, and predictability of the hazard determined by repeated use of the warning system. Results supply indication on perception time and mental elaboration of the collision warning system alerts. In particular reliable warning quickened the decision making process, misleading warnings generated automation complacency slowing visual search for hazard detection, lack of directed experienced slowed the overall response while unexpected failure of the device lead to inattentional blindness and potential pseudo-accidents with surprise obstacle intrusion.

1. Introduction

Reaction time (RT) is a parameter of drivers' behavior that has concrete implications for road safety (Green, 2000; Summala, 2000). Prompt and adequate driving reaction in traffic situations can make the difference to avoid road accidents, especially when facing dangerous and critical situations like a lead vehicle sudden brake, or a crossing pedestrian coming from a blind spot of the road (Groeger, 2001). Implementation of advanced driver assistance systems (ADAS) could empower better responses supplying to driver's flaws in order to potentially reduce the number of rear-end collisions or car-pedestrian accidents (Ben-Yaacov et al., 2002).

However, the introduction of ADAS has several implications for road safety. Driving with advanced driver assistance systems can change the nature of a brake reaction situation, especially when the assistance device controls some driving task in place of the driver (Kramer et al., 2007; Radlmayr et al., 2014). Using a forward collision warning system (FCW) turns the driver into a supervisor that has to monitor not only the driving scene, but also the vehicle's automatic warning alerts. The driver has to eventually decide whether the information coming from the device is considered reliable, and then deciding to press the brake or take-over control. Expectations can affect this process especially in particular driving situations that may need an intelligent response due to ADAS use limitations (Bertozzi et al., 2013; Creaser et al., 2007; Vlassenroot et al., 2011).

This monitoring task does not only potentially affect driving performance as a secondary task, but it could also lead to different

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cognitive resource distribution during the driving task as transfer of some driving abilities, such as risk perception, can be temporarily delegated to the assistance systems (Merat et al., 2012). That create a different kind of driving task, and this is why the canonical fixed values for RT used by vehicular accident reconstruction and infrastructure and transportation institutions (e.g., Burg and Rau, 1981) may be worth of reconsidering, as the increasingly technological complexity toward automation is constantly improving new safety device in the market (Broggi et al., 2009; Huth and Gelau, 2013). A more specific analysis on the effects on BRT of expectancy generated by a collision warning device can be useful to better explore the interaction of drivers in emergency braking situations and provide quantitative contributions for safety systems design (Habibovic and Davidsson, 2011).

1.1. Expectancy and take-over control in brake reaction times

Many studies have set up different research paradigms and instrumentations to investigate BRT (Green, 2000). Since the origin of scientific psychology, the factors that are able to influence RT were analyzed. Psychologist and physiologist have measured the difference of RT as function of physiological variables such as the duration and intensity of the signals (Froeberg, 1907; Hsieh et al., 2007), as well as methodological variables such as simple vs. recognition vs. choice experiment (Donders, 1869; O'Shea and Bashore, 2012). Brake reaction time (BRT) is considered a multi-component cognitive skill (Deery, 1999), susceptible to driving experience (Crundall et al., 1999; Horswill and McKenna, 2004), subjective risk perception and emotional evaluation of the driving situation (Kiss et al., 2007; Rosenbloom et al., 2011) and dependent on driver's expectations. Expectancy seems to be the variable that is best to be able to explain most of the variance of the RT variability (Koustanaï et al., 2008). However, a better focus on the construct of expectancy in interaction with a collision warning device needs to be further analyzed (Aust et al., 2013) in particular a specific in-depth analysis on the role of the different component that produce expectations in real-world, assisted emergency braking events is desirable (Dingus et al., 2006). How can the introduction of a collision warning system affect BRT? How does it interact with driver's expectations? And how can the supervision/response process be measured?

In cognitive psychology expectancy is a motivational theory that explains people's actions based on previous knowledge, self-assessment of coping skills, and perceptions of what will happen in order to successfully complete an event (Clark et al., 2014; Feldman, 2011). It is possible to manipulate the creation of expectations with four main components: the presence/absence of anticipatory information, previous direct experience, reliability of the mental representations of the event and predictability of the situation (Balzarotti et al., 2010; Schunk and Zimmerman, 2012; Wickens et al. 2001). The emotive system is also important in regulating expectations, as its main function is to focus the subject's attentional resources more quickly on the relevant aspects of a stimuli, while triggering a set of possible ready responses based on previous experiences (Frijda, 2009; Oschner et al., 2002). A collision warning system should help drivers to interpret the development of driving situation and support the decision making process, especially when they may not have all the information required to safely avoid an accident. The decision to press or not the brake made with coherent anticipatory information from a collision warning device can solicit adequate mental scheme of the actions to perform in a particular driving situation, allowing faster brake response (Abelson, 1981; Garling et al., 2001; Neal et al., 2006) and a pre-activation of the limbs (Damasio, 2005; Kobiela, 2011).

However, collision warning systems may not always work in all traffic situations or cannot signal all the potential dangers on the road (Maltz and Shinar, 2007). The presence of incomplete information coming from the warning device, could influence the perceptual and evaluation process, and lead to potentially inadequate expectations on the actions to be performed (Megías et al., 2011; Seitz et al., 2009). Studies of aviation safety on automation complacency (Parasuraman and Manzey, 2010) have shown that inattentional blindness (Simmons and Chabris, 1999) can be created by a warning device when shifting from monitoring an assisting device to performing a task (Bailey and Scerbo, 2007). In simulated flight pilots fail to detect a clear stimulus when target stimulus is unexpected and incomplete or incorrect representations of the situation are given by the warning device (Kennedy et al., 2014).

A systematic analysis in real-life driving of the effect of expectations generated by a warning device could highlight what particular component of expectations can shape driver's response time in emergency situations, and in particular how automation complacency can be elicited by the interaction with the collision warning device in real life driving.

1.2. Measuring the effect of expectations

In order to measure the influence of the warning device on the four main components of expectancy, it is important to obtain an external physical measure of driver's internal evaluation of the monitoring task of the warning device, other than the brake reaction task. Considering the main response that a driver can perform during an emergency braking, it is possible to distinguish at least five types of actions that have been used in different BRT studies to record the different psychological process that take place during an emergency braking: (A) perceive the stimuli; full awareness may not be present at this first stage, but gaze response time (GRT) (Aust et al., 2013) is a useful parameter to measure sensation and perceptual elaboration of the visual image in the motor and occipital cortex and in the cortical area that classify objects for potential functions (Schreij and Olivers, 2013; van der Burg et al., 2011). The emotional recognition and appraisal of the stimuli could be activated even before the involvement of voluntary attention and gaze orientation, especially in hazardous situations (Russell et al., 2003), and would produce not only eye movements, but also changes in facial expression configurations, head and posture movements (Ekman et al., 2002). For these reasons, capturing this initial reaction could give important information on how the driver is evaluating the hazard situation (Scherer, 2005). (B) Time for mental processing, which is the time it takes from the perception to the first recordable change in driving behavior. In a normal driving condition at constant speed the first reaction in a brake-reaction task should be the rise of the accelerator pedal, and/or a steering maneuver to avoid the danger. Release of accelerator pedal has been temporally defined at the beginning of decreasing pressure on the accelerator pedal (Green, 2000), while other researches (e.g., Warshawsky-Livne and Shinar, 2002) have found difference also in the action of (C) complete lift of the foot from the accelerator, that represent the speed execution of the first recordable complete reaction on the pedals. (D) Movement time: that is the time needed for the motor and muscular system to perform the shift movement of the foot from the accelerator toward the brake. It is useful to record the execution speed once the decision to brake has been taken by the driver. (E) Beginning of the actual pressure on the brake pedal, required to begin the brake engagement, crucial to trigger the beginning of the device response time (Martin et al., 2010).

These five actions may be considered the progressive steps of a brake reaction process with an automatic transmission car. But