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Adaptive warning signals adjusted to driver passenger conversation: Impact of system awareness on behavioral adaptations

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ABSTRACT

The study investigated behavioral adaptation caused by warning signals that adaptively support drivers engaged in a passenger conversation. Novel advanced driver assistance systems (ADAS) could monitor the driver state to provide warnings adjusted to the driver's current need for support. While first research indicates positive effects of dynamically adjusting ADAS, the overall safety potential of such adaptive systems remains unclear as little is known about adverse behavioral effects. Occasional inappropriate support due to an incorrect prediction of the current driver state might lead to critical situations when drivers are aware of the adaptive nature of the system and thus rely on the expected system behavior. To better understand behavioral adaptation to dynamically adjusting warnings, 46 participants driving on a test track reacted to two types of warnings (auditory, vibrotactile-auditory) while engaging in driver-passenger conversation or not. In a compensating warning strategy, vibrotactile-auditory warnings were displayed during conversations and auditory warnings in situations without conversation. This strategy was compared to a non-compensating warning strategy in which these assignments were reversed. The impact of behavioral adaptation was measured by considering reactions to simulated failures of these strategies. The role of system awareness for behavioral adaptation was investigated by manipulating awareness of these warning strategies across groups. We found that vibrotactile-auditory warnings reduced the detrimental effects of conversation on reaction times. Crucially, adverse behavioral adaptation was observed whenever an expected vibrotactile-auditory warning was replaced by an auditory warning but this effect was restricted to drivers in the awareness group. The results show that adaptive warning signals optimize the effectiveness of warnings during driver-passenger conversation but adverse behavioral adaptation develops when drivers are aware of the underlying warning strategy. This implies that future adaptive systems are less likely to be associated with behavioral adaptation if the adaptive nature of the system remains unnoticeable to the driver. Our findings could be used for developing and optimizing user-centered ADAS.

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1. Introduction

Driver distraction due to secondary activities has been identified as a major contributing factor for accidents (Dingus et al., 2016). For instance, conversations have been found to impair scanning behavior (e.g., Harbluk, Noy, Trbovich, & Eizenman, 2007; Recarte & Nunes, 2000), situation awareness (e.g., Gugerty, Rakauskas, & Brooks, 2004; Kass, Cole, & Stanny, 2007; Ma & Kaber, 2005) and reaction times (RT) (e.g., Consiglio, Driscoll, Witte, & Berg, 2003; Strayer & Johnston, 2001). Advanced driver assistance systems (ADAS) such as forward collision warning (FCW) systems, lane departure warning (LDW) systems or blind spot detection systems monitor the driving scene and provide the driver with real-time assistance. However, most current systems do not fully account for impairments associated with secondary task engagement. Moreover, whereas ADAS that flexibly adjust to task-specific deficits could further mitigate the risk in distracted driving, gauging these systems to the needs of a distracted driver might lead to adverse effects due to behavioral adaptation, particularly when drivers are aware of the system behavior (e.g., Weller & Schlag, 2004). Here we show that warning strategies that dynamically adjust to the driver's current need for support are associated with benefits in overall safety, and demonstrate how system awareness promotes adverse behavioral adaptations.

The potential of driver assistance adjusted to the driver's needs to enhance safety and acceptance has been investigated for different ADAS such as Lane Keeping Assistance (Blaschke, Breyer, Färber, Freyer, & Limbacher, 2009), Adaptive Cruise Control (ACC) (Hajek, Gaponova, Fleischer, & Krems, 2013) or FCW systems (Jamson, Lai, & Carsten, 2008; Lee, McGehee, Brown, & Reyes, 2002). When designing warnings, exact characteristics of the distracting activity and associated impairments in information processing have to be considered because not every warning can support a distracted driver efficiently (e.g., Biondi, Strayer, Rossi, Gastaldi, & Mulatti, 2017; Bueno et al., 2013; Mohebbi, Gray, & Tan, 2009). Moreover, warnings should provide maximally efficient support for distracted drivers but should still be associated with a high level of acceptance for attentive drivers that do not require support (Smith, Witt, Bakowski, Leblanc, & Lee, 2009). For attentive drivers, early warnings might be interpreted as nuisance alarm (e.g., Lee et al., 2002) whereas urgent warnings that promote fast reactions (e.g., Haas & Casali, 1995; Naujoks, Kiesel, & Neukum, 2016) might be associated with annoyance (Politis, Brewster, & Pollick, 2013). At worst, compliance will decrease or systems might be disabled (McKeown & Isherwood, 2007). Adaptive warnings that dynamically adjust to the current state of driver distraction could support a distracted driver who needs more time to respond to a critical event (e.g., Strayer, Drews, & Johnston, 2003). At the same time, such adaptive warnings could prevent that undistracted drivers receive unnecessary warnings which could lower acceptance considerably.

When evaluating an ADAS, it is not sufficient to investigate initial changes in performance. One also has to consider behavioral adaptations defined as behaviors "which may occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change" (OECD, 1990, p. 23). For instance, initial positive effects of an ADAS might be undermined if the perceived safety benefit promotes risky behavior. Various forms of behavioral adaptations have been found for different ADAS. A first indicator of behavioral adaptation are changes in primary task performance, such as a reduced headway or increased speed which were found when drivers drove with ACC (e.g., Hoedemaeker & Brookhuis, 1998; Rudin-Brown & Parker, 2004) or an advanced FCW (Muhrer, Reinprecht, & Vollrath, 2012). Second, several studies found changes in secondary task involvement. Drivers engaged more in non-driving related tasks while using congestion tail warnings (Naujoks & Totzke, 2014) or ACC (Rudin-Brown & Parker, 2004; Stanton, Young, & McCoulder, 1997), but not while using an advanced FCW (Muhrer, et al., 2012). Finally, behavioral adaptations can be derived from driver behavior during system failures. For instance, driver reactions to the omission of an expected support can serve as a surrogate measure of the driver's trust and reliance on the system. Such adverse effects in response to a system failure were found for ACC usage (Rudin-Brown & Parker, 2004; Stanton et al., 1997). If an adaptive ADAS relies on probabilistic estimations of a driver state, it is prone to failures in the adaptation of system behavior. These failures can emerge when inadequate support is provided due to the detection of an incorrect driver state, e.g., when drivers receive low support instead of high support in distraction situations. The resulting unexpected system behavior can lead to delayed reactions and an increased risk of accidents. As adaptive ADAS will never be perfectly reliable, driver reactions to failures present a universal risk in adaptive ADAS.

The exact mechanism underlying the occurrence of behavioral adaptations is still subject of ongoing research (e.g., Elvik, 2004; Weller & Schlag, 2004; Wilde, 1998). As behavioral adaptations are difficult to predict (Kulmala, 2010), more insight into risk factors promoting behavioral adaptation is needed to inform the development of countermeasures. Whereas many risk factors like personality traits (e.g., Rudin-Brown & Parker, 2004), workload or situational awareness (e.g., Weller & Schlag, 2004) are difficult to modify, factors associated with the design of ADAS could be directly addressed by developers. In this context, the awareness of the safety measure and its behavior is reported as crucial variable that affects how likely behavioral adaptation will occur (e.g., OECD, 1990; Elvik, 2004; Hedlund, 2000; Stanton & Young, 1998; Weller & Schlag, 2004; for a review see Grembek, 2010). Grembek (2010) defines the perceptibility of the system in the context of protection systems as "the extent to which [it] can be sensed" (p. 26). In a study, Grembek (2010) analyzed fatality rates in combination with survey data to investigate implications of the perceptibility of different protection systems such as airbags, helmets or structural side impact improvements. He found that the association between adverse behavioral adaptation and resulting fatalities was particularly high for protection systems that were easily perceived and therefore associated with increased system awareness. However, to our knowledge the association between perceptibility and specific impairments in driver behavior (which could further lead to fatalities) has never been empirically studied in a real driving context.