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Behavioral adaptation caused by predictive warning systems – The case of congestion tail warnings

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ABSTRACT

Wireless communication technologies (e.g., C2X-communication or mobile telephony and broadcasting) make it possible to forewarn drivers of dangerous traffic situations. Using a motion-based driving simulator with $N = 16$ participants, it has already been possible to illustrate an increase in traffic safety based on early, precise congestion tail warnings on motorways (Totzke, Naujoks, Mühlbacher, & Krüger, 2011). The paper at hand presents an additional evaluation of the study with regard to (negative) 'behavioral adaptation'; that is to say, non-intended changes in driving behavior based on the introduction of congestion tail warnings. As part of the above-mentioned study, older and younger participants drove through road sections with different traffic conditions (free flow vs. synchronized traffic) performing different test situations (approaching different congestion tails with vs. without assistance of the warning system). In order to investigate behavioral adaptation effects, drivers completed additional road sections in which congestion tail situations were possible, but did not occur. In these situations, an in-vehicle warning device displayed that a congestion tail warning was possible ('assistance possible') or not ('assistance not possible'). During test drives with potential assistance, negative behavioral adaptations can be found: (1) increase of maximum speed, (2) decrease of minimum time-to-collision (TTC_{min}) when following another vehicle in free flow traffic and (3) increased intensity of performing a secondary task compared to driving without assistance. The reduction in TTC_{min}-values applied in particular to older drivers, whereas an increased secondary task involvement was mainly found among younger drivers during synchronized traffic. The results indicate that the introduction of predictive warning systems may cause behavioral adaptations that may limit the intended safety effect of the warning system. With this in mind, it is advisable to include the assessment of (negative) behavioral adaptations into research concepts when evaluating predictive warning systems.

1. Introduction

1.1. Motivation

Wireless communication technologies (e.g., C2X-communication or mobile telephony and broadcasting) provide the possibility of assisting drivers with predictive warnings in potentially dangerous driving situations. It has been shown repeatedly that predictive warning systems have the ability to enhance active driving safety (e.g., Lenné & Triggs, 2008;

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Mahr, Cao, Theune, Schwartz, & Müller, 2010; Naujoks, Grattenthaler, & Neukum, 2013; Naujoks & Neukum, 2014). However, the introduction of these forward-looking warning systems, as with Advanced Driver Assistant Systems (ADAS) in general (Brookhuis, De Waard, & Janssen, 2001), may also lead to non-intended effects on driving behavior, e.g., increase of vehicle speed or decrease in following distance. Thus, their intended positive effects may not be realized or may not occur in their entirety (Martens & Jenssen, 2012). According to Marberger (2007), such unintended behavioral changes may be defined as so-called 'improper use' of driver assistance systems. From the perspective of product liability, a further distinction between so-called 'abuse' (willful contrary use), and 'incorrect use' (unintended misuse) is of importance (Gasser et al., 2012), as incorrect use caused by poor understanding of a system's performance and limitations could cause a driver assistance system to be 'defective' (van Wees & Brookhuis, 2005). In view of incorrect use, the goal of the present study was to assess non-intended behavioral changes caused by a predictive congestion tail warning system. Although a growing body of research on the effectiveness of such congestion tail warnings exists, the topic of non-intended behavioral changes has been neglected in the published research about this new type of warning system.

1.2. Behavioral adaptations: definition, explanatory models and empirical findings

It must be noted that the above-mentioned differentiation of 'abuse' and 'incorrect use' is not always clear from a practical point of view since the information provided by the manufacturers regarding intended use of an ADAS is sometimes ambiguous. Another issue is the difficulty to define what drivers are entitled to expect from the respective ADAS on the basis of objective standards (van Wees & Brookhuis, 2005). For this reason, during the empirical study of foreseeable misuse (Marberger, 2007), the focus was directed towards the concept of so-called negative 'behavioral adaptation' (OECD, 1990). Behavioral adaptations are not-intended changes in behavior of traffic participants after changes to the traffic system (OECD, 1990) and thus include both willful contrary use and unintended misuse:

> "Behavioural adaptations are those behaviours 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." (p. 23).

According to Martens and Jenssen (2012), the most prominent example of behavioral adaptation is the introduction of antilock braking systems (ABS): Sagberg, Fosser, and Sætermo (1997) showed that driving with ABS lead drivers to keep shorter following distances. The emergence of such negative behavioral adaptations has been described many times in traffic-psychological behavior models and has been illustrated in empirical studies (e.g., Forward Collision Warning (FCW) and Adaptive Cruise Control (ACC): Cotté, Meyer, & Coughlin, 2001; Fancher et al., 1998; Hoedemaeker & Brookhuis, 1998; Janssen & Nilsson, 1993; Rudin-Brown & Parker, 2004; Ward, Fairclough, & Humphreys, 1995). Explanatory models interpret these findings as:

- Adaptation to risk perception (e.g., Fuller, 1984; Näätänen & Summala, 1976; Wilde, 1988): Here, the assumption is made that during driving, drivers assess the perceived risk and compare it with their subjectively acceptable risk. A decrease of the perceived risk (e.g., by the introduction of safety measures) results in a discrepancy to the subjectively acceptable risk and the likelihood of discrepancy-reducing behavior (e.g., risky driving) increases. Thus, a rise in subjective safety after the introduction of a safety measure may lead to a riskier driving style.
- Cognitive information processing (e.g., Rudin-Brown & Noy, 2002; Weller & Schlag, 2004): Here, the basic assumption is that behavioral adaptations are caused by mental representations. These are obtained from information provided by the system or interactions with the system (e.g., the function of the ACC can be extracted from the operating manual; however, it can also be learned by using the system). In case of erroneous or incomplete assumptions about the intended use, behavioral adaptation may result. The build-up and utilization of knowledge can be affected by personality factors (e.g., locus of control) as well as driver expectations (e.g., trust in the system).

The conditions that lead to behavioral adaptation after the introduction of a safety measure are subject of ongoing research. According to Bjørnskau (1995), behavioral adaptations depend on (1) how easy the change to the road system is detectable, (2) if road users have already adapted their behavior to the target factor of the safety measure, (3) the size of the positive effect on safety regarding the target factor, (4) if the safety measure reduces the probability of being involved in an accident and (5) if additional utility can be gained from the behavioral adaptation.

Up to now, results of studies evaluating behavioral adaptation to ADAS are of a mixed nature (Dragutinovic, Brookhuis, Hagenzieker, & Marchau, 2005). There are studies indicating behavioral adaptations to these systems (e.g., maintaining higher driving speeds or insufficient headways while driving with FCW or ACC, Hoedemaeker & Brookhuis, 1998; Janssen & Nilsson, 1993; Muhrer, Reinprecht, & Vollrath, 2012; Rudin-Brown & Parker, 2004; Ward et al., 1995) as well as contrary findings (e.g., fewer or equal occurrences of insufficient headways or lower driving speeds while driving with FCW or ACC; Bao, LeBlanc, Sayer, & Flannagan, 2012; Ben-Yaacov, Maltz, & Shinar, 2002; Burns, Knabe, & Tevell, 2000; Fancher et al., 1998; Janssen & Nilsson, 1993; Stanton, Young, & McCaulder, 1997). An important aspect that has sometimes been neglected in previous research is the assessment whether the detected behavioral effects lead to safety–critical consequences (e.g., if a behavioral adaptation in car-following behavior is not only present but has to be classified as safety–critical with regard to common threshold values for the identification of critical following behavior). Another issue that has rarely been addressed is the question if behavioral adaptations also affect the drivers' distribution of attention. For example,