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Designers beware: Response retrieval effects influence drivers' response times to local danger warnings

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ABSTRACT

The present study investigates the effect stimulus–response binding processes in action control have on drivers' behavior. Warning displays of driver assistance systems usually consist of several features, even those that may have no particular meaning for a currently to-be-executed response. Yet, research on distractor processing has shown that all features in a selection situation are integrated with responses and thereby can later on directly influence behavior due to feature-based retrieval of responses (which can be compatible or incompatible in the current situation). In four experiments we investigated the influence of ignored display-features on responses to local danger warnings. Participants responded manually (Experiment 1, $N = 30$) to the display colors and ignored additional icons (depicting a particular danger) on the displays. We approached responding in a driving and braking situation by using foot pedals for the responses (Experiment 2, $N = 29$), using a go/no-go task (as to imitate braking vs. no braking; Experiment 3, $N = 60$), and a real driving situation (Experiment 4, $N = 25$). We observed clear effects of feature-based response retrieval on performance when the features were relatively complex, while participants reacted via foot pedals as well as while driving a car. The repetition of an ignored feature facilitated behavior if the response also repeated, but hampered different responses. It is concluded that the possible influence of distractor–response binding on drivers' responses should be taken into account for the design of local danger warnings in driver assistance systems.

1. Introduction

While driving a car, we are generally exposed to a continuous stream of visual, auditory, and tactile information of which some are crucial to perceive and respond to and others are irrelevant for the currently executed actions. In order to facilitate fast and correct responses, some cars use warning signals to indicate hazards like lane deviation or another car being within the blind spot. Factors that have been shown to influence the effect of in-car-warnings include the timing of warnings, warning location, whether warning locations are distributed or centralized, warning modality, and the reliability of the driver assistance system (e.g., Abe & Richardson, 2006; Horrey & Wickens, 2004; Lee, Gore, & Campbell, 1999; Lee, McGehee, Brown, & Reyes, 2002). Some advanced driver assistance systems give different warnings as to indicate the kind of upcoming hazard that has to be avoided (see Cummings, Kilgore, Wang, Tijerina, & Kochhar, 2007; Thoma, Lindberg, & Klinker, 2008). That is, a driver is alerted to different hazards by different signals. Such signals are meant to fasten the

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process of situation identification and thus enable an earlier choice of response to avoid potential collisions. Interestingly, Cummings and colleagues (2007) found no advantage of situation specific alarms over a general master alarm that gives the same warning regardless of the kind of upcoming hazard. Apparently, help on situation identification does not boost adequate responding (see also Ho, Cummings, Wang, Tijerina, & Kochlar, 2006; Thoma et al., 2008).

Yet another way in which warnings could affect driving performance, might be due to a direct influence on response execution. Notably, Cummings and colleagues found most inaccuracies in drivers' behavior in cases of false positive alarms. That is, if an alarm signal but no cause was present, drivers sometimes aggressively braked or steered without a real cause. Recent theories of action control may explain part of these results. For example, the Theory of Event Coding (Hommel, 1998, 2004, Müsseler, Aschersleben, & Prinz, 2001) assumes that features of stimuli, people respond to and the response itself are integrated in one episodic memory trace or *event file*. Repeating part of this event file then triggers the reactivation of the entire episode. That is, the repeated encounter of the same stimulus retrieves the response that is stored in the same event file. This episodic retrieval process is a core feature of automatization in perception and action (Logan, 1988; Treisman, 1992). Therefore, with an increasing number of experiences of the same episode, an influence of learned associations between stimuli and responses will influence responding in addition to the mentioned retrieval effects. Yet, importantly for the present considerations, an influence due to response retrieval on the basis of stimulus–response bindings is possible after a single encounter of a stimulus–response combination. Retrieving a previous event file can facilitate perception and action in case of a complete match between the previous and current episode, but it can also impair the perception of novel stimuli and interfere with responding if the retrieved event file contains a mismatch with some of the features or response requirements of the current situation (Denkinger & Koutstaal, 2009; Hommel, 1998, 2004; Treisman, 1992). Such retrieval at a false positive alarm in the study of Cummings and colleagues (2007) would have retrieved the braking or steering response the driver (correctly) executed at the last encounter of the signal resulting in a repetition of this action even though no real cause was present at this particular encounter of the signal. Since responses were not analyzed by their relation to the previous warning signal and response, it cannot be decided whether response retrieval or some different mechanism (e.g., learned associations between signals and responses) led to these errors. Yet, as the authors point out, such inappropriate responses could lead to chain reactions in real traffic and should be avoided. Even if an alarm is not false positive, an adequate response to, say a forward collision warning can be different on different occasions. In one situation it might be more adequate to brake, while in another a sharp steering movement might be necessary (for example because of a following car). Thus, the response retrieval effect might also be an explanation, why no difference was observed between collision specific warnings and one general master alarm. In both cases, not only the situation, but also the adequate response had to be identified.

With the present experiments we aim to investigate, whether retrieval effects may indeed influence drivers' performance. One the one hand, this becomes increasingly relevant with the already large and increasing number of warnings provided by driver assistance systems. With these various information and warnings it becomes more likely that different warnings appear in short succession, which increases the probability of retrieval effects due to repeated display features. On the other hand, such influence is also relevant regarding future driver assistance systems that could be designed to prompt a response instead of indicating a certain hazard. With increasingly more information that can be analyzed by future cars due to car-to-car and car-to infrastructure communication (see Ho et al., 2006), such aid may be possible. One system that assumes that braking can be correctly prompted in future scenarios, is currently developed at the *German Research Center for Artificial Intelligence* (Saarbrücken, Germany) for the project simTD (Safe and Intelligent Mobility – Testfield Germany; http://www.sim-td.de/). The displays of this system prompt the driver by means of a color code as to which response is required. For example, in an advance warning, the driver is prompted to be attentive and not to respond yet. Later on, in a critical situation he/she might be prompted to brake. In addition, the displays include pictographic information about the type of the approached situation (for some examples of similar displays, see Fig. 1). If the response, indicated by the display color, is integrated with the centrally presented icon that indicates the hazardous situation, this icon may retrieve the response the next time it is presented, both if the same, but also if a different response is necessary at this encounter.

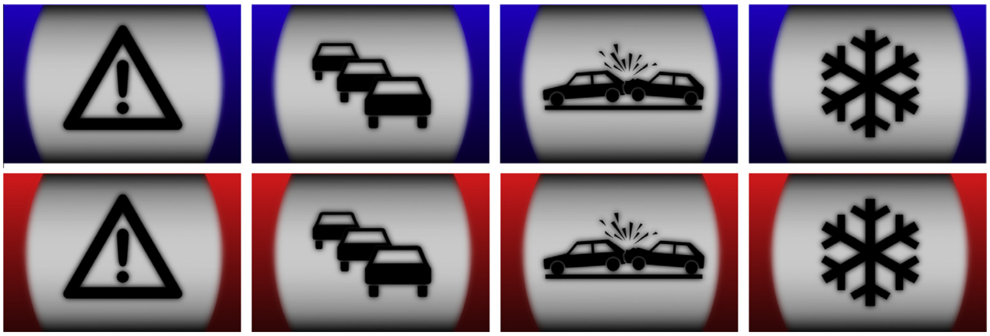

Fig. 1. Examples for color coded warning displays. The same displays were used as stimuli in Experiments 1 through 4. Note that the backgrounds could be presented in blue or red in Experiment 1 and in blue, red, yellow or green in Experiments 2 through 4. The images at the center were always black and white. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)