DESIGN OF EFFECTIVE FEEDBACK: UNDERSTANDING DRIVER, FEEDBACK, AND THEIR INTERACTION

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Summary: Risky driving behaviors such as speeding, close car following and engaging in non-driving related secondary tasks are commonly observed and may increase crash risks. Providing effective feedback to drivers of their risky behaviors may decrease the likelihood of hazardous situations, thereby reducing crashes or crash severity. However, inappropriate feedback could lead to distraction and/or added workload to the driver, resulting in undesirable effects on road safety. Successful design of effective feedback builds on a comprehensive understanding of the characteristics of the driver, the feedback, and their interaction. As a first step to this approach, we summarize literature and propose a cognitive model of driver-feedback interaction. This model considers characteristics of the driver and the feedback, and illustrates three feedback loops through which feedback can influence the driver. Although still at a preliminary stage, the model provides a framework for future feedback design and empirical investigations.

INTRODUCTION

Human error is estimated to be the sole cause in 57% of all traffic crashes and a contributing factor in over 90% of them (Treat et al., 1979). Specifically, inappropriate speed choice and gap acceptance decisions, close car following, and improper visual scanning behaviors have been identified to increase crash risks (e.g., Klauer et al., 2006; Kloeden et al., 1997). As a countermeasure to these risky driving behaviors, feedback can be provided to improve response to road events (e.g., faster reactions) and induce positive behavioral changes (e.g., reduced tendency to speed) (Donmez, Boyle & Lee, 2008a).

Traditional driver feedback methods such as variable message signs, though widely used for decades, cannot be tailored to personal needs and may be absent in many situations. Therefore, these methods may not have long term influence on driving behavior. For example, although drivers demonstrate better speed limit compliance when they see either a warning that their speed was being monitored or the average travelling speed at the site, or both, on a variable message sign, they speed back up once they pass the sign (Wrapson, Harre & Murrell, 2006). With the advances in vehicle technology, it is now possible to deliver consistent feedback personalized for an individual driver. Such feedback, when presented properly, can provide both immediate benefits on driving performance and long-term positive changes in behavior (Donmez et al., 2008a). It has been found that drivers have increased compliance rates when speed limit information is presented inside the vehicle in a consistent manner (Lai, Carsten & Birang, 2012). In addition, in-vehicle feedback targeting driver distraction was able to re-direct driver's attention back to the road from a secondary task (Donmez, Boyle & Lee, 2007), and reduce the tendency to engage in distractions (Donmez, Boyle & Lee, 2010).

However, designing effective feedback is not straightforward (Young, Birrell & Stanton, 2011). For example, to mitigate distraction, various feedback strategies may be adopted depending on the level of automation (e.g., warning vs. taking control from the driver), locus of control (e.g., driver vs. system initiation of a strategy), and the particular task being modulated (e.g., driving vs. non-driving related) (Donmez et al., 2006). In addition, the same feedback method may lead to differential effects on drivers depending on driver characteristics (Agerholm et al., 2012; Lai et al., 2012). To successfully design feedback, it is necessary to understand the driver, the feedback, and the interaction between the two.

Driver

Driver characteristics are good predictors of the type and severity of exhibited risky driving behaviors. Examples of such characteristics include age (Jonah, 1990), gender (Begg & Langley, 2001), driving experience (Williams, 1998), attentional ability (Owsley, 1994), memory capability (Carr & Ott, 2010), and personality (Gulliver & Begg, 2007). In general, risky driving behaviors are more commonly observed among drivers who are younger, male, and possess higher risk tolerance (Begg & Langley, 2001; Gulliver & Begg, 2007). Younger drivers often engage in speeding, close car following, and driver distraction, which have been linked to their inexperience in driving, risk-seeking personalities, and peer pressure (Gulliver & Begg, 2007). In contrast, older drivers are more likely to exhibit failure to observe, improper gap acceptance decisions, and delayed motor responses. These problems are mainly attributed to age-related degradation of perceptual and motor abilities, slower processing speed, and declines in attention and executive functions (Owsley, 1994; Daigneault et al., 2002).

These driver characteristics likely determine whether and how well a driver may benefit from feedback. Supporting evidence emerge from research in workplace productivity and education as well as the driving domain. In a workplace, individuals who are more willing to seek and receive feedback from their evaluators often demonstrate higher acceptance toward feedback, and benefit more from it (London & Smither, 2002). Similarly, when real-time feedback on vehicle speed was provided on a display, drivers with higher levels of feedback acceptance were less likely to speed (Agerholm et al., 2012). In a focus group study, compared to mid-age drivers, older drivers reported higher level of acceptance of and trust in a proposed in-vehicle feedback mechanism which might alert the driver to discontinue their phone use or lock the driver out from the interaction (Donmez et al., 2006). Thus, it appears that driver characteristics influence the acceptance of feedback, which in turn moderates its use. In addition, near-crashes are quickly forgotten by drivers (Chapman & Underwood, 2000), making it difficult for them to learn from past driving events. Learning from experience is particularly problematic for drivers with poor memory capabilities, such as individuals with mild cognitive impairment or amnesia. These drivers may encounter greater difficulty in recalling the details of their driving when feedback is presented retrospectively, thus a replay of the event or an effective cue supporting memory retrieval might be necessary.

Feedback

Design characteristics of feedback can greatly influence the effectiveness of feedback. These characteristics fall into three major categories: ‘when’, ‘what’, and ‘where’. ‘When’ includes the trigger of feedback (e.g., eyes off road, over speed limit), the timing of feedback (e.g., during driving, after driving), and the duration of feedback (e.g., seconds, minutes). ‘What’ includes the modality of feedback (e.g., visual, auditory), reinforcement type (e.g., positive vs. negative reinforcement), and the information content of feedback (e.g., discrepancy feedback which points out a gap between the current performance and the standard, or corrective feedback which provides specific procedural and situational knowledge needed to complete a driving task). ‘Where’ includes the location of feedback (e.g., in-vehicle head-up display, a web page).

Evidence from research on education and workplace productivity reveals that negative feedback may result in higher levels of intentional effort from an individual to change behavior, compared to positive feedback (Kluger & DeNisi, 1996). However, negative feedback, especially when perceived to be highly negative, may induce an adverse emotional reaction, leading to decreased acceptance or even rejection of feedback (Kluger & DeNisi, 1996). Particularly, in the driving domain, it has been noted that carefully combined positive and negative feedback may lead to benefits in both driving behavior and acceptance toward feedback (Donmez et al., 2008a).

Studies on driver feedback have also examined the effects of timing, modality, and saliency of feedback. It has been shown that while concurrent feedback can provide immediate benefits (Donmez et al., 2007), it may also pose a distraction and may have to be delayed a few seconds until the overall demand is lower (Arroyo, Sullivan & Selker, 2006). Feedback provided after a drive, in general, can lead to a positive behavioral change (Donmez et al., 2008b). Larger benefits can be observed if feedback is provided both during and after driving (Donmez et al., 2008b). In addition, visual feedback may not be as effective as auditory feedback if presented in real-time as it may not be salient enough to convey an efficient warning message (Cao et al., 2010), or may induce a visual distraction (Scott & Gary, 2008), but may be more appropriate when presented after a drive. When providing real-time alerts to avoid driving hazards, a sufficient level of feedback saliency is necessary to capture driver’s attention immediately (Cao et al., 2010). Therefore, designers should consider potential interactions among feedback design parameters both in terms of feedback effectiveness as well as the associated risk of distracting the driver from the primary task of driving. Further, feedback design needs to take into consideration the balance between driver acceptance of feedback, its immediate effectiveness, as well as its long term effects.

A COGNITIVE MODEL OF DRIVER-FEEDBACK INTERACTION

We propose a high level cognitive model to describe driver-feedback interaction. This model takes into consideration driver characteristics (e.g., attentional and memory abilities, personality) and feedback design parameters (e.g., timing, content). Here we present an initial model which is separated in two: the left part concerns cognitive processes that take place during driving, while the right part represents cognitive processes after driving. The model includes four components: limited attentional resource of the driver, mental model of safe driving, memory of past driving events, and feedback loops. Here we describe each component in more detail.

Limited Attentional Resource

At any given moment, a driver is only able to perform a limited number of tasks, as each task costs a portion of the limited attentional resource (Feng, Pratt & Spence, 2012; Wickens, 1978). In Figure 1, the white vertical dividers divide the resource among tasks. If a driver engages in a secondary task, the portion of attentional resource devoted to driving becomes smaller. In the current presentation of the model, a secondary task is illustrated; however, a secondary task may not be present depending on the unsafe behavior of interest. Processing real-time feedback will also consume a certain amount of attentional resources. As a result, the design of real-time feedback needs to consider its perceptual saliency, its processing demand, the current workload from the driving task, and the individual's attentional capacity.

Memory

After each road trip, the driver maintains memory about the driving events. The amount and vividness of memory degrades with time (Baddeley, 1999). Even near crashes are not retained well, with an estimated 80% of near crashes forgotten after two weeks (Chapman & Underwood, 2000). As a result, memory support must be provided for feedback presented after a drive to assist the recall of events from a single trip or over a long period of time.

Mental Model of Safe Driving

This mental model consists of a driver's procedural and situational knowledge of safe driving. Such knowledge not only comes from learning as a novice driver, but is also affected by personality and is constantly updated according to driving experience, feedback, and perceived social norms (Ajzen, 1991). This mental model guides decisions and choices of intentional behaviors during driving. For example, if a driver perceives a significant increase in the demand of the driving task, he may stop conversing with a passenger to fully concentrate on driving.

Feedback

Feedback may be provided during driving and also after a trip (Donmez et al., 2008a, 2008b). Feedback timing as well as other parameters such as modality, reinforcement type, and information content influence the effectiveness of feedback through three specific feedback loops in this model (as numbered ① ② ③ in Figure 1).

The first loop (①) reflects feedback provided during driving. For example, when a warning is presented to re-direct attention to the roadway, a driver may withdraw from the secondary task, or devote less attentional resource to it (the position of the divider moves). Saliency and modality of feedback provided during driving influence the likelihood of feedback capturing driver's attention and the processing demands it will place on the driver. For example, an auditory alert is likely to capture a driver's attention immediately even when the driving task is difficult (Scott & Gary, 2008). As a result, careful consideration of the saliency and modality of feedback provided during driving is essential to prevent feedback from becoming a distraction.

The second loop (②) describes an introspective process that a driver may engage in after a trip. For instance, a driver may adjust her future car following behavior, if she finds herself in a near crash due to failure of maintaining a safe following distance. However, the effect would differ among drivers given differential memory capability. Still, this feedback loop appears to be less robust as memories of near accidents often decay quickly (Chapman & Underwood, 2000).

The third loop (③) illustrates feedback which can be presented after a trip. With cues to facilitate memory retrieval and information on social norms, this loop can be powerful to modify a driver's mental model of safe driving, and thus to alter driving behavior. The strength of this loop can also be affected by reinforcement type (Kluger & DeNisi, 1996) and feedback content, mediated by drivers' acceptance (Donmez et al., 2008a). For example, if feedback is provided based on a driver's performance over an extended period of time, positive feedback can be effective to motivate a driver to keep investing effort for behavioral changes (Kluger & DeNisi, 1996). In addition, information aimed to correct misperceptions of unsafe driving behaviors that commonly exist in the society can be provided via this feedback loop. Such feedback can be effective by calibrating perceived social norms on safe driving behaviors. A good example is the reduction of drinking and driving through campaigns (Perkins et al., 2010).

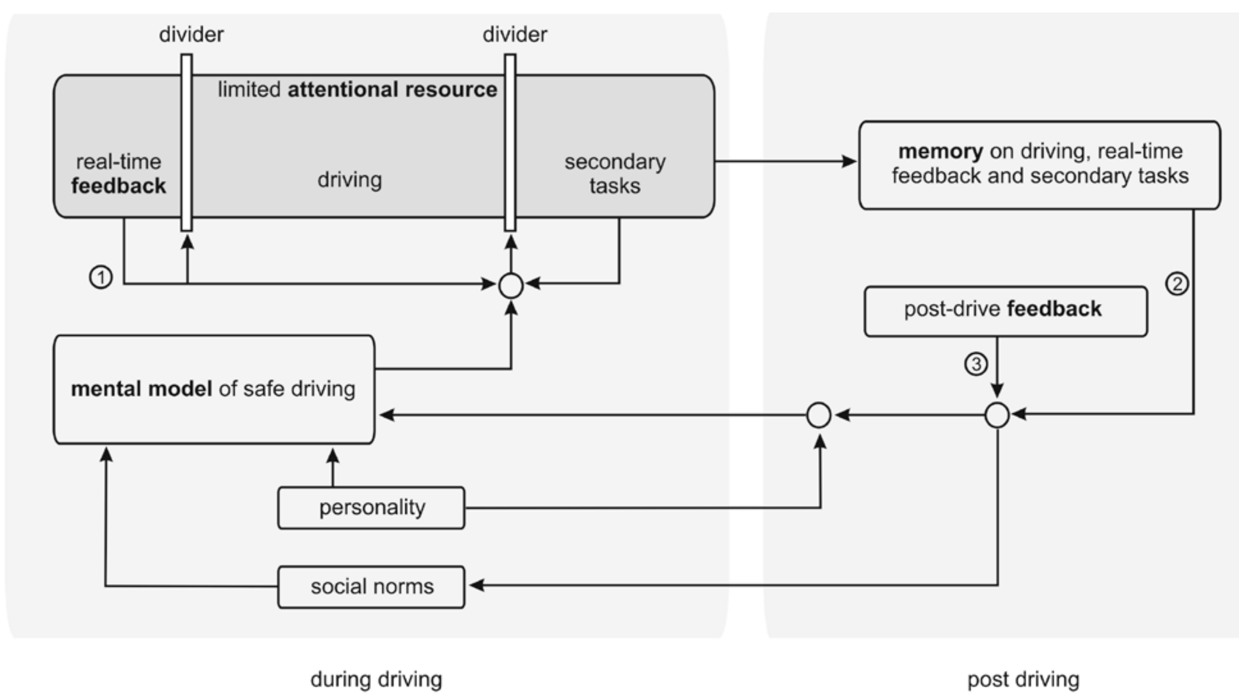

Figure 1. A cognitive model illustrating driver-feedback interaction

FUTURE DIRECTIONS

The current model provides a basic illustration of the cognitive interaction between the driver and the feedback. Our next step is to expand the model to be more comprehensive with respect to theories on attention (e.g., Wickens, 1978), memory (e.g., Baddeley, 1999), and the mechanisms of behavioral feedback interventions (e.g., Kluger & DeNisi, 1996).

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