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DESIGNING FEEDBACK TO INDUCE SAFER DRIVING BEHAVIORS: A LITERATURE REVIEW AND A MODEL OF DRIVER-FEEDBACK INTERACTION

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Abstract

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 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. This driver-feedback interaction model provides a framework for future feedback design and empirical investigations.

Executive Summary

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; Neyens & Boyle, 2007). 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; Lee et al., 2013).

We propose a high level model to describe cognitive, personality, social, and behavioral components involved in driver-feedback interaction. The cognitive component includes attention and memory processes. The personality component includes personality traits such as self-efficacy and locus of control. The social component involves social influences (e.g., effects from perceived social norms) on driver-feedback interaction. The behavioral component includes mechanisms of behavioral changes induced by feedback. Our model considers characteristics of both the driver (e.g., cognitive ability, personality) and feedback (e.g., timing, modality). It also illustrates three feedback loops through which feedback can affect drivers. This model provides an initial step in understanding driver-feedback interaction and to improve the design of effective feedback for drivers.

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Chapter 1: Unsafe Driving Behaviors

1.1 Definition

In this report, we define unsafe driving behaviors as improper driving behaviors which can lead to potential safety hazards and which a driver exhibits due to his/her incapabilities or improper intentional choices. Examples of unsafe driving behaviors include speeding, improper gap acceptance decisions, close car following, failing to obey traffic lights or signs, and driver distraction.

1.2 Crash Statistics

Unsafe driving behaviors have been identified as significant causes of traffic crashes (NHSTA, 2010; World Health Organization, 2003; Blows et al., 2005). Among the 5.4 million motor vehicle crashes reported by the police in the United States in 2010, as many as 21.4% were caused by driving too fast, 7.2% resulted from failure to yield right of way, 6.6% were associated with driver distraction, and 5.5% were due to operating vehicle in an erratic, reckless or negligent manner (NHSTA, 2010). Experimental studies also confirm that unsafe driving behaviors lead to degraded driving performance and subsequently increase crash risks (Begg et al., 1999; Cooper & Zheng, 2002; Horberry et al., 2006; Klauer et al., 2006; Kloeden, Ponte & McLean, 2001; Lam, 2003; Leung & Starmer, 2005; Neyens & Boyle, 2007; Ranney et al., 2000; Wierwille, 1993). Take cell phone use while driving for example; using a mobile phone interferes with driving, by competing for limited mental resources necessary to complete the visual, auditory, motor and integrative cognitive processes required for the driving task (Ranney et al., 2000; Wierwille, 1993; Strayer et al., 2003). Particularly, the visual manual tasks involved in cell phone use (e.g., dialing, texting) drastically increase the risk of engaging in safety critical events (Fitch et al., 2013). Conversing on a phone, although not found to increase crash risks in a recent naturalistic study (Fitch et al., 2013), has been linked to an increase in misses of important road events and slower responses to hazards in many laboratory studies (Atchley & Dressel, 2004; Consiglio et al., 2003; Strayer et al., 2003). It has also been linked to a greater severity of injuries once a crash took place (McEvoy et al., 2005), in particular when an older driver was involved in the crash (Liu, 2012).

1.3 Mitigation Strategies

As a countermeasure to these risky driving behaviors, feedback can be provided to drivers 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 a message noting that their speed was being monitored and / or the average traffic speed 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). Drivers exhibit increased compliance rates when speed limit information is presented inside the vehicle in a consistent manner (Lai, Carsten & Birang, 2012). Similarly, 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. For example, in an analysis of feedback design to enhance safety and environment-friendly driving behaviors, it was found that while the objectives largely overlapped, there were conflicts under certain circumstances (Young, Birrell & Stanton, 2011). In addition, choosing a proper algorithm for detecting unsafe driving behaviors such as distracted driving is a complicated task (Lee et al., 2013). The effectiveness of feedback builds on a high detection rate. However, when a high detection rate comes with a high level of false alarms, drivers are less likely to trust and accept feedback. Moreover, development of effective feedback needs to consider various other critical factors. For example, driver distraction mitigation needs to take into account 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, Boyle and Lee, 2003; Donmez et al., 2006). It is important to consider these dimensions as they may place significant influences on a driver's reaction to feedback. For example, when a driver is distracted but no danger is yet approaching, an informing strategy may be used to provide important information that otherwise is missed by the driver when distracted. However, when a potential danger is detected and projected to happen shortly if no action is taken, an intervening strategy can be more effective in which the vehicle takes over control to ensure a quick reaction (e.g., steering, braking).

In general the same feedback method may lead to differential effects on drivers depending on driver characteristics (Agerholm et al., 2012; Donmez et al., 2006; Lai et al., 2012). For example, with an advisory intelligent speed adaptation system, drivers demonstrated a significant reduction in speeding, with younger and less experienced drivers having greater benefits. Further, some drivers will be more reluctant than others to adopt feedback and alter their behavior (Agerholm et al., 2012). For example, older drivers demonstrated greater acceptance and trust toward receiving warnings for potential dangers and being locked out from interacting with a distracting in-vehicle technology (Donmez et al., 2006).

These previous studies suggest that to successfully design feedback, it is necessary to understand the driver, the feedback, and the interaction between the two.

Chapter 2: Driver

2.1 Characteristics Related to Unsafe Driving Behaviors

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), cognitive ability (Owsley, 1994), and personality (Gulliver & Begg, 2007).

2.1.1 Age.

Younger drivers, especially teenagers, commonly exhibit risky driving behaviors (Jonah, 1990; Rhodes & Pivik, 2011; Begg & Langley, 2001; Gulliver & Begg, 2007). They often engage in speeding, close car following and driver distraction, which have been linked to their inexperience in driving, risk-seeking personalities, and peer pressures (Gulliver & Begg, 2007). Younger drivers on average perceive risky driving behaviors to be much less dangerous than middle aged drivers (Deery, 1999; NHTSA, 2004; Rhodes & Pivik, 2011). Such an attitude toward unsafe driving behaviors may be related to younger drivers' over confidence in their driving abilities (Deery, 1999). It has been found that younger drivers overestimate their ability to deal with hazardous situations and to recover from an error (Brown, 1982).

Unsafe driving behaviors are also observed among older drivers, more frequently than among middle aged drivers. This age-related difference has been linked to older drivers' greater level of distractibility, failure to observe, improper gap acceptance decisions, and delayed motor responses (for a review, see Anstey et al., 2005). These problems are mainly attributed to degrading perceptual and motor abilities, slower processing speeds, and declines in attention and executive functions (Daigneault et al., 2002; Owsley, 1994). Older drivers are less able to extract information from a cluttered visual environment, leading them to take improper actions and subsequently experience hazards (Ball et al., 1993; Owsley, 1994). In addition, although older drivers in general do not intentionally seek to engage in a secondary task while driving, they are susceptible to distractions while driving (Janssen & Brumby, 2010; Strayer & Drew, 2004; Strayer, Drew & Johnston, 2003; for a review, see Ranney, 2008). Not only their attention is easily diverted by in-vehicle technology such as cell phones and GPS systems, they also face increasing challenges from tasks inherent to driving such as navigation (Aksan et al., 2012; Rizzo, 2011; Boer, Cleij, Dawson & Rizzo, 2011).

2.1.2 Gender.

In general, male drivers are more likely to be involved in traffic crashes, particularly serious crashes, compared to females (Evan, 1991; NHSTA, 2010). This gender difference is apparent among all ages, and is greatest for drivers who are young and who have limited driving experience (Maycock et al., 1991). The underlying reason for the difference in crash risks is suggested to be the differences in intentional driving behaviors (e.g., Åberg & Rimmö, 1998; Lawton et al., 1997; Storie, 1977). This claim is substantiated by males committing more traffic violations such as speeding, drunk driving, and other risk taking behaviors than females (Åberg & Rimmö, 1998; Blockley & Hartley, 1995; Lawton et al., 1997; Reason et al., 1990).

2.1.3 Driving experience.

Inexperience is a major reason that contributes to high crash rates among younger drivers (McCartt, Shabanov & Leaf, 2003; Ranney 1994, McGwin and Brown 1999, Groeger 2000). After the first few months of licensure, crash risks per kilometer driven drops significantly (Gregersen et al., 2000; LaBerge-Nadeau, 1997; Mayhew et al., 2000), particularly for at-fault crashes and serious traffic violations (Waller et al., 2001). Two possible underlying mechanisms have been suggested to explain the association between inexperience and high crash risks (for a review, see Trick et al., 2004, pp. 400-401). One reason is that inexperienced drivers lack necessary knowledge for efficient and appropriate judgments (e.g., knowledge- and rule-based processes, Rasmussen 1982, Reason 1990). The other reason is that routine tasks, such as controlling the vehicle, only become automatic after much experience, making it much more difficult for inexperienced drivers to drive and attend to other things (e.g., a secondary task, Shinar, Meir & Ben-Shoham, 1998; Summala, Hieminen & Punto, 1996; Wikman, Nieminen & Summala, 1998).

2.1.4 Perceptual and cognitive abilities.

Perceptual and cognitive functions such as sensation, perception, and attention are crucial to driving (for reviews, see Reger, 2004; Wheatley, 2001). Declines in perceptual and cognitive functioning has been shown to significantly degrade driving performance in on-road examinations (e.g., Aksan et al., 2012; Wood et al., 2008; for a review, see Anstey et al., 2005), and lead to higher crash risks (Ball et al., 1993; Galski et al., 1993; Lundberg et al., 1998; Reger et al., 2004). In the following sections, we review aspects of perceptual and cognitive abilities that are related to driving.

2.1.4.1 Sensation and Perception

Visual acuity

Visual acuity is the acuteness of vision. A sufficient level of visual acuity ensures the driver to have a clear recognition of the visual environment when travelling at a certain speed. Without good visual acuity, a driver would not be able to perceive critical road events until very close, resulting in delayed responses (Strano, 1993). Declines in visual acuity commonly observed among older populations, particularly those with ocular diseases such as cataracts and glaucoma (Haegerstrom-Portnoy, Schneck, & Brabyn, 1999; Klein et al., 1995), have been associated with increased crash risks (Burg, 1967, 1968; Foley, Wallace & Eberhard, 1995; Hills & Burg, 1977; McCloskey et al., 1994; Owsley, McGwin & Ball, 1998; Ivers et al., 1999).

Visual acuity can be measured using standard tests such as the *Snellen Chart* (Snellen, 1862). The Snellen Chart consists of lines of letters with differential sizes. Participants are required to recognize and report the letters until being unable to. A threshold, as the indication of visual acuity, is determined by the minimal physical size of the recognized letters. Such a visual acuity test can be carried out using either a wall-mounted paper chart, or with advanced equipment which presents letters in various randomized patterns.

Contrast sensitivity

Contrast sensitivity describes the ability to distinguish between differential levels of luminance in a visual environment. A sufficient level of contrast sensitivity is necessary for driving conditions such as at night or in glare, where little contrast exists between an object and its background (Stressel, 2000). Similar to visual acuity, contrast sensitivity also declines with age and with the development of ocular diseases such as cataracts and diabetic retinopathy (Arundale, 1978; Derefeldt, Lennerstrand & Lundh, 1979). Impairment in contrast sensitivity has also been linked to increased crash rates (Marottoli et al., 1998).

Contrast sensitivity may be measured using the *Pelli-Robson Letter Contrast Sensitivity Test* (Pelli, Robson & Wilkins, 1988). The Pelli-Robson chart consists of lines of letters with decreasing contrast between the letter and the background so that the letters gradually become more difficult to recognize. Participants are required to report all the letters until being unable to. Contrast sensitivity can also be measured by computerized methods using Gabor patches (e.g., Li et al., 2009). Participants are required to identify the Gabor signal among multiple presentations.

Contrast of the Gabor is modulated depending on the participant's accuracy on the identification task. A threshold is determined when the accuracy drops to a predetermined low level.

Visual field

Visual field is the spatial extent of the environment from which information can be registered on retina. The size of the visual field is a critical visual function predicting driving outcomes (Johnson & Keltner, 1983). For example, constriction of visual field significantly impairs on-road driving performance (Johnson & Keltner, 1983; Wood & Troutbeck, 1992), because the driver can only perceive an insufficiently small area of the visual environment with each glance.

Visual field can be measured using perimetry such as the automated *Humprey Field Analyzer* (Zeiss Humphrey Systems, Dublin, CA, such as the method used in Wood, 2002). A visual field test may be static or kinetic, during which a participant makes a report when seeing a point of light flash.

2.1.4.2 Attention

Our brain has to deal with a vast amount of information. At each second, around 10 billion bits of information arrive at the retina, but only 10 thousand bits are selected for processing at the level of the visual cortex (Raichle, 2010). This process involves selection.

Attention is the process of selectively focusing on some information from the environment while ignoring other information (e.g., James, 1890; Broadbent, 1958; Deutsch & Deutsch, 1963). At any given moment during driving, a driver must select the most important information from the cluttered environment for processing, and also choose the most appropriate response. The vital role of selective attention in driving has been confirmed by numerous research (e.g. Ball et al., 1988; Goodman et al.,1999; Treat et al., 1979; Utter, 2001; for a review, see Trick et al., 2004). Here we describe the most relevant aspects of attention including attentional filtering, orienting of attention, divided attention, and the distribution of attention in space (for a comprehensive framework of studying attention in the context of driving, see Trick et al., 2004).

Attentional filtering

One aspect of attentional selection is filtering. This function suppresses information that is irrelevant to the task, allowing limited attentional resource to be concentrated only on information that is critical to the current situation. For example, when driving through a downtown street, a driver needs to suppress the processing of messages flashed on advertisement boards, but focus on traffic lights and the behavior of nearby vehicles and pedestrians. To measure the function of filtering, a flanker task (e.g., Eriksen & Eriksen, 1975) can be used. In a flanker task, a target is presented within the presence of surrounding distractors. Participants need to identify the target without being influenced by the distractors.

Orienting of attention

The orienting of attention involves moving the attentional focus to particular locations in the visual field. The orienting function enables a driver to make use of cues in the environment such as traffic signs and the layout of the road. A driver makes predictions of situations according to the environmental cues to guide attention. For example, when seeing a sign indicating a lane will be merging from the right side, a driver may expect traffic coming from the right side thus paying more attention to that side when driving through the merging area. The orienting of attention can be examined by the Posner cueing paradigm (Posner, 1980). In a cueing task, participants are presented a cue indicating the likely location of the target. The cue directs participants' attention toward the indicated location, giving a selection advantage to a target that later occurs at the indicated location as compared to targets occurring at other locations.

Divided attention

Divided attention occurs in situations when a driver is engaged in multiple tasks simultaneously. For example, when a driver talks on a phone while driving, he needs to divide attention between the phone conversation and the driving task. Given the limited amount of attentional resource available (Pashler, 1984; Wickens, 1978), divided attention normally leads to impairments on some or all of the tasks. Such impairment is very well documented in the literature on driver distraction (for reviews, see Bayly, Young & Regan, 2008; Drews & Strayer, 2008; Gordon, 2008; Regan et al., 2008). The dual task paradigm can be used to examine divided attention. In a dual task situation, participants are required to perform two tasks simultaneously. Examples of dual tasks include identifying a central target while noticing a peripheral item (Ball et al., 1988, 1993; Feng & Spence, 2008), remembering the colors and locations of one set of items while counting the number of items in another set (Feng, Spence & Pratt, 2012), walking and talking (Kemper, Herman & Lian, 2003), and driving while detecting a peripheral flash (Owens et al., 2013).

Spatial distribution of attention

The spatial distribution of attention is the deployment of limited attentional resource over space. Most research on the spatial distribution of attention focus on the visual domain (e.g., Ball et al., 1988; Feng, 2011; Hassen et al., 2008). The term 'attentional visual field' has been used to describe the fraction of the visual field within which visual information may be selected by attention (Feng, 2011, p.4). Research on aging and driving has shown that the attentional visual field attenuates significantly with age (Ball et al., 1988; Sekuler, Bennett & Mamelak, 2000). This decline in attention has been associated with higher risks observed in on-road driving studies and with increased self-reported crashes (Clay et al., 2005; Hassen et al., 2008; Owsley & McGwin, 2004; West et al., 2010).

The spatial distribution of attention can be measured by the *Useful Field of View (UFOV)* task (e.g., Ball et al., 1988; Owsley & McGwin, 2004) or the *Attentional Visual Field (AVF)* task (e.g., Feng, 2011). In the UFOV task, participants are required to identify a target in the center, while noticing the direction of a peripheral target (in the presence or absence of distractors). The AVF also requires participants to identify a target among distractors across an extended visual field; however, no central task is introduced. The AVF task does not contain the component of divided attention, but simply provides a measure of one's ability to identify a target among distractors across an extended visual field.

2.1.5 Personality.

2.1.5.1 Aggression

Aggression as a personality trait represents an individual's bold behavior in diverse situations over time (Baron & Richardson, 1994; Berkowitz, 1993; Scheier et al., 1978). Drivers who have higher levels of aggressiveness in personality measures, are more likely to demonstrate aggressive driving behaviors, including speeding, following too closely, and excessive lane changing (Lajunen & Parker, 2001), and thus, have an increased likelihood of crash involvement (Beirness, 1993).

Aggression can be measured by various methods, including self-reports, peer reports, and provoking scenarios (Bushman & Anderson, 1998; O'Connor, Archer & Wu, 2001). The Buss-Perry Aggression Questionnaire is a self-report assessment that asks respondents to indicate how well each item (e.g., ‘I have become so mad that I have broken things’) describes oneself on a Likert scale (Buss & Perry, 1992). This self-report method has been shown to be an effective measure of aggression and has been widely adopted in research (e.g., Bushman, 1995; Harris, 1995; Meesters et al., 1996). In addition to self-reports, reports from family members and friends about an individual based on daily observations are also used to assess aggression of the particular individual (Buss & Perry, 1992; O’Connor, Archer & Wu, 2001). This peer-report method uses the same questionnaire items as in self-report, but the rating is based on how well the items describe a close individual rather than the respondent him/herself. There is, in general, good consistency between self-report and peer-report methods (O’Connor, Archer & Wu, 2001). The third method involves laboratory procedures to mimic provoking scenarios that may generate aggressive actions in real life (Anderson & Bushman, 1997; Berkowitz, 1989). In line with this idea, questionnaire items may introduce hypothetical scenarios that are provoking and ask respondents about their feelings and possible actions (e.g., ‘imagine yourself in the following situation: …, how would you feel in this situation?’). One example is the Aggressive Provocation Questionnaire which has been shown to correlate highly with self-reported measures of aggression (O’Connor, Archer & Wu, 2001).

2.1.5.2 Impulsiveness

Impulsiveness is another type of personality trait that can significantly affect driving behavior (Hansen, 1988; Owsley, McGwin & McNeal, 2003; Smith & Kirkham, 1981). Individuals with high level of impulsiveness are less able to exert self-control and hold back their instant reactions (Costa & McCrae, 1989), thus are more likely to interpret other drivers’ behaviors as provocation and react aggressively (Lajunen & Parker, 2001). In a study examining the relation between driver characteristics and driver behavior, it was found that drivers with higher level of impulsiveness reported more driving errors and violations (Owsley, McGwin &

McNeal, 2003). In general, high level of impulsiveness has been linked to drinking and driving, less seatbelt use, and reduced capability of noticing traffic signs (Loo, 1979; Hansen, 1988; Stanford et al., 1996). Impulsiveness is also associated with aggression, anger, and risk taking during driving (Stanford & Barratt, 1992; Dahlen et al., 2005; Zuckerman, 1994).

Impulsiveness can be measured by self-report questionnaires. One widely used scale is the Eysenck & Eysenck (1978) Impulsiveness Questionnaire. This questionnaire contains three subscales that examine impulsiveness (e.g., 'do you often do things on the spur of the moment?'), venturesomeness (in other words, risk aversion, e.g., 'do you quite enjoy taking risks?'), and empathy (e.g., 'would you feel sorry for a lonely stranger in a group?'). Respondents answer 'Yes' or 'No' to each item. The Eysenck & Eysenck (1978) *Impulsiveness, Venturesomeness and Empathy Questionnaire* has been used to study driver behaviors and has demonstrated a link between impulsiveness and unsafe driving (Owsley, McGwin & McNeal, 2003).

Another widely used assessment of impulsiveness is the *Barratt Impulsiveness Scale* (Barratt, 1959). The Barratt Scale investigates the underlying mechanisms of impulsiveness, and separates contributions of attentional (e.g., 'I am restless at the theater or lectures'), motor (e.g., 'I do things without thinking'), and cognitive factors (e.g., 'I often have extraneous thoughts when thinking'). The Barratt Impulsiveness Scale has been extensively used to understand various disorders such as substance abuse and bipolar disorders (for a review, see Stanford et al., 2009).

2.1.5.3 Risk taking

Risk-taking disposition is an aspect of personality which describes how willing an individual is to seek for tension, risk, and adventure (Keinam, Meir & Gome-Nemirovsky, 1984), and is closely related to personality traits such as impulsiveness and sensation seeking (for a review, see Zuckerman & Kuhlman, 2000). In the context of driving, risk-taking disposition has been associated with unsafe driving behaviors such as speeding, careless lane changing, and drinking and driving (Burn & Wilde, 1995; Iversen, 2004; Trimpop, 1994).

Risk-tasking disposition can be measured by the venturesomeness subscale of the Eysenck & Eysenck (1978) *Impulsiveness, Venturesomeness and Empathy Questionnaire*. In this subscale, 16 items describing venturesomeness are included (e.g., 'Do you like diving off the highboard?'; 'Would you enjoy fast driving?'). Scores on this venturesomeness subscale have been shown to provide good predictions of traffic violations (Renner & Anderle, 2000). A similar measure mentioned in literature is the *High-Risk Personality Inventory*, which is a self-report tool designed to identify individuals who seek for tension, risk, and adventure (Keinam, Meir & Gome-Nemirovsky, 1984). It has been found that individuals with a higher degree of risk-taking disposition measured with this tool reported more traffic violations and incidences of speeding (Trimpop, 1994).

2.1.5.4 Sensation seeking

Sensation seeking is a personality trait that illustrates how much an individual wants novel and intense stimuli (Arnett, 1994; Zuckerman, 1990). Higher degrees of sensation seeking have been linked to drinking and driving, speeding, racing other drivers, and many other traffic violations (Arnett, 1990, 1996; Arnett et al., 1997; Burns & Wilde, 1995; Greene et al., 2000). In a literature review of 40 studies (Jonah, 1997), it was found that sensation seeking is a significant contributor to risky driving and collision involvement.

In transportation research, the *Arnett Inventory of Sensation Seeking* is often used to measure the degree of sensation seeking (e.g., Dahlen et al., 2005). The Arnett Inventory is a self-report questionnaire in which respondents rate how well each item describes oneself on a Likert scale (e.g., 'When I listen to music, I like it to be loud'). Research has shown Arnett Inventory of Sensation Seeking to be a valid measure with high internal consistency as well as predictive ability on self-reported risky driving behaviors (Arnett, 1994, 1996; Arnett et al., 1997; Dahlen et al., 2005).

2.2 Characteristics Related to Learning from Feedback

2.2.1 Age.

Age-related changes in perception, attention, executive function, and motor skills (for a review, see Anstey et al., 2005) create significant challenges for feedback design. For older drivers, the saliency of feedback needs to be adjusted according to a driver's perceptual capability (e.g., larger fonts for visual displays, higher volume for auditory feedback). Further, feedback needs to be easy to understand without placing much load on a driver's executive function (e.g., intuitive rather than complex navigation instructions). Older drivers demonstrate highly different preferences in vehicle technologies compared to younger drivers (Kim, Wogalter & Mayhorn, 2010). For example, compared to younger drivers, older drivers raise more concern about vehicle interface design not meeting their demands and favor analog displays, and bigger and brighter labels on the vehicle dashboard.

2.2.2 Cognitive abilities.

2.2.2.1 Distractibility

Distraction happens in daily life and is a significant cause of errors in the completion of an everyday task (Broadbent et al., 1982; Wallace et al., 2002). Distractibility reflects how easily an individual is distracted (involuntarily) by task irrelevant information. For example, older drivers are less likely to ignore distractors in a cluttered visual environment (Sekuler, Bennett & Mamelak, 2000), thus they are more likely to miss critical targets, such as a stop sign, a pedestrian, or another vehicle. Patients with Attention Deficit Hyperactivity Disorder (ADHD) have problems suppressing cognitive distraction therefore cannot maintain their attention on a specific task for an extended period of time. As a result, these patients have difficulties in completing tasks due to distraction (e.g., Barkley, 2004).

Distractibility can play an important role in determining how well a driver may benefit from real-time feedback. The driving task itself, particularly in difficult situations, is cognitively challenging. Thus, processing real-time feedback may place extra mental workload on the cognitive system. While a driver with low distractibility may be able to decline or delay the processing of real-time feedback when the mental workload is very high, a driver with high distractibility may not be able to do so. As a result, the real-time feedback may become a distractor rather than an aid for drivers with high distractibility. Design of effective feedback needs to consider distractibility as an important driver characteristic.

Several methods exist for measuring distractibility in a general daily functioning context. These methods include self-reported questionnaires and laboratory experiments from a purely cognitive perspective. The Cognitive Failure Questionnaire (CFQ) (Broadbent et al., 1982) is an instrument for assessing a person's likelihood of committing an error in the completion of an everyday task. Among 25 total items, 9 items indicate everyday distractibility (Broadbent et al., 1982; Wallace et al., 2002). Similarly, the Adult ADHD Self-Report Scale (ASRS) examines an individual's sustained attentional function as reflected in daily activities (Kessler et al., 2005). In addition to questionnaires, cognitive experiments have also been used to test an individual's ability to identify targets in the presence of distracting stimuli (e.g., Tipper and Baylis, 1987; Forster and Lavie, 2007).

There is a lack of a measurement which can be easily administrated outside the laboratory to directly examine a driver's distractibility as reflected in driving behavior. Such a measurement has yet to be developed, with the incorporation of typical driver distraction situations, such as day dreaming and attending to roadside advertisements too frequently and for too long. In the driving context, distraction may be a result of a driver voluntarily seeking to engage in secondary tasks, or being cognitively unable to block out irrelevant information while focusing on the important information. Therefore, in a measurement of driver distractibility, it is important to distinguish these two cases.

2.2.2.2 Memory

Memory about road trips is formed and preserved by the driver. Not every piece of information about past driving events will be coded in driver's memory. It has been found that, even near crashes are mostly forgotten (about 80%) after two weeks (Chapman & Underwood, 2000). Memory capability represents the amount and quality of information an individual preserves after a certain period of time (Baddeley, 1999). Significant individual differences exist in memory capability. As the learning from past driving experiences depends on the memory of past road trips, the memory capability of a driver should affect how well the driver can learn from previous experiences. Inferior memory capability diminishes access to details of past events, preventing a driver from conducting self-assessment and learning. As a result, memory support should be provided, particularly for drivers with poorer memory capabilities, to enhance the recall of past driving events and to promote learning.

Memory capability can be assessed using various methods. A general clinical measurement is the Mini Mental State Exam (Folstein, Folstein & McHugh, 1975). This mental state exam evaluates an individual's broad range of cognitive functions, including memory, attention, language abilities, and spatial skills. Scores on the Mini Mental State Exam have been shown to be sensitive to cognitive changes, and thus this exam has been widely used as a screening tool for mental illness such as Alzheimer's disease. In a cognitive laboratory setting, more specific assessments such as a memory span task can be administered. For example, in an operational span task (e.g., McCabe, 2008), participants are required to memorize a list of words presented. Before the presentation of each word, an arithmetic question (e.g., '6×8=?') is shown and participants have to report the answer to the question. At the end of the entire list (e.g., five words), participants are required to recall as many words as possible. If a participant is correct on the entire word list and all the arithmetic questions, a longer word list is then presented (e.g., from five words to six words).

2.2.3 Personality.

2.2.3.1 Self-efficacy

Self-efficacy is the belief about one's own ability to complete tasks and achieve goals (Bandura, 1977). Individuals with high self-efficacy are more confident about completing a task, and are more likely to exert effort and to sustain effort for a longer period of time (Schunk, 1990). It has been shown that self-efficacy affects health behaviors, such as smoking, physical exercise, and seat-belt use (Schwarzer & Fuchs, 1996). Similarly, self-efficacy likely influences driver confidence and motivation in behavioral change. Drivers with high self-efficacy may be more confident and willing to learn driving skills and correct unsafe driving behaviors, while drivers with low self-efficacy may be more reluctant to receive feedback and initiate behavioral change.

Self-efficacy can be measured using a general self-efficacy scale. There are several different versions of this scale, including the General Self-Efficacy Scale (Sherer et al., 1982), the General Perceived Self-Efficacy Scale (Schwarzer & Jerusalem, 1995), and the New General Self-Efficacy Scale (Chen et al., 2001). In general, these scales are very similar to each other and all have been shown to be good measures of self-efficacy (Scherbaum, Cohen-Charash & Kern, 2006). Take Sherer et al.'s (1982) General Self-Efficacy Scale for example; respondents indicate how much they disagree or agree with each item on a Likert scale. An example item is 'If I can't do a job the first time, I keep trying until I can'. A higher score on the scale indicates a higher level of self-efficacy.

2.2.3.2 Locus of control

Locus of control is the belief about how much the cause of an event can be attributed to internal vs. external factors (Rotter, 1990). It can significantly affect a driver's behavior (Stanton & Young, 2000) and how the driver will benefit from feedback. Drivers with high internal locus of control are more likely to attribute consequences of driving to their own driving ability, are more concerned about their driving ability, and thus would be more receptive to feedback that can help them improve.

The most widely used measure of locus of control is Rotter's (1966) scale of internal versus external control of reinforcement (for a review, see Furnham & Steele, 1993). In this scale, respondents answer 'yes' or 'no' to each questionnaire item (e.g., 'unfortunately, an individual's worth often passes unrecognized no matter how hard he tries'). Another questionnaire worth mentioning is the Duttweiler (1984) Internal Control Index. Different from Rotter's scale, Duttweiler's questionnaire uses Likert scale and has been suggested as the most reliable questionnaire for testing locus of control among adults (Furnham & Steele, 1993).

Chapter 3: Feedback

3.1 Definition

Feedback as a behavioral change technique has been used widely in different domains including learning, health behavior intervention, and human resource management (e.g., Atkins & Wood, 2002; Kelly & McLaughlin, 2012; Kreuter & Strecher, 1996). Feedback is a useful technique to enhance learning of new knowledge, improve task performance, and facilitate beneficial changes in daily behavior (for reviews, see Kluger & DeNisi, 1996; Smither, London & Reilly, 2005).

In the context of driving, *feedback to drivers* can be defined as *the information available to the driver regarding the state of the driver-vehicle system* (adapted from Donmez, 2007, p.8). This definition is elaborated in the following four aspects.

First, the driver-vehicle system includes the driver, the vehicle, the driving environment, and the interactions among them. As a result, information provided through feedback can describe aspects of any of these components of the system. For example, feedback can be provided to warn a driver when the driver looks away from the road ahead for too long (about the driver), can be information on the travelling speed (about the vehicle), warning about obstacles ahead in the driving environment or traffic information (about the environment, e.g., “express moves slowly until exit A”), or notification to the driver that the current travel direction is not correct to reach the planned destination (interaction).

Second, feedback can provide information regarding past, current, and near future (as predicted) states of the driver-vehicle system. During driving, feedback may be provided to the driver about what is happening, such as the current speed and headway time. The driver may also receive information about potential hazards that are predicted to happen if no action is taken. In addition, after driving, evaluation of and educational information on driving may also be available to the driver.

Third, the aim of feedback is to enhance driving performance, to promote learning, and to correct unsafe driving behaviors. More specifically, feedback may be provided to warn the driver about potentially hazardous situations, to facilitate learning of what is unsafe to do while driving, and to alter driver behavior.

Fourth, feedback not only includes information that is naturally present in the driving environment, but also information that can be artificially presented to augment the existing feedback. For example, position of the vehicle with respect to lane markings provides natural feedback to drivers. This feedback can be enhanced with additional information such as a lane deviation warning.

3.2 Traditional and Emerging Methods

Drivers currently receive feedback from various sources that shapes their driving. For example, variable message signs are displayed by the side of the road to communicate educational messages and traffic conditions (e.g., “Don’t drink and drive”, “Drive according to weather and road conditions”). Passengers in the vehicle may provide notifications and comments on the environment and the behaviors exhibited by the driver. In addition, police surveillance imposes potential negative consequences for unsafe driving behaviors, discouraging drivers from committing traffic violations.

Although traditional methods have been shown to have some effect in reducing unsafe driving behaviors (e.g., Hutton, et al., 2002; Joscelyn & Jones, 1980; Van Houten et al., 1985; Wrapson, Harre & Murrell, 2006), there are several significant limitations. First, these traditional feedback methods cannot be tailored to fit each individual driver’s needs. An educational message reminding drivers not to drink and drive may not be so useful for drivers who never drink and drive. Research has confirmed that feedback messages tailored to the individual are much more useful than untailored messages (Kreuter & Strecher, 1996). Second, these methods do not provide consistent feedback over an extended period of time. One of the major reasons for drivers repeatedly demonstrating unsafe driving behaviors is the lack of negative consequences for committing unsafe driving (Fuller, 1988, 1991). Human behavior is strongly shaped by immediate consequences (Skinner, 1953). Positive consequence increases the frequency of behavior, while negative consequence decreases it. Take speeding for example, drivers may choose to speed if they perceive the relative frequency and certainty of positive consequences (e.g., arriving on time) to be much greater than those of negative consequences (e.g., crashing or getting a ticket).

As a result, benefits on reducing unsafe driving behavior from traditional feedback methods is often very limited. For example, posting the percentage of drivers not speeding on a highway sign led to a decrease in the speed of vehicles traveling past the sign (Van Houten, Nau & Marini, 1980; Van Houten & Nau, 1981). However, this positive effect lasted only 6 km from the position of the sign (Van Houten & Nau, 1983). Similarly, when drivers perceive that their speed is being monitored and displayed on a variable message sign, they demonstrate better speed limit compliance. But once they pass the sign, they speed back up (Wrapson, Harre & Murrell, 2006).

These issues may be overcome by emerging vehicle technology. With an advanced in-vehicle information system, we are now able to deliver personalized feedback to a driver in a consistent manner. These in-vehicle information systems, such as a forward collision system (Lee et al., 2002), a lane departure warning system (Suzuki & Jansson, 2003), an intelligent speed adaptation system (Lai, Carsten & Birang, 2012), or an assistive driving advisory system (e.g., CarCoach, Arroyo, Sullivan & Selker, 2006; Sharon et al., 2005), have been shown to benefit drivers in certain aspects of the driving task.

These systems facilitate the delivery of feedback which is situation specific, thus is accurately tailored to driver's need. In addition, feedback messages can be delivered consistently over an extended period of time as long as the in-vehicle information system is turned on. As a result, each unsafe driving behavior will be followed by an immediate consequence, generating correct associations of consequences and behaviors in the driver's mind. Furthermore, feedback provided after a road trip can incorporate other methods for facilitating behavioral changes. These methods include self-assessment and use of perceived social norms. Self-assessment enhances drivers' awareness of their own state regarding health, cognitive function, driving ability, and current driving practices (Eby, Molnar & Shope, 2000). In a study using workbook to enhance self-awareness and self-assessment in older drivers, 75% of the participants reported becoming more aware of changes in their health and cognitive functioning which could influence their driving (Eby et al., 2003). Perceived social norms also affect drivers' decision on whether to engage in unsafe driving behaviors (Beck & Treiman, 1996; Read, Kirby & Batini, 2002). A driver is more likely to commit unsafe driving when the driver perceives the particular unsafe driving behavior to be common in the community (Åberg et al., 1997; Zaidel, 1992).

Much promise has been shown with feedback provided by in-vehicle information systems. For example, vocal and visual feedback from an in-vehicle tutoring system led to a reduction in a variety of unsafe driving behaviors (de Waard, van der Hulst & Brookhuis, 1999). Similarly, incorporating speed limit information into the vehicle by an intelligent speed adaptation system resulted in at least 30% reduction in speeding (Lai, Carsten & Birang, 2012). Beyond immediate effects, in-vehicle feedback systems can also have a long-term impact on driving behavior (Ben-Yaacov, Maltz & Shinar, 2002; Donmez et al., 2008a). An in-vehicle feedback system targeting driver distraction was able to redirect drivers' attention back to the road from a secondary task (Donmez, Boyle & Lee, 2007), and reduced drivers' tendency to engage in distraction (Donmez, Boyle & Lee, 2010), with some positive effects sustained once the system was removed (Donmez, 2007). In another system designed to improve drivers' headway maintenance, drivers became capable of maintaining longer and safer headways after a brief interaction with the system; the benefits lasted for at least six months (Ben-Yaacov, Maltz & Shinar, 2002).

Despite the potential benefits of in-vehicle feedback technology, there also exists an increasing concern that such systems, when in conflict with the primary driving task, may become a source of distraction (Verwey, 2000). In an attempt to examine the effect of green driving tools (provide real-time feedback for environment-friendly driving) on driving safety, Young, Birrell & Stanton (2011) conducted an analysis of the goals of safe driving and green driving. It was found that while the two goals are consistent in most cases, under certain circumstances, they are in conflict, leading to difficulties in design. To guide the design of feedback for mitigating driver distraction, Donmez and her colleagues (2003) proposed a taxonomy of distraction mitigation strategies. According to this taxonomy, 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). These dimensions can affect drivers' reaction to the system and consequently impact its effectiveness (Donmez, Boyle & Lee, 2006; Donmez et al., 2006). Overall, understanding the goals, parameters, and potential pitfalls of feedback is critical for feedback design.

3.3 Parameters

Design parameters 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).

3.3.1 "When".

3.3.1.1 Timing

Feedback can be provided both during driving and after a road trip. For example, when a vehicle deviates from its lane, a real-time warning can be presented to the driver. Such warning has to be concise and has to communicate a salient message to the driver. In contrast, post-drive feedback can include much more comprehensive information that will provide evaluation, knowledge, and context. A driver can receive a summary of performance on a particular road trip, highlights of specific incidents where unsafe driving behavior was executed, knowledge on what would be the appropriate behavior, and even a replay of these incidents as a context for learning.

Real-time feedback such as a warning is used to notify the driver about a potentially hazardous situation or an improper action that may lead to hazardous events. In a feedback system designed to prevent rear-end collisions, warnings were provided to drivers when the headway time fell below a critical threshold (Scott & Gray, 2008). With the assistance from this feedback system, drivers were able to initiate braking earlier than they did without the system. In another system, feedback on drivers' off-road eye glances was presented on an in-vehicle visual display to mitigate driver distraction (Donmez, Boyle & Lee, 2007). This feedback system significantly reduced drivers' engagement in distracting activities and subsequently increased drivers' focus on the roadway. In the above cases, feedback was provided as soon as a potential hazardous situation or an improper action was detected. However, some studies suggest that, sometimes, it may be more appropriate to delay feedback for a few seconds (Arroyo et al., 2006; Sharon et al., 2005). When the driver is cognitively overloaded, a concurrent feedback message may compete for driver's attention and interfere with the ongoing driving task. Delaying feedback can mitigate the potential disruption while still providing some positive effects on driving. With one such feedback system, researchers found that messages guiding drivers to a certain acceleration pace are more effective when presented at the end of their acceleration action compare to during acceleration (Sharon et al., 2005).

While studies have shown that real-time feedback can lead to positive effects on immediate driving performance (e.g., Donmez et al., 2007; Marshall et al., 2010), it does not necessarily help drivers gain the skills essential for driving better. Research on learning suggests that real-time feedback harms the learning process as it does not allow a learner enough time to make self-assessment and self-correction (Kulhavy & Anderson, 1972; Schroth, 1992). Real-time feedback in general does not appear to provide durable benefits on driving behavior (Van Houten & Nau, 1983; Wrapson, Harra & Murrell, 2006). In addition, drivers may develop overreliance on real-time feedback and may fail to act appropriately if the feedback technology is not present or fails. For example, drivers may depend on a warning system to identify potential hazards and may not take action until a warning is presented. Further, drivers may become more comfortable engaging in distracting activities if a system provides a cue on when to switch their attention to the driving task.

Post-drive feedback, in contrast, can result in long-term benefits on driving behavior (Donmez et al., 2008b). After a road trip, the task to perceive and comprehend feedback no longer has to compete for limited cognitive resources available while driving. Thus, it is possible to provide more detailed information. The drivers can learn what is unsafe during driving, how to act in particular situations, whether their driving has improved from previous road trips, and how their driving compares to other drivers. In an effort to reduce driver distraction, Donmez et al., (2008b) evaluated post-drive feedback on safety critical situations. Drivers responded faster to lead vehicle braking events after receiving post-drive feedback and the benefit was greater when feedback was provided both during and after driving.

3.3.1.2 Trigger

Certain aspects of the driver, the vehicle, and the environment can indicate potentially hazardous situations and can be used to trigger feedback. For example, in a feedback system targeting driver distraction, measurements of the driver that indicate distraction may be monitored, including eye movements, heart rate variability, brain electrical activity, and driving performance. These measures are not equal and some may be more suitable than others under certain conditions. For instance, when a driver engages in a visual distraction, monitoring off-road glances would be useful. However, when the driver engages in an auditory distraction such as a conversation or a cognitive distraction like day dreaming, monitoring off-road glances would not provide useful information. Given the complexity of driver distraction, it may be necessary to administer a combination of measures, including driving performance which is a measure independent of the type of distraction, and can also be used for issues other than distraction such as fatigue or driving under the influence.

3.3.1.3 Duration

Each feedback message may be presented very briefly (e.g., several seconds) or for an extended period (e.g., several minutes or hours). The duration of each feedback message has to be determined by the driver's response and the requirements for feedback saliency. When presented in real-time, feedback such as a warning that is too brief may not be salient enough to capture the driver's attention. However, if a warning is presented for an extended period of time, especially after a driver has noticed what he is being warned about, such a warning will likely annoy the driver and may even become a source of distraction. When presented after a road trip, feedback that is too brief may not allow enough information to be presented to effectively facilitate behavioral change. For example, a driver receiving just a grade (e.g., A, B, C) may not benefit as much as when information about specific situations is provided (e.g., a video recording of a hazardous situation that the driver just experienced, with explanation of what behavior is proper / improper). However, if post-drive feedback contains too much information and goes on for too long, a driver may feel bored and may choose not to receive it anymore.

Feedback may be available to the driver for a short or long period, depending on the nature of the targeted problem and how long a driver takes to adopt the desired behaviour. Learning lane keeping may only take a few warnings from an in-vehicle system, while learning to make a left turn properly at a busy intersection may take much longer. The amount of time it takes to learn different driving skills or to alter different unsafe driving behaviors varies. In addition, for a particular driving skill or unsafe behavior, this amount of time also differs among individual drivers. Novice drivers may be faster at learning safe driving procedures, compared to an experienced driver who has to overcome a resistant unsafe driving habit. Ideally, the duration of feedback presentation should be personalized for each driver based on the learning progress.

3.3.2 "What".

3.3.2.1 Modality

Feedback can be delivered through a variety of sensory modalities, including vision, audition, and touch. All these sensory modalities have been shown to be good channels for communicating feedback (e.g., Ben-Yaacov, Maltz & Shinar, 2002; Boyle & Mannering, 2004; Donmez, Boyle & Lee, 2007; Ho, Reed & Spence, 2006; Kim et al., 2012).

Visual channel is commonly used for delivering real-time feedback. For example, a brief message may be display on an in-vehicle display to inform drivers about the driving environment (Boyle & Mannering, 2004). Given that the visual channel is highly occupied during driving (Sivak, 1996), it may not be easy to convey an efficient warning message when it is not visually salient enough (Cao et al., 2010); or if the message is highly salient and captures driver's attention, it may induce a visual distraction (Hirst & Graham, 1997). For post-drive feedback, visual messages would be very appropriate as information can be presented not only in text, but also in graphs and videos.

In many cases, real-time feedback can also be delivered as auditory messages. In contrast to the visual channel, the auditory channel is omnidirectional and thus is highly appropriate for warning the driver of hazardous situations which require immediate action. For example, in an in-vehicle collision avoidance warning system, a beep was provided to the driver when the headway distance to a lead vehicle breached a critical level (Ben-Yaacov, Maltz & Shinar, 2002). After using this feedback system, drivers were able to maintain longer and safer headway distances. While auditory feedback is useful in communicating a warning, the sound has to be carefully adjusted to avoid masking from the ambient noise.

Drivers naturally receive tactile feedback while driving. For example, drivers rely on force feedback from the steering wheel to form an internal model of the vehicle dynamics such as lateral acceleration of their vehicle (Gillespie, 1992; Toffin et al., 2007). The tactile channel has started to receive more attention from designers in the recent years. Tactile feedback interfaces are being developed to provide turn-by-turn instructions on route navigation (Kim et al., 2012) and to warn drivers for rear-end collisions (Ho, Reed & Spence, 2006; Scott & Gray, 2008). In a study comparing the effects of tactile, visual, and auditory warnings for a collision avoidance system, tactile warnings outperformed both visual and auditory warnings (Scott & Gray, 2008), although tactile feedback may be easily masked in an actual driving environment which is mobile and full of vibrations.

Feedback can also be provided using a combination of multiple sensory modalities (Ho, Reed & Spence, 2007; Kim et al., 2012; Lee et al., 2002). Lee and his colleagues (2002) examined a collision avoidance system which used simultaneous visual and auditory warnings. It was found that such a system not only benefits drivers who are distracted by a secondary task, but also undistracted drivers, by reducing accelerator release times. In another study, younger drivers, although not older drivers, benefited from the addition of tactile feedback to the existing combination of visual and auditory feedback in a turn-by-turn instructed navigation task (Kim et al., 2012).

3.3.2.2 Reinforcement type

According to behavioral psychology, feedback is reinforcement (Skinner, 1953). Positive reinforcement leads to lasting behavioral modification, while negative reinforcement inhibits the behavior to occur again. 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).

In the driving domain, negative feedback can be a warning or a message pointing out the disparity between the driver's performance and the expected/enforced standard (e.g., a speeding ticket). In contrast, positive feedback can be praise about good driving performance or a positive behavioral change, or a reduction of insurance premium due to good driving record. In an in-vehicle feedback system, carefully combined positive and negative feedback may lead to benefits in both driving behavior and acceptance toward feedback (Donmez et al., 2008a).

Rewards, as an example of positive feedback, can have a significant effect on driving behavior. Research has shown that reward programs can facilitate behavioral changes (Bandura, 1977; Geller et al., 1990; Skinner, 1953). For example, delivering small prizes to drivers and passengers has been effective for promoting seatbelt use (for a review, see Geller, 1984). In-vehicle feedback systems may incorporate rewards by linking daily driving data recorded by the feedback system to automobile insurance. If drivers realize that how they actually drive has a larger weight on their insurance than it currently does, they may become more cautious while driving.

3.3.2.3 Content

Content of feedback, particularly content of post-drive feedback, can include a variety of information. According to a theory in feedback intervention (Kluger & DeNisi, 1996), feedback leads to behavioral change in three different ways: 1) affect (by normative feedback); 2) motivation (by discrepancy feedback); and 3) learning (by corrective feedback).

Normative feedback indicates a driver's performance relative to others', such as "you performed better than average". This type of feedback takes effect on changing behavior by directing attention to the self but not the task process (Carver & Scheier, 1981; Wicklund, 1975; Vallacher & Wegner, 1987). Thus, when receiving praise of the self, performance on simple tasks improve but performance on cognitively demanding tasks deteriorate (Baumeister, Hutton & Cairns, 1990).

Discrepancy feedback provides information on what has been achieved on changing behavior. An example would be "your headway maintenance improved from last time". This type of feedback can induce motivation to make a change. It has been found that people prefer to receive positive discrepancy feedback (Carver & Scheier, 1990; Hsee & Abelson, 1991). As a result, discrepancy feedback should be provided to drivers to keep the drivers on the change trajectory when positive behavioral change happens.

Corrective feedback involves pointing out an error and providing information to correct it. It includes error flagging, directive feedback and explanatory feedback (Graesser, Person & Magliano, 1995). As noted by Donmez and her colleagues (2008a), 1) error flagging involves detecting and identifying an error; 2) directive feedback includes instructions on how to recover from the error; 3) explanatory feedback consists of diagnosing the cause of the error (e.g., misconception) and providing detailed knowledge on how to perform the task. Corrective feedback can be delivered in forms such as a warning or an instruction during driving, and a thorough evaluation of the driver's performance with detailed instructions after a road trip.

3.3.3 "Where".

3.3.3.1 Location

Real-time feedback can be presented at various locations in the vehicle. Visual feedback to mitigate driver distraction may be provided on an in-vehicle information display, on the dashboard, or even on the windshield as a head-up display. In a system designed to provide real-time feedback to distracted drivers, when a driver looked away from the road for too long, a color strip appeared on the top portion of an in-vehicle display, or an LED light strip was lit on the vehicle dashboard in front of the driver (Donmez, Boyle & Lee, 2007). Both locations of visual feedback yielded significant benefits in mitigating distraction. Note that when warning a driver about a potentially hazardous situation in the driving environment, the effective location for visual feedback would depend on the current visual focus of the driver. Given that attention will be automatically directed to where visual feedback is presented, it would make more sense to display feedback closer to the windshield. However, visual feedback outside the current attentional focus may also be missed.

Similar to visual feedback, both auditory and tactile signals also have the ability to direct a driver's attention in a certain direction (Ho, Reed & Spence, 2006; Ho, Tan & Spence, 2005; Rochlis & Newman, 2000). Recent research demonstrated that tactile feedback provided via vibrations along the seatbelt can alert the driver about potential collisions including directional information about the collision (Ho, Reed & Spence, 2006). As noted before, it is also possible to combine multiple modalities. However, a combination of visual, auditory and tactile feedback in one system would need careful consideration of the characteristics of the channels, the trigger of feedback, the driver's state, and the cognitive process of multi-sensory integration (Spence & Driver, 1997).

Post-drive feedback can also be presented at various locations such as an in-vehicle information system, and/or personal devices (e.g., a home computer, a smartphone). It would be more convenient and encouraging for drivers to receive post-drive feedback if such information is accessible at a variety of locations. Overall, interface design to convey information effectively across platforms and learning environments is essential to facilitate drivers' willingness to receive and benefit from post-drive feedback.

Chapter 4: A Model of Driver-Feedback Interaction

We propose a high level cognitive model to describe driver-feedback interaction. This model aims to take into consideration driver characteristics (e.g., attentional and memory capacity, personality, perceived social norms) and feedback design parameters (e.g., timing, content). The model we describe includes a general model and its expansion in terms of attentional processes (e.g., Baddeley, 1999), memory processes (e.g., Wickens, 1978), and feedback intervention (e.g., Kluger & DeNisi, 1996).

4.1 A General Model

Here we present a general model which is separated in two: the left part concerns cognitive processes that take place during driving, while the right part represents cognitive processes that take place after driving. The model includes six components: limited attentional resource of the driver, mental model of safe driving, memory of past driving events, personality, perceived social norms and feedback loops. Here we describe each component in more detail.

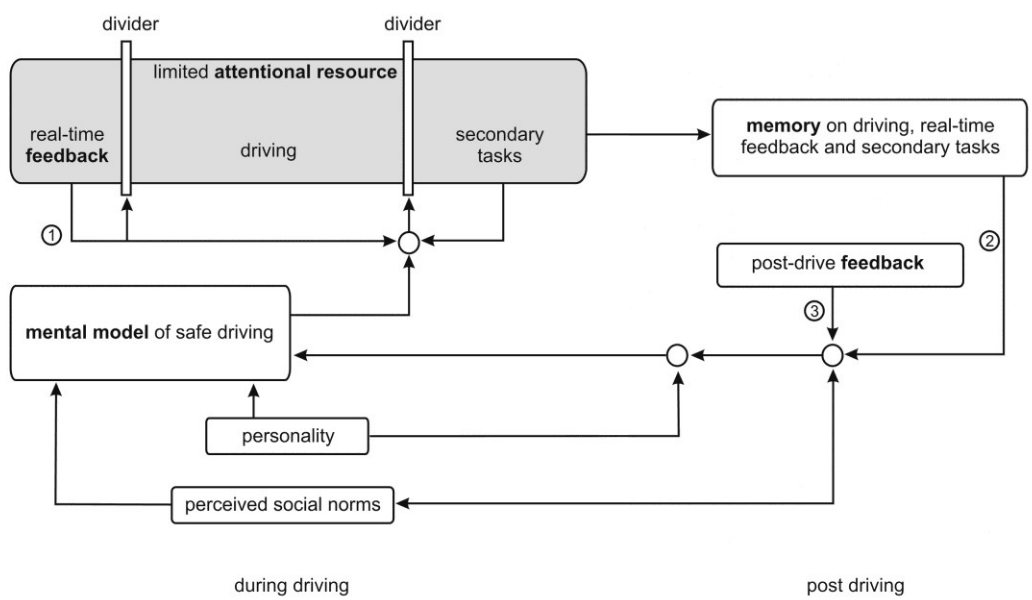

Figure 1. A cognitive model illustrating driver-feedback interaction.

Attention.

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 (Pashler, 1984; Wickens, 1978). In Figure 1, the vertical white dividers split this resource across different 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. The position of the dividers may depend on the secondary task and a driver's distractibility (ability to suppress distracting information). 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 longer 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 constantly updated according to driving experience, feedback, and perceived social norms (Ajzen, 1991). In addition, this mental model is also mediated by the driver's personality traits, such as aggressiveness, impulsiveness and sensation seeking. It guides decisions and choices of intentional behaviors during driving. For example, a driver may drive at 55 mph along a rural road where the speed limit is 45 mph as he may think that it is safe to do so.

Personality.

Personality traits such as aggressiveness, impulsiveness, and sensation seeking affect mental model of safe driving. For example, individuals who show aggressiveness in personality measures are likely to demonstrate aggressive behavior in driving such as driving well above the speed limit, cutting in front of other vehicles, and speeding up to prevent other vehicles from passing (Lajunen & Parker, 2001). In addition, individuals with high levels of impulsiveness are less able to exert self-control and hold back their instant reactions (Costa & McCrae, 1989), thus are more likely to interpret other drivers' behaviors as provocation and react aggressively (Lajunen & Parker, 2001). Sensation seeking is another significant personality factor that strongly influences one's likelihood of engaging in risky driving behaviors such as speeding, drinking and driving, and not wearing seatbelts (Jonah, Thiessen & Au-Yeung, 2001).

Other personality characteristics such as self-efficacy and locus of control mediate how well a driver benefits from post-drive feedback. Self-efficacy is the belief about one's own ability to complete tasks and achieve goals (Bandura, 1977). Drivers with high self-efficacy may be more confident and more willing to learn driving skills and correct unsafe driving behaviors. In contrast, drivers with low self-efficacy may be more reluctant to receive feedback and initiate a behavioral change. Similarly, locus of control is the belief about whether an individual has the control over events that affect her (Rotter, 1990). Drivers with high internal locus of control would attribute consequences of driving to their own driving ability, and thus would be more motivated to correct unsafe driving behaviors.

Perceived Social Norms.

A driver's perception of others' beliefs (Ajzen & Fishbein, 1980) and behaviors (Deutsch & Gerard, 1955) fall under perceived social norms. In our model, there are two distinct types of perceived social norms: 1) perceived norms related to unsafe driving behaviors; 2) perceived norms related to the adoption of feedback.

Social norms significantly influence driving behaviors, such as drinking and driving (Beck & Treiman, 1996), speeding (Read, Kirby & Batini, 2002), and cell phone use while driving (Riquelme, Al-Sammak & Rios, 2010). When a driver perceives certain unsafe driving behaviors to be common among other drivers in the community, and thus socially acceptable, the driver is more likely to engage in those behaviors (Åberg et al., 1997; Zaidel, 1992). Post-drive feedback may target to alter a driver's perception of such social norms to ultimate change the behavior itself. Thus, perceived social norms related to unsafe driving behaviors can be seen as a mediating factor between post-drive feedback and mental model of safe driving.

Perceived social norms related to technology adoption significantly influence one's interaction with technology (Dickinger, Arami & Meyer, 2008; Rogers, 1995). Similarly, perceived social norms related to the adoption of driver feedback technology can affect a driver's acceptance of and trust in feedback, therefore moderate the effect of feedback on mental model of safe driving. In other words, when a driver perceives the feedback technology to be widely adopted by other drivers in the community, she would become more likely to trust in the technology and make use of it.

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. Salient feedback, such as 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 failing to maintain a safe following distance. However, the effect would differ among drivers given differential memory capacity and quality. 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. In general, a positive correlation exists between the strength of a social norm and the intention to act (Ajzen & Fishbein, 1980). Calibrating social norms has also proven effective in the driving domain, such as through campaigns on drinking and driving (Perkins et al., 2010).

4.2 Attentional Process

Figure 2 illustrates an expansion of the general driver-feedback interaction model in terms of attentional processes. This expansion describes the utilization of limited attentional resource during driving, and how a driver's attentional capacity, a secondary task, and real-time feedback can affect the allocation of attention.

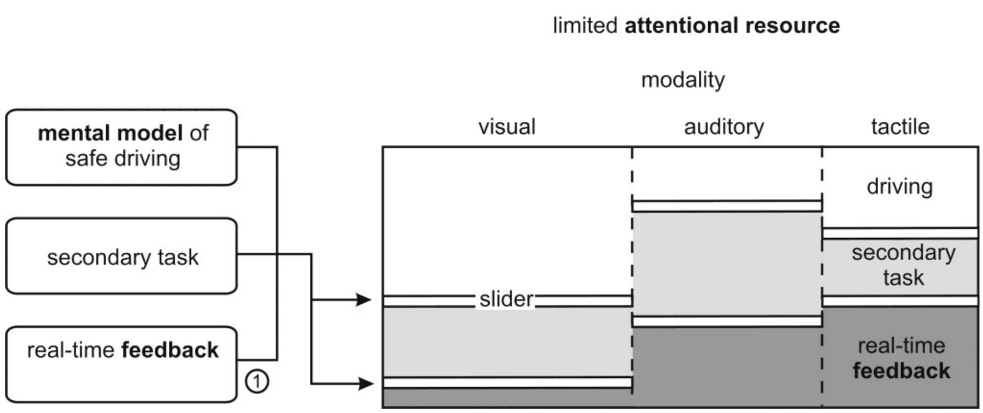

Figure 2. Attentional processes involved in driver-feedback interaction.

Allocation of attentional resource to various tasks (e.g., driving, secondary tasks, processing real-time feedback) is determined jointly by factors internal to the driver such as distractibility and mental model of safe driving, as well as external factors including demands from various tasks and real-time feedback (via feedback loop ①, as numbered in Figure 1). The sliders divide attentional resources among various tasks (i.e., driving, secondary task, and real-time feedback). The allocation of attentional resources is a result of dynamic competitions among the driving task, the secondary task, and feedback mediated by the driver's attentional capability.

Further, the proportion of resources assigned to process real-time feedback depends on the perceptual saliency of feedback, the driver's distractibility, and the mental model of safe driving. A highly salient feedback message is more likely to capture drivers' attention; and a driver with high level of distractibility may assign more attentional resource to feedback, but also may have difficulty shifting attention back from feedback to the primary driving task. A driver's mental model of safe driving determines how safe a driver feels to engage in processing of feedback. In a subjectively determined unsafe situation (e.g., the driver wants to maintain focus on the road while a feedback message is visually displayed on the dashboard), the driver may decide to ignore feedback. Similarly, the proportion of resources assigned to process a secondary task is determined by the driver's distractibility, the perceptual saliency and demand of the secondary task, the mental model of safe driving, and real-time feedback.

In this expansion of the model, we conceptualize attentional resources to be separated based on modality with some flexibility to unify. This conceptualization is an adaptation of both the multiple resources (e.g., Wickens, 1978, 1980, 2002) and the single resource (e.g., Kahneman, 1973; Navon, 1990) theories of attention. In the multiple resource theories, different sensory modalities are viewed as preserving their own pools of attentional resources. For example, when a driver is presented with a set of instructions while driving, performance on both the driving and the comprehension of instructions is better when the set of instructions is read to the driver, compared to when the set is visually displayed (Parkes & Coleman, 1990). In contrast, single resource theories suggest attentional resource to be a uniform central processing constraint regardless of processing modality and stage (Pashler, 1984). This view is also supported by abundant experimental evidence. For example, talking on a cell phone (mostly auditory) impairs driving performance (mostly visual); and talking on a hands-free cell phone can be as detrimental to driving as talking on a handheld cell phone (Strayer et al., 2003). Our model reflects the separation of attentional resources among sensory modalities. However, the separations are illustrated in dashed rather than solid lines, suggesting that such separation is flexible and the pools of resource can be unified under certain circumstances to reflect a more unified central processing constraint.

There are mainly three sensory modalities considered in the current model: visual, auditory, and tactile, as they are the most relevant sensory modalities during driving and are technically feasible for being implemented as part of a feedback system. According to this model, feedback would be less likely to interfere with the driving task when it is presented in a modality (or modalities), which has more free resources. For instance, when a driver's visual channel is fully occupied by a difficult road condition or information from an in-vehicle display, auditory or tactile feedback can be more appropriate. However, if a driver is involved in a cell phone conversation, a visual or tactile warning might be more effective. As a result, the current model suggests dynamic analyses of the mental workload on each modality to determine how real-time feedback should be presented.

4.3 Memory Process

Figure 3 illustrates another expansion of the general driver-feedback interaction model, this time in terms of the memory and learning processes. This expansion describes the formation, storage, and retrieval of memory of driving events, learning from experience (or information in memory), and how post-drive feedback can facilitate these processes.

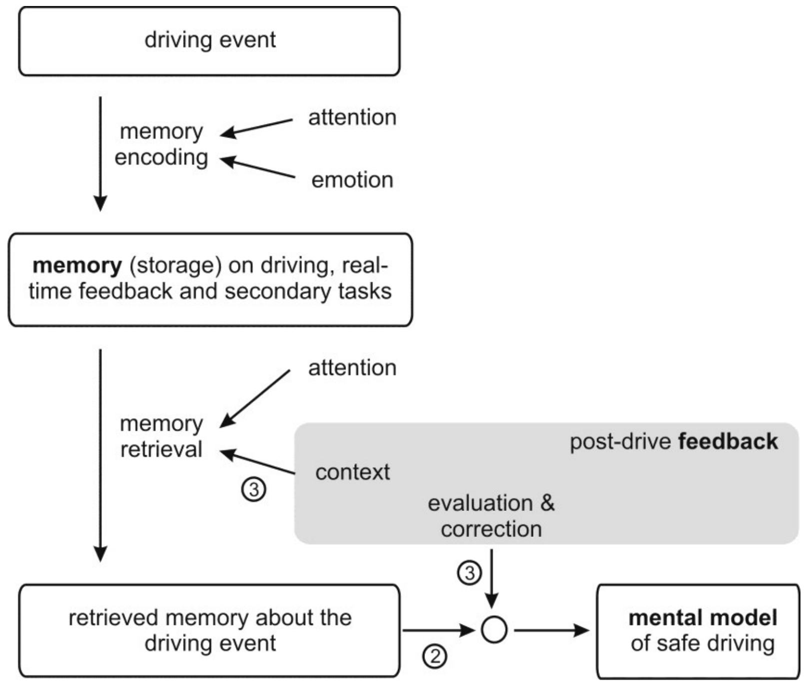

Figure 3. Memory processes involved in driver-feedback interaction.

While driving, drivers encode events into their memory. Memory encoding is affected by both attention and emotion. Information is encoded into memory with greater amount and quality when more attentional resource is available throughout the process (for a review, see Chun & Turk-Browne, 2007). During driving, attentional resources may be mostly utilized for the driving task, leaving little for encoding memory. Particularly, when a driver day dreams or is involved in a conversation, there will not be much attention devoted to memory encoding, resulting in fewer events being memorized and with poorer quality. Higher emotional states can also affect encoding. For example, a near accident may be more memorable than regular driving events, although it too has been shown to be forgotten rather quickly (Chapman & Underwood, 2000). Over time, the quality of memory degrades.

Memory retrieval is the recalling of information from memory storage. Due to the nature of human memory (that we forget), not every piece of information can be retrieved. A driver may still remember vividly what has happened one day after a trip, but may not remember much after one week; and after one year, most of the detailed information may be forgotten. Attention and contextual information are important factors that affect the retrieval success (Godden & Baddeley, 1975). When the environmental context during memory encoding and retrieval are the same, it is easier to recollect the piece of memory. For instance, to facilitate a driver to retrieve memory of one particular left turn in the past road trip, simply referring the event as 'a left turn' would not be as beneficial as providing details (e.g., the left turn near building X). Therefore, if post-drive feedback can provide contextual information, effective memory cues, or a playback of the driving event (via feedback loop ③, as numbered in Figure 1), recalling of information would more likely be successful.

Evaluation and corrective feedback provided post-drive combined with available memory (both retrieved by the driver and supported by post-drive feedback) can then guide the mental model of safe driving.

4.4 Mechanisms of Feedback

Figure 4 illustrates an expansion of the general driver-feedback interaction model in terms of feedback content: 1) normative feedback, 2) discrepancy feedback, and 3) corrective feedback.

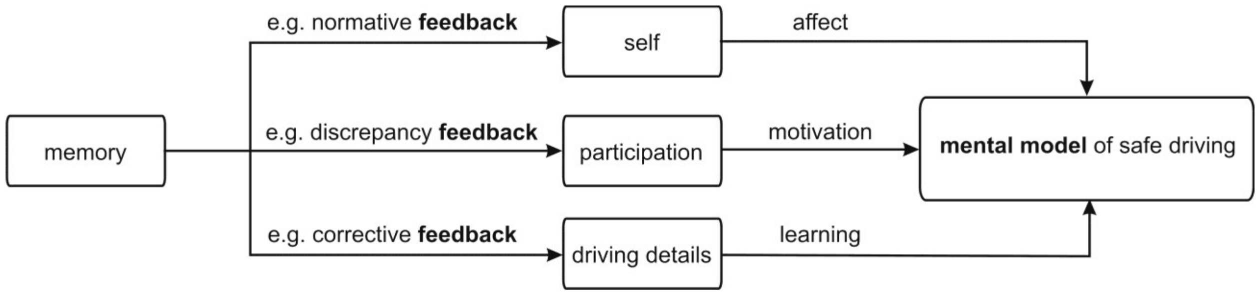

Figure 4. The effect of feedback content on mental model of safe driving.

Normative feedback presents a driver's performance in relation to others' performance. Thus, this feedback content taps into a driver's self-esteem and influences the mental model of safe driving via emotion and affect. Discrepancy feedback identifies an existing achievement in behavioral change and influences the mental model through motivation. For example, when a positive behavioral change occurs, positive discrepancy feedback can be provided to encourage the driver to continue in this path. Corrective feedback identifies errors made by the driver and provides information on how to correct these errors. These three types of feedback change behavior through very different mechanisms. An analysis of the driver and the targeted behavior is necessary to choose the most suitable feedback type(s).

Chapter 5: Future Directions

In this literature review, we summarized existing knowledge on driver characteristics and feedback properties that relate to the effectiveness of feedback for encouraging safer driving. We also proposed a cognitive-behavioral model of driver-feedback interaction. This model reflects the interactions among characteristics of the driver and the feedback, and also illustrates the feedback loops through which feedback can influence the driver. This driver-feedback interaction model provides a framework for future empirical investigations and driver feedback design.

Guided by the proposed driver-feedback interaction model, future research will focus on the empirical examinations of various aspects of the model. These investigations can include (but are not limited to) the following general topics.

1) the effect of cognitive characteristics on feedback effectiveness;
2) the effect of personality characteristics on feedback effectiveness ;
3) the effect of social influences on feedback effectiveness;
4) design of feedback to meet attentional needs of drivers (considering individual differences in distractibility);
5) design of feedback to meet memory needs of drivers (considering individual differences in memory capability);
6) design of feedback to fit drivers' personalities (considering individual differences in locus of control, self-efficacy).

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