DRIVING WISDOM: IMPROVING RISK MANAGEMENT OF COMMON DRIVING HAZARDS

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ABSTRACT

Nearly 50% of accidental deaths in the Army during 2006 occurred in privately-owned vehicles – more than from any other source. As a result, the Army has been actively pursuing ways of reducing POV deaths and injuries among soldiers by improving driver training programs. An extensive literature has examined the link between driving hazards and risk assessment with crash metrics. Drivers begin by identifying a hazard, and then must assess the risk and decide whether or not they can handle it. More experienced drivers are consistently better at recognizing hazards and assessing risk and may also adopt better strategies for mitigating risk. By identifying and teaching these strategies, younger drivers can be trained to respond to risks in safer ways.

We have devised a unique method for understanding the strategies that more experienced drivers use, and for validating the impact that these strategies have on driving safety. Using a combination of critical incident interviews and reviews of naturalistic driving data we identified common hazards and designed a case-based driving scenario that incorporates those hazards and allows for the use of associated strategies. We implemented the scenario in a driving simulator to empirically demonstrate that the use of appropriate strategies can reduce the risk of the common hazards in the scenario. Then the scenario was embedded in an online training system that prompts users to respond with text descriptions of their likely driving behavior. Using machine learning technologies, the response is assessed, and relevant feedback, incorporating practical strategies for reducing risk, is returned.

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Over 50% of accidental deaths in the Army during 2006 occurred in privately owned vehicles (POV) (crc.army.mil/Report/Fy06yearend.doc), the most attributable to one source. As a result, the Army has been actively pursuing ways of reducing POV deaths and injuries among Soldiers. In order to do this, a better understanding of the hazards that affect 20-35 year old drivers is required. In addition to developing an understanding of the kinds of hazards that are important, we have investigated the optimal strategies for preventing or mitigating crash involvement in the presence of one or multiple hazards. Using qualitative research methods, we have been able to identify several strategies that may improve driving safety. By combining these methods with a driving simulator experiment we were able to validate the use of strategies, and their effectiveness for reducing crash risk. We were able to translate this research into a driving training program that educates drivers to better understand hazards and their associated risks, and respond to these hazards with appropriate strategies.

We began by developing a knowledge base of hazards. Most hazards, including internal states such as fatigue and stress, are poorly understood, studied in isolation, and/or minimally documented. Because of this we focused on developing a knowledge base that includes relevant information about each individual hazard as well as responses to naturalistic situations (which typically involve multiple hazards), in the form of practical strategies that may prevent or mitigate the likelihood of crash involvement. This knowledge base was developed through a combination of exploratory data collection, including critical incident and expert driver interviews, and a review of existing data sources such as the VA Tech 100-Car Study, and experimental data collection using a driving simulator to establish the impact of selected hazards. This combination of methods was chosen to increase the accuracy of knowledge about hazards, and to provide converging evidence of the importance of the identified hazards, underlying causes, and responses to mitigate risk.

We conceive of driving skill, and especially risk assessment, as a form of tacit knowledge. That is, it is dependent on knowledge that is acquired from experience (as opposed to explicit instruction) and that is often difficult to articulate verbally (Legree, Heffner, Psotka, Martin, & Medsker, 2003). Because tacit knowledge is difficult to articulate, verbal self-reports of the causes of behavior can be unreliable (e.g., Nisbett & Wilson, 1977). Because of this, we selected research methods to provide converging evidence from interviews and naturalistic driving data and more controlled empirical research that compared verbal self-reports of risk mitigation strategies with controlled observations of driving simulator performance, and objective measures from the simulator experiment. This allowed us to develop practical guidelines for drivers, including the identification and validation of appropriate risk-mitigating responses to a variety of common driving hazards.

DRIVING HAZARDS AND RISK ASSESSMENT

Very young drivers are the most likely to be involved in crashes, with over 35 crashes per million miles recorded for drivers aged 16. Drivers in their 20s are still more than twice as likely to be involved in crashes (9 per million miles) than drivers in their 40s (4 per million miles) (Mayhew & Simpson, 2002). Drivers aged 20 to 35 have generally mastered the mechanics of driving and have several years experience. An extensive literature has examined the link between driving hazards and risk assessment with crash metrics.

According to Deery (1999), identifying driving hazards is the first step in accurately assessing the risk associated with hazards. Once drivers have identified a hazard, they must assess the risk and decide whether or not they can handle it. Hazard perception is recognized as an important component of driving skill and has even been included in licensing processes in several countries (Whelan, Groeger, Senserrick & Triggs, 2002).

Past research suggests that many hazards lead to an increase in crash involvement because they reduce driver attention to the forward roadway. As a result, strategies that prevent or mitigate crash involvement are likely to include an attentional component. For example, many experienced drivers reported trying to think ahead, into the future, to predict what other drivers will do and what events might occur. The idea was to be better prepared and to experience fewer unexpected events. As a direct result of this approach, many drivers allowed more following distance between cars and adopted more defensive driving strategies.

In addition, we wanted to extend our investigation of driving hazards to include emerging hazards such as those that may face Soldiers after redeploying. Soldiers deployed to Iraq typically spend up to 15 months without driving a POV. In addition, the driving they do in Army combat vehicles may follow much different guidelines than POV traffic laws. For example, Soldiers need to scan the sides of roadways for debris and other signs of improvised explosive devices (IEDs). Soldiers in theater quickly learn to avoid traffic congestion and save lives by driving on the median, against traffic, or off-road. What are the consequences of "tactical driving" for Soldiers post-deployment? What unique risks may affect them?

METHODS FOR INVESTIGATING HAZARDS AND RISK ASSESSMENT

There are several ways to identify hazards and establish the risk, or likelihood of a crash, associated with those hazards. Techniques that have been used effectively to date include self-report questionnaires (Deery & Fildes, 1999), statistical analysis of archival driving records (Neyens & Boyle, 2007), video clips taken from a driver's perspective (Crundall, Van Loon, & Underwood, 2006), simulated hazardous situations in a driving simulator (J. D. Lee, Caven, Haake, & Brown, 2001), closed-driving courses (Chaparro, Wood, & Carberry, 2005), and on-road testing (Falkmer & Gregersen, 2005).

While survey and archival data, including crash reports, are interesting and provide valuable information on actual incidents, they cannot adequately explain the combinations of events that lead to crashes. Crash reports may list only one of several causes for an accident. Self-report interviews and surveys may also fail to describe completely the number and interactions between driving hazards, as they rely on drivers' sometimes-faulty memories and questionable self-report validity (Nisbett & Wilson, 1977). Driving simulators and driving courses are useful alternatives to crash reports and self-report data, but cannot simulate the full range of internal and external factors involved in a real environment. None of these methods explicitly attempt to identify the practical strategies that people use to mitigate risk. We believe that converging methods are needed to provide the best understanding of the most common hazards, their associated risks, and risk-mitigation strategies.

By reviewing the literature for analyses of crash report and survey data we identified promising internal and external driving hazards. We then used the 100-Car Naturalistic Driving Study results (Dingus, et al., 2006) to verify that these hazards are in fact encountered by people in day-to-day driving; identifying common precursors to crashes and other driving incidents increases the validity of selecting hazards to study. We then conducted critical incident interviews to allow a more in-depth analysis of the complex situations that lead to crash situations. The interviews also helped us to develop a realistic scenario, based on common hazards, for use in the driving simulator experiment and, ultimately, the training tool. The scenario was used to empirically demonstrate in a driving simulator the link between these hazards (reported and observable), risk-mitigation strategies, and resulting safety related driving events.

It can be difficult to implement some internal hazards in a driving simulator, such as major life stressors. However, several may be easily implemented, such as distractions related to conversing on cell phones. An additional limitation of using a simulator is that participants' behaviors may not provide insight into their reasons for engaging in a particular behavior in response to a driving hazard. In order to avoid this limitation, we interviewed participants following their participation in the simulator experiment. To improve recall and elicit the most accurate descriptions possible, the interviews were conducted in the simulator itself (with the participant still in the driver's seat), and the scenario video displayed on the surrounding projection screens. The interviews probed participants for their reactions and strategies to the experiment scenario they had just completed, as well as for examples from their personal driving histories. In this way we hoped to maximize the benefits of using a carefully controlled environment to validate the impact of driving hazards, risk assessment, and driver responses.

DRIVING HAZARDS AND ASSOCIATED STRATEGIES

We began building our database by reviewing the literature for analyses of crash report and survey data. We then used the 100-Car Study data (Dingus, et al., 2006) to verify hazards that are encountered by people in day-to-day driving, and to identify common precursors to crashes and other driving incidents. Cross-referencing the scholarly literature with data from the 100-Car Study also helped to increase the validity of selecting hazards to investigate. Finally, we conducted critical incident interviews with participants including both Soldiers and civilians, to allow a more in-depth analysis of the complex situations that lead to crash situations and to help us develop realistic scenarios based on common hazards. We also elicited strategies that experienced drivers use when driving, whether the strategies are general or specific to particular hazards.

Since our primary concern was to improve our understanding of the human element of driving safety, we chose to exclude factors that are outside the immediate locus of control of drivers, such as weather, geography, and traffic patterns (data on these topics are included as they pertain to driver behavior, such as hazard avoidance tactics). We further narrowed our list to represent the most common, and relevant, hazards in the literature and the 100-Car Study.

Then we selected a subset of these common hazards that occurred together in a realistic scenario drawn from participant interviews. The scenario was adapted to allow it to be used as both a training scenario and in the driving simulator. We will limit our discussion of driving hazards and associated strategies to the ones included in the scenario and subsequent driving simulator experiment.

Driver Distraction and Inattention

In the 100-Car Study, 93% of lead vehicle rear-end crashes and near crashes involved driver inattention or distraction (Dingus, et al., 2006). Strutts et al (2001) distinguish between distraction and inattention. Distraction refers to a driver's delay in the recognition of information needed to safely accomplish the driving task because of a triggering event. Driver distractions are a common component of everyday driving, and many distractions are neither new nor technological in nature. Rather, they are aspects of everyday driving that people seldom think about, such as eating and drinking (Stutts et al., 2003). In the 100-Car Study, the most common distractions were cell phone use and passenger distractions.

Cell Phones

As noted by Lee et al (2007), engaging in cell phone conversations has the potential to impair driving performance (Alm & Nilsson, 1994) and decrease drivers' sensitivity to roadway objects (Strayer & Johnston, 2001). However, when comparing speaking to listen-only tasks, drivers' attention allocation was found to be more undermined by the cognitive demand of voice interactions (Lee et al., 2007). The 100-Car study looked at wireless devices by type (cell phone, PDA) as well as behavior (texting, dialing, talking). While cell phone dialing proved to be much worse than talking, the behavior occurred much less frequently. Consequently, talking was associated with more crashes and near crashes than dialing.

Passengers

Passenger related distractions were the second most common source of inattention-related near crashes, and incidents identified in the 100-Car Study with three of the 24 single vehicle crashes involved passenger-related inattention. The 100-Car Study found that adjacent (i.e. front seat) passengers were more distracting than passengers in the rear seats. However, limited information was available about the passengers in the study due to concerns about passenger confidentiality. As a result, most passenger behavior had to be inferred from the driver responses.

Cognitive Load

Cognitive load may also act as a distraction while driving. Cognitive load may be defined generally as any additional effort required due to increased workload, whether from more demanding driving conditions, or external or internal hazards. Operating devices that do not require glances away from the road, such as speech recognition systems, can nevertheless impose a cognitive load that may interfere with driving performance. This cognitive load has the potential to impair drivers' ability to maintain vehicle control (Rakauskas, Gugerty, & Ward, 2004). Cognitive load can also delay or interrupt cognitive processing of roadway-related information, resulting in longer reaction times (J. D. Lee, Caven, Haake, & Brown, 2001), degraded speed and headway control (Strayer & Drews, 2004), and less effective use of environmental cues to anticipate when to brake (Jamson, Westerman, Hockey, & Carsten, 2004). Lee, Lee and Boyle (2005) suggest that drivers' degree of self-awareness is situation-dependent. When the driving demands are higher, the presence of a secondary task decreases the strength of the association between objective performance and subjective confidence in such performance. This imprecision may lead drivers to improperly estimate their ability to handle difficult, hazardous situations when they are cognitively loaded. These results suggest that providing drivers with feedback about their degree of distraction could enhance their ability to manage interactions with potentially distracting in-vehicle devices. Feedback might be most valuable for situations that challenge a driver's attentional capacity. It may also be possible to train drivers to better estimate their degree of distraction, which could greatly reduce the impact of distracting hazards.

Mood, Emotion and Affect

Aggressive driving includes tailgating, abrupt lane changes, and speeding, alone or in combination. These potentially dangerous behaviors are traffic offenses, but are not criminal behavior (Rathbone & Huckabee, 1999). According to law enforcement personnel survey responses, there appears to be a slightly higher incidence of road rage incidents during the Friday afternoon peak travel times, under moderately congested conditions, and in urban areas.

Aggression is associated with unsafe behaviors and traffic accidents (Kontogiannis, 2006). And in the 100-Car Study, aggressive driving, which included speeding and willful disregard of traffic laws, was associated with 20% of single vehicle crashes and an additional 4% of near crashes. However, while angry or threatening driving is related to crash involvement, direct confrontation is rare; furthermore, the relationship between milder expressions of frustration and crash involvement may not be significant (Wells-Parker et al., 2002).

Tactical Driving

We define tactical driving as context-specific driving behaviors that people implement to improve safety and/or survival in non-typical circumstances. Such circumstances occur in both military and non-military settings. Examples include driving in the middle of the road and speeding around corners where IEDs or snipers may be present, or driving an ambulance or other emergency vehicle. To date, little research has been done on the effect of switching between tactical driving and non-tactical driving, although the Military Operational Medicine Research Program (MOMRP) does include some aspects of tactical driving in their redeployment Battlemind training (http://www.battlemind.org/). Questions remain regarding the frequency of switching, whether short-term (as in the case of an ambulance driver who switches back to his POV every day at the end of his shift), or long-term (a Soldier who resumes POV driving after a year spent driving large military vehicles across the desert).

Risk Mitigating Strategies

Definitions of "safe driving behavior" in the literature and standard defensive driver training often include the obvious—e.g., driving within the speed limit; non-aggressive maneuvering; maintaining a safe braking distance; seat-belt use; and avoidance of driving when impaired by alcohol or other substances, or sleep deprivation (IDriveSafely.com, 2007; Strecher et al., 2006). Such definitions, and the resulting recommended strategies, are often inadequate solutions to the contexts in which actual driving behavior—safe or otherwise—occurs.

So what strategies do experienced drivers actually use to reduce their crash involvement? Drawn from the interviews with drivers, as well as interviews with the simulator experiment participants, we identified several possible risk mitigating strategies. Some strategies we received from experienced drivers were general, for example looking three cars ahead to "see into the future" of what other drivers are about to do. But reported strategies also included practical risk reduction tactics that were used in specific situations.

Distractions, Cell Phones and Passengers

While most people we spoke with admitted to at least occasional engagement in distracting activities, interviews with experienced drivers revealed a range of passive and active risk mitigation strategies. One woman reported not bothering to repair the broken cup holder in her car as a way of keeping herself from drinking coffee on her morning commute. Another man used his wife as a "secretary" in the car. She would answer the phone, read maps and directions, and look for street signs while he drove.

The more experienced drivers admitted to speaking on their cell phones while driving, but indicated that they would be less likely to answer (or make) a call when they felt the environment had more risk than usual. For example, they would be less likely to take a call when they were distracted by being late to work or driving in heavy traffic. However, one very interesting reported strategy from a simulator participant, was to answer the phone as a way to reduce internal tension following a scary, unexpected event in the simulator drive. This call was answered after the participant felt that the danger had passed. In general people felt that they were able to judge how safe the conditions were before making the decision to answer their cell phone.

Frustration and Stress

Strategies included diffusing stress about getting to work on time by reminding yourself that work will still be there when you arrive, and that penalties for arriving late are not worth the risks of unsafe driving. A few respondents indicated that having a child in the car made them less willing to take risks by driving aggressively in response to time pressure. The reluctance to engage in aggressive driving in response to time pressure was also reported as a factor of changing priorities due to driving conditions, so that as driving conditions demanded more attention, the participant was less likely to drive aggressively. Another driver indicated that in real life (not in the simulator) she might stop and take a breather if she was becoming too upset, or if something rattled her while driving (such as a close call). Another common strategy was to use an alternate route when stuck behind a slow vehicle, or to avoid heavy traffic, to prevent feeling frustrated in the first place. One simulator participant reported using music to help her stay calm when feeling frustrated by other drivers.

Tactical Driving

One Soldier reported that after returning from Iraq he chose not to drive, and instead had his wife do all the driving for a few months. He did not feel safe driving, mainly because he felt he was easily distracted. He also found that for a short period of time after his return he continued to adhere to adaptive tactical driving practices that were out of place in a suburban American context, such as driving in the middle of the road to avoid potential hazards. While this strategy may not work for Soldiers with limited support networks, it is certainly an easy strategy to apply when there is another driver available.

SIMULATOR EXPERIMENT

The goals of the driving simulator experiment were to verify that the selected driving hazards had a measurable impact on crash involvement metrics, establish that expert drivers responded more effectively to the presence of these hazards, and develop a better understanding of the interaction of the driving hazards and effectiveness of risk mitigation behaviors. Following the simulator experiment, participants were interviewed and asked to describe their strategies for managing risk during the experimental drives. It is especially interesting to be able to compare self-reports of strategy use with objective measures of whether they did indeed use the reported strategies, and how effective the strategies were in reducing risk.

Experiment Design

This experiment featured a 2 x 2 x 2 x 2 mixed design with stress/frustration (lead vehicle, no lead vehicle) and cognitive load (to-do list, no to-do list) as within-subjects factors and type of distraction (cell phone, passenger) and age (older, younger) as between-subjects factors. The stress/frustration manipulation involved a lead vehicle that appeared in front of the driver's vehicle, going approximately 5 miles below the speed limit. Cognitive load was manipulated as a series of lists that participants were asked to remember while driving. Distractions included either a cell phone, which rang at predetermined times during the drives, or a passenger, who read messages to the driver at equivalent, predetermined times. Finally, participants were considered either experienced, or less-experienced drivers.

Each participant completed five drives in the simulator. All five of the experimental drives included voice or text messages that were distracting in nature, and a clock that was displayed on the windshield to convey a sense of time pressure. Participants were instructed to search for pedestrians who wore gray-blue shirts, a manipulation designed to mimic a tactical driving strategy of scanning roadsides for potential threats. These factors were manipulated across the five separate drives that each participant completed. The first four drives were carefully controlled and featured specific combinations of hazards. Drive 5 was identical to Drive 1, except that unexpected roadway events were added to Drive 5 and instructions to participants were slightly different. A bonus of $5 was provided if participants reached the destination within 10 minutes in Drive 5, a manipulation designed to increase the salience of the time pressure manipulation present in all drives. An interview was conducted in the simulator upon completion of the drives, and participants were asked to reveal strategies and decision-making processes when facing hazards in the simulator experiment and in real-world driving. Participants were encouraged to share practical strategies for managing risks in driving. The interviewer also queried participants about details of the driving history, including typical behaviors and any accidents they may have had.

Participants

Twenty-four participants were recruited through newspaper advertisement and electronic mail advertisement to take part in this experiment. They all had an active driver's license for at least five years, normal or corrected-to-normal vision, normal color vision, and normal hearing abilities, were native English speakers, and were between 20 and 35 years old (younger group) or 40 and 55 years old (older group). Special care was given to ensure that participants in the younger group (n = 12) have had traffic-related accidents or incidents in the past but participants in the older group (n = 12) did not. Participants were compensated for their time at the rate of $8 per hour.

Apparatus and Task

Data were collected at 60 Hz with the high fidelity Beckman Institute Driving Simulator, a fixed-base, automatic transmission 1998 Saturn SL, with 8-channel 360º projection screens. The driving scenarios and movement of the participant's vehicle and interactive vehicles were simulated using DriveSafety's Vection™ Software and their HyperDrive Authoring Suite (Version 1.6.1). Video recordings from three cameras were also collected. A SmartEye Pro three-camera, world-referenced infrared eye tracking system gathered driver attention data in a non-intrusive manner.

The driving task required participants to follow the speed limit, maintain the vehicle in the center of the lane, and drive in a straight, two-lane urban road on a sunny day. In each experimental drive, parked cars and pedestrians were positioned along the road, in the parking lane and on the sidewalks, respectively. There was a constant flow of ambient traffic in the opposing lane. Participants were asked to imagine that they are running late for work and had about 10 minutes to get to their destination. Participants were encouraged to be at work on time, and a clock was displayed on the windshield to remind them of the remaining time (see Figure 1). Each drive took approximately 12 minutes to complete. Participants were asked to monitor the driving environment, obey traffic laws, and drive as safely as they normally would. In three of the experimental drives, a vehicle drove at 5 mph below the speed limit immediately in front of the subject vehicle. This slow lead vehicle (see Figure 1) forced the participants to drive below the speed limit, and a closely following vehicle was also present to further reinforce the frustration related to the slow lead vehicle.

Figure 1. Image from driver's forward view, with a countdown clock, slow lead vehicle, target pedestrian, and parked vehicles.

If participants did not get to work within 10 minutes, they could continue driving and the clock would countdown to "0" and then display "time out" on the windshield. When they reached the destination they were to pull over and park in front of a yellow building.

Target pedestrians in gray-blue shirts were randomly positioned on sidewalks in each experimental drive. Half of the target pedestrians were walking on the sidewalk and the other half were standing still during each drive. Participants were asked to search for the target pedestrians and then press a button on the steering wheel as soon as a target was detected. Targets were equally likely to be on either sidewalk. Figure 1 shows a standing target pedestrian on the left sidewalk. Non-target pedestrians who wore black, brown, white, green, and red shirts or dresses were randomly positioned on sidewalks in each drive.

Participants in the cell phone condition were asked to check their voicemail on their blackberry phone and manually activate the voicemail while driving by pressing a button. Participants in the passenger condition were asked to listen to text messages on their blackberry phone, delivered by an experimenter who sat in the passenger seat in the driving simulator. In three of the experimental drives, the first voicemail or text message (Memory call) contained a list of items to do when participants got to work. They were told to remember the to-do list and were asked to write them down at the end of each drive. For example, one of the messages was from a boss who asked the employee to do a few things.

In all of the experimental drives, while participants were searching for the target pedestrians, they also received three voice or text messages (Distracter calls). These messages did not contain any to-do lists, but conveyed a sense of time pressure and were meant to distract the drivers. For example, the message could be from a boss, asking the whereabouts of the employee and the reason for his absence at work. The experimenter who played the role of the passenger would deliver the text messages with appropriate intonations to mimic the emotions that would have been there if the message sender were to leave a voice mail on a cell phone. The messages ranged from 40 to 55 seconds in length.

Drive 5

Drive 5 was designed to allow participants to freely drive, whether performing safe and necessary behaviors to manage risks, or to engaging in risky, aggressive driving to arrive at work on time. The manipulations were identical to Drive 1, with a few important exceptions. After receiving the first message with a to-do list, participants were given the option of not taking the three distractor calls. Participants in the passenger condition could talk to the passenger if they felt like it. Three unexpected roadway events were included: 1) the slow lead vehicle braked suddenly, inviting a rear-end collision for drivers following too closely, 2) a child darted out in front of the driver, and 3) a vehicle ran a stop sign at an intersection and braked at the last second to avoid colliding into the subject vehicle.

Near the end of the drive there was a section on the road where there was no parked vehicle in the parking lane, and participants were able to pass the slow lead vehicle by using the parking lane, if they chose to do such a risky maneuver in order to make it to work on time. And finally, if participants chose to pass the slow lead vehicle, they could reach the destination within 10 minutes and receive the $5 bonus that was offered.

Procedure

At the beginning of the experimental session, participants completed an informed consent form and two personality questionnaires while seated in the driving simulator. They were asked to make adjustments to the seat and mirrors to suit their size and preference. Participants were asked to follow the speed limit, maintain the vehicle in the center of the lane, and drive safely as they normally would. The driving scenario was described, namely that they are an employee running late for work on a Monday morning. A countdown clock (starting from 10 minutes) was displayed on the windshield to remind participants of the remaining time. Participants then received instructions regarding the experimental tasks: 1) when there is one, listen to and remember the to-do list, 2) for participants in the cell phone condition, press a button in the center console when there is a ring tone to activate voicemail and listen to the voice messages; for participants in the passenger condition, listen to the text messages delivered verbally by the passenger, and 3) search for pedestrians in gray-blue shirts and press a button on the steering wheel when detection is made. Participants drove through a practice drive to become familiar with all the tasks and the dynamics of the simulator. An experimenter sat in the simulator and went through the practice drive with participants to ensure that participants understood the instructions.

Following the practice drive, participants were reminded of the tasks they needed to perform in each of the experimental drives. They were also informed that they had 10 minutes to reach the destination. Two of the first four drives included a to-do list in the first voice or text message. Participants needed to remember the to-do list while driving and write down the items in the list at the end of the drive. Three distractor calls would occur after the first call, while participants searching for target pedestrians. For drives that did not include the to-do list, participants still listened to the three distractor calls but would not be asked to remember anything. Upon completion of each experimental drive, participants were asked to rate subjectively the level of frustration, mental demand, and time pressure they experienced during the drive. A short break was provided to the participants before performing the next experimental drive. The first four experimental drives were counterbalanced across drivers according to a Latin square design. Drive 5 was always the last, and the exit interview began shortly after the completion of Drive 5. The experimental session took approximately three hours to complete.

Results

We began by verifying that the experimental manipulations had the intended effect. We found that participants reported higher ratings of frustration in the presence of a slow lead vehicle, $F(1,57) = 19.71$, $p < .0001$, with the highest rating of frustration from participants in the passenger condition who also had to recall a memory list, $F(1,57) = 4.42$, $p = .039$. Higher ratings of mental demand were reported in the presence of a slow lead vehicle, $F(1,57) = 5.45$, $p = .023$, and when there was a memory list to recall, $F(1,57) =$

11.95, $p = .001$. Interestingly, having to recall a memory list increased mental demand more for older drivers than for younger drivers, $F(1,57) = 4.10$, $p = .047$.

Table 1 shows the percentage of drivers who decided to answer the distracter cell phone calls, or asked their passengers to read them, during drive 5. Older drivers were less likely to listen to the messages in the cell phone condition, but were more likely to ask their passenger to read them.

Table 1. Percentage of drivers in each group who listened to cell phone messages during drive 5.

Group	Age	Took Calls
Phone	Younger	67%
Phone	Older	44%
Passenger	Younger	50%
Passenger	Older	61%

Table 2 shows the percentage of drivers that engaged with each of the unexpected events that occurred in drive 5. The first unexpected event was the lead vehicle that suddenly braked in front of the driver, and the percentages indicate the number of drivers that rear-ended this vehicle. Younger drivers were more likely to rear end the vehicle, as older drivers were more likely to have longer following distances giving them time to stop. The second unexpected event was the child that ran in front of the vehicle. The percentages indicate the number of drivers that had NO reaction to the event. Overall, older drivers and drivers in the passenger condition were more responsive. In fact, the younger drivers in the cell phone condition failed to react 100% of the time. The third unexpected event was the vehicle that ran the stop sign at the intersection. Again, the percentage in the table indicates the number of drivers who failed to react to this event. Once again, older drivers were more responsive, as were drivers with passengers.

Table 2. Percentage of drivers in each group who failed to react to each unexpected event in drive 5.

Group	Age	Hit LV	Child	Stop Sign
Phone	Younger	80%	100%	40%
Phone	Older	33%	50%	33%
Passenger	Younger	67%	33%	17%
Passenger	Older	50%	0%	0%

We also examined the accuracy of detecting the target pedestrians during the drive. During Drive 5, older drivers had higher overall target detection accuracy, $F(1,20) = 11.06$, $p = .003$, detection during calls, $F(1,20) = 7.19$, $p = .014$, and not during calls, $F(1,20) = 13.85$, $p = .001$, than their younger counterparts. In addition, when drivers were listening to the memory call in Drive 5, the mean velocity was lower for older drivers than their younger counterparts, $F(1,19) = 11.29$, $p = .003$.

During Drive 5 younger drivers passed the slow lead vehicle more often than did older drivers (see Table 3), and younger drivers were also more likely to speed (see Table 4). These behaviors resulted in younger drivers getting to work on time more frequently, and receiving the $5.00 bonus more often, than older drivers.

Table 3. Percentage of drivers in Drive 5 that passed the slow lead vehicle.

Group	Age	Passed LV
Phone	Younger	60%
Phone	Older	33%
Passenger	Younger	33%
Passenger	Older	33%

Table 4. Percentage of drivers who were speeding during the last portion of Drive 5 to try to reach the destination on time.

Group	Age	Speeding
Phone	Younger	100%
Phone	Older	83%
Passenger	Younger	100%
Passenger	Older	67%

The results of the simulator experiment demonstrate that older drivers handled unexpected events better. They braked earlier, and were more likely to swerve to avoid obstacles. Older drivers were also more thorough scanners, and noticed more target pedestrians – even while listening to cell phone calls. Older drivers were also less willing to engage in aggressive driving to reach work on time and win the $5.00 bonus. These results map nicely onto the self-reported strategies of many of the older drivers. They frequently reported that they tried to avoid unexpected events by anticipating what other vehicles were doing, which likely contributed to their increased ability to react to the unexpected events in drive 5. Older drivers were also more likely to adopt a strategy of trying to keep everything in perspective and not worrying about getting to work on time so they could focus on driving more safely.

DRIVER TRAINING SYSTEM

Scenarios play an important role in instruction and performance assessment of tacit knowledge (Cianciolo et al., 2006). We implemented the scenario in a web-based training system. The scenario used in the simulator experiment was presented in text along with video from the simulator experiment so that learners could experience each driving situation as it played out with both visual and auditory cues that would normally be present while driving. Open-ended questions associated with the scenario provide an authentic way of assessing what people know and how they would respond to the driving situation presented.

In the past, scoring open-ended responses involved prohibitive cost and time. However, by using Latent Semantic Analysis (LSA), a machine learning algorithm, it is possible to automatically score lengthy essay responses and provide instant feedback about the content and quality of responses, opening the door for the development of real-world assessments that can be used for both training and assessment purposes.

A multi-dimensional semantic space, customized to the military and driving domains, was constructed using relevant electronic text sources. The scoring system was then trained using a set of responses from drivers. Each response was analyzed to produce a vector within the semantic space. Then the centroid of all the response vectors was computed to represent the "consensus" response. The scoring system had access to responses from both expert and less experienced drivers. The novice responses were included in the calculations of the centroid and were also used for comparison purposes as described below.

Each new response is scored by comparing its LSA vector with the consensus vector. Responses that are within a predetermined threshold are scored as "pass." Responses outside the threshold are scored as "fail." For both passing and failing responses, the scoring system compares the new response vector to the set of all training responses, expert and less experienced, and returns the closest match. Feedback for both passing and failing responses is automatically constructed by using an LSA-based "gap" analysis technique. A set of feedback items, constructed from expert responses, is analyzed to see which item, when added to the new response, most improves its original consensus-based score. This feedback item is returned with the response score. By using LSA to create individualized feedback for learners we are able to instruct them on specific, relevant, strategies missing from their response. In this way, we anticipate being able to increase the speed with which drivers acquire the necessary tacit knowledge of the sort demonstrated by experienced drivers in the simulator experiment to increase the safety of their driving.

CONCLUSIONS

We found support for our approach to studying the strategies that experienced drivers use, and for identifying the strategies that may actually lead to reduced crash involvement. Combining interviews with a driving simulator experiment allowed us to collect self-reported strategies, design an experiment to allow these strategies to be used, and then verify that using the strategies actually led to safer driver. For example, experienced drivers reported that they try to stay one step ahead of other drivers by imagining what the drivers may do in the near future. The simulator experiment was designed to include a non-conventional "free" drive that allowed participants to behave more naturally, and contained a number of unexpected events that could lead to crashes. This gave participants the opportunity to respond as they would when driving their own vehicle, including applying their reported strategies. Indeed, experienced drivers in the simulator behaved consistently with their reported strategies, namely paying more attention to other drivers and trying to anticipate their moves. This in turn led experienced drivers to be more responsive to the unexpected events, and to be involved in fewer crashes. In essence, we have developed a research method that allows us to identify and capture the elusive tacit knowledge that older, more experienced drivers have.

We believe that using this approach will allow us to build an effective training system specifically designed to increase tacit knowledge of risk assessment and appropriate risk-mitigating strategies. Because these strategies can be made explicit through this research approach, we will be able to improve the state of the art in driving safety education. Our work will continue to focus on developing this research into a full-fledged driver training program. Once the program is complete, we anticipate a small-scale implementation that will allow pre-post testing to determine the effectiveness of the training system.

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