An Empirical Assessment of Driver Motivation, Emotional Response and Driving Conditions on Driver Risk Decisions

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ABSTRACT

Problem: Limited empirical evidence has been developed for models of motivation in driving. Approach: We used a high-fidelity driving simulator. Driver conformance with social norms was manipulated by varying traffic patterns. Time and performance-based payment systems were used to assess the effect of incentive on driver motivation. The complexity of the driving environment was investigated as a mediating factor. Findings: Risky behavior, specifically higher driving speed, was observed with the performance- versus time-based payment system. Drivers conformed with social norms associated with specific traffic patterns. Higher roadway complexity interacted with the motivational factor manipulations and produced lower driving speeds. Conclusion: Motivational models can be supported by empirical evidence on driver performance and are promising for explaining and understanding driver risk-taking behavior.

Keywords: Driver motivation model, perceived safety, traffic patterns, incentive factors, driving environment complexity
INTRODUCTION

Understanding how drivers adapt to dynamic driving environments is considered to be critical in the development of new technologies to support driver information needs and overall roadway safety (Michon 1985). Driver “behavior adaption” has been extensively investigated in terms of perceptual and motor skills under different road conditions. However, driving, as a self-paced task, is not limited to “skills” (Williams and O'Neill 1974). Drivers determine their task demands to a large extent based on emotional factors and motivation to a goal (Näätänen and Summala 1974). Motivations, such as time goals, conservation of effort, maintenance of speed and progress, pleasure in driving, need to be taken into account in order to accurately model driver behavior. Hence, there has been a recent increase in research devoted to exploring the influence of motivation on driving (Näätänen and Summala 1976).

Two approaches have been taken to develop models of motivation in driver behavior (Summala 2007), including: (1) the motivation measurement approach, which attempts to identify measures to explain driver behavior; and (2) the proxemics approach, which explores driver behavior in space and time dimensions. The motivation measurement approach includes uni-dimensional and multi-dimensional models. Among these, Näätänen and Summala (1976) multi-dimensional threshold model of driver action has been used to interpret risky decisions under various conditions. In their model, driver behavior is modified not only according to changes in the degree of complexity of traffic situations, but it is based on perceptions of risk. Driver goals also play an important role in the model, as they dictate the level of task difficulty. This model also makes three major assumptions: 1) monitoring for present or anticipated risks is the major inhibitory mechanism in driver behavior; 2) drivers’ goals and motives push them towards performance limits; and 3) safety margins are key indicators of driver control. The third assumption of the model is related to a key concept of the proxemics approach, i.e., safety margins reflect driver time and spatial judgments.

Motivational factors influence driver behavior by triggering emotions. Emotions can be closely related to states of driving. As suggested by Russell and Barrett (1999), emotion can be broken-down into two major dimensions, pleasure and intensity. Comfort in driving is considered as a pleasant experience without any strong emotions being triggered. Drivers also expect normal daily driving to be a “fluid experience”. It has been demonstrated that these motives, comfort and fluidity of experience, play an important role in determining daily driving behavior (Näätänen and Summala 1976). However, if these motives expand based on driver pursuit of strong emotions, such as thrill-seeking, this can easily lead to hazardous behavior, including speeding. Other motivations in driving, include being in a hurry, coping with social pressure (caused by other driver behaviors) and competition, which may cause driver anxiety.

One example of how motivations work in the driving domain was Summala's (2007) observation of social norms. Because rule following is a major motivation for safe driving and avoiding fines, compliance with rules makes drivers feel
“comfortable” or “pleasant”. Summala (2007) discussed that compliance with rules (e.g., speed limits) is based not only on the law, but also on social norms. For example, drivers tend to maintain closer headways in high density traffic (within 1.7s headway time of a lead vehicle). Many drivers are uncomfortable with large headways in this situation due to the distance being outside the social norm to which they are accustomed (Ohta 1993). In addition, Haglund and Åberg (2000) found that driver behavior is closely linked to the behavior of other drivers; that is, a driver who perceives others to drive at excessive speeds is also more likely to drive faster than a driver who perceives others to comply with limits (also see Ulfarsson, Shankar et al. 2001). However, the above studies all involved observations of real-life driving environment conditions. Thus, the motivations of drivers were not controlled manipulations under specific traffic environment.

In addition to social norms, roadway complexity may also affect driver risk assessments. For instance, it has been documented that visual clutter due to complexity of the environment may affect driver visual attention and other cognitive capabilities, leading to different perceived safe distances to surrounding vehicles (Jin and Kaber 2009; Zhang, Jin et al. 2009). Driving under complex conditions, drivers may perceive the need to be more cautious in order to compensate for demands on cognitive resources. Interestingly, it has been observed that although interstates are designed for smooth flow, which may lead to perceptions of less complexity, lane changes are performed less often and with lower urgency, as compared to local highways (Olsen 2003). This may be explained by driver motivation to conform with social norms. For example, high-traffic density in urban environments may cause feelings of frustration leading to lane changing and reduced headways (Ohta 1993). The visual clutter due to roadway complexity and the need for following social norms may conflict with each other in determining driver perceived safety. There is a need to more fully explore the potential interaction effect of these variables on driver behavior.

In order to extend the current knowledge of driver adaptation in terms of motivation and emotion factors, this study aimed at: (1) providing empirical evidence of the influence of extreme emotions (urgency, anxiety and tension) on driver risk-taking decisions by triggering emotions with incentives, i.e., drivers received more rewards if they completed a goal within a certain time; (2) investigating the effects of social norms on driver behavior by simulating different traffic patterns (other drivers’ behavior); and (3) further exploring the effects of environment complexity on driver behavior.

**METHOD**

**APPARATUS**

A STISIM Drive™ M400 driving simulator (System Technology Inc., Hawthorne, California.), was used to present subjects with different driving environments and to
assess their risk-taking decisions on speed under various motivation and traffic conditions. The simulator modeled a Ford Taurus with a drag coefficient of 0.32 and maximum braking rate of 1.4g. The simulator provided a 135 degree field of view of the driving environment through three 37 in. HDTV monitors. The simulator included a modular steering unit with a full-size steering wheel, turn indicators and a horn, as well as a modular accelerator and brake pedal unit, and audio system.

**PARTICIPANTS**

Based on pilot study results (mean responses and variations in driver performance under different test conditions), a total of 10 participants were recruited for the study to ensure a test power (1-β) greater than 0.80 for each of the fixed experiment manipulations. All participants were required to have a valid driver’s license with no restrictions and 20/20 vision or to wear corrective glasses or lenses. The recruitment of participants was balanced for gender. The mean age of the participants was 23.3 yrs. (SD=1.34). The average driving experience was 4 yrs. (SD=1.56).

**DRIVING TASKS**

Eleven different driving tasks, including three training and eight experiment tasks, were used in the research. Each of the tasks lasted for 12~15mins. Subjects were asked to do their best in exhibiting normal, daily driving behaviors. Although there were speed limit and crossing signs along the road, no simulated enforcement for speeding was imposed on the subjects. Because of the lack of a direct penalty for speeding, it is possible that driver behavior may have been more liberal, including higher than normal speeding rates. However, any such effect was expected to occur across the test conditions. Drivers were also aware that speeding might increase their chance of being in a crash and that they would not receive additional incentives for performance, if they collided with another car.

The first training trial required subjects to follow a lead vehicle on a two-lane road with horizontal curves to ensure they had sufficient skill for maintaining a lane. The second training trial included a two-lane road on which a lead vehicle varied its speed according to a sinusoidal speed profile. This trial was intended to familiarize subjects with distance judgments in the simulation. The driver was asked to maintain a comfortable distance from the lead vehicle. The third training trial was aimed at familiarizing drivers with passing maneuvers. Subjects were asked to follow a car at a comfortable distance and then, after the lead vehicle slowed down, overtake it.

The experiment trials exposed subjects to four traffic patterns (described in next section), with two replications under a city and a country environment. Subjects were required to respond to the traffic patterns and the environments according to
their own experiences. They were also required to respond to the incentive factor (described in next section), i.e., act as if they were in a hurry when paid for performance vs. time. Subjects were required to follow a predefined driving route, including three turn maneuvers. The route was the same throughout all experiment tasks for all subjects.

**INDEPENDENT VARIABLES**

*Roadway Complexity:* Under the complex condition, participants were presented with an inner-city environment, including large commercial buildings along the road and many pedestrians. There were two lanes on each side (left and right) of the road, divided by double yellow lines (solid or dashed; see Figure 1). There were 12 four-way intersections in the environment that divided the driving route into 13 blocks. Speed limits changed between intersections in all trials following the sequence 40, 20 and 40 mph, according to school zones, road configuration, etc. The speeds limits were used to encourage social norms under different traffic patterns and to influence driver behavior. Traffic lights at the intersections all had the same durations: yellow time was 4–5 sec; red time was 15–45 sec; and green time was equal to red. The simple scenario presented subjects with a country driving environment, which included a few houses, water tanks and barns along the road (see Figure 1). The number of pedestrians was substantially less than in the city environment. Similar to the city environment, there were 12 four-way intersections that divided the driving route into 13 blocks. The roadway characteristics were the same as in the city environment.

![Figure 1. Image of complex and simple driving environment.](image)

*Traffic Pattern:* Traffic patterns were used to assess the influence of behavior of other drivers, i.e., social norms and pressure, on subject driver speed decisions. Traffic patterns were simulated by manipulating traffic volume and traffic speed, as shown in Table 1. Four out of nine combinations of traffic speed and volume, representing typical driving conditions, were examined in the current study. The four traffic patterns included “traffic jam”, smooth traffic flow at the speed limit (“normal” driving condition), “speeding”, and “school zone”. During the smooth traffic flow section, slow vehicles (traveling 10 mph slower than the speed limit) occasionally appeared in each lane, forcing the driver to perform overtaking. Each of the four test patterns was presented in two street blocks (each 2500 ft. long) in
each test trial. Based on prior observational studies (Ohta, 1993), it was expected that this distance would allow subjects sufficient time to experience social norms according to the traffic patterns and possibly conform.

*Incentive Factors:* In half the test trials, drivers were motivated through a performance-based payment system. Drivers arriving at a predefined destination on-time and without accident received compensation more than double that received by those arriving late or having suffered any accident. The exact pay rate for drivers was $5/trial. In this way, driver motivation and emotional state (arousal) were manipulated. A regular time-based payment system was offered for the remaining four trials with a rate of $5/hr.

**Table 1.** Control factors in traffic patterns.

<table>
<thead>
<tr>
<th>Volume vs. Speed</th>
<th>Slow (v&lt;20mph)</th>
<th>Normal (35~40mph)</th>
<th>High (&gt;45mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (&gt;20 cars in view/min)</td>
<td>Traffic Jam</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Normal (10–12 cars in view/min)</td>
<td>School Zone</td>
<td>Normal</td>
<td>---</td>
</tr>
<tr>
<td>Low (5–7 cars in view/min)</td>
<td>---</td>
<td>---</td>
<td>Speeding</td>
</tr>
</tbody>
</table>

Note: The speed limit adopted in this study for “normal” driving was 40 mph.

**EXPERIMENTAL DESIGN AND DEPENDENT VARIABLES**

A split-plot design was used for the experiment (Montgomery 2006). The whole-plot level of the design contained two factors, including driving environment complexity and states of driver motivation. Driver exposure to each combination of whole-plot factors was repeated twice. In order to allow sufficient time for the incentive factor to influence driver behavior, participants were randomly assigned to start with either the time- or performance-based payment system and to complete four trials under that system. They continued with the other payment system for the remaining trials. Each trial presented one of the two levels of complexity, i.e., either rural or city. Environment complexity was balanced within payment system. The order of driver exposure to the levels of complexity was assigned in such a manner that half of the subjects began with the high complexity scenario and the other half with the simple scenarios.

The subplot in the design, a single trial, contained four types of traffic patterns, including the traffic jam, school zone, smooth traffic flow at the speed limit, or speeding. There were 10 blocks in each simulated driving environment. As previously mentioned, each traffic pattern was featured in each of two blocks. The first and last blocks of a trial always involved normal driving. The remaining eight blocks of a trial were randomly assigned to one of the four traffic patterns. Data was only collected from the 2nd block until the 9th block of a trial. For each traffic pattern segment, data collection did not begin until the subject’s vehicle was 300ft into the segment. The frequency of occurrence of specific traffic pattern sequences in the design was balanced to address carryover effects from one pattern to another.
under a particular incentive system and complexity condition combination.

The STISIM Drive™ software logged data for each experiment trial and the logs were used to derive speed measures, including maximum speed, average speed, and percentage of time in violation of the speed limit.

RESULTS

Maximum Speed: A logarithmic transformation was applied to this response. The transformed data conformed with the assumptions of the ANOVA. ANOVA results revealed that payment system (F(1,67)=15.73, p=0.0002), environment complexity (F(1,67)=6.92, p=0.0106) and traffic pattern (F(3,219)=367.7, p=<.0001) all had significant effects on maximum speed. The performance-based payment system produced an increase in maximum speed (42.0±0.3 mph) compared to the time-based payment system (44.7±0.3 mph). In addition to this, drivers maintained higher maximum speed under the rural (42.2±0.3 mph) versus city (44.3±0.3 mph) driving environment. Tukey-Kramer’s test revealed that all four traffic patterns were significantly different from each other. The maximum speed occurred when other vehicles were speeding (55.2±1.1 mph), followed by normal driving (47.4±1.11 mph) and the school zone (40.7±1.1 mph). The minimum speed occurred when driving in a traffic jam (30.2±1.1 mph).

Speeding percentage: Non-parametric test results based on the Wittkowski procedure (1988) revealed that traffic pattern (χ(3)= 386.2, p=<.001) had a significant effect on the percentage of time drivers committed speeding violations. Post-hoc test results for traffic pattern revealed that driving in the school zone produced the highest speeding rate (82±2%), followed by zones in which other vehicles were speeding (64±2%) and when other vehicles maintained the speed limit (27±2%). In the traffic jam, no speeding was observed. It was suspected that speeding violations observed in the school zone might be attributable to carryover speed by drivers from earlier high-speed segments. The traffic jam pattern provided no opportunity for drivers to speed because of the high-traffic density.

In general, the speed limit was much lower in the school zone, as compared to other three traffic patterns (25 mph vs. 40 mph). In order to determine whether drivers drove faster at the beginning of the school zone blocks and committed more speeding violations as a result of higher speeds under other, earlier traffic patterns, the two blocks of a school zone were divided into four segments, including Block 1-Early, Block 1-Late, Block 2-Early, and Bock 2-Late (1100 ft/segment). The percentage of speeding across these segments in the school zones was then analyzed by using the Wittkowski procedure (1988). The non-parametric test revealed that the four segments had no significant difference in speeding violation rates (χ(3)= 1.9302, p=0.1587). This finding indicates that speeding in the school zones was more likely due to the low limit and lower traffic density allowing drivers the opportunity to speed.
DISCUSSION

Motivation Factor (Payment System): The results of the experiment suggested that the performance-based payment system motivated drivers to perceive urgency and to hurry in many situations. Drivers commented that they felt tension in test trials (cf., Russell and Barrett 1999). They increased their maximum speed (41.99±1.04mph vs. 44.73±1.04mph) and exhibited more risky driving behavior under the performance payment system. Therefore, driving incentive or motive is a critical factor to include in any motivational driving model.

Complexity: Drivers produced higher maximum speed under the rural scenario compared to city (42.41±1.04 mph vs. 44.31±1.04mph). It may be possible that visual clutter, due to the increased environment complexity, led to a more conservative choice of speed.

Traffic Pattern: The current study findings were consistent with previous research. Driver vehicle speed and speed deviations were affected by the speed of vehicles in adjacent lanes and lane speed deviations (Ulfarsson, Shankar et al. 2001). The largest value for maximum speed appeared when other vehicles were speeding, followed by driving in traffic at the speed limit, in a school zone and in traffic jam. Contrary to expectation, drivers speed more in the school zone compared to the other three traffic patterns. As previously mentioned, this may have been due to the low speed limit and normal traffic volume in the zone leading to more speed violations. However, the speed in the school zone was much lower compared to driving in traffic either at the speed limit or above the speed limit. This suggests that although drivers had a tendency for frequent speed violations, they still behaved more conservatively when driving in the school zone.

CONCLUSION

The contributions of the present research include: 1) empirical justification for factors in Näätänen and Summala’s model of driver action (1976) - variables that were statistically significant in determining driver safety decisions were identified; 2) identification of additional variables, specifically environment complexity, that mediate the influence of emotions on driver behavior; and 3) demonstration of an effective experimental methodology for manipulating driver emotional states. There was strong empirical evidence of the effects of social norms on driver behavior, induced through different traffic patterns (other drivers’ behavior), as well as levels of roadway complexity. This was tested in terms of speed performance measures. Drivers appear to be influenced by surrounding vehicles, e.g. they maintain high speeds in speeding segments, and they exhibit caution in speed control based on visual clutter in driving environments. With respect to assessing the influence of extreme emotions (urgency, hurry and tension) on driver risk-taking decisions, emotions were triggered in this study through motivational factors. The
performance payment system caused drivers to hurry and they tended to take more risks by increasing their speed.

In general, any new motivation model based on Näätänen and Summala model should incorporate the factors of: (1) social norms; (2) task difficulty; and (3) motivational/emotional factors.

**Applications:** In addition to these theoretical contributions, the current study indicates that new in-vehicle technologies should be developed to provide adaptable warnings or assistant drivers based on emotional states. Changes in driver risk-taking decisions occur, in part, due to emotion state changes. Driver emotions can be assessed by various real-time monitoring systems, such as heart rate monitors (for valence (happiness) level), and galvanic skin response (for arousal). Such monitoring systems could provide real-time measures to predict speed changes or other risk-taking behaviors associated with extreme emotions. In this way, in-vehicle warning or assistant systems could be programmed to make corresponding modifications, such as increased warning intensity or sensitivity when sensors on drivers indicate tension, etc.

**Limitations:** The main limitation of this study is that only one motivational factor was assessed, i.e., an incentive system for creating driver tension. It is possible that other emotions may also play significant roles in driver behavior, e.g., excitement, depression. In addition to this, although the current study successfully manipulated a motivational factor, it was limited in terms of quantifying the exact extent to which driver perceived safety criteria changed relative to specific levels of the factor. Additional research is needed to assess a finer-grain manipulation of driver incentive and its impact on speed control or other measures. Furthermore, the driver population investigated in current research was limited (the mean age of the participants was 23.3 yrs). It is possible that middle-age drivers and elderly drivers may have different driving behaviors due perceptions of different social norms and different sensitivities to motivational factors. Future studies should consider using an even larger sample of drivers in repeated testing.

It should also be noted that, due to limitations in the fidelity of the driving simulator, drivers were aware that their safety would not be compromised in the experiment trials. Hence, they may not have experienced the same level of stress as would occur in real-world driving under similar circumstances and, consequently, they may have behaved more aggressively. Thus the results observed in this study, should also be validated with real world data under similar conditions.

**Future Research:** Future studies should be conducted to examine motivational factors that may cause other emotions (e.g. depression and excitement) in modeling driving behavior. In addition, there is a need to investigate the behavior of drivers with different backgrounds in terms of exposure to traffic. Drivers who mainly drive in city environments may be accustomed to high-density traffic, and hence, perceive less environment complexity compared to drivers who mainly drive in rural environments, when each type of driver is exposed to the same level of roadway complexity. Thus, there is a need to study individual differences in terms of driver background on perceptions of visual clutter and any corresponding effect on safety decisions.
REFERENCES


