DIFFERENCES IN OFF-ROAD GLANCES: THE EFFECTS ON YOUNG DRIVERS' PERFORMANCE

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ABSTRACT Young drivers display more risk-taking behavior than other age groups. Performing distracting tasks is a risky behavior that young drivers tend to engage in, but may not be able to compensate for appropriately. A driving simulator study with 53 young drivers (aged 18 to 21) was conducted to assess the level of engagement with an in-vehicle secondary task. A cluster analysis revealed three groups of drivers that significantly differed based on eye glance behavior and driving performance: drivers with low risk, moderate risk, and high risk behavior. A subgroup of these drivers was provided with feedback to help modulate their distracting activities. The results suggest that the riskiest group benefited most from feedback. The findings have implications for developing better crash countermeasures to mitigate the effects of distraction.

INTRODUCTION

Driving involves complex interactions between the driver, vehicle, and environment. Breakdowns in any of these interactions undermine driving safety. The introduction of in-vehicle and carried-in devices (e.g., cell phones, and mp3 players) raise concerns that the demands of such systems may conflict with the demands of driving. Driver distraction can be defined as diminished attention of the driver to the driving task. A driver's willingness to engage in a non-driving task and the attentional demands placed on the driver by that task can contribute to distraction. Vehicular crashes caused by driver inattention and resulting from driver distraction are a major concern (Brookhuis, De Waard, & Fairclough, 2003; Neyens & Boyle, 2007; Stutts & Hunter, 2003; Wang, Knipling, & Goodman, 1996). The growing number of potentially distracting devices can further undermine safety (Verwey, Brookhuis, & Janssen, 1996) and poses even greater hazards to young drivers (Lee, 2007).

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Distracting activities may pose a particular risk to younger drivers because they may neglect hazards and direct their attention to the roadway less effectively (Fisher et al., 2002). Inexperienced drivers make longer fixations, and scan smaller areas of the visual scene compared to experienced drivers (Mourant & Rockwell, 1972). With experience, their scanning adjusts to reflect the spatial-temporal characteristics of hazardous situations (Brown & Groeger, 1988). As an example, drivers' scanning becomes more sensitive to road type with experience (Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003). Both crash data as well as on-road and simulator studies show that crashes among young drivers are a result of failures of attention and visual search (McKnight & McKnight, 2003; Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005). With respect to sharing the attentional demands of the roadway with a secondary task, Wilkman et al. (1998) showed that young and inexperienced drivers tended to look away from the road with longer and more variable glances compared to those with more experience. Specifically, 29% of young drivers had glances longer than three seconds, while the more experienced drivers had no glances that long.

Young drivers have a higher risk for crash involvement, in part because they are generally more likely to take risks while driving (Deery, 1999; Ferguson, 2003; Williams, 2003). They may also be particularly vulnerable to distractions because of their greater propensity to engage in distracting activities (Olsen, Lerner, Perel, & Simmons-Morton, 2005). Substantial evidence suggests that stable attitudes and behavioral differences influence crash involvement (Parker, Manstead, Stradling, Reason, & Baxter, 1992). Specifically, a survey of college students' driving behavior showed that those students who reported a high level of sensation seeking were more likely to not wear seat belts and to drive aggressively. These drivers were also more likely to report that they would drive faster on highways and on wet roads when driving a vehicle with anti-lock brakes (Jonah, Thiessen, & Au-Yeung, 2001). A survey of 198 drivers between the ages of 16 and 19 revealed several distinct types of drivers, which varied according to risk-taking propensity. Such risk-taking included speeding, driving-related aggression, and hostility (Deery & Fildes, 1999). A subsequent simulator study showed impaired attention-management performance of these drivers in high-workload situations (Deery & Fildes, 1999). Overall, individual differences associated with risk taking may have a strong effect on the degree to which young drivers engage in distracting activities.

Appropriate feedback can help diminish both the impact and the amount of risk-taking behavior (Donmez, Boyle, & Lee, 2007, 2008, in press). The advances in technology make it possible to provide feedback based on the driver state as well as roadway state. For example, eye tracking systems allow us to alert the drivers if their eye glances toward a secondary task exceeds a particular threshold, and sensors within a vehicle allow feedback to be designed based on how far a driver may deviate from the center of their primary lane.

A model developed by Wierwille & Tijerina (1998) showed that glance frequency and duration to an in-vehicle task is highly correlated to crash likelihood. Other studies have shown that feedback regarding driver state and performance can also help drivers modulate their distracting activities and generate faster reactions to roadway events (Donmez et al., 2007, 2008). Ideally, a system designed to provide such feedback would clearly discriminate between risky and non-risky scanning behavior, otherwise drivers are likely to regard the system as a source of annoyance rather than of useful information. The objective of this study is to identify risky young drivers based on their glance behavior, and to assess how well feedback guides risky drivers to more appropriate glance behavior (i.e., diminish the risky glance behavior) and driving performance (i.e., mitigate the effects of risky glance behavior).

METHOD

Participants

There were 53 participants between the ages of 18 and 21 (female: n=26, $\overline{X}$ = 19.6, S = 1.12; male: n=27, $\overline{X}$ = 19.6, S = 1.08) in this study. Participants were paid $15 per hour, and then had the opportunity to earn a bonus of up to $15. Drivers recruited had to be frequent drivers (i.e., they drove more than three days a week) with at least 2 years of driving experience.

Apparatus

The experiments were conducted with a medium-fidelity, fixed-based simulator with a 50-degree visual field powered by Global Sim, Inc.'s DriveSafety™ Research Simulator. All graphics for roadway layouts, markings, and signage conform to American Association of State Highway and Transportation Officials (AASHTO) and Manual of Uniform Traffic Control Devices (MUTCD) design standards. A 7-inch LCD (60-Hz frame rate at 640 x 480 resolution) mounted on the dashboard by a small stand was used in the experiment for the presentation of the visual messages used in the secondary task. The viewing angle from the driver's eye point is approximately 18 degrees. A Seeing Machines eye tracker was used to collect eye movement using the FaceLab 4.2™: an eye and head tracking system that enables analysis of natural behavior by using a set of cameras as a passive measuring device.

Experimental Design

Each participant completed one identical experimental drive (approximately 7 minutes long). The drive took place on a two-lane rural road with oncoming traffic. Participants were instructed to drive at 45 mph (72 km/h), and to follow a lead vehicle that periodically braked at a mild rate of deceleration (0.2 g) for five seconds. Before a lead vehicle braking event, the lead vehicle adjusted its speed to obtain a headway time of 1.8 sec. There were a total of 10 braking events in one drive. Driving performance was assessed by averaging the minimum time-to-collision (TTC) values over these 10 events. Minimum TTC is defined as the minimum time it takes to collide with an object given the instantaneous relative speed and distance.

Participants completed this drive while performing an in-vehicle secondary task, which has been shown to undermine driving performance (Donmez et al., 2007). The task was designed to simulate visual, motor, and cognitive distractions typical of many in-vehicle system interactions (e.g. scanning an MP3 play-list). Participants were given the freedom to interact with the secondary task whenever they felt comfortable, in order to ensure that eye movement patterns were an indicator of willingness to engage in the distraction. However, there was also monetary compensation based on speed and accuracy to provide an incentive to engage in the distracting task. For that reason, all drivers engaged in the distracting task but at varying levels.

After participants completed the necessary Internal Review Board (IRB) consent forms, they were asked to complete one practice drive to become familiar with the simulator controls and the secondary task. All participants then completed the experimental drive. The data from this single drive is used to cluster the drivers based on their eye movement patterns (hence how they engage in distractions). A glance to the in-vehicle display was recorded when the driver's gaze vector intersected with the in-vehicle display. The number of glances to the in-vehicle display and the mean glance duration to the in-vehicle display were used to cluster the drivers.

Clusters

Ward's Hierarchical Clustering method was used to find groupings in the data based on the number and mean duration of glances to the in-vehicle display. This analytical technique partitions a data set into groupings (clusters), on the basis of similarities or distances (Johnson & Wichern, 2002). Cluster analysis has previously been used to investigate various transportation issues, such as the relation between cultural traits and transport risk perception (Oltedal & Rundmo, 2007), the associations between personal activity and travel patterns (Ma & Goulias, 1997), drivers' braking response to collision warnings (Lee, McGehee, Brown, & Reyes, 2002), driver's propensity to change behavior based on information received by driver system (Conquest, Spyridakis, Haselkorn, & Barfield, 1993), and private and commercial drivers' travel behavior (Ng, Barfield, & Mannering, 1998).

Clustering of data was performed using PROC CLUSTER procedure in SAS 9.1. Distances between clusters were computed using Ward's minimum-variance method. The two variables used were the mean duration and the number of glances to the in-vehicle display. Since the variables with large variances tend to have more effect on the resulting clusters than those with small variances, the data was standardized with the inclusion of STD option in PROC CLUSTER.

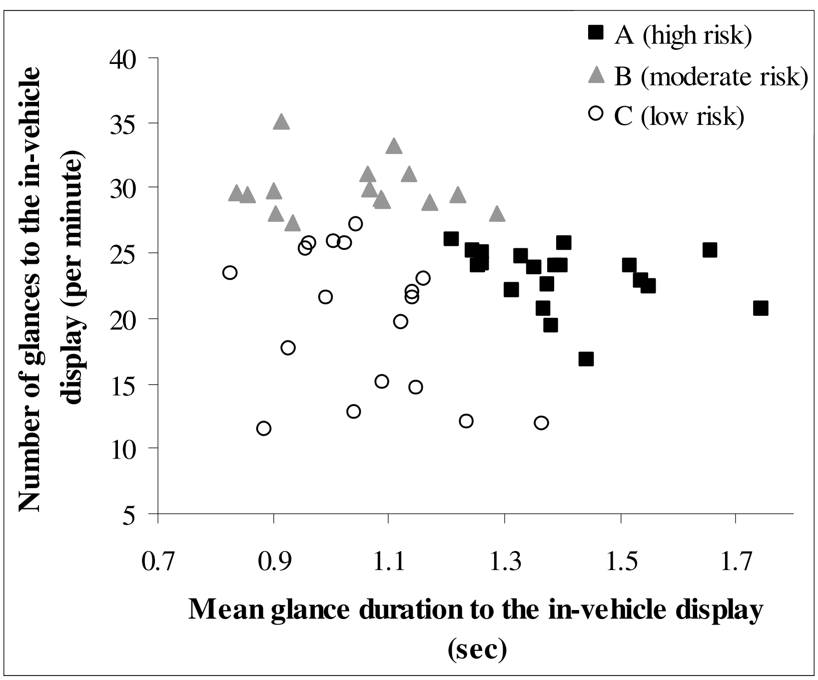

Figure 1. Each driver in the glance space along with cluster membership

As mentioned in the experimental design section, clustering was based on data from a single drive, which all participants completed while performing a secondary task without receiving any feedback. Specifically, the number and duration of glances to the in-vehicle display was used to cluster the drivers. There were three clusters identified (Figure 1). These three clusters

(A, B, and C) accounted for over half of the variation in the data (60 %). Statistical analysis on eye movement patterns revealed that Cluster A (n=20) had the longest mean duration of glances to the in-vehicle display when compared to Clusters B (n=15) and C (n=18) (Table 1, Figure 2). The glance frequencies were the largest for Cluster B followed by Cluster A and then Cluster C.

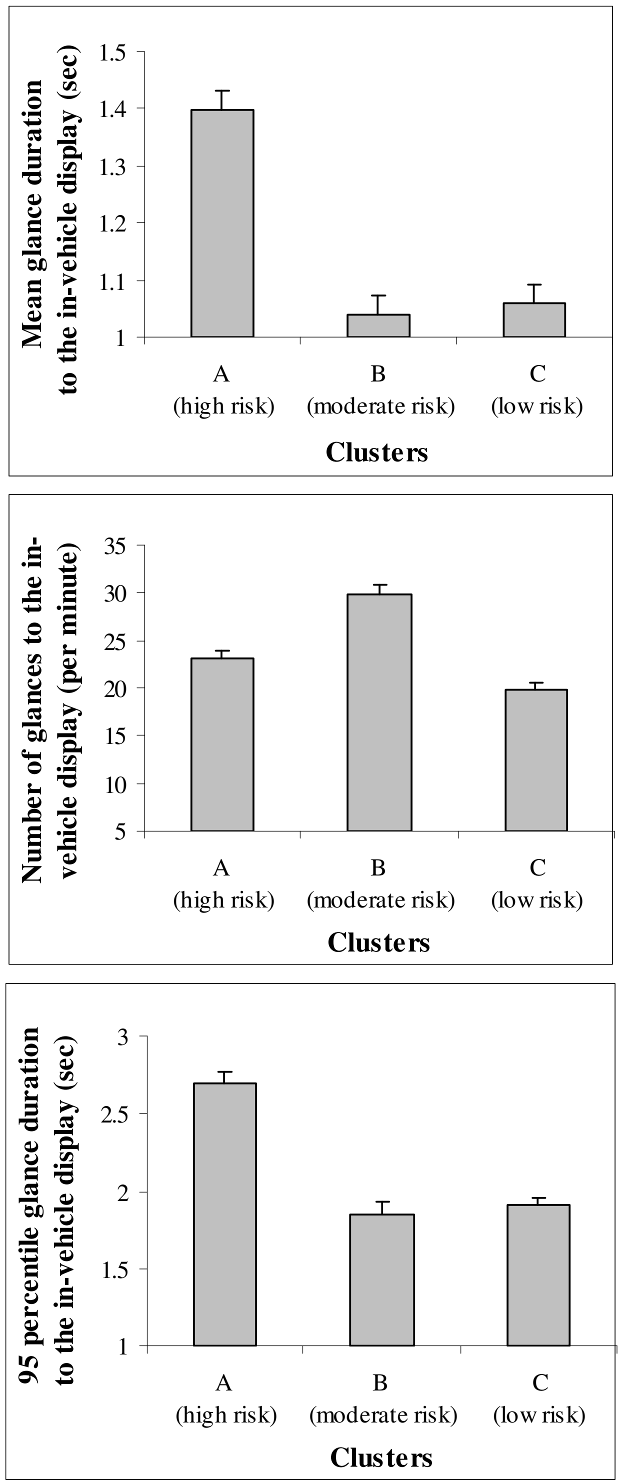

Figure 2. Eye glance measures for the three clusters (means and standard errors)

Horrey & Wickens (2007) indicate that unsafe conditions leading to a crash reside not at the mean of a distribution but rather in the tails. Therefore, the in-vehicle glances which are larger in duration need specific consideration. The 95 percentile value for the glance duration to the in-vehicle display was also analyzed (Table 1, Figure 2). The results were aligned with the results obtained for the mean glance duration. That is, Cluster A had the longest 95 percentile glance durations when compared to Clusters B and C.

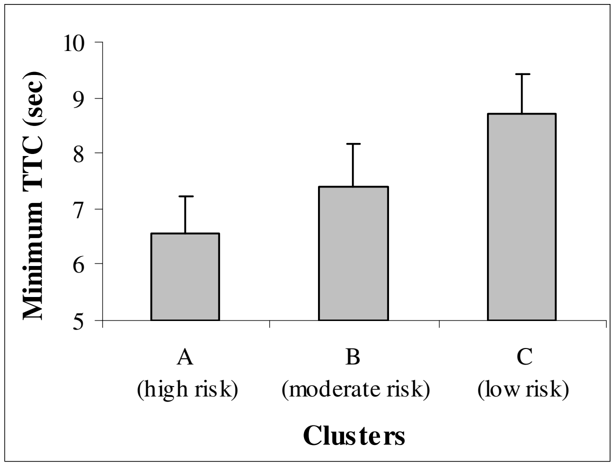

Figure 3. Minimum TTC values for different clusters (means and standard errors)

Table 1. Statistical comparisons between three clusters.

Comparison	Estimate (Δ)	*t*-value	df	*p*	95% Confidence Interval (CI)
Mean glance duration to the in-vehicle display					
Cluster A (high risk) vs. C (low risk)	0.34 s	7.63	50	<.0001	(0.25, 0.43)
Cluster A (high risk) vs. B (moderate risk)	0.36 s	7.71	50	<.0001	(0.27, 0.46)
Cluster B (moderate risk) vs. C (low risk)	-0.02 s	-0.45	50	0.66	(-0.12, 0.07)
Number of glances to the in-vehicle display per minute					
Cluster A (high risk) vs. C (low risk)	3.36	2.81	50	0.007	(0.96, 5.77)
Cluster A (high risk) vs. B (moderate risk)	-6.78	-5.38	50	<.0001	(-9.31, -4.25)
Cluster B (moderate risk) vs. C (low risk)	10.14	7.87	50	<.0001	(7.56, 12.73)
95 percentile glance duration to the in-vehicle display					
Cluster A (high risk) vs. C (low risk)	0.79 s	8.09	50	<.0001	(0.59, 0.97)
Cluster A (high risk) vs. B (moderate risk)	0.84 s	8.22	50	<.0001	(0.64, 1.05)
Cluster B (moderate risk) vs. C (low risk)	-0.05 s	-0.51	50	0.61	(-0.26, 0.16)
Minimum TTC					
Cluster A (high risk) vs. C (low risk)	-2.16 s	-2.23	50	0.03	(-4.12, -0.21)
Cluster A (high risk) vs. B (moderate risk)	-0.82 s	-0.80	50	0.43	(-2.87, 1.23)
Cluster B (moderate risk) vs. C (low risk)	-1.35 s	-1.29	50	0.20	(-3.45, 0.76)

Cluster C had significantly longer minimum TTC during lead vehicle braking events when compared to Cluster A (Table 1, Figure 3). The estimated value for Cluster B was between these two clusters but was not significantly different. Cluster C exemplifies safe driving behavior with low number and duration of off-road glances. Drivers in Cluster A tend to be riskier with a higher number of and longer off-road glances. Cluster B also has high number of off-road glances, but shorter duration off-road glances than Cluster A. A performance decrement will occur if drivers have many long in-vehicle display glance durations. However, many short in-vehicle display glances might not degrade performance. Henceforth, the clusters are labelled as low risk (Cluster C), moderate risk (Cluster B), and high risk drivers (Cluster A).

Demographics

The mean ages of the drivers were 19.6 (S = 1.22), 19.9 (S = 0.86), and 19.4 (S = 1.09) for high, moderate and low risk groups, respectively. They were not significantly different across the three clusters ($F(2,47)=0.91$, $p=0.4$). There were 9 females and 11 males among the high risk drivers; 4 females and 11 males in the moderate risk group; and 13 females and 5 males in the low risk group ($\chi^2(2)=7$, $p=0.03$).

The Effect of Feedback

The effect of feedback for these three clusters was also investigated. The type of feedback tested was a combined concurrent (provided in real-time) and retrospective feedback (provided after a trip), which alerted the drivers of high distraction levels and of incidents that may have occurred (e.g., lane deviations). A previous study showed that this type of feedback can enhance driving performance and behavior (Donmez et al., 2008).

In order to examine the effect of feedback, 27 of the 53 drivers that completed the first drive were observed while driving the exact same route seven more times. They performed these drives while engaging in the same secondary task, with participants randomly assigned to receive feedback or not. Drivers in the feedback condition (n=15) received feedback on all seven drives and drivers in the no feedback condition (n=12) received none for all seven drives. In the no feedback condition, there were three drivers from the high risk group, three drivers from the moderate risk group, and six drivers from the low risk group. In the feedback condition, there were six, five and four drivers in high, moderate, and low risk groups, respectively.

The analysis on mean glance duration to the in-vehicle display revealed that feedback altered glance behavior of the high risk group (Figure 4). In particular, high risk drivers who received feedback had shorter mean glance duration to the in-vehicle display when compared to high risk drivers who did not receive feedback ($F(1,20.5)=10.79$, $p = 0.004$). For this group of drivers, feedback decreased mean glance duration by an estimated 0.40 sec (95% CI: 0.15, 0.66). There was no interaction with drive, and hence this effect was fairly constant over time. Feedback inhibited the increase in the long glances of high risk drivers over time. Compared to high risk drivers who did not receive feedback, with each additional drive, high risk drivers who received feedback had an estimated 0.09 sec shorter 95 percentile glance duration to the in-vehicle display (95% CI: 0.01, 0.17). There were no significant effects of feedback on the number of glances to the in-vehicle display.

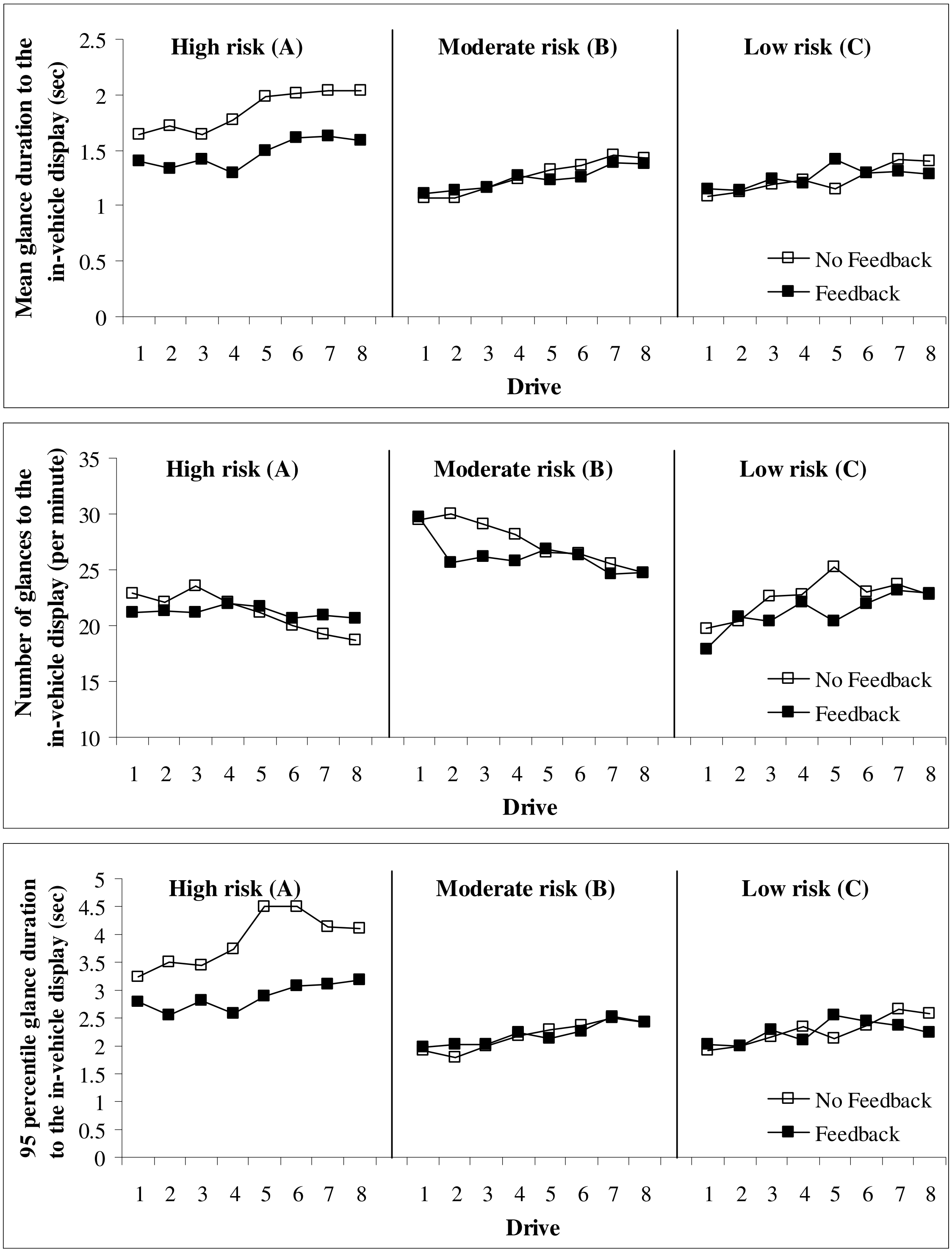

Figure 4. Eye glance measures for different cluster groups with and without feedback

Feedback also mitigated the effects of risky glance behavior for high risk drivers, by increasing the minimum TTC values over time (Figure 5). Among high risk drivers, for each additional drive, feedback increased the minimum TTC by an estimated 0.90 sec (95% CI: 0.50, 1.29). At the end of the eighth drive, high risk drivers who received feedback had an estimated 4.19 sec (95% CI: 1.10, 7.28) larger minimum TTC when compared to moderate risk drivers who received feedback.

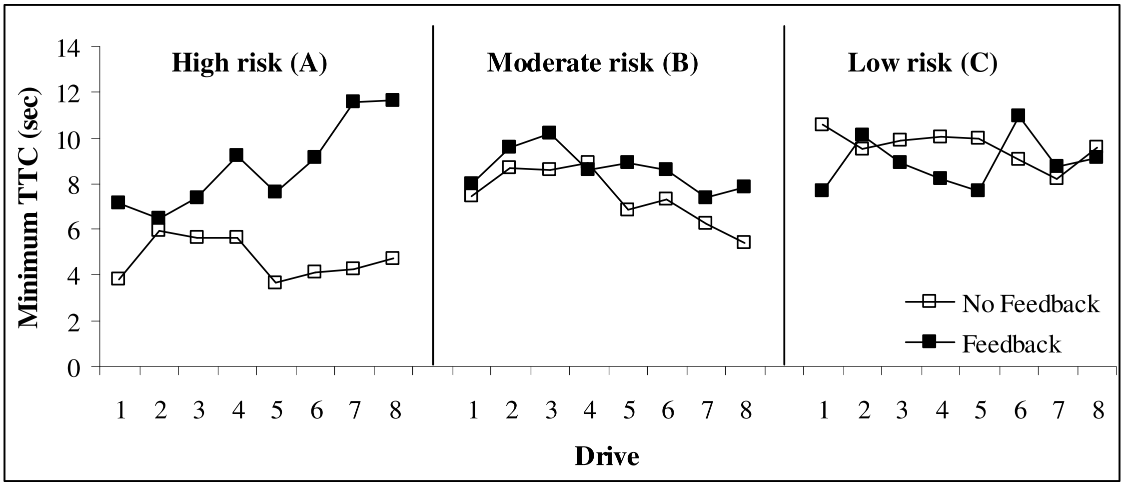

Figure 5. Minimum time-to-collision values for different cluster groups with and without feedback

DISCUSSION

This study demonstrates that differences do exist among young drivers with some exhibiting more risky glance patterns than others. Of the three clusters revealed, the low risk cluster had the least amount of off-road glances. These glances were also short in duration. The high risk cluster looked away from the road for the longest periods and had the slowest response to a braking lead vehicle. The moderate risk cluster had many off-road glances but with shorter duration.

The low risk cluster consisted of a larger proportion of female drivers (72% female), whereas the moderate risk cluster was mostly males (27% female). The high risk cluster had approximately equal number of males and females. Previous studies on young drivers have shown substantial differences between gender (Laapotti & Keskinen, 1998), among personality variables such as sensation seeking (Jonah, 1997; Jonah et al., 2001), and as young drivers begin to accumulate driving experience (Williams, 2003). A study compared the crash and conviction rates of 28,500 Finnish novice drivers in age brackets of 18 to 20, 21 to 30, and 31 to 50 years old. When examined in terms of the levels of driving tasks (Michon, 1985), the results showed young novice drivers, particularly males, had a greater number of strategic and tactical errors, and that females tended to have greater problems at the operational level of driving behavior (Laapotti, Keskinen, Hatakka, & Katila, 2001).

The findings of this study suggest that drivers differ in how they modulate their attention to secondary tasks and that these differences influence their driving performance. The strong differences between the three groups of drivers suggest that a subgroup of young drivers exist that might benefit from feedback regarding their risky glance behavior. In fact, feedback altered the eye glance behavior of the high risk group. In particular, high risk drivers who received feedback had shorter mean glances to the in-vehicle display when compared to those who did not receive feedback. Moreover, this effect was fairly constant over time. In addition to diminishing risky eye glance behavior, feedback also helped mitigate the effects of such behavior for the high-risk drivers, by helping them achieve larger minimum TTC values over time when responding to lead vehicle braking events. At the end of the eighth drive, high risk drivers who received feedback had significantly larger minimum TTC values than moderate risk drivers who also received feedback. The enhanced response to the lead vehicle braking events for the high risk group can also be a result of the diminished risky eye glance behavior. That is, the drivers may have responded better to roadway events because they had shorter glances to the in-vehicle display.

In contrast to the fairly constant eye glance behavior, the minimum TTC values enhanced over time. This differential enhancement in the lead vehicle braking response may be attributed in part to better modulation of attention with feedback. Moreover, when feedback was provided, the high risk cluster had even better driving performance than the moderate risk cluster. It can therefore be concluded that feedback can diminish risky eye glance behavior, and also help drivers learn how to better modulate their attention.

The risky behavior in this study was defined using eye glance behavior and driving performance. In a study that examined the effects of feedback on training teenage drivers, McGehee, Raby, Carney, Lee, & Reyes (2007) defined risky behavior based on observed incidents. The data from 26 teenage drivers showed an 89 percent decrease in the number of incidents for the more at-risk teen drivers. However, the McGehee et al. (2007) study did not have a comparative baseline group (i.e., drivers with no feedback). This present study does include a baseline and therefore, provides further insights into the benefits of feedback.

McKnight & McKnight (2003) suggest that young drivers drive in a risky fashion mostly because they are clueless, rather than careless drivers. That is, a great majority of non-fatal young driver accidents are due to errors in attention and visual search, rather than blatantly risky behavior. The brief exposure to feedback in this current experiment is highly unlikely to shift a stable personality trait like risk-taking tendency. However, given that feedback was able to help high risk drivers diminish their risky eye glance behavior, it appears that feedback can in fact help clueless young drivers understand the risks they are not fully aware of. It is recognized that the effect estimates generated from a driving simulator study may not be directly comparable to on-road performance. However, based on the findings of simulator validation studies (Godley, Triggs, and Fildes, 2002), the relative (not absolute) benefits of feedback to different risk groups would still be expected. Additional on-road research is needed to provide better insights on the magnitude that risky eye glance behavior and driving performance may have.

The most effective means of delivering feedback to risky drivers depends on the factors that guide such behavior. If the risky behavior stems from knowingly incurring greater risk at the level of tactical driving behavior, then analysis of drivers' decision making capabilities and better training might be most effective. If risky behavior stems from poor modulation of attention at the level of operational driving behavior, then real-time feedback that directs drivers' attention back to the road might be most effective. Thus, further research focusing on the strategic, tactical, and operational level may provide greater insight into the benefits of different feedback types. Moreover, a critical concern with feedback is how drivers might respond to feedback with long-term use. Although the results of this experiment are very promising, issues of driver acceptance and willingness to adapt in the long-term will determine whether providing drivers with feedback can mitigate the growing problem of distraction for young drivers.

CONCLUSIONS

This study suggests that young drivers are not a homogenous population and respond to distractions quite differently. Drivers who have many long glances to an in-vehicle display (i.e., riskiest drivers) perform worse than those who have few short glances. Moreover, many short duration in-vehicle display glances might not degrade performance. The results also suggest that feedback can provide great benefits to the riskiest drivers, by decreasing the mean glance duration to an in-vehicle display and by enhancing response to a lead vehicle braking event. Therefore, feedback can diminish risky glance behavior and also mitigate its effects. This has implications for systems designed to help mitigate the effects of distraction.

ACKNOWLEDGMENTS

This research was partly funded by Dwight David Eisenhower Graduate Fellowship, National Highway Institute, U.S. Department of Transportation, and a National Science Foundation Career Award. Data collection for this project was also provided, in part, by Gregor Veeser.

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