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Mitigating driver distraction with retrospective and concurrent feedback

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Abstract

Objectives: An experiment was conducted to assess the effects of retrospective and combined retrospective and concurrent feedback on driver performance and engagement in distracting activities.

Background: A previous study conducted by the authors showed that concurrent (or real time) feedback can help drivers better modulate their distracting activities. However, research also shows that concurrent feedback can pose additional distractions due to the limited time and resources available during driving. Retrospective feedback, which is presented at the end of a trip (i.e., post-drive), can include additional information on safety critical situations during a trip and help the driver learn safe driving habits.

Method: A driving simulator study was conducted with 48 participants and 3 conditions: retrospective feedback, combined feedback (both retrospective and concurrent), and no feedback (baseline case).

Results: The feedback conditions (retrospective and combined) resulted in faster response to lead vehicle braking events as depicted by shorter accelerator release times. Moreover, combined feedback also resulted in longer glances to the road.

Conclusions: The results suggest that both feedback types have potential to improve immediate driving performance and driver engagement in distractions.

Application: Combined feedback holds the most promise for mitigating the effects of distraction from in-vehicle information systems.

Keywords: Driver inattention; Eye movements; Feedback; Workload; Trip-report; In-vehicle distractions; Post-drive information

1. Introduction

Vehicular crashes cause more than 3000 deaths each day across the globe (Peden et al., 2004). In the US, motor vehicle crashes are among the top ten causes of death (CDC, 2005). For those aged 4–34, motor vehicle crashes rank as the number one cause (Subramanian, 2006). Driver distraction is a growing problem that is estimated to cause between 13 and 50 percent of all US crashes (Neale et al., 2005; Stutts et al., 2001; Sussman et al., 1985; Wang et al., 1996). The introduction of in-vehicle information systems (IVIS), such as cell phones and navigational displays, can greatly influence these numbers due to conflicts that may exist between the in-vehicle task and the demands of driving. One way to mitigate distraction is by providing feedback to the driver to enhance immediate performance as well as to induce behavioral change.

From a system-design perspective, feedback is the information available to the operator regarding the state of the joint operator-machine system. In the context of driving, immediate feedback on driving performance (e.g., lane position) is inherent in the driving task. Designers can augment this feedback using sensors and various display technology (e.g., auditory collision warnings). Drivers can receive real time or concurrent feedback at the moment the event occurs. Such feedback has potential to enhance immediate performance. Drivers can also receive retrospective feedback after the events occur (i.e., information presented once a trip is completed). Such feedback can help the drivers understand how safe they are while driving and may eventually change their long-term behavior. Retrospective feedback can support the memory of critical incidents and driver understanding of the degree to which their engagement in distracting activities results in critical incidents. Thus, timing can influence how drivers respond to feedback.

Donmez et al. (2007b) investigated the effects of concurrent feedback on driver performance. The results of that study showed that concurrent feedback positively altered driver interaction with an in-vehicle secondary task. Late accelerator release

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in response to a lead vehicle braking event was observed in those drivers that were distracted. The results showed that drivers in the concurrent feedback condition glanced to the in-vehicle display less frequently compared to those in the no feedback condition. Moreover, when given feedback, drivers' glance duration to the road between in-vehicle glances was longer.

Donmez et al. (2007b) showed that concurrent feedback can be beneficial in helping drivers modulate their distracting activities. However, there is a possibility that concurrent feedback may interfere with immediate task performance and may not be completely effective in mitigating distraction (Arroyo et al., 2006; Munro et al., 1985). Limited processing time and resources available during driving may undermine driving performance with concurrent feedback. The limited time that can be allocated to concurrent feedback also makes it impossible to provide detailed information regarding the event that triggered the feedback. As a consequence, concurrent feedback may not convey the information necessary to guide behavior. However, this information can be useful in helping drivers assess their overall driving performance by highlighting the persistent behavior that leads to errors.

In the absence of feedback, drivers tend to forget their roadway incidents very quickly (Chapman and Underwood, 2000). Therefore, there is potential to help drivers better assess driving performance and modify behavior by refreshing the drivers' memory of their last trip. In addition, drivers often overestimate their ability (McKenna and Lewis, 1991), and feedback can help calibrate their perceived performance (i.e., how safe they think they drive) with their actual performance. Hence, retrospective feedback can be used to provide drivers information for mitigating driver distraction, alerting them of the influence of fatigue, age related impairments or even train them to be more aware of certain situations. For example, using retrospective feedback, young drivers can be made aware of the type of incidents that may occur due to speeding, a distracting activity or even passenger conversations.

Retrospective feedback has not been studied systematically in the driving domain and is the primary focus of this study. Because concurrent feedback has been shown to help distracted drivers, a system that combines both concurrent and retrospective feedback might have additional benefits. That is, a combination of concurrent and retrospective feedback may reinforce each other, with concurrent feedback highlighting incidents during the drive so that retrospective feedback provided afterward is more understandable.

The main objective of this current experiment was to assess the effects of retrospective and combined (both concurrent and retrospective) feedback on driving performance and engagement in distractions. This was assessed by comparing these two feedback conditions to a baseline group where the drivers performed the same driving and distracting tasks without feedback. Specific research questions investigated included whether providing retrospective feedback regarding drivers' performance helps drivers adopt safer driving behavior and whether combined feedback provides additional benefits. The effects of feedback were assessed with measures of subjective and objective driving performance, as well as engagement in distractions.

2. Methods

2.1. Participants

Forty-eight participants between the ages of 18–21 (female: $n=23$, $\bar{X}=20.2$, $S=0.73$; male: $n=25$, $\bar{X}=20.3$, $S=0.89$) completed the study. The participants possessed a valid U.S. driver's license, and had at least one year of driving experience. They were native English speakers, were screened for hearing impairments and colorblindness, and had not driven a driving simulator in the last two years. Participants were compensated US$ 15 per hour for their participation and had the opportunity to receive up to US$ 10 extra based on their secondary task performance.

2.2. Apparatus

The experiment was conducted with a medium fidelity, fixed-based simulator powered by Global Sim Inc.'s DriveSafety™ Research Simulator. The simulator used a 1992 Mercury Sable vehicle cab equipped with a force feedback steering wheel and had a 50° visual field. The driving scenarios were created by HyperDrive™ Authoring Suite. A FaceLab 4.1™ eye tracker, which uses cameras as passive measuring devices, was used to collect eye movement data. The eye tracker recognized in real time whether the participant was looking at the road or at the in-vehicle display. Eye tracking and driving data were collected at 60 Hz. A 7 in. touch-screen LCD (60 Hz frame rate at 640 × 480 resolution) mounted on the dashboard above the center instrument panel was used for presentation of the visual messages for the secondary task as well as feedback. The display was positioned 40 cm (15 in.) to the right of the center of the steering wheel and 8 cm (3 in.) above the center of the speedometer. With respect to the driver, the screen was turned approximately 15° toward the driver and located 33° lateral to and 15° below the driver's line of sight.

2.3. Driving task

Participants completed one practice drive in addition to four experimental drives (each approximately 7 min). The drives took place on two-lane rural roads with straight and curved road segments (three 400 m radius and three 200 m radius), with traffic in the opposing lanes. The participants were instructed to drive at a comfortable speed that was not above the speed limit of 73 km/h (45 mph) and follow a lead vehicle that periodically braked at a rate of 0.2 g (gravitational acceleration) for 5 s. Before a lead vehicle braking event, the lead vehicle speed was adjusted to obtain constant time headways of 1.8 s. Ten braking events took place in a drive. A constant level of fog (sight distance: 300 m) was employed during the scenario to decrease the drivers' ability to anticipate an approaching curve.

2.4. Experimental design and independent variables

The experiment used a mixed factorial design with feedback type as a between-subject condition: no feedback (17 partici-

Table 1
Thresholds for incident triggers in trip-report as defined by severity level

Incident type	Variable of interest	Severity level		
		Low	Medium	High
Speeding	Speed	25–27 m/s	27–29 m/s	>29 m/s
Too close to lead vehicle	Time to collision	1.8–3 s	1–1.8 s	<1 s
Lane deviation	Duration of deviation	<1.5 s	1.5–4 s	>4 s
Collision with lead vehicle	Crash (binary)	No	No	Yes
Collision with oncoming traffic	Crash (binary)	No	No	Yes

pants), retrospective feedback (17 participants) and combined concurrent and retrospective feedback (14 participants). Each participant completed four consecutive drives (drive 1, drive 2, drive 3 and drive 4). This was done to increase the amount of exposure to feedback. Drive was a within-subject variable. The road geometry was same for all four drives. Participants completed these drives while performing an in-vehicle secondary task. This task was also used by Donmez et al. (2007b) and was designed to simulate visual, motor and cognitive distractions typical of many IVIS interactions (e.g., scanning an MP3 play-list).

After each drive, the group with retrospective feedback received a trip-report. If there were no critical incidents (defined in Table 1) during the drive, participants received positive feedback (Fig. 1a) to increase driver acceptance of the trip-report. Previous research shows that positive feedback helps promote acceptance (Branderburg and Mirka, 2005; Fogg and Nass, 1997). In this experiment, incidents occurred in 40 of the 68 drives in the retrospective feedback condition and in 38 of the 56 drives in the combined feedback condition. If there were any incidents, a timeline showed the incidents (long red bars), appropriate responses to lead vehicle braking (long green bars), and the locations of the distractions (Fig. 1b).

The high (displayed with medium-length orange bars), and medium (short yellow bars) levels of distraction (Fig. 1b and c) presented in the trip-report were based on an algorithm used in Donmez et al. (2007b). This algorithm defined the momentary distraction level as a function of the current off-road glance duration, β_1, and the total off-road glance duration during the last 3 s, β_2, with the relative influence of the current glance duration as α. These factors then defined a momentary value of distraction, γ, for the algorithm: $\gamma = \alpha\beta_1 + (1-\alpha)\beta_2$. A two-tier feedback was used with a threshold, γ', of 2 s for medium level of distraction and γ'', of 2.5 s for high level of distraction with α of 0.2. Pressing on the incident button (shown as "Incident 1" in Fig. 1b) brought up a new frame with more detailed

Fig. 1. Trip-report (a) positive feedback for no incidents, (b) overview when there are incidents and (c) detailed information on the incident.

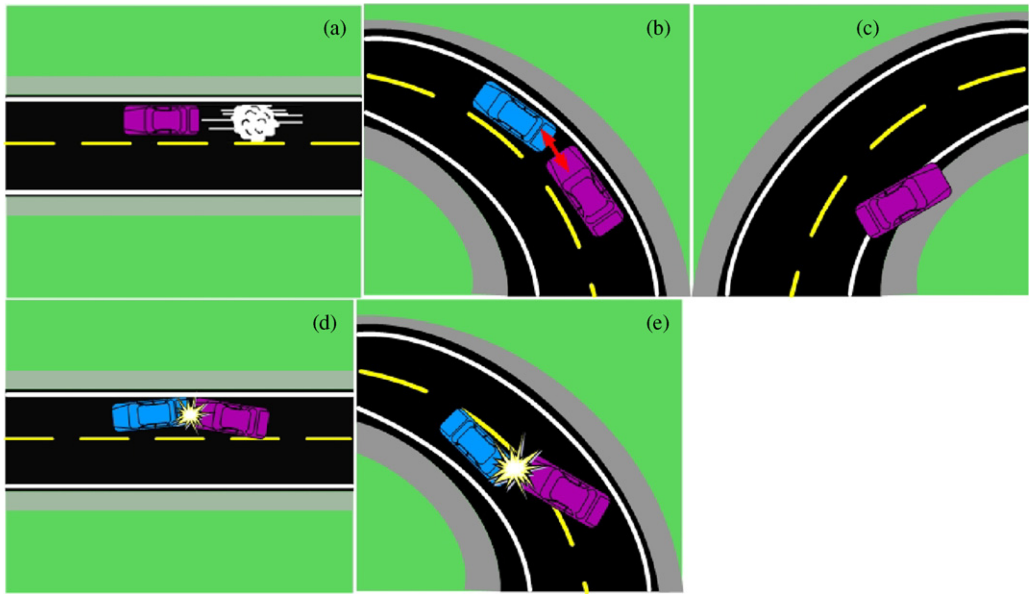

Fig. 2. Incident visualization: (a) speeding, (b) too close to lead vehicle, (c) lane deviation, (d) collision with lead vehicle and (e) collision with oncoming vehicle.

information on the incident (Fig. 1c). The incident type (Fig. 2), the distraction level during the incident (low/none, medium or high) and the severity level of the incident (low, medium or high) (defined in Table 1) were included in this detailed frame. The "overview" button took the participant back to the trip-report overview to the point where the red bar of the viewed incident was grayed out. Once the participants went through all incidents, they were given the ability to review again. The combined feedback group received the trip-report at the end of each drive and also received concurrent feedback during each drive.

For concurrent feedback, if the momentary distraction value (γ) exceeded 2 s, a yellow-strip appeared on the top of the display. If the momentary distraction value exceeded 2.5 s, then orange strips appeared on both sides of the yellow strip to create a more salient alarm. The concurrent feedback used in this study was the same as Donmez et al. (2007b). Because this study is an initial attempt to assess the effects of retrospective feedback, and a study already assessed concurrent feedback (Donmez et al., 2007b), a separate condition of only concurrent feedback was not included in the experimental design.

2.5. Procedure

After participants signed the informed consent, the eye tracker was calibrated for the participants' facial characteristics. The participants then practiced the secondary task until they became comfortable. This was followed by a 5 min acclimation drive to familiarize the participants with the driving simulator while performing the secondary task. The participants then completed four drives (each approximately 7 min long). After each drive the participants completed a series of questionnaires which asked them to rate the workload they experienced, their perceived risk and their general attitudes towards the safety systems. Participants were then debriefed and compensated. Overall, the study took approximately 2 h.

2.6. Dependent variables

The experiment assessed the differences in driving performance and eye-movement patterns between different drives and compared these across treatments. Lead vehicle braking response, interaction with in-vehicle display (i.e., eye movements and button presses) and subjective responses to questionnaires were analyzed.

The dependent variables for lead vehicle braking event response were averaged over 10 braking events. This was done to obtain stable estimates of drivers' response. The dependent variables analyzed for each lead vehicle braking event response are accelerator release time, minimum time-to-collision (TTC) and minimum acceleration. The initial reaction to the lead vehicle braking is captured in the accelerator release time which is defined as the time from the onset of the lead vehicle braking event until the time the driver releases the accelerator. Minimum TTC is the shortest time-to-collision during a braking event, where TTC is calculated by assuming the driver was to continue in the same path at the same velocity. Minimum acceleration is the minimum acceleration (or maximum deceleration) value reached by the driver during the braking event. Both minimum TTC and minimum acceleration are indicators of the safety outcome of a braking event (Donmez et al., 2006).

In order to immerse the driver in a realistic scenario with some degree of experimental control, the lead vehicle speed was adjusted to maintain a 1.8 s headway time before a lead vehicle braking event. Therefore, headway distance varied depending on the driver's speed. However, the headway distance can influence critical cues that guides a driver's braking behavior, such as the rate of expansion of the visual angle of the lead vehicle, which is a function of vehicle size, distance and relative velocity (Lee, 1976). Thus, the inclusion of a covariate explaining the differences in cues is necessary to draw the right conclusions from the statistical analysis (Donmez et al., 2007a). In this experiment, the height and width of the lead vehicle were constant since there was only one lead vehicle. Moreover, for small angles, the tangent of the angle can be robustly approximated as the value of the angle itself (for 22.5°, the error of this approximation is only 6%). Therefore, inverse headway distance (i.e., the reciprocal of the headway distance) at the onset of the lead vehicle braking event was considered as a covariate in the analysis of the braking event response and kept in the model if significant.

For eye movement behavior, two variables were analyzed that define driver's scanning process: duration of eye glances to the in-vehicle display, and duration of glances to the road in between glances to the in-vehicle display. A decrease in the first variable and an increase in the second one suggest a diminished level of distracting activity.

After each drive, all participants were asked to rate their driving safety and the effect of the distracting task on their driving performance. Participants in feedback conditions were also asked if feedback enhanced their driving performance. The responses were collected on a five-point Likert scale. Mental effort (Zijlstra, 1993) and perceived risk (Tsimhoni et al., 2003) questionnaires were given to every participant after each drive. Mental effort and perceived risk questionnaires were on a scale of 0–150 and 1 [driving on an easy road perfectly alert]–10 [driving with eyes closed], respectively. A system acceptance questionnaire (Van Der Laan et al., 1997) was also given to participants in the two feedback conditions. This questionnaire composed of nine questions along a scale of −2 to +2, investigating two dimensions of acceptance: usefulness and satisfying. For the combined feedback condition, participants filled out two separate acceptance questionnaires for concurrent and retrospective feedback (i.e., trip-report).

3. Results

A preliminary analysis demonstrated strong correlations between accelerator release time and minimum TTC ($\rho = -0.68$, $p < 0.0001$). Because these two dependent driving performance measures are correlated, MANOVA is performed on these variables to control for inflation of the Type I error. Significant findings are followed-up with univariate analysis to assess the magnitude of the effect that each independent variable has on the dependent variables. The univariate analyses on the continuous dependent variables were performed with SAS 9.1 PROC MIXED procedure. A compound symmetry covariance structure was chosen for the repeated measure 'drive' based on the Akaike (1979) information criterion.

There were two specific comparisons that were of particular interest. The first involved the magnitude of the differences in feedback over time with emphasis on changes from the first to last drive. The second focused on changes that may occur in performance after drivers receive feedback for several periods. This comparison examined the differences among feedback types within the last drive. It should be noted that the first drives were identical for the no feedback and retrospective feedback conditions since retrospective feedback was presented only at the completion of a drive. For that reason, no significant differences were expected when comparing the first drives of the no feedback and the retrospective feedback conditions. However, the first drive for the combined feedback condition is not a baseline and actually includes concurrent feedback. Previous research shows that concurrent feedback has an effect on driver interaction with IVIS (Donmez et al., 2007b). Hence, the results for the first drive of combined feedback might differ from the results for the first drives of the other two feedback conditions.

3.1. Lead vehicle braking response

The MANOVA results indicated that there were significant effects for the main effect of drive (Wilks' Lambda $F(6,264) = 8.21$, $p < 0.0001$) and the interaction effect of drive and feedback type (Wilks' Lambda $F(12,264) = 2.00$, $p = 0.02$). The univariate analysis reported below suggests that the effect of drive is attributable to the differences observed in both accelerator release time and minimum TTC. However, the interaction effect is only due to the differences observed in accelerator release time.

Figs. 3 and 4 show the estimated means for reaction times and the safety outcomes for the lead vehicle braking events. The accelerator release times suggest that both retrospective and combined feedback is beneficial to the driver. The main effect of drive ($F(3,134) = 12.55$, $p < 0.0001$) and the interaction of drive and feedback type ($F(6,135) = 3.04$, $p = 0.008$) were significant. The covariate, inverse headway distance, also had a significant effect ($F(1,163) = 44.16$, $p < 0.0001$) with a negative coefficient estimate (−91.9). This demonstrates that accelerator release time and inverse headway distance are inversely related. As one would expect, a longer headway is associated with a longer accelerator release time. Pair-wise comparisons between levels of significant effects showed that accelerator release time was longer in drive 1 compared to the following drives (Table 2). This suggests that there was a learning effect associated with the driving task. For drive 4, both retrospective and combined feedback resulted in shorter accelerator release times than no feedback. Therefore, with accumulated exposure, both feedback types resulted in faster response to lead vehicle braking. Appro-

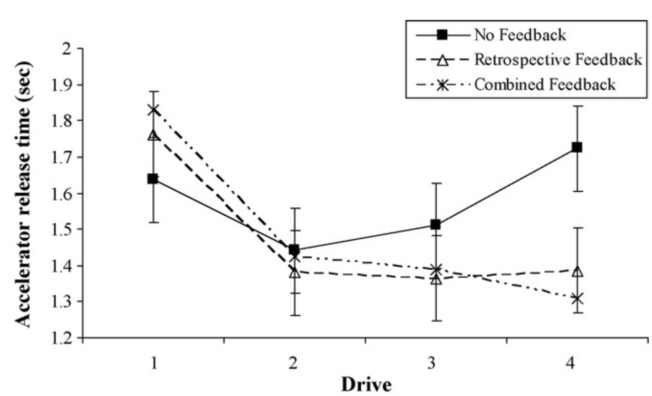

Fig. 3. Reaction to lead vehicle braking events (estimated means and standard error bars).

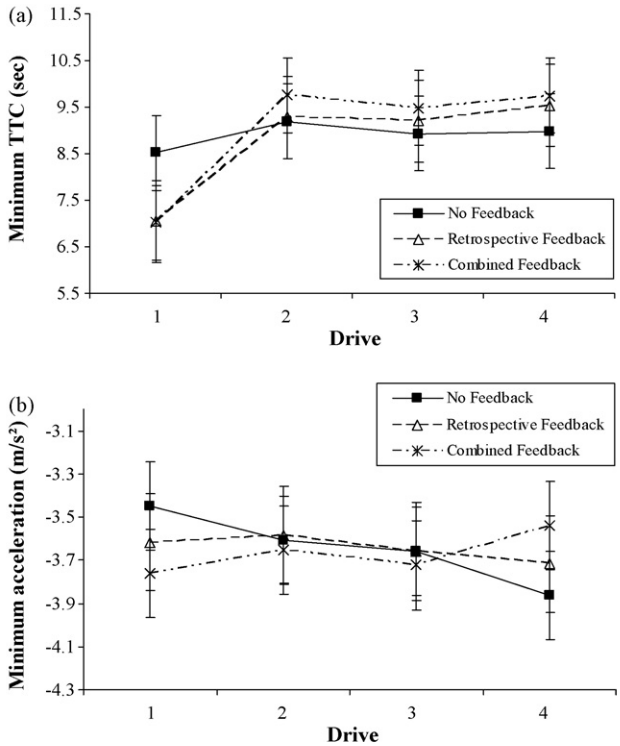

Fig. 4. Safety outcomes for lead vehicle braking event response (estimated means and standard error bars) (a) minimum TTC and (b) minimum acceleration.

priate contrasts were used to compare the change from drive 1 to drive 4 across different feedback types (i.e., drive 4 minus drive 1). The difference between drive 4 and drive 1 for the no feedback condition, compared to the feedback conditions, showed that feedback led to a larger difference from the first to last drive. That is, the decrease in accelerator release time from drive 1 to drive 4 was larger for feedback conditions. This suggests that both feedback types enhanced drivers' response over time.

There difference in minimum TTC between the last (drive 4) and first drives (drive 1) in the no feedback condition was significantly smaller than the differences observed in the two feedback conditions. This suggests that, over time, both retrospective and combined feedback resulted in a greater increase in minimum TTC when compared to the no feedback condition. For minimum acceleration, the difference between drive 4 and drive 1 for the no feedback condition was larger than combined feedback. No feedback condition generated more intense braking over time whereas combined feedback results in a less intense braking response.

3.2. Interaction with in-vehicle display: eye movements and button presses

For the duration of glances to the in-vehicle display, the main effect of drive was significant ($F(3,134) = 12.24$, $p < 0.0001$) (Fig. 5a). Duration of glances to the in-vehicle display was shorter in drive 1 and drive 2 compared to drive 3 and drive 4 (Table 3), suggesting that the participants got more comfortable performing the secondary task. The difference in glance duration to the in-vehicle display between drive 4 and drive 1 for no feedback was significantly longer than those of combined and retrospective feedback. The increase in glance duration over time is the largest for the no feedback condition.

The two main effects drive ($F(3,134) = 4.33$, $p = 0.006$) and feedback type ($F(2,45) = 4.22$, $p = 0.02$) were significant for glance duration to the road (Fig. 5b). Duration of glances to the road was longest in drive 2, which followed the first presentation of the trip-report. In general, combined feedback resulted in longer glances to the road compared to no feedback and retrospective feedback. Therefore, combined feedback had an overall positive impact on drivers' engagement in the distracting activity. Donmez et al. (2007b) observed a similar finding for concurrent feedback, where concurrent feedback resulted in on average 0.18 s longer on road glances than no feedback.

Table 2
Significant pair-wise comparisons for lead vehicle braking response

Pair-wise comparison	Estimate (Δ)	*t*-Value	d.f.	*p*-Value	95% confidence interval (CI)
Accelerator release time					
Drive 1 vs. drive 2	0.33 s	5.30	134	<0.0001	(0.21, 0.45)
Drive 1 vs. drive 3	0.32 s	5.19	135	<0.0001	(0.20, 0.45)
Drive 1 vs. drive 4	0.27 s	4.31	135	<0.0001	(0.15, 0.39)
No feedback vs. retrospective feedback on drive 4	0.34 s	2.02	86.6	0.046	(0.006, 0.67)
No feedback vs. combined feedback on drive 4	0.41 s	2.37	85	0.02	(0.07, 0.76)
No feedback vs. retrospective feedback for the difference between drive 4 and drive 1	0.46 s	3.11	134	0.002	(0.17, 0.76)
No feedback vs. combined feedback for the difference between drive 4 and drive 1	0.61 s	3.95	134	0.0001	(0.30, 0.91)
Minimum TTC					
No feedback vs. retrospective feedback for the difference between drive 4 and drive 1	−2.02 s	−2.52	134	0.01	(−3.61, −0.43)
No feedback vs. combined feedback for the difference between drive 4 and drive 1	−2.25 s	−2.69	134	0.008	(−3.91, −0.60)
Minimum acceleration					
No feedback vs. combined feedback for the difference between drive 4 and drive 1	0.63 m/s^2	2.68	134	0.008	(0.16, 1.09)

Table 3
Significant pair-wise comparisons for interaction with in-vehicle display

Pair-wise comparison	Δ	t-Value	d.f.	p-Value	95% CI
Glance duration to in-vehicle display					
Drive 1 vs. drive 3	−0.08 s	−3.41	134	0.0009	(−0.13, −0.04)
Drive 2 vs. drive 3	−0.12 s	−4.65	134	<0.0001	(−0.16, −0.07)
Drive 1 vs. drive 4	−0.09 s	−3.73	134	0.0003	(−0.14, −0.04)
Drive 2 vs. drive 4	−0.12 s	−4.97	134	<0.0001	(−0.17, −0.07)
No feedback vs. retrospective feedback for the difference between drive 4 and drive 1	0.12 s	2.00	134	0.047	(0.001, 0.08)
No feedback vs. combined feedback for the difference between drive 4 and drive 1	0.16 s	2.55	134	0.02	(0.04, 0.28)
Glance duration to road					
Drive 1 vs. drive 2	−0.12 s	−2.39	134	0.02	(−0.22, −0.02)
Drive 2 vs. drive 3	0.12 s	2.37	134	0.02	(0.02, 0.22)
Drive 2 vs. drive 4	0.18 s	3.49	134	0.0007	(0.08, 0.28)
No feedback vs. combined feedback	−0.46 s	−2.70	45	0.01	(−0.80,−0.11)
Retrospective feedback vs. combined feedback	−0.41 s	−2.38	45.1	0.02	(−0.75, −0.06)
Number of button presses per minute					
Drive 1 vs. drive 4	−2.46	−10.07	134	<0.0001	(−2.95, −1.98)
Drive 2 vs. drive 4	−2.37	−9.66	134	<0.0001	(−2.85, −1.88)
Drive 3 vs. drive 4	−1.25	−5.11	134	<0.0001	(−1.74, −0.77)
Drive 1 vs. drive 3	−1.21	−4.99	134	<0.0001	(−1.70, −0.73)
Drive 2 vs. drive 3	−1.11	−4.58	134	<0.0001	(−1.59, −0.63)

Drive had a significant effect on the number of button presses per minute ($F(3,134) = 44.33$, $p < 0.0001$) with the last drive resulting in the largest number of button presses (Fig. 6). This demonstrates that with more exposure to the secondary task, the drivers also became more comfortable with the secondary task.

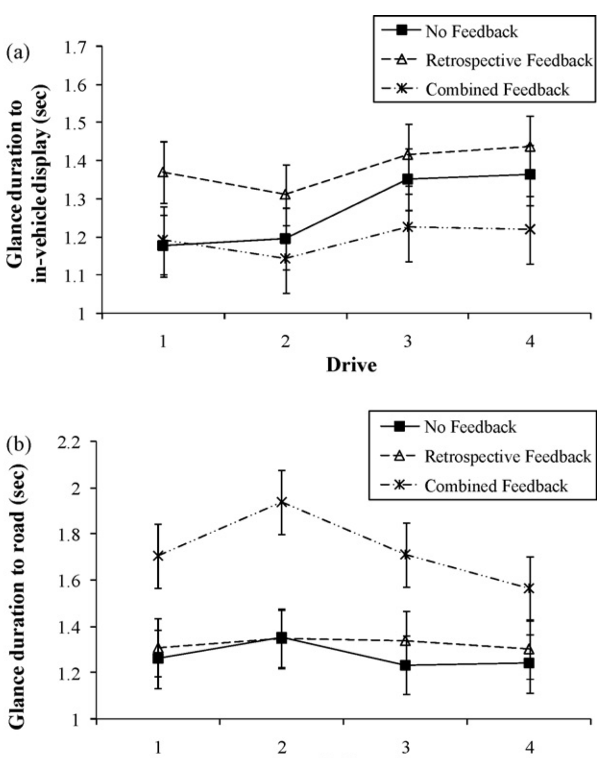

Fig. 5. Eye-movements (estimated means and standard error bars) (a) glance duration to the in-vehicle display and (b) glance duration to the road.

3.3. Subjective measures

Both feedback type ($F(2,45) = 10.76$, $p = 0.0002$) and drive ($F(3,135) = 7.46$, $p = 0.0001$) had a significant effect on perceived level of risk (Fig. 7a). In general, drivers with no feedback perceived greater risk when compared to retrospective and combined feedback (Table 4). This suggests that the drivers were aware of their performance decrement with the secondary task (i.e., late accelerator release when compared to feedback conditions). Perceived risk levels dropped as the number of drives completed increased.

A logistic regression was developed to predict perceived risk based on the number of different incident types (i.e., lane deviation, speeding and too close to lead vehicle) and eye movements. Collision was not included in the regression as a covariate since there were no collisions in this experiment. Glance durations to the road and to the in-vehicle display were used to represent eye movements. The outcome variable, perceived risk, was coded as low risk for responses lower than 6 (out of 10), and high risk

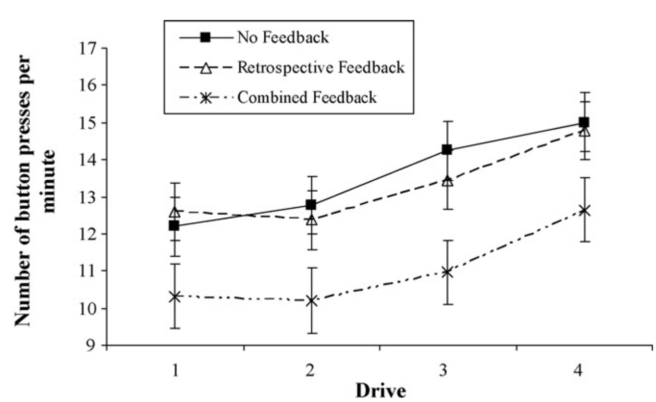

Fig. 6. Number of button presses per minute (estimated means and standard error bars).

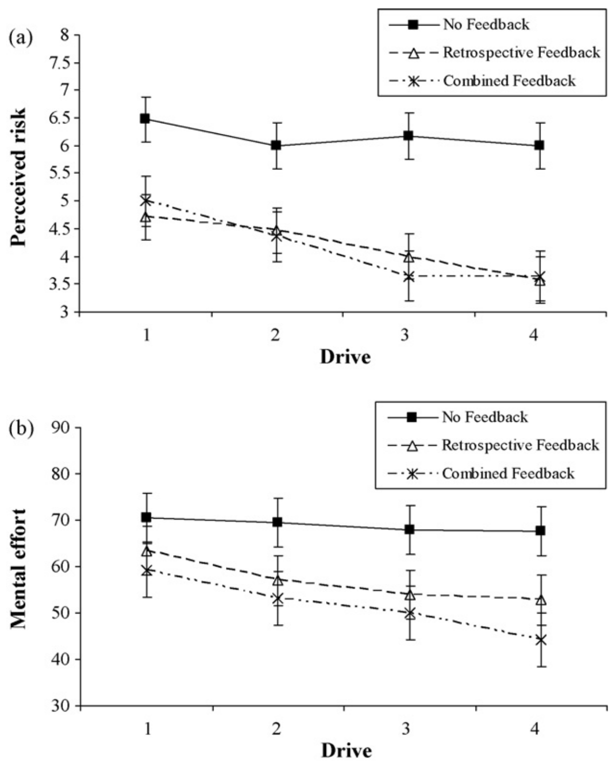

Fig. 7. Subjective measures (estimated means and standard error bars) (a) perceived risk and (b) mental effort.

for responses 6 or higher. The value 6 represents driving at 20 miles per hour faster than traffic on an expressway. Glance durations to the road, lane deviations, and speeding were significant. Goodness of fit tests suggested that the model was appropriate (Pearson $\chi^2(187) = 191$). High glance duration to the road was correlated with a decreased likelihood of perceiving high risk (OR (95% CI): 0.47 (0.22, 0.99), $\chi^2(1) = 3.9$, $p = 0.048$). High

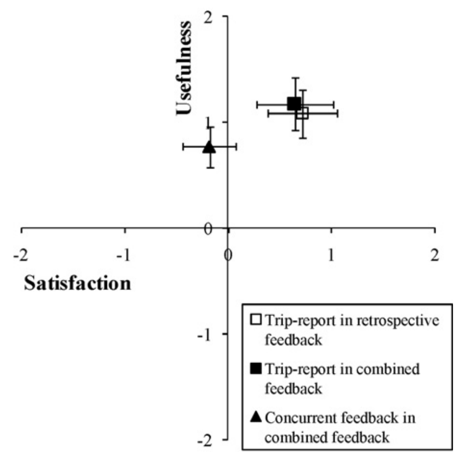

Fig. 8. Acceptance of feedback (estimated means and 95% confidence intervals).

number of lane deviations (OR (95% CI): 1.16 (1.04, 1.30), $\chi^2(1) = 7.29$, $p = 0.01$) and speeding (OR (95% CI): 1.31 (1.05, 1.63), $\chi^2(1) = 5.58$, $p = 0.02$) were indicative of increased odds for perceiving high risk.

Mental effort was highest for drives 1 and 2, and lower in the last drive (Fig. 7b). These results can be attributed to increased driver familiarity with the secondary and the driving tasks. The 95% confidence intervals for the mean acceptance scores, which exclude zero, reveal that drivers generally found both feedback types to be useful (Fig. 8). The trip-report was also found to be satisfying by the drivers in the retrospective and combined feedback conditions. The satisfaction response for concurrent feedback (presented as part of combined feedback) is not significantly different than zero since the 95% confidence interval for the mean includes zero. Still, there is a general positive attitude towards both feedback types. The results for concurrent

Table 4
Significant pair-wise comparisons for subjective measures

Pair-wise comparison	Δ	*t*-Value	d.f.	*p*-Value	95% CI
Perceived risk					
No feedback vs. retrospective feedback	1.96	4.02	45	0.0002	(0.99, 3.05)
No feedback vs. combined feedback	2.02	3.94	45	0.0003	(0.98, 2.94)
Drive 1 vs. drive 2	0.45	2.01	135	0.046	(0.01, 0.89)
Drive 1 vs. drive 3	0.79	3.52	135	0.0006	(0.4, 1.23)
Drive 1 vs. drive 4	0.97	4.41	135	<0.0001	(0.54, 1.43)
Drive 2 vs. drive 4	0.54	2.40	135	0.02	(0.09, 0.98)
Mental effort					
Drive 1 vs. drive 2	4.55	2.12	135	0.04	(0.31, 8.80)
Drive 1 vs. drive 3	7.15	3.33	135	0.001	(2.91, 11.39)
Drive 1 vs. drive 4	9.55	4.45	135	<0.0001	(5.31, 13.97)
Drive 2 vs. drive 4	5.00	2.33	135	0.02	(0.75, 9.24)
Usefulness					
Drive 1 vs. drive 3	−0.17	−2.33	86.1	0.02	(−0.32, −0.03)
Drive 1 vs. drive 4	−0.21	−2.86	86.1	0.005	(−0.36, −0.06)
Satisfaction					
Drive 1 vs. drive 2	−0.29	−2.42	87	0.02	(−0.53, −0.05)
Drive 1 vs. drive 3	−0.38	−3.18	87	0.002	(−0.62, −0.14)
Drive 1 vs. drive 4	−0.47	−3.91	87	0.0002	(−0.72, −0.23)

Table 5
Subjective responses relating to driving performance

Feedback type	Response				
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
My driving was safe					
No feedback	9	32	11	16	0
Retrospective feedback	1	6	22	25	14
Combined feedback	0	10	12	33	1
Distracting task worsened my driving					
No feedback	0	0	1	38	29
Retrospective feedback	0	7	6	41	14
Combined feedback	0	1	7	36	12
Performance of trip-report enhanced my driving					
Retrospective feedback	2	11	19	33	3
Combined feedback	0	4	18	34	0
Performance of concurrent feedback enhanced my driving					
Combined feedback	2	6	16	31	0

feedback are consistent with the findings of Donmez et al. (2007b).

Driver acceptance of the trip-report was compared across the two conditions which included the trip-report (i.e., retrospective and combined feedback). Acceptance of the trip-report as part of retrospective and combined feedback were not significantly different ($p > 0.05$). However, first drive resulted in a lower level of acceptance when compared to following drives. This suggests that drivers' acceptance of the trip-report increased with exposure. The acceptance data for the concurrent feedback (presented as part of combined feedback) could not be included in this analysis because only the combined feedback group received this type of feedback and comparison with another condition was not feasible.

When the participants were asked whether or not the secondary task worsened their driving performance, the majority indicated that it did (Table 5). Most of the participants also thought that both retrospective and concurrent feedback enhanced their driving performance.

4. Discussion

This study assessed the effects of retrospective only and combined concurrent and retrospective feedback on driving performance and driver engagement in distracting activities. The results showed that driving performance improved from the first to last drive for all conditions, suggesting a learning effect, which was enhanced by feedback. As assessed by the difference between the last and first drive, driving performance improved more for the feedback conditions (retrospective only and combined) when compared to the no feedback condition. Donmez et al. (2007b) showed that this same secondary task delayed accelerator release by 0.4 s on the average. For the last drive in this current study, where drivers had already been exposed to feedback several times, both feedback types resulted in significantly faster reaction to lead vehicle braking events. Specifically, retrospective feedback resulted in 0.34 s and combined feedback resulted in 0.41 s faster accelerator release response compared to no feedback. In terms of driving performance measures, no significant differences were found between the two feedback types: both retrospective and combined feedback enhanced driving performance.

As participants completed more drives, their glance duration to the in-vehicle display increased and their glance duration to the road decreased across all conditions. This was also accompanied with increased number of button presses. This suggests that drivers became more comfortable performing the task. However, the no feedback condition resulted in a larger increase in glance duration to the in-vehicle display from first to last drive when compared to both retrospective and combined feedback. This suggests that both of these feedback types can induce positive behavior in terms of how long the drivers look at the in-vehicle display. Moreover, combined feedback resulted in longer on-road glances than both no feedback and retrospective feedback. Specifically, there was a 0.46 s average difference between combined feedback and no feedback. Donmez et al. (2007b) also showed that, given concurrent feedback in one drive, drivers' glance duration to the road was on average 0.18 s longer than no feedback. This suggests that the longer on-road glances found in the current study may be partially driven by the concurrent component of combined feedback. However, the additional benefit from 0.18 to 0.46 s may be attributed to the interactions between retrospective and concurrent components, or increased exposure to feedback with multiple drives, or both. Further research is needed to differentiate between the effects of these three underlying mechanisms. Based on these findings, combined feedback appears to be more promising than retrospective feedback. Even if a direct statistical comparison cannot be made to the concurrent feedback investigated by Donmez et al. (2007b), this current study shows that combined feedback does combine the benefits of retrospective feedback and concurrent feedback (i.e., faster reaction times and longer glances to the road, respectively).

Subjective driver responses were aligned with the objective data. Drivers, who received no feedback, perceived more risk and also had worse driving performance compared to drivers who received feedback. The logistic regression results also showed a relationship between perceived risk, driving performance and eye movements. However, it is unclear what determines driver's perceived level of risk. The relation between perceived risk and driving behavior and how feedback affects this relationship merits further research.

Most of the participants felt the secondary task impaired their driving performance. Participants also felt that feedback (retrospective only and combined) enhanced their driving performance. Drivers also seemed to accept the feedback. The trip-report, which is included in both feedback conditions, was found to be useful and satisfactory. Concurrent feedback as a supplement to retrospective feedback was also perceived to be useful. The acceptance of concurrent feedback is also consistent with findings from Donmez et al. (2007b). Acceptance of feedback is important because driver acceptance plays a critical role in the use of discretionary systems and hence in their effectiveness. If feedback is provided retrospectively, it is particularly important to consider driver acceptance to ensure that drivers attend to feedback. Otherwise, once a trip is completed the drivers can leave their cars without receiving feedback. Toledo and Lotan (2006) investigated feedback on driving performance presented on a personal web page over a 5-month period. Drivers could access the information on all previous trips and compare their performance with other drivers. The initial exposure to feedback had a positive effect on safety, but this effect diminished over time as drivers accessed their web pages less frequently. Acceptance and frequent use of feedback can be encouraged by an interface that is aesthetically pleasing and easy to use. Including positive feedback, as it was done in this study, may also have a powerful effect on acceptance and use.

This study represents an initial attempt to investigate different feedback timings, and has limitations. Retrospective feedback implemented in a driving simulator can be substantially different from retrospective feedback in the real world. In this experiment, retrospective feedback was provided after each 7 min drive, which artificially increased driver exposure to feedback. However, in a real-world situation, feedback may not be encountered quite so frequently. Therefore, the effectiveness of prolonged use of retrospective feedback will need to be investigated. The visual presentation of feedback may also need to be redesigned to facilitate the debriefing of multiple incidents over longer drives.

The retention of feedback after days or months and under different scenarios should also be investigated. One possible way to enhance the retention of feedback is to provide cumulative feedback, which is a comprehensive summary of past driving performance and driver behavior (Donmez et al., in press). Cumulative feedback integrates driving data over many trips that might span several weeks or months. This can also help the drivers assess their overall driving performance by highlighting those persistent behaviors that lead to errors. As an initial investigation, McGehee et al. (2007) explored the effectiveness of feedback in modifying the behavior of teenage drivers. The preliminary results of 26 teenage drivers over a 6-month period suggest a significant decrease in the number of incidents for the more at-risk teenage drivers. However, because there was no baseline group (i.e., drivers with no feedback) observed in the same time period, more research is still needed to assess the exact benefits of cumulative feedback.

One should be cautious in generalizing the results of this experiment to longer exposure. Drivers may adapt to these systems in unforeseeable ways with extended exposure to feedback (e.g., over months). Future research should investigate such adaptation issues before implementing these systems in the vehicle.

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