

# Reading Text While Driving: Understanding Drivers' Strategic and Tactical Adaptation to Distraction

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**Objective:** In this study, we investigated how drivers adapt secondary-task initiation and time-sharing behavior when faced with fluctuating driving demands.

**Background:** Reading text while driving is particularly detrimental; however, in real-world driving, drivers actively decide when to perform the task.

**Method:** In a test track experiment, participants were free to decide when to read messages while driving along a straight road consisting of an area with increased driving demands (demand zone) followed by an area with low demands. A message was made available shortly before the vehicle entered the demand zone. We manipulated the type of driving demands (baseline, narrow lane, pace clock, combined), message format (no message, paragraph, parsed), and the distance from the demand zone when the message was available (near, far).

**Results:** In all conditions, drivers started reading messages (drivers' first glance to the display) before entering or before leaving the demand zone but tended to wait longer when faced with increased driving demands. While reading messages, drivers looked more or less off road, depending on types of driving demands.

**Conclusions:** For task initiation, drivers avoid transitions from low to high demands; however, they are not discouraged when driving demands are already elevated. Drivers adjust time-sharing behavior according to driving demands while performing secondary tasks. Nonetheless, such adjustment may be less effective when total demands are high.

**Application:** This study helps us to understand a driver's role as an active controller in the context of distracted driving and provides insights for developing distraction interventions.

**Keywords:** time-sharing behavior, secondary-task initiation, eye-glance patterns, ocular measures, off-road glances, fluctuating driving demands

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## **INTRODUCTION**

Driver distraction diverts drivers' attention away from critical tasks for safe driving to competing tasks (Lee, Young, & Regan, 2009) and has emerged as a major cause of motor vehicle crashes. National Highway Traffic Safety Administration (NHTSA) data show that 16% of fatal crashes and 21% of injury crashes in 2008 were attributed to driver distraction (Ascone, Lindsey, & Varghese, 2009). Likewise, the 100-Car Naturalistic Driving Study showed that driver distraction was associated with approximately 23% of crashes and near crashes (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006).

Distraction can take a driver's eyes off the road (visual distraction), mind off the road (cognitive distraction), and hands off the steering wheel (manual distraction) (NHTSA, 2010). One of the worst potential distractors is reading text information while driving, as it imposes both visual and cognitive interference to driving, thereby compromising safety by degrading drivers' vehicle control and ability to detect hazards (Drews, Yazdani, Godfrey, Cooper, & Strayer, 2009; Hoffman, Lee, McGehee, Macias, & Gelatly, 2005). This scenario is compounded by the fact that in-vehicle information systems as well as nomadic devices are increasingly able to present drivers with text and other information to read.

The deleterious impact of distraction on performance notwithstanding, drivers are not passive recipients of nondriving (secondary) tasks in the real world as they are in many experimental settings. Rather, drivers actively manage the distribution of their attention between driving and competing tasks and select when to initiate or attend to a secondary task. This active role of drivers in moderating driving and competing

tasks is well described by Fuller's (2005) task capability interface (TCI) model wherein drivers monitor and compare the current level of task demands against their perceived capability (i.e., range of acceptable task difficulties). As task demands approach or even exceed capabilities, drivers will modify their behavior in order to bring them back into alignment. In this model, the ability of drivers to accurately predict the current and immediate future state of the road is one of the key elements. Ideally, this moderation coincides with a realistic appraisal of current and forecasted driving demands as well as the availability of driver attentional resources. In other words, drivers have the potential to adapt to distraction according to the driving situation. The adaptation can take the form of tactical adjustments, including speed reductions or changes in task management policy (e.g., longer gaps between interactions), or a more strategic adaptation, such as the active avoidance of high-demand situations. Nonetheless, when adaptation fails (i.e., task demands exceed driver capability), the performance of one or both tasks will suffer, possibly endangering safety.

Although the TCI perspective can characterize the dynamic relationship between task demands and driver capacity, drivers' adaptive behavior to distraction has not been well studied. A limited number of studies suggest that drivers often do not take full advantage of their adaptive potential when initiating secondary tasks. Authors of one study found that drivers initiated different types of secondary tasks regardless of the current driving demands even when areas of lower demands were readily available (Horrey & Lesch, 2009). Similarly, Lerner and Boyd (2005) reported that roadway type (e.g., freeway, arterial) did not affect drivers' self-reported willingness to engage in secondary tasks; nonetheless, at certain maneuvers (e.g., exits, merges, turns), drivers were less willing to distract themselves. However, Lerner and Boyd did not examine the timing and strategy by which drivers coordinate their activities when approaching these transitions to higher demands.

Whereas strategic adaptation involves the purposeful delay or planning of to-be-performed secondary tasks, adaptation at the tactical level

is manifested by drivers' time-sharing behaviors between concurrent driving and secondary tasks, in an attempt to achieve optimal or at least sufficient performance in both. Consistent with the TCI model, Senders, Kristofferson, Levison, Dietrich, and Ward (1967) modeled this behavior as an impulse to reduce uncertainty regarding the roadway situation. As drivers look away from the road, the uncertainty accumulates at a rate that depends on the current driving situation (e.g., road type). When the uncertainty reaches a certain threshold, drivers feel compelled to look back to the road. Drivers can also modify the rate of uncertainty accumulation by changing vehicle speed. Building upon these studies, Hoffman and others (2005) decomposed a text-reading task into an iterative sequence of on- and off-road glances and explored how drivers adapt to the workload of secondary tasks. The results suggested that, besides driving demand, time-sharing behavior was also affected by how text information was presented and controlled (e.g., compared with two lines, displaying four lines of text at a time led to longer off-road glance duration).

Now, a substantial body of literature has dealt with performance implications of distracted driving using mandatory distraction, wherein drivers are motivated or forced to conduct secondary tasks while driving. However, there are relatively few controlled studies that allow drivers to control the initiation of secondary tasks (strategic adaptation; cf. Horrey & Lesch, 2009) and encourage natural time sharing with driving (tactical adaptation). In the current study, carried out in an instrumented vehicle on a test track, we used a text-reading task as distraction to examine whether the type and timing of driving demands, and the formatting of text, influence drivers' strategic decision making and tactical time sharing in a situation in which drivers are fully aware of workload levels and transitions.

To the extent that drivers actively seek reduced demands while driving, we hypothesized that drivers would choose the area with relatively low driving demands to initiate text reading. They would also be more likely to initiate the task when the transition to high driving demands is farther away (i.e., when they had more time before driving demands increased)

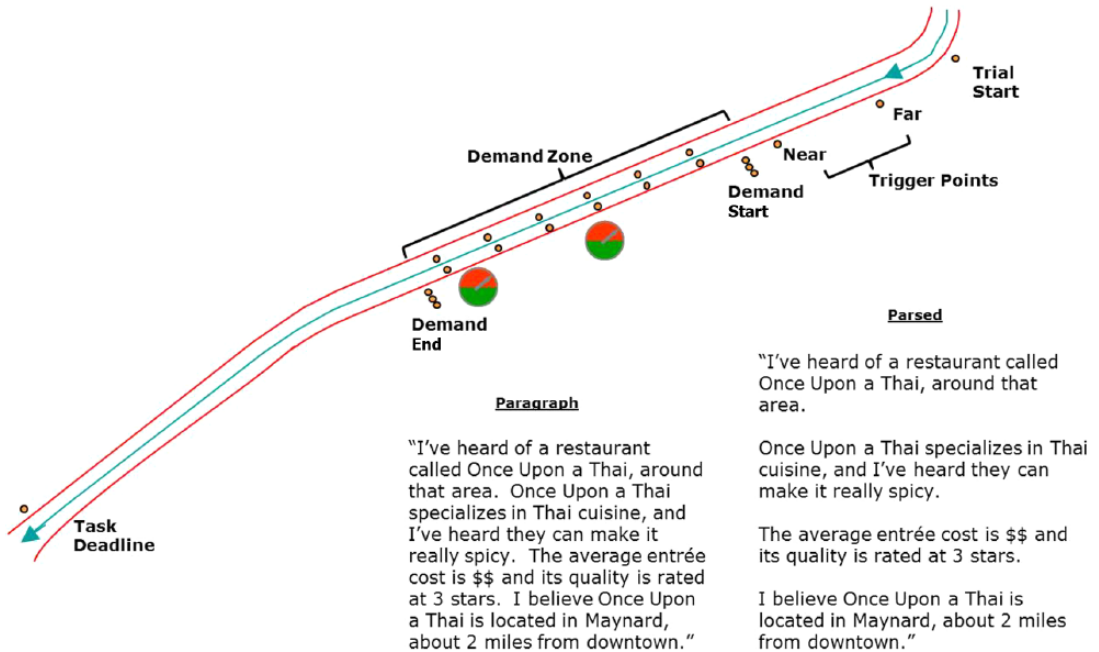


Figure 1. Track layout showing the trial start and end points, the trigger points, and the demand zone. Samples of the parsed and paragraph message formats are also shown.

compared to closer by. We expected that drivers would adapt to higher driving demands by looking away from the road for shorter durations and by keeping their eyes on the road for longer periods of time. We also expected that messages in single-paragraph format would lead to longer off-road glances compared to messages parsed by sentence because the former lacks natural breaking points, which may motivate drivers to read more information per glance.

## METHOD

### Participants

Seventeen healthy drivers (7 males and 10 females), ages 25 to 55 ( $M = 45.4$ ,  $SD = 6.6$ ) years old, from the local area of Hopkinton, Massachusetts, participated in the study. All participants possessed a valid U.S. driver's license, had at least 20/40 corrected visual acuity and normal color vision, and were fluent in English. On average, drivers drove approximately 17,800 km per year ( $SD = 7,400$ ) and reported an average experience of 1.4 crashes in their lifetime ( $SD = 1.3$ ). Participants were compensated at the rate of \$20 per hour for their participation.

The study and protocol were reviewed and approved by the institutional review board at the Liberty Mutual Research Institute for Safety.

### Apparatus

Participants drove a 2002 Ford Windstar minivan on parts of a two-lane, 0.8-km closed test track (Figure 1). The vehicle was instrumented with onboard sensors and computers to control data acquisition and secondary tasks. The onboard computers recorded vehicle data and video from four camera views (forward view, driver's face, foot pedals, and a wide-angle in-cab view) at 30 Hz. A 26.4-cm High Bright LCD touch screen (Earth Computer Technologies, Inc., San Juan Capistrano, CA) was mounted near the center console, approximately 54 cm diagonal offset from the forward field of view, to display messages.

### Driving Task

For each experimental trial, drivers drove the length of the track from the "trial start" to the "task deadline," a distance of approximately 350 m (Figure 1). A demand zone—the area

between “demand start” and “demand end”—varied according to four conditions:

- **Narrow lane condition:** Participants needed to drive through a narrow, curving path lined with orange traffic cones, which required precise lateral control of the vehicle. The cones were placed within a single lane of travel (effectively restricting the lane width). The gap between the traffic cones was approximately 2.4 m; the width of the vehicle was approximately 1.9 m.
- **Pace clock condition:** Two pace clocks were set up on the left side of the road at the locations indicated by half-green/half-red circles in Figure 1. The hand of the clocks moved at a constant speed, circling the clock in approximately 8 to 14 s. Participants were instructed to adjust their speed as they approached a pace clock so that the vehicle would pass the clock when the hand was in the green portion. In making adjustments, participants needed to avoid speeding excessively (over 30 mph), driving too slowly (under 5 mph), or stopping completely. The pace clock task required precise longitudinal control of the vehicle. This condition was carried out on a regular-width lane.
- **Combined condition:** Participants drove through the narrow lane while attempting to comply with the two pace clocks.
- **Baseline (low demands):** Drivers drove on a regular-width, straight lane without needing to comply with the pace clocks.

When not being used, traffic cones were placed on the lane markers (i.e., regular lane width), and the pace clocks were turned off (participants were instructed to ignore the clocks). The speed adjustments required for the pace clock task notwithstanding, participants were instructed to drive at the speed that they felt comfortable, but 25 mph was a reasonable limit.

### Reading Task

During trials, participants read a message displayed on the touch screen. The message included information regarding a made-up restaurant and was intended to mimic the sorts of information that might be provided by location-based services, such as price ranges, reviews, and distance from current location (examples in Figure 1). The messages were designed so that

average readers could finish reading the messages within the constraints of the low-demand section of the track (i.e., from the end of the demand zone to the task deadline). Depending on the condition, the message was presented in either paragraph format or parsed by sentence and was made available at either the far or near trigger point, relative to the demand zone (Figure 1). Participants had approximately 5 s before entering the demand zone (i.e., the vehicle passed the first traffic cone) from the far trigger point and approximately 3.5 s from the near trigger point.

### Experimental Design

This study employed a  $4 \times 3 \times 2$  within-subject design. Four types of driving demands (baseline, narrow lane, pace clock, combined) were crossed with three levels of message condition (no message, paragraph, parsed), and message condition was nested by two trigger points (far, near), resulting in five combinations (only paragraph and parsed conditions were crossed with trigger points). Participants experienced each of the four demand levels in four separate blocks and experienced each combination of message condition and trigger point twice in one block. The order of the blocks was counterbalanced across participants, and the order of the trials within the blocks was randomized.

### Procedure

Upon arrival, participants read and signed the informed-consent document. Then, they completed a vision test for acuity and color blindness using a Titmus Vision Tester (Titmus Optical, Inc., Chester, VA) and filled out demographic and driving behavior questionnaires. An experimenter described experimental trials and gave instructions on the tasks that participants performed in the trials. Then, participants drove in the instrumented vehicle along the experimental route (Figure 1) for several laps to acclimate to the vehicle, four levels of driving demand, and experimental trials. After that, participants completed the four experimental blocks. During the experiment, an experimenter sitting in the passenger seat signaled the start of the task at the given trigger point. Participants were free to decide when and how to perform

the task once a message became available and were required only to try to complete it before reaching the task deadline. In an attempt to reduce experimental demand characteristics, no specific instruction was provided concerning task priority, only for participants to perform both the driving and reading tasks as best they could. After finishing each trial, participants answered a question related to the message to gauge their recall or processing of the material. After each experimental block, participants filled out a modified NASA Task Load Index (NASA-TLX) questionnaire to evaluate their workload level (Hart & Staveland, 1988; Horrey & Lesch, 2009) and their performance on each of the two tasks (i.e., driving and reading). After the drives, participants filled out a post-experimental questionnaire and payment form. We debriefed and thanked them for participating in the study.

### Dependent Variables

For drivers' strategic adaptation to distraction, we defined task initiation as the driver's first glance to the display and used task initiation location and initiation time. Initiation location described where the vehicle was located when the task was initiated, relative to the demand zone: before, during, or after the zone. Initiation time measured the duration from the appearance of the message until task initiation.

To examine time-sharing behaviors of drivers, we defined off-road glances as glances to the in-vehicle display (engaged in reading messages). We calculated four aggregated eye-glance measures and plotted the average percentage of eyes-off-road time for the different sections of the track in the experimental trials. The eye-glance measures included average duration of off-road glances when participants drove in the demand zone (in-zone) and after leaving the demand zone (out-zone) and average duration between two consecutive off-road glances (i.e., on-road glances) in the zone and after the zone.

To obtain task initiation and eye-glance variables, experimenters reviewed video data frame by frame to mark the time when the vehicle entered or left the demand zone and to identify the glances to the in-vehicle display. A cross-check of

20% of the data was validated by a second experimenter, and interrater reliability was over 95%.

Moreover, we were interested in the overall NASA-TLX workload score, secondary task performance items on the NASA-TLX questionnaire, and drivers' responses to the comprehension questions. The overall NASA-TLX workload score was calculated by averaging the rating of seven items.

## RESULTS

All analyses were conducted with SAS 9.2. We used Friedman's tests (PROC FREQ) to examine the main effects of driving demands, message format, and trigger points on task initiation time and the four eye-glance measures and used multinomial linear mixed model (PROC GLIMMIX) for task initiation location and message comprehension. We also used mixed models (PROC MIXED) to test the effects of driving demands on the overall NASA-TLX and ratings for secondary task performance. All statistical tests considered the dependency within subjects using compound symmetry as the covariance structure and used a criterion of statistical significance ( $\alpha$ ) of .05. For post hoc analysis,  $p < \alpha/m$  led to the rejection of the null hypothesis, where  $m$  represented the number of the hypotheses (i.e., Bonferroni correction). The values and comparison statistics of dependent variables across driving demands, message formats, and trigger points are listed in Tables 1, 2, and 3, respectively.

### Task Initiation

*Task initiation location.* Driving demands significantly affected initiation location (Figure 2a). Under the baseline condition, participants started to read messages before the demand zone in the majority of trials. Nonetheless, under the three increased-demand conditions (narrow lane, pace clocks, combined), participants tended to start reading while driving in the demand zone. Only on a small percentage of trials did participants wait until after the demand zone to initiate the reading task.

There was no significant effect of message format on initiation location. However, there was a significant effect of trigger point on task initiation location. The far trigger point produced more task

**TABLE 1:** Values and Comparison for Dependent Variables Across Driving Demands

Dependent Variable	Driving Demands				Comparison
	Baseline	Narrow	Clock	Combined	
Initiation location					
Before	114 (84)	46 (40)	53 (39)	38 (28)	$F(6, 480) = 18.2, p < .001$
During	20 (15)	48 (41)	79 (59)	83 (61)	
After	2 (1)	22 (19)	3 (2)	16 (12)	
Initiation time	0.8 (1.4)	2.5 (5.4)	4.7 (5.6)	8.0 (8.2)	$Q_3 = 163.4, p < .001$
Average off-road glance duration in-zone	1.2 (1.3)	0.8 (1.0)	1.3 (1.4)	0.9 (1.1)	$Q_3 = 115.1, p < .001$
Average off-road glance duration out-zone (in seconds)	1.4 (1.5)	1.4 (1.6)	1.5 (1.6)	1.5 (1.7)	$Q_3 = 12.9, p = .005$
Average on-road glance duration in-zone	0.7 (0.7)	1.6 (2.1)	1.0 (1.2)	0.9 (1.2)	$Q_3 = 86.9, p < .001$
Average on-road glance duration out-zone	0.5 (0.6)	0.5 (0.7)	0.5 (0.6)	0.5 (0.6)	$Q_3 = 5.8, p = .1$
Overall NASA-TLX score	40 (12)	43 (13)	47 (13)	51 (16)	$F(3, 48) = 8.2, p < .01$
NASA-TLX performance in the reading task	52 (17)	50 (14)	53 (14)	46 (18)	$F(3, 48) = 1.67, p = .19$
Reading comprehension	113 (83)	100 (86)	113 (84)	111 (82)	$F(3, 500) = 0.3, p = .9$

Note. The values listed are frequency (percentage) for initiation location; median (mean), in seconds, for initiation time and four eye-glance measures; mean (standard deviation) for NASA-TLX measures; and the number of correct cases (accuracy) for reading comprehension. TLX = Task Load Index.

**TABLE 2:** Values and Comparison for Dependent Variables Across Message Formats

Dependent Variable	Message Formats		Comparison
	Paragraph	Parsed	
Initiation location			
Before	125 (48)	126 (48)	$F(2, 480) = 0.6, p = .6$
During	112 (43)	118 (45)	
After	24 (9)	19 (7)	
Initiation time	2.3 (5.1)	2.2 (5.2)	$Q_1 = .002, p = .97$
Average off-road glance duration in-zone	1.1 (1.2)	1.1 (1.2)	$Q_1 = 0.8, p = .4$
Average off-road glance duration out-zone	1.5 (1.6)	1.4 (1.5)	$Q_1 = 14.0, p < .001$
Average on-road glance duration in-zone	0.7 (1.3)	0.7 (1.2)	$Q_1 = .05, p = .8$
Average on-road glance duration out-zone	0.5 (0.6)	0.5 (0.6)	$Q_1 = 1.5, p = .2$

Note. The values listed are frequency (percentage) for initiation location and median (mean), in seconds, for initiation time and four eye-glance measures.

initiations before the demand zone compared to during the zone, whereas the near trigger point did the opposite. Both conditions had a similar percentage of task initiations after the zone.

*Task initiation time.* Drivers tended to initiate the task later under increased driving demands (Figure 2b). The baseline condition produced the shortest initiation time (narrow,  $Q_1 = 59.4$ ,

TABLE 3: Values and Comparison for Dependent Variables Across Trigger Points

Dependent Variable	Trigger Points		Comparison
	Near	Far	
Initiation location			
Before	97 (37)	154 (59)	$F(2, 480) = 21.13, p < .001$
During	145 (55)	85 (33)	
After	22 (9)	21 (8)	
Initiation time	1.9 (5.1)	2.8 (5.1)	$Q_1 = 1.23, p = .3$
Average off-road glance duration in-zone	1.1 (1.2)	1.1 (1.2)	$Q_1 = 0.05, p = .8$
Average off-road glance duration out-zone (in seconds)	1.5 (1.6)	1.5 (1.6)	$Q_1 = 3.2, p = .1$
Average on-road glance duration in-zone	0.7 (1.3)	0.8 (1.2)	$Q_1 = 1.1, p = .3$
Average on-road glance duration out-zone	0.50 (0.6)	0.53 (0.7)	$Q_1 = 4.3, p = .04$

Note. The values listed are frequency (percentage) for initiation location and median (mean), in seconds, for initiation time and four eye-glance measures.

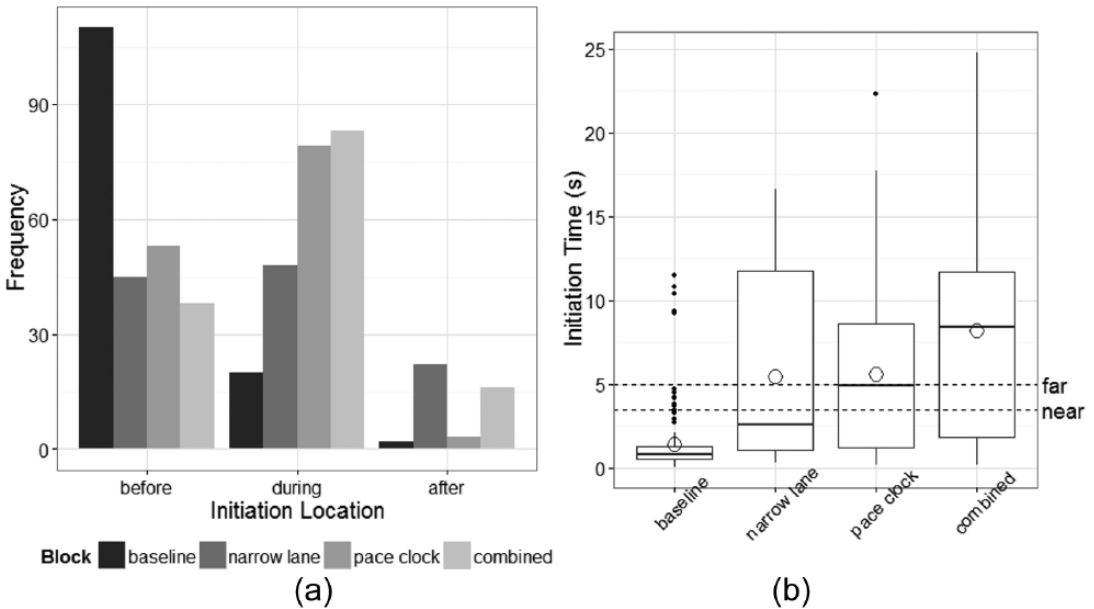


Figure 2. The comparison of (a) initiation location and (b) initiation time across driving demands. In (b), circles indicate the mean, and dashed lines indicate average time from the appearance of messages to the demand zone for the near and far trigger points.

$p < .001$ ; clock,  $Q_1 = 92.8, p < .001$ ; combined,  $Q_1 = 120.2, p < .001$ ; adjusted  $\alpha = .008$ ), the combined condition produced the longest initiation time (narrow,  $Q_1 = 16.2, p < .001$ ; clock,  $Q_1 = 25.0, p < .001$ ; adjusted  $\alpha = .008$ ), and the narrow-lane condition and pace-clock condition were in between and not significantly different

from each other. Also, we did not find a significant difference across either message formats or trigger points for task initiation time.

**Eye-Glance Behaviors**

Average off-road glance duration when drivers drove in the demand zone varied only across

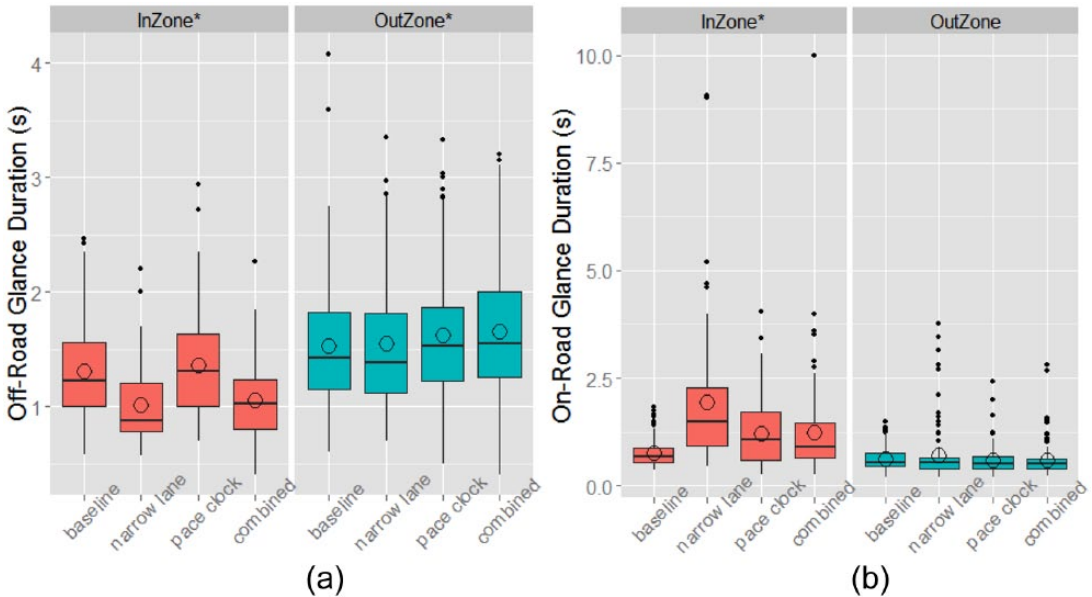


Figure 3. Box plots to compare off-road and on-road glance duration when drivers drove during (in-zone) and after (out-zone) the demand zone across driving demands. Circles indicate the mean, and asterisks indicate significant effects across driving demands.

driving demands, whereby the baseline condition and the pace-clock condition produced longer off-road glances than the narrow-lane condition and the combined condition (Figure 3). After drivers passed the demand zone, their average off-road glances increased from an average of 1.2 s (median = 1.1 s) in the zone to 1.6 s (median = 1.5 s) after the zone (Friedman's tests,  $Q_1 = 157.9$ ,  $p < .01$ ). Average duration of off-road glances after the zone was significantly different across driving demands (Figure 3) and message formats. Given the importance of especially long glances (e.g., Klauer et al., 2006), we also examined the proportion of glances exceeding 2 s in the various conditions. In general, the pattern of results was consistent with that of the average glance duration described previously.

The average duration between two consecutive off-road glances (i.e., on-road glances) when participants drove in the demand zone was also affected by driving demands (Figure 3). The narrow-lane condition produced the longest on-road glance duration, whereas the shortest on-road glance duration occurred under the baseline condition, with glances in the pace-clock condition and the combined condition falling in

between. After drivers passed the demand zone, the duration of on-road glances dropped significantly (Friedman's tests,  $Q_1 = 123.3$ ,  $p < .001$ ), from an average 1.2 s (median = 0.9 s) to 0.7 s (median = 0.5 s). Average duration of on-road glances after the zone varied only across trigger points.

We further explored the average percentage of eyes-off-road time for the different sections of the track in the experimental trials (Figure 4; a total of equidistant 20 sections from demand start to task deadline). Under the baseline condition, participants kept a high, relatively uniform, percentage of time with eyes off road during the demand zone (~50%); however, under the other three conditions, participants did not intensively work on the reading task (<20%) until they passed the halfway point or approached the end of the demand zone.

### NASA-TLX Workload Rating and Message Comprehension

The overall NASA-TLX score showed significant differences across driving demands. As expected, the combined condition obtained the highest scores, followed by the pace-clock



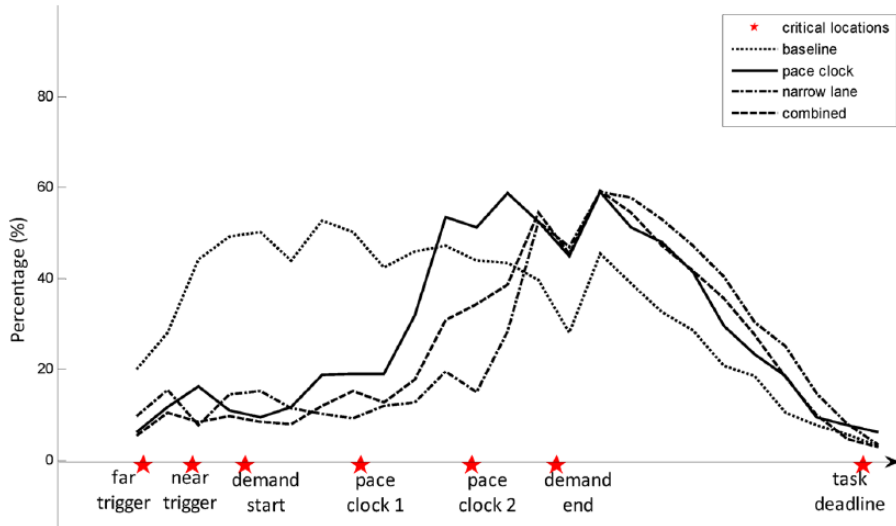


Figure 4. Percentage of eyes-off-road duration across the experimental trials.

condition, then the narrow-lane condition, and the baseline condition. Drivers did not rate in-vehicle task performance differently across driving demands, which was consistent with the actual performance on message comprehension across driving demands (average accuracy for post-trial questions on message content was 84%). Message comprehension did not differ significantly across message formats or across trigger points.

## DISCUSSION

In this study, we examined driver's adaptation to an in-vehicle reading task with known and foreseeable fluctuations in driving demands. One strength of this study is that drivers could control when to perform the secondary tasks, thus rendering task management somewhat more realistic. In most cases, drivers initiated the secondary task before they had passed the demand zone even though they would have had enough time to complete the task if they had waited. That is, drivers did not actively seek areas with relatively lower driving demands when initiating secondary tasks, which is largely consistent with Horrey and Lesch (2009). This trend was relatively consistent throughout the experiment, as we did not find significant changes in drivers' initiation strategy over time. At the same time, we found that when drivers

performed the reading task, they produced 10% more driving errors (including pace-clock violations and traffic cone strikes) than in baseline conditions, though the comparison was not statistically significant. Following Fuller's (2005) TCI model, this overall pattern could reflect an insensitivity to task difficulty or the failure to properly calibrate one's own capabilities to the current demands, which might be manifested in drivers' overconfidence in their own driving skills (e.g., Wogalter & Mayhorn, 2005) or by gaps in drivers' knowledge of their performance while distracted (Horrey, Lesch, & Garabet, 2008). Both can lead drivers to underestimate the risk of performing secondary tasks while driving and to engage in such tasks in inappropriate situations.

However, the connection between drivers' decisions and perceived risk still merits more research. Both survey and on-road studies show that drivers believe that driving with distraction is less safe and are unwilling to perform secondary activities if perceived risk is high (Lerner, Singer, & Huey, 2008; Young & Lenne, 2010). Nonetheless, this result is not consistent across all studies, especially those focusing on younger drivers. One study showed that perceived risk had little effect on younger drivers' behavior in texting while driving (Atchley, Atwood, & Boulton, 2011). Combined with findings that teen

drivers expressed confidence about their multitasking ability (Lerner et al., 2008), these results suggest that although younger drivers agree that performing secondary tasks is risky in certain situations, they feel comfortable performing the tasks because they believe that they can complete the tasks without endangerment. Atchley and colleagues (2011) also suggested that the decision to initiate a secondary task itself may change drivers' attitude to risk and make drivers think the road safer. Although involving younger drivers, rather than the current sample, these latter studies are informative in their own right and illustrate the need for additional research on different age groups in light of possible generational or cohort effects.

Drivers in the current study did not tend to postpone the in-vehicle activity until they reached a "low-demand" section; however, they made short-term adjustments when facing an upcoming increase of driving demands—drivers delayed the reading task until they entered the demand zone for both far and near trigger points, especially in the combined condition. Nonetheless, they did not delay in the baseline condition. Collectively, these results suggest that drivers avoided initiating the secondary task before an immediate transition to higher driving demands. At that moment, they might feel uncertain about the upcoming driving situation and want to react and adjust to accommodate the new demands before undertaking additional workload. It is possible that they are in the process of updating their perception of task difficulty and comparing it against their desired range of task difficulty (Fuller's [2005] TCI model). That said, Horrey and Lesch (2009) did not find any difference in patterns of in-vehicle task initiation when they explored low-to-high and high-to-low workload transitions. While variations in the driving and in-vehicle tasks employed could account for these experimental differences, more work is certainly merited on the impact of workload fluctuations and transitions on strategic decision making.

Task initiation did not vary across message formats, which is consistent with the results in Hoffman and colleagues' (2005) study—drivers are unlikely to adjust their initiation of messages according to how the message is presented

(automatic scroll vs. manual scroll in that study). Again, this outcome suggests that when initiating a secondary task, drivers may not attempt to avoid a more demanding task.

On the other hand, drivers' time-sharing behaviors reflected by off- and on-road glance duration varied across different levels of driving demands and according to their location on the track (in-zone and out-zone). Although the three levels of driving demands impacted the challenge of lateral and longitudinal control differentially, they also varied with respect to the time course of demand fluctuations and predictability of the situation. For example, the pace-clock condition represented more discrete, but less predictable (the timing when the arm would move to the green portion of the clock was random), demands, whereby drivers needed to monitor the clocks as they were approaching them and could read messages at other times. That demand therefore led to not only longer off-road glances compared to the narrow-lane or combined conditions, but similar to the baseline condition, but also longer on-road glances within the demand zone—possibly driven by long glances to the clocks upon approach (Figure 3). In contrast, the narrow-lane condition represented relatively continuous and predetermined demands because of the frequency and proximity of the traffic cones. As such, drivers needed to continuously track the locations of traffic cones and probably had less opportunity to read or were forced to read smaller portions of a message at a time compared to the baseline condition; therefore, we observed shorter in-zone off-road glances and longer in-zone on-road glances in the narrow lane condition (Figure 3).

If drivers adapted to the demands under the combined condition (with both discrete and continuous control demands) in the same manner, one might expect that the in-zone off-road glance duration would be similar to that observed under the continuous demands (i.e., narrow-lane condition), and in-zone on-road glance duration would be longer than with both the continuous and discrete demands. However, this was not the case for the latter: In-zone on-road glance duration was equivalent to that in the pace-clock condition but shorter than that under the narrow-lane condition (Figure 3). That is, when roadway

situation became more complex (the addition of two types of demands in the combined condition, corroborated by the higher overall NASA-TLX workload score), drivers did not devote more attention to the roadway than they did in cases of continuous distraction. Although drivers could be achieving more efficient processing when demands are combined in certain manners (Liang & Lee, 2010), this outcome could present a particularly dangerous tendency whereby drivers can compromise the driving task (insufficient examination of the driving environment) when driving or total demands increase. This phenomenon was also apparent in the time course for the experimental trials.

Figure 4 showed two trends of time-sharing behavior. Under the baseline condition, drivers consistently engaged themselves in the reading task after a message became available, and the intensity was approximately 50% of time spent on reading messages. Under the increased demands, drivers engaged in the reading task less frequently (intensity < 20%) at the beginning and then started to increase the intensity of the task in the middle of the demand zone, reaching the peak (averaging about 50%) before the end of the zone. The intensity in the pace-clock condition started to increase first, followed by the combined condition and then the narrow-lane condition. That the combined condition fell between the other two conditions reflects or further corroborates the notion that drivers did not adapt to driving demands in the manner in which demands were aggregated. On the other hand, the fact that the intensity of task engagement increased across time under the higher demands suggests that drivers' estimation of the risk may actually decrease as exposure increases—even though the demands/risks remain the same. Nonetheless, this projection needs to be further investigated with a longer demand zone since simply approaching the end of the zone could also influence risk estimation of drivers.

Drivers may also adjust momentary task engagement based on how secondary tasks are presented. We found that drivers tended to look at paragraph messages for longer duration than they did parsed messages after they passed the demand zone. Nonetheless, this effect was not significant while drivers were in the demand

zone, suggesting that this adjustment to the secondary task demands is moderated by driving demands. The inconsistency of the latter results with Hoffman and colleagues' (2005) study—time-sharing behavior was also affected by how text information was presented and controlled—may reflect the influences of driving environments (simulator vs. testing track) and which aspects of message format are tested. More work devoted to the study of information format and composition is certainly merited.

*Limitations.* Although we sought to create a scenario where drivers could freely choose when to perform a secondary task, the introduction of a task deadline could have impacted how drivers approached the task in two important ways. First, the constraints might have precluded the possibility of more sophisticated strategic behavior, such as the complete postponement of the reading task until the trial was over and the vehicle was stopped. Although the main focus of the current work was on the available demand levels and the transition points, we do note that other studies have offered drivers an even wider array of strategic options (including pulling over) and have shown that drivers generally do not capitalize on these opportunities (e.g., Horrey & Lesch, 2009). Second, and importantly, the task deadline could have induced the perception that drivers would not have sufficient time to complete the reading task unless they initiated it early on. Ideally, over the course of the practice, drivers would have established the different task demands and affordances of the track layout so that they would correctly perceive that the reading task could be completed within the low-demand zone. Also, participants were allowed reducing speed to accommodate the task if they felt some time constraints (e.g., in the experiment, average speed when drivers drove in the low-demand zone was 21.3 mph in the baseline condition and 19.7 mph in other three conditions). We note that in a total of 43 instances when the task was initiated in the low-demand zone, drivers were always able to complete the task before the deadline.

It is also important to note that the driving situations were fixed, and so the location of demands was generally predictable and well anticipated, which was not fully representative

of a real-world driving situation. For example, there was no ambient traffic on the track and no unexpected hazards during the experiment. Nonetheless, the design was intended to control (not to consider) additional sorts of demand fluctuations experienced in the real world. As such, our demand zones might therefore be analogous to more stable aspects of a typical drive, such as a construction zone at a fixed location for an extended duration or highway entrances and exits that a driver might encounter regularly as part of his or her daily commutes. Although the specific circumstances change with each exposure (e.g., other cars, pedestrians), drivers are likely to develop general expectations regarding the inherent demands of these locations. It follows that our current approach would not fully generalize to more transient (and therefore less predictable) aspects of driving, such as a situation in which a heavy truck pulled into a car's path. Such transient, unpredictable elements of driving—even the mere prospect of these sorts of events—certainly impact the overall demands and could also impact drivers' decisions regarding secondary task involvement. Future work should incorporate both aspects (expected and unexpected workload fluctuations) into an experimental design.

We also note that the current reading task reflects only one possible in-vehicle activity, and although drivers in our sample appeared motivated to perform the tasks well, it might not reflect those types of tasks that drivers are personally invested in or highly motivated to perform in their daily lives. A more thorough understanding of these motivational influences as well as task priorities on decisions concerning potentially distracting activities is certainly an important area for future study.

Furthermore, the definition of task initiation used in this study (i.e., the first glance to the in-vehicle system) might not necessarily represent a decision to become involved in the task. However, we stuck with this definition because the result of using the later glances (e.g., the second glances) presented a similar pattern of results as the original definition. Also, the potential for memory decay for the text information might push drivers to initiate the reading task later in a

trial so that they could maintain more information in working memory for the comprehension check after each trial. Nonetheless, this effect was apparently masked by drivers' tendency of initiating the task early. In spite of these limitations, the current study offers some unique and important data points in this domain.

To conclude, drivers do not seek a low-demands driving situation to initiate secondary tasks. Nonetheless, drivers may avoid an immediate transition from low to high demands of driving when initiating the tasks; however, they are not discouraged from such activities when demands are already elevated. Concerning time sharing, drivers adjust their attention allocation between secondary tasks and primary (driving) tasks according to the demands of driving. Nonetheless, the results suggest that this kind of adjustment is less effective when total demands are high.

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### KEY POINTS

- In a test track study, drivers' strategies with respect to the initiation of text reading and time-sharing behavior were explored when faced with fluctuating driving demands.
- Drivers do not seek a low-demands driving situation to initiate secondary tasks. Nonetheless, drivers may avoid an immediate transition from low to high demands of driving when initiating the tasks; however, they are not discouraged from such activities when demands are already elevated.
- Drivers adjust their attention allocation between secondary tasks and primary (driving) tasks according to the demands of driving. Nonetheless, the results suggest that this kind of adjustment is less effective when total demands are high.

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