ASSESSING INTERFERENCE FROM MENTAL WORKLOAD USING A NATURALISTIC SIMULATED DRIVING TASK: A PILOT STUDY

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Previous work has shown that drivers engaged in concurrent cognitive tasks exhibit some adaptive behaviors to enhance safety, such as increasing their headway distance, despite the fact that other aspects of safety might be compromised. However, these studies often test steady-state behaviors (e.g., car-following) that might not be representative of traffic situations in which drivers' goals and intentions are constantly changing (i.e., involving tactical vehicle control). In two simulator experiments, we examined the impact of mental workload on drivers engaged in a "naturalistic" tactical driving task. In Experiment 1, we explored the safety margins (distances) that drivers maintain between themselves and vehicles around them when completing a passing maneuver. In Experiment 2, we examined safety margins and performance under less constrained, yet more realistic and dynamic conditions. In both experiments, we found no evidence that drivers adjust their safety margins to account for the additional demands of performing a cognitive task. The implications for steady-state experimental scenarios versus more dynamic ones are discussed.

Concerns over driver distraction have grown in recent years, with increasing evidence for the effects of cognitive or mental distraction on driving performance (e.g., Strayer & Johnston, 2001; Recarte & Nunes, 2000; 2003). Although concurrent mental tasks typically degrade driving performance (see Horrey & Wickens, 2006), drivers can adjust their driving performance to partially compensate for cognitive impairments, thereby maintaining their safety. For example, drivers engaged in a cell phone conversation or secondary task increased their headway in a car-following situation (Ranney, Harbluk, & Noy, 2005; Strayer & Drews, 2004; Strayer, Drews & Johnston, 2003), a strategy that allows greater room to respond in an emergency (cf. Alm & Nilsson, 1994).

Despite the consensus that concurrent tasks impair driving, most studies have examined driving under scenarios that might artificially constrain driving performance. For example, many studies use car-following scenarios in which drivers try to maintain a safe headway while following a lead vehicle that may brake periodically. This task captures many aspects of steady-state car-following—maintaining vehicle headway, lane position, speed, etc. (i.e., low level, operational control; Michon, 1985)—but it might not accurately reflect the task demands for more complex driving situations because following is only one component of driving. Common driving events such as passing other vehicles (i.e., tactical control; Michon, 1985) require more than following, and more variable driving situations might be differentially affected by concurrent task interference. In passing other vehicles, drivers might systematically vary their headway depending on their intentions, and varying headway might be more (or less) cognitively demanding than maintaining a constant headway.

In two experiments, we examined the impact of mental workload on various measures of driving safety, focusing predominantly on safety margins around the driver's vehicle. In Experiment 1, drivers had to pass slower moving vehicles in the presence of fast moving vehicles in the adjacent lane. In Experiment 2, drivers were given more freedom to initiate passing maneuvers and lane changes in response to changing traffic conditions, providing a more realistic and less constrained driving context. Together, these tasks allow the assessment of driving safety in a dynamic context involving tactical control of the vehicle, and perhaps a more generalizable evaluation of the impact of concurrent cognitive load on driving performance.

Although the term "naturalistic" usually refers to on-road studies of driver behavior (e.g., Dingus, Klauer, Neale et al., 2006), here we use the term to describe traffic scenarios that approximate normal driving situations (beyond maintaining a steady-state) and involve more aspects of tactical vehicle control (vs. operational control).

EXPERIMENT 1

Methods

Participants. Sixteen drivers from the University of Illinois volunteered for this study (M = 20.8 yrs; 8 males, 8 females). The average years driving experience was 4.7 (SD = 2.0), and the average annual mileage was 11,360 km (SD = 9060). All participants had self-reported normal or corrected-to-normal visual acuity. Drivers were awarded course credit for their participation.

Materials. This study was conducted in the Beckman Institute Driving Simulator, a fixed-base simulator consisting of a 1998 Saturn SL positioned in a wrap-around environment with 135° forward and rear visual fields. Road and traffic information was visible through the interior and exterior rear-view mirrors. DriveSafety's Vection™ software (version 1.6.1) controlled the simulation.

The traffic environment consisted of a four-lane divided freeway, with two lanes in either direction. Traffic in the right-hand lane moved slower (40 mph) than traffic in the left-hand lane (70 mph). In order to control for vehicle size and the associated visual angle, all the vehicles in the simulation were 4-door sedans. Vehicle separation was 140 to 180 m (this distance was determined randomly).

Procedure. At the start of the 40-minute session, drivers completed a consent form and demographic and driver behavior questionnaires. They then were introduced to the simulator and given a few practice blocks in order to familiarize themselves with the simulator control dynamics and secondary task (described below).

For each experimental block, a cruise control mechanism maintained a speed of 55 mph, in the absence of input from the driver (e.g., braking or accelerating). The driver was instructed to stay in the right-hand lane, except to pass slower moving vehicles. Thus, drivers had to monitor traffic in both lanes in order to determine when it was safe to initiate the passing maneuver. During this maneuver, they could disengage the cruise control (either by braking or accelerating). Drivers were further instructed to return their vehicle to the right-hand lane and to allow the cruise control to re-engage once they had finished passing. Therefore, a constant approach velocity was maintained for subsequent vehicles.

There were two experimental blocks, which were counterbalanced across drivers. In one, drivers performed only the passing task (single-task). In the other (dual-task), drivers performed a concurrent mental arithmetic task while performing the passing task (e.g., Brookhuis, de Vries & de Waard, 1991); they were given a three-digit number (e.g., 967) and were instructed to count backwards by 3 at a rate of once every 2 seconds (they received an auditory prompt to help them maintain this pace).

For each block, drivers passed 20 vehicles in the slow-moving lane over a period of approximately 9 minutes. Figure 1 illustrates the primary dependent measures. In general, these distance measures reflect the amount of space that drivers maintain around their vehicle (i.e., safety margins). Larger distances mean that drivers allowed more room for error or, in the case of tailway distance, allowed more room for other drivers to respond. We used the lane marker (i.e., the lane index) to determine when drivers were initiating a lane change. We also measured headway when drivers pressed the brakes prior to the lane change to measure how close drivers came to the lead vehicle before disengaging the cruise control. (Note: the experimenter monitored performance of the secondary task during runtime to ensure that it was completed, but counting accuracy was not assessed.)

Results

We used a series of planned pairwise comparisons to examine differences between single- and dual-task conditions (Keppel, 1982). These results are shown in Table 1. Interestingly, drivers under dual-task conditions did not demonstrate increased safety margins immediately prior to or after changing lanes in order to preserve safety; for example, there was no difference in headway between single- and dual-task conditions prior to (HD_A) or after (HD_B) changing lanes. In fact, in the dual-task condition drivers were somewhat closer to the lead car before they pressed their brakes to disengage the cruise control (BD), although this difference between the dual-task and the single-task was only marginally significant.

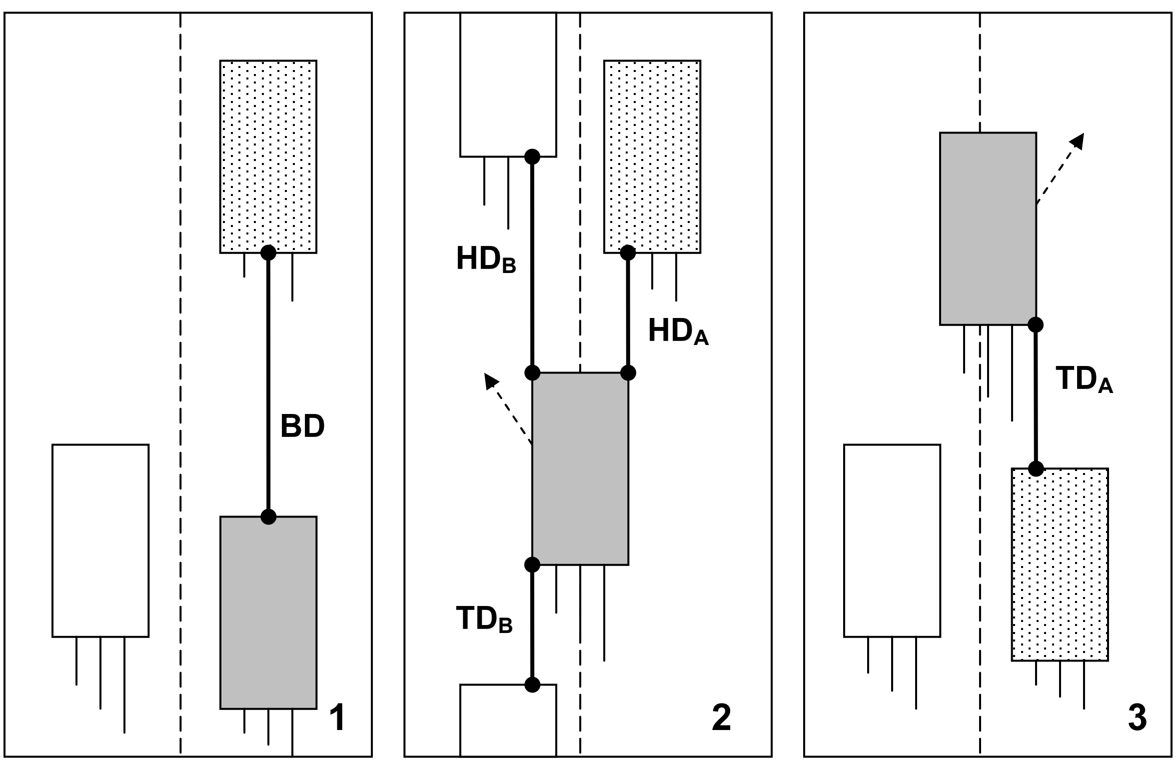

Figure 1. Summary of the primary dependent measures for the driving task. Simulator vehicle is dark in color. (1) Prior to the passing maneuver, BD = braking distance; i.e., headway distance when brakes are initially depressed. In general, this was applicable when a faster-moving vehicle prevented the driver from safely initiating the passing maneuver. (2) During the passing maneuver we assessed several safety margins: HD_A = headway distance to the vehicle being passed. HD_B = headway distance to the vehicle in the new lane. TD_B = tailway distance to the following vehicle in the new lane. (3) As the passing maneuver is being completed, TD_A = tailway distance to the passed vehicle, in the original lane.

	HD_A	HD_B	TD_A	TD_B	BD
Single-Task	25.2	26.5	39.8	76.7	42.3
Dual-Task	23.9	24.3	39.7	79.3	38.8
T statistic (df = 15)	0.7	1.4	.04	.63	1.8
p-value	.50	.19	.97	.54	.09

Table 1. Mean distance measures (in m) for the primary dependent variables across task condition. See Figure 1 for explanation of acronyms.

There were no reliable differences in tailway distances ($TD_{A,B}$), across condition (see Table 1).

Discussion

Drivers performing a passing task and concurrent mental task did not increase their safety margins (distances) with respect to other vehicles in order to compensate for cognitive impairments. These findings contradict evidence from some steady-state car-following tasks in which drivers under dual-task conditions increase their headway to maintain safety when performing a secondary task (e.g., Strayer et al., 2003; Ranney et al., 2005). With respect to braking distances, drivers might even decrease their safety margin when mentally engaged in another task, relative to single-task conditions.

As we mentioned previously, the current task arguably captures more dynamic and tactical elements of driving, including goals and intentions, than do more steady-state driving scenarios, such as car-following. Adaptive behaviors that are characteristic of one driving situation (e.g., increased headway in dual-task, car following situations) may not generalize to all types of driving situations. As such, any positive behaviors associated with mental distraction should be carefully assessed in more naturalistic driving scenarios.

Although our passing task incorporated more goal-directed aspects of naturalistic driving than do steady-state following tasks, it also was unrealistic in that the fast and slow moving vehicles were all moving at the same speeds and the other vehicles never changed lanes. This lack of traffic variability and the reliance on a cruise control mechanism might limit the generalizability of this result to more natural passing situations. In Experiment 2, we examined passing and driving safety under conditions that more closely approximate real traffic situations. In doing so, we hoped to elicit more natural (or normal) driving behaviors and to examine the effect of a dual task on driving performance under these conditions.

EXPERIMENT 2

Methods

Participants. Eighteen drivers from the University of Illinois volunteered for this study (M = 18.9 yrs; 7 males, 11 females). The average years driving experience was 3.0 (SD = 0.7), and the average annual mileage was 3375 km (SD = 3662). All participants reported normal or corrected-to-normal visual acuity. Drivers were awarded course credit for their participation.

Materials. The simulator was the same as in Experiment 1, but we did not include a cruise control mechanism. The traffic environment consisted of a six-lane divided freeway with three lanes in either direction. The posted speed limit was 55 mph (90 kph). Vehicle traffic varied in speed (64 to 122 kph, randomly determined for each vehicle) and faster vehicles spontaneously passed slower moving vehicles by changing lanes. All ambient vehicles maintained safe headways with respect to surrounding vehicles. This variability in vehicle separation and speed quickly led to naturalistic traffic congestion in which some regions had dense traffic and others had light traffic.

Procedure. At the start of the 40-minute session, drivers completed an informed consent form and various questionnaires, followed by a few practice blocks for the driving and secondary task.

Drivers completed one block of single-task driving as well as one block while performing the same counting task as in Experiment 1 (dual-task). Each block lasted approximately 8-minutes. The order of the two experimental blocks was counterbalanced across drivers.

For each block, drivers were asked to merge onto the freeway and to drive as they normally would, given the current traffic conditions. They were free to change lanes and pass vehicles as they saw fit. We purposely avoided any specific instructions, in an attempt to elicit more naturalistic driving behavior. We did, however, ask that drivers avoid excessive speeding.

We used several of the relevant measures shown in Figure 1; we also measured variability in lane-keeping performance, average velocity, the frequency of lane changes, and the frequency of braking responses. (Note: for Experiment 2, we did assess the accuracy of the secondary task, including errors and failures to respond to the prompt; however, we do not report those results here.)

Results

As for Experiment 1, we used pairwise comparisons to examine differences between single- and dual-task conditions (Keppel, 1982). The results are shown in Table 2. Overall, lane-keeping was more precise (less variability) in the dual-task condition than in the single-task driving, suggesting that drivers might have been more focused on the road ahead of them when completing the secondary task—to the benefit of performance (e.g., Brookhuis et al., 1991). In general, lane keeping performance is buffered from dual-task interference (see Horrey & Wickens, 2006 for details).

Although there were no overall differences across conditions in the frequency of lane changes or mean velocity, drivers did brake somewhat more frequently in the dual-task condition than in the single-task condition—a result that was marginally significant.

As in Experiment 1, there was no difference between the two conditions in the average headway distance when a lane

	HD_A (m)	HD_B (m)	Min. HD_A (m)	Min. HD_B (m)	TD_B (m)	VarLane (m)	Brake	Lane Chg	Spd (m/s)
Single-Task	56.6	73.6	11.8	20.3	95.1	0.39	6.6	11.1	26.6
Dual-Task	55.1	67.1	10.5	19.9	95.0	0.33	9.8	10.2	26.3
T statistic (df = 17)	0.3	2.1	0.9	0.08	0.01	5.8	1.9	0.7	0.5
p-value	.80	.05	.40	.94	.99	<.001	.07	.51	.65

Table 2. Primary dependent measures across task condition, averaged across driver. Varlane = variability in lane keeping. Spd = speed. Lane chg = number of lane changes / vehicles passed. Brake = number of times that brakes were pressed.

change was initiated (HD_A). Furthermore, there was no difference in the minimum headway distances (i.e., the shortest headway distance observed for each driver). However, on average, drivers pulled in closer behind lead vehicles in the target lane (HD_B) when performing a concurrent task than in single-task conditions. There was no difference in tailway distance across condition.

Discussion

As in Experiment 1, drivers did not adaptively modify their safety margins when engaged in a concurrent mental task. Specifically, drivers in the dual-task condition did not increase their headway while passing or changing lanes (cf. Strayer et al., 2003; Ranney et al., 2005 in a car-following task).

Furthermore, drivers were more likely to use their brakes in the dual-task condition than in the single-task condition. To the extent that increased braking reflects impairment in more gradual speed adjustments as a function of traffic, the ability to continuously monitor traffic and adjust speed as needed might be impaired under dual-task conditions. Increased variability in speed control for distracted drivers has been demonstrated elsewhere (e.g., Horrey & Wickens, 2004), suggesting that this explanation is plausible.

Thus, drivers engaged in a mentally demanding concurrent task (a) did not increase their safety margin when changing lanes, in contrast to studies that examine steady-state car-following (e.g., Strayer et al., 2003) and (b) might actually have reduced margins of safety with respect to adjacent lanes of traffic (i.e., HD_B).

GENERAL DISCUSSION

These experiments on the effects of concurrent cognitive load on driving suggest that more naturalistic, albeit simulated driving scenarios might produce a different pattern of results than more steady-state driving scenarios. Adaptive behaviors such as increasing headway in car-following under dual-task conditions might occur only in restricted, steady-state situations that do not require dynamic changes in driving goals and intentions. As such, evidence for positive behaviors associated with in-vehicle devices derived from such steady-state tasks might not generalize to more tactical driving tasks.

Dynamic, goal-directed situations, such as those employed here, pose a greater need for adaptive safety behavior because the situation changes often. Drivers must distribute attention across multiple vehicles and scene regions (e.g., rearview mirror, blind spot, lead vehicles, trailing vehicles, vehicle speeds, etc.), and a concurrent task reduces the resources available for continuous updating of speed, lane position, and headway necessary to maintain safe driving distances in varied traffic. Whereas all of the events in our scenario were somewhat predictable and gradual (e.g., passing cars typically maintained speed without braking unexpectedly), the impact of a dual task might be even greater if unexpected or sudden traffic changes required an immediate response. Future research can examine whether performing a concurrent task while driving under naturalistic conditions leads to even greater disruption of the detection and avoidance of such unexpected hazards.

Although we have attempted to create scenarios that are more naturalistic and that will elicit more normal responses from drivers, our method has several limitations. First, both studies use a simulator instead of an actual vehicle on the road. As such, they cannot be considered “naturalistic” in the traditional sense (e.g., Dingus et al., 2006). Second, in allowing drivers more freedom in the driving task, we necessarily sacrifice some control over vehicle interactions. For example, some drivers did not initiate lane changes as often as others (we note that all drivers did initiate at least *some* lane changes). In future studies, the length of the scenarios could be increased to allow for more opportunities for interaction. Despite these limitations, our studies show the importance of using goal-driven and less constrained traffic scenarios to explore driver safety and adaptive behavior when performing concurrent cognitive tasks.

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