Jun 24th, 12:00 AM

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Kidd, David G and Monk, Thomas A. The Effects of Dual-Task Interference and Response Strategy on Stop or Go Decisions to Yellow Light Changes. In: Proceedings of the Fifth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, June 22-25, 2009, Big Sky, Montana. Iowa City, IA: Public Policy Center, University of Iowa, 2009: 260-267. https://doi.org/10.17077/drivingassessment.1330

THE EFFECTS OF DUAL-TASK INTERFERENCE AND RESPONSE STRATEGY ON STOP OR GO DECISIONS TO YELLOW LIGHT CHANGES

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Summary: Distractions can interfere with driving by causing central processing bottlenecks. In addition to performance decrements, central processing delays may also impair decision-making during critical driving maneuvers such as stop or go decisions at intersections. It was hypothesized that distractions would delay the stop or go decision leading to more go responses. Participants drove 4 simulated drives and made stop or go decisions at intersections with and without a distracting task. Distractions did not result in more go responses at intersections. Additionally, dual-task interference in braking responses was found to be dependent upon participants' response strategies. Theoretical implications of response strategy on processing bottlenecks were discussed.

INTRODUCTION

Intersection crossings are associated with 45% of crashes in the United States (Subramanian & Lombardo, 2007). Distraction is one factor known to interfere with drivers' abilities to perform critical maneuvers (Alm & Nilsson, 1995; Horrey & Wickens, 2006). One theory that has been used to explain how distractions interfere with information processing is the central bottleneck model. The central bottleneck model proposes that central processes, such as decision and response selection, are limited to serial processing (see Pashler, 1998 for a review). When two tasks try to access the central processing stage at the same time, only one task gains access, and central processing of the other task is delayed. Processing delays are greatest when there is a large temporal overlap in the central processing stage between two tasks, but decreases as the tasks become separated – a phenomenon known as the psychological refractory period (PRP) effect. Recently, Levy, Pashler, and Boehr (2006) and Monk and Kidd (under review) demonstrated the PRP effect with distractions during critical driving events. These findings suggest that distractions can create a central processing bottleneck that impairs drivers' ability to process information efficiently.

Distracted drivers have been shown to respond slower (Hancock, Lesch, & Simmons, 2003), brake harder (Harbluk, Noy, Trbovich, Eizenman, 2007), and make more errors (Liu & Lee, 2005) when responding to traffic light changes. In addition to degrading performance, distractions may also influence stop or go decisions. If a distraction coincides with a yellow light change, central processing of the yellow light could be delayed. During this delay, drivers continue to move closer to the intersection and may be less likely to stop at the intersection when response selection finally occurs. The limited empirical evidence studying the effects of distractions on stop or go decisions is mixed. Cooper et al. (2003) found that distracted drivers tended to stop more often to yellow light changes than non-distracted drivers. However, Monk and Kidd (under review) found that distracted drivers were more likely to make go responses compared to non-distracted drivers.

The purpose of this study was to examine the effects of dual-task interference on stop or go responses to a yellow light change. In the current study participants completed four drives in a driving simulator where they responded to yellow light changes at varying distances from the intersection. During two of the drives, participants responded to a secondary task at the same time as a yellow light change. It was hypothesized that central processing bottlenecks in dual-task trials would lead to greater number of go responses compared to single-task trials. Additionally, significantly slower braking responses were expected in dual-task trials compared to single-task trials when drivers stopped at the intersection.

METHOD

Participants

Thirty-two undergraduate students (23 men, 9 women) were recruited from the George Mason University undergraduate subject pool and received course credit for participating. All participants had a valid driver's license and were at least 18 years of age. Participants ranged in age from 18 to 31 years (*M* = 21.1 years) and had an average of 53.9 months (*SD* = 33.5) of driving experience. Three additional participants were recruited, but withdrew from the study due to simulator sickness and were replaced.

Apparatus and Tasks

The experiment was conducted using the George Mason University driving simulator. The driving simulator was an open-cab simulator with a motion-base system that included 90-degree yaw motion to simulate turning and a single-degree of pitch motion to simulate braking and acceleration. The traffic environment was displayed across three 42-inch plasma displays with 180-degrees field-of-view. Scenarios were developed using Realtime Technologies, Inc.'s (RTI) SimVista (Version 2.24) and run with RTI's SimCreator. Participants responded to secondary tasks using the turn indicator and response buttons mounted on the left and right spokes of the force-feedback steering wheel. Data from the vehicle inputs was collected at 60 Hz.

Stop/Go Task. At some intersections, the traffic light changed from green to yellow requiring participants to make a stop or go decision. Participants were told that the traffic lights may or may not change to yellow in the scenario. If a yellow light change occurred, participants were instructed to come to a complete stop if it was safe to stop, but to go through the intersection if it was safer to do so. The duration of the yellow light was 4.5 seconds.

Pedestrian Task. At some intersections, a pedestrian appeared in the grass at the near right hand corner of the intersection. Participants responded to the pedestrian's shirt color and orientation. Participants pressed the right response button if the pedestrian was wearing a red shirt and pressed the left response button if the pedestrian was wearing a white shirt. An auditory feedback tone was sounded when either response button was depressed, but did not provide information about response accuracy. Participants responded to the pedestrian's orientation using the turn indicator. Participants activated the left turn signal when the pedestrian was facing left and activated the right turn signal when the pedestrian was facing right. Participants were instructed to make both a shirt color and orientation response as quickly and accurately as possible and could respond to shirt color and orientation in any order they desired.

Design

Two fully crossed, within-subjects factors were manipulated in this study. First, single- and dual-task intersection trials were manipulated between drives. In single-task drives, the stop/go and pedestrian tasks never occurred together and in dual-task drives the two task stimuli were presented simultaneously (i.e., stimulus onset asynchrony was 0 ms). The second factor was time to stop line (TSL). The onset of the yellow light was based upon TSL – the time it would take the participant's vehicle to reach the intersection stop line at its current velocity (e.g. Caird, Chisholm, Edwards, & Creaser, 2007). Six different TSL values were used in this study, 2.1, 2.35, 2.6, 2.85, 3.1, and 3.35 seconds.

Each participant completed four 15-minute experimental drives, 2 single-task drives and 2 dual-task drives. Single- and dual-task drive order was counterbalanced using a Latin Square design. In each drive, participants encountered 20 signalized intersections, consisting of 6 single-task pedestrian task trials and either 6 single-task stop/go task trials, or 6 dual-task stop/go task trials depending on the drive condition. The stop/go and pedestrian tasks were presented at each level of TSL and were randomly assigned across the 20 intersections for each drive.

Procedure

First, participants completed a short demographic survey and were screened for 20/20 visual acuity and normal color vision. Participants' propensity for motion sickness was also assessed. Participants were strongly encouraged not to participate if they scored as prone to motion sickness but were allowed to participate if they chose.

After screening, participants completed 1 practice drive and 4 experimental drives. All 5 driving scenarios consisted of a four-lane roadway, 2 lanes traveling in each direction, with a series of signalized intersections and gentle turns. Participants were instructed to stay in the right hand lane for the duration of the drive, to avoid making lane changes, and to proceed straight at all intersections. The speed limit was 40 miles per hour for each drive and no ambient traffic was present in any of the driving scenarios.

The first drive that participants completed was a 15-minute practice drive. The practice drive consisted of 16 intersections, 8 with the single-task pedestrian stimulus, 4 with the single-task stop/go task, and 4 dual-task trials. Once comfortable with the driving simulator and experimental tasks, participants completed the experimental drives with up to a 15-minute break between each. Between drives, participants completed a survey where they estimated their driving performance. The survey results were intended for another study and will not be discussed further. At the end of the study participants were debriefed and dismissed.

RESULTS

Stop/Go Decisions

The purpose of the current study was to examine the effects of distractions on stop or go decisions in response to yellow light changes. Stop or go responses were recorded at each yellow light change. A stop response was recorded if the driver's speed dropped below 0.1 m/s before clearing the intersection, and a go response was recorded if the driver did not attempt to bring the vehicle to a stop at the intersection. Overall, participants stopped at 53.4 % of the intersections. The rate of stop decisions also varied as a function of TSL (see Table 1). Participants were least likely to stop when the light change occurred 2.1 seconds from the stop line and were most likely to stop when the light change occurred at 3.35 seconds from the stop line. Similar to Caird, et al. (2007), the 50/50 stop or go decision point observed in this study was slightly less than 2.6 seconds to stop line.

Comparing stop responses between single- and dual-task trials, participants stopped slightly more often in dual-task trials (54.2 % stop decisions) compared to single-task trials (52.7 % stop decisions). A similar pattern was observed across each TSL condition, except for the 2.85 condition, where drivers stopped more often in dual-task trials.

Table 1. Percent of stop responses for each condition by time to stop line

Condition	Time to stop line (sec)						
	2.10	2.35	2.60	2.85	3.10	3.35	Overall
Single-task	14.5	25.4	50.8	65.1	73.0	87.1	52.7
Dual-task	16.4	30.2	52.5	57.1	78.8	87.5	54.2
Overall	15.4	27.8	51.6	61.1	76.0	87.3	53.4

Response Time

Braking and pedestrian task response time (RT) in single- and dual-task conditions was compared to look for evidence of dual-task interference. For stop trials, brake RT was calculated as the time from yellow light onset to the first depression of the brake pedal. Pedestrian RT was calculated as the time from the appearance of the pedestrian stimulus until the initiation of the first button or blinker response. Linear mixed models were used to analyze the response time data and t-values greater than or equal to 2 were considered significant at the $\alpha = .05$ level. Brake RTs and pedestrian RTs less than 200 ms and pedestrian RTs greater than 4.5 seconds were not considered in the following analyses (< 0.1% of total data).

Brake RTs were 48 ms slower in dual-task trials (M = 1000 ms, SD = 270) than single-task trials (M = 952 ms, SD = 226), however, this difference was not significant (b = 18.9, SE = 91.2, t = .2). Brake RTs, however, were affected by TSL. Brake RTs were significantly faster in the 2.1 TSL condition compared to the 2.85, 3.1, and 3.35 TSL conditions (b = 223.9, SE = 73.5, t = 3.0; b = 220.5, SE = 72.8, t = 3.0; and b = 262.7, SE = 72.1, t = 3.6, respectively). A dual-task effect was observed in the pedestrian task (b = 176.5, SE = 74.6, t = 2.4). Pedestrian task RTs were nearly 300 ms slower in dual-task trials (*M* = 1393 ms, *SD* = 648) compared to single-task trials (*M* = 1099 ms, *SD* = 372). Thus, contrary to expectations, the pedestrian task did not appear to interfere with braking responses, but braking responses appeared to interfere with pedestrian task responses.

Response Strategy

It was surprising that the pedestrian task did not interfere with braking responses considering that numerous studies have found distraction effects in braking responses (see Horrey & Wickens, 2006). After closer investigation of stop decision trials, it became apparent that participants engaged in two different dual-task response strategies. In 56% of dual-task stop trials participants responded to the stop/go task before responding to the pedestrian task, while the remaining 44% participants responded to the pedestrian task first.

According to central bottleneck theory, response strategies would dictate the locus of dual-task interference. If response selection occurred in the pedestrian task before the stop/go task, then the stop/go task would be delayed and slower brake RTs would result. If drivers responded to the stop/go task before the pedestrian task then evidence of dual-task interference would be seen in pedestrian task RTs.

Stop decision trials were grouped by response strategy, brake first and pedestrian first. Observations were collapsed across TSL since the main effect of response order was the comparison of interest and similar proportions of observations for each response strategy were observed at each level of TSL.

Response strategy had a significant influence on brake and pedestrian task RTs (see Table 2). There was no dual-task interference in brake RTs for the brake first response strategy (b = -27.1, SE = 26.5, t = 1). Braking responses in the pedestrian first strategy, however, were significantly slower than single-task braking responses (b = 238.5, SE = 36.1, t = 6.6) and braking responses in the brake first strategy (b = 265.6, SE = 39.4, t = 6.7). Pedestrian task RTs were significantly slower in dual-task trials compared to single-task trials regardless of whether a pedestrian task response (b = 123.3, SE = 26.5, t = 4.6) or braking response was made first (b = 740.3, SE = 37.6, t = 19.7). However, pedestrian RTs were significantly longer in the brake first strategy than pedestrian first strategy (b = 617, SE = 42.7, t = 14.5). As predicted by the central bottleneck model, the pedestrian first strategy interfered with central processing in the stop/go task and the brake first strategy interfered with central processing in the pedestrian task.

Table 2. Brake and pedestrian task response time by response strategy

Response Strategy	Brake RT (ms)		Pedestrian task RT (ms)	
	M	*SD*	*M*	*SD*
Dual-Task: Pedestrian First	1234	296	1175	518
Dual-Task: Brake First	953	190	1942	740
Brake Task Only	989	235	--	--
Pedestrian Task Only	--	--	1099	372

DISCUSSION

The results supported a central bottleneck account of dual-task interference in driving (e.g., Levy et al., 2006; Monk & Kidd, under review), but, unexpectedly, this effect resulted in a greater rate of stop responses. Distractions were expected to encourage more go responses at intersections, because central processing delays would cause stop or go decisions to occur closer to the intersection. Similar to Cooper at al. (2003), however, participants tended to stop more often when distracted. This is surprising considering that distractions led to more go responses in a similar experimental paradigm as the current study (Monk & Kidd, under review). A possible explanation for this discrepancy is discussed below.

Different response strategies may have affected stop or go decisions in dual-task trials differently depending on the order of central processing. For example, when participants responded to the yellow light before the pedestrian task, response selection in the stop/go task would not be delayed resulting in similar rates of stopping as single-task trials. When participants responded to the pedestrian task before the stop/go task, however, response selection would have been delayed. As a result, drivers would be closer to the intersection (shorter TSL) when response selection occurred and would be more likely to make a go response. Unfortunately, response strategy could only be determined for stop trials and not go trials, so the current study could not explore this prediction. Future studies should explore the effects of task prioritization and response strategy on stop or go decisions.

The two different response strategies provided an opportunity to observe the effects of processing bottlenecks on both braking and pedestrian task responses. Figure 1 shows the mean response time for each component of the stop/go and pedestrian tasks.

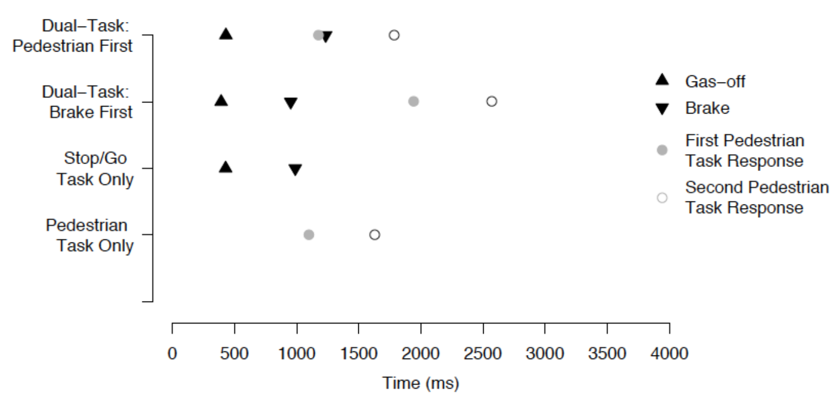

Figure 1. Average response times by response strategy

Compared to single-task trials, dual-task braking responses were 245 ms slower when participants responded to the pedestrian task first. Similarly, dual-task pedestrian task responses were 843 ms slower than single-task trials when participants made a brake response first. These findings supported the existence of a central bottleneck that affected both tasks depending on response strategy.

The effect of response strategy on braking responses has important implications for driver safety. When participants engaged in the brake first response strategy the stop/go task was protected from the performance degradation observed in the pedestrian first strategy. Furthermore, participants seemed to place a higher priority on the stop/go task since the brake first strategy occurred more often than the pedestrian first strategy. Participants may have preferred the brake first strategy to protect driving performance from the pedestrian task, which was not in direct service of the driving task (e.g., Cnossen, Meijman, & Rothengatter, 2004). High priority distractions that directly serve the driving task (e.g., destination entry) may be more likely to cause central processing bottlenecks and interfere with driving compared to distractions of lower priority. Future research should explore how task priority influences central processing bottlenecks.

In conclusion, the findings in the present study provided additional support for a central bottleneck explanation of dual-task interference in driving. Furthermore, response strategy and task prioritization seemed to play a critical role in the locus of dual-task interference and warrants attention in future research.

REFERENCES

Alm, H. & Nilsson, L. (1995). The effects of a mobile telephone task on driver behaviour in a car following situation. *Accident Analysis and Prevention, 27*, 707-715.

Caird, J. K., Chisholm, S. L., Edwards, C. J., & Creaser, J. I. (2007). The effect of yellow light onset time on older and younger drivers' perception response time (prt) and intersection behavior. *Transportation Research Part F*, *10*(5), 383-396.

Cooper, P. J., Zheng, Y., Richard, C., Vavrik, J., Heinrichs, B., & Siegmund, G. (2003). The impact of hands-free message reception/response on driving task performance. *Accident Analysis and Prevention, 35,* 23-35.

Cnossen, F., Meijman, T., & Rothengatter, T. (2004). Adaptive strategy changes as a function of task demands: a study of car drivers. *Ergonomics, 47*(2), 218-236.

Hancock, P. A., Lesch, M., & Simmons, L. (2003). The distraction effects of phone use during a crucial driving maneuver. *Accident Analysis and Prevention, 35*, 501-514.

Harbluk, J. L., Noy, Y. I., Trbovich, P. L., & Eizenman, M. (2007). An on-road assessment of cognitive distraction: Impacts on drivers’ visual behavior and braking performance. *Accident Analysis and Prevention, 39*, 372-379.

Horrey, W. J. & Wickens, C. D. (2006). Examining the impact of cell phone conversations on driving using meta-analytic techniques. *Human Factors, 48*(1), 196-205.

Liu, B. & Lee, Y. (2005). Effects of car-phone use and aggressive disposition during critical maneuvers. *Transportation Research Part F, 8*, 369-382.

Levy, J., Pashler, H., & Boer, E. (2006). Central interference in driving - is there any stopping the psychological refractory period? *Psychological Science*, *17* (3), 228-235.

Monk, C. A. & Kidd, D. G. (under review). Should I stop or should I go now? Central processing delays in yellow light stop/go decisions.

Pashler, H. (1998). *The psychology of attention*. Cambridge, MA: The MIT Press.

Subramanian, R. & Lombardo, L. (2007). *Analysis of fatal motor vehicle traffic crashes and fatalities at intersections, 1997-2004* (No. DOT HS 810 682). Washington, DC: US Department of Transportation.