Effects of Simulator Practice and Real-World Experience on Cell-Phone–Related Driver Distraction

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Objective: Our research examined the effects of practice on cell-phone–related driver distraction. **Background:** The driving literature is ambiguous as to whether practice can reduce driver distraction from concurrent cell phone conversation. **Methods:** Drivers reporting either high or low real-world cell phone usage were selected to participate in four 90-min simulated driving sessions on successive days. The research consisted of two phases: a practice phase and a novel transfer phase. **Results:** Dual-task performance deficits persisted through practice and transfer driving conditions. Moreover, groups reporting high and low real-world experience exhibited similar driving impairments when conversing on a hands-free cell phone. **Conclusions:** These data indicate that practice is unlikely to eliminate the disruptive effects of concurrent cell phone use on driving. **Application:** Multiple regulatory agencies have considered, or are currently considering, legislation to restrict in-vehicle cell phone use. Findings reported herein may be useful to inform these public policy decisions.

INTRODUCTION

Several studies have provided converging evidence that talking on a cell phone while driving increases the risk of being involved in a collision (Laberge-Nadeau et al., 2003; McEvoy, Stevenson, & McCartt, 2005; Redelmeier & Tibshirani, 1997). Furthermore, researchers have found that in-vehicle cell phone conversation impairs a number of component driving performance variables, including reaction time to braking events (Alm & Nilsson, 1995; Brookhuis, de Vries, & de Waard, 1991; Consiglio, Driscoll, & Witte, 2003; Strayer & Johnston, 2001), driver speed (Brown, Tickner, & Simmonds, 1969; Shinar, Tractinsky, & Compton, 2005), and probability of missing traffic signals (Hancock, Lesch, & Simmons, 2003; Strayer & Johnston, 2001). The current literature does not, however, adequately address whether practice in this dual-task combination can reduce or eliminate the impairment from in-vehicle cell phone use.

The few studies that have investigated the potential moderating role of cell phone and driving experience on the concurrent performance of these two tasks have used different approaches, the most straightforward of which is to assess dual-task performance between groups that differ in terms of real-world usage. In the cases in which frequency-of-usage data were gathered, it was not a significant moderator of impairment (McKnight & McKnight, 1993; Strayer, Drews, & Johnston, 2003). Although statistical power was not reported in either study, these null findings alternatively suggest that real-world experience may have no effect on cell phone and driving performance, that the learning effect may be too small to reliably detect, or that the dependent measures assessed in these investigations were insensitive to practice.

A second method for assessing the role of learning on cell phone and driving performance involves repeating driving conditions over a number of days or weeks. In the earliest driving research that used repeated experimental conditions, Brookhuis et al. (1991) had 12 participants of varying ages, who had no previous in-vehicle cell phone experience, drive an instrumented vehicle in real traffic for 1 hr each day for 15 days. Overall, heart rate variability, indicative of a decline in mental workload, and math errors on the surrogate telephoning task proved to be sensitive to practice. However, dual-task improvement was not observed on any of the driving-related variables.

By contrast, a more recent study by Shinar et al. (2005) found that 96 min of dual-task simulator-based practice, distributed over 5 days, was sufficient to eliminate driving impairment from cell

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phone use in a group of considerably more experienced drivers. Notably, dual-task learning was primarily observed on the mean and standard deviations of lane position, steering angle, and speed. Additionally, learning was greatest when driving was coupled with a math task rather than naturalistic conversation.

From these results, Shinar et al. (2005) concluded that previous driving research had likely overestimated real-world impairment by forcing the driving pace, using unnatural conversation surrogates, and failing to repeat the driving condition. Nevertheless, the fact that learning was observed only on driving measures with fairly consistent stimulus-response performance requirements suggests that the findings may not apply to less predictable aspects of driving, such as strategic vehicle control and response to sudden-onset events.

Indeed, research suggests that task structure is the primary determinant of skill learning and multitasking performance (Schneider & Shiffrin, 1977). Two tasks with nonoverlapping resource demands and consistent stimulus-response requirements elicit the least amount of dual-task interference, whereas two tasks that compete for similar resources and have inconsistent stimulus-response requirements typically show the greatest concurrence costs (Kramer, Larish, & Strayer, 1995; Wickens, 2002).

In addition, carefully controlled dual-task research suggests that even compatibly structured tasks cannot be simultaneously performed as quickly as each task in isolation, regardless of practice (Pashler, 1984; Tombu & Jolicœur, 2004). Although driving and cell phone conversation are thought to be resource compatible (Horrey & Wickens, 2003), simultaneous task performance may be limited by the irascible central processing bottleneck thought to exist in response selection (Levy, Pashler, & Boer, 2006; Pashler, 1984). However, to the extent that the consistent, and ultimately predictable, components of either the conversation or the driving task are not fully automated, additional practice with either or both of the tasks may free up processing resources, resulting in increased dual-task performance (see Norman & Bobrow, 1975).

Each of the aforementioned studies provides a piece to the puzzle of whether practice can reduce or eliminate driver impairment from concurrent cell phone use, yet the puzzle is not complete. Using similar study designs, Shinar et al. (2005) and Brookhuis et al. (1991) observed discrepant patterns of dual-task improvement, whereas the assessments of experience by McKnight and McKnight (1993) and Strayer et al. (2003) suggest that real-world usage may not moderate this dual-task interference. The purpose of this paper is to resolve these findings.

The Current Study

The current study assessed the effect of practice on concurrent driving and phone conversation using two converging methods. First, only participants who self-reported either high or low in-vehicle cell phone use were selected to participate in the research. Second, participants performed 4 days of simulator-based practice in either city or highway driving conditions and then drove in a novel city or highway transfer condition, which allowed us to assess the extent and generalizability of any improvement that may have occurred during practice.

Based on the performance requirements of both driving and naturalistic conversation, we expected to observe driving interference on the less predictable, and more demanding, aspects of driving (i.e., collisions attributable to unexpected events, brake reaction time to unpredictable lead vehicle braking, and context-dependent speed compliance). Repeating the practice scenarios, we reasoned, would reduce any initial unpredictability, and thus we expected to observe a relative decrease in dual-task driving interference. However, we expected that once participants transferred to the unfamiliar driving scenario, the inconsistent stimulus-response requirements of driving and naturalistic conversation would overtax performance and that drivers would again show dual-task impairment.

METHODS

Participants

Sixty participants were selected from a multiple-choice driving survey administered to 660 undergraduate psychology students at the University of Utah. Eligible participants reported driving more than 41 min per day while concurrently using their cell phone either less than 5% (N = 30; age M = 24.8 years, SD = 6) or greater than 41% (N = 30; age M = 21.4 years, SD = 4.7) of the time. (These cutoffs represented the upper and lower limits of available response options on the driving survey.)

Upon arrival for research evaluation, participants again completed a driving survey. During the (approximately) 3 months between initial screening and research participation, real-world cell phone use and driving reports remained stable (minutes spent driving per day: low experience mean = 56.9, high experience mean = 52.1; percentage of time conversing on a cell phone while driving: low experience mean = 6.6%, high experience mean = 50.4%). All participants had normal or corrected-to-normal visual acuity and a valid driver's license.

Stimuli and Apparatus

A PatrolSim high-fidelity fixed-base driving simulator, illustrated in Figure 1, was used in the study. The simulator incorporates proprietary vehicle dynamics and realistic traffic conditions. The dashboard instrumentation, steering wheel, and gas and brake pedals were taken from a Ford Crown Victoria® sedan with an automatic transmission.

Four unique driving scenarios were used, two from a city road database and two from a highway database. Each pair of scenarios differed in terms of direction of travel, location of braking events, and vehicle model.

Highway driving scenarios. The highway road database simulated an 18-mile multilane beltway with on- and off-ramps, overpasses, and two- and three-lane traffic in each direction. Each scenario included seven gradual turns constituting 13% of the drive, none of which required slowing to navigate. Distracter vehicles were programmed to drive somewhat faster than the pace car in the left lane or lanes, providing the impression of steady traffic flow.

Participants were instructed to follow a pace car and to maintain an approximate headway of 2 s. The pace care was programmed to travel at 105 kph (65 mph) in the right-hand lane and to brake 40 times at fixed locations. During braking, the lead vehicle decelerated at a rate of 0.34 *g* to one of four minimum speeds: 48 kph (30 mph), 56 kph (35 mph), 64 kph (40 mph), and 72 kph (45 mph). If participants applied their brakes and the proscribed speed minimum was reached by the lead vehicle, then the lead vehicle would regain speed at a rate of 0.075 *g*. If, however, the participant failed to depress the brake, the pace car would continue deceleration. In no other way was the speed of the lead vehicle dependent upon the speed of the participant vehicle. After 18 miles, the highway scenarios automatically terminated (approximately 18 min).

City driving scenarios. The city road database simulated a 2-square-mile mixed downtown and residential environment with traffic lights, stop signs, and two- and one-way roads. Directional arrows embedded in the driving environment provided instructions for navigation. The posted speed limit changed periodically among 25, 35, and 45 mph (40, 56, and 72 kph). Ten stoplights were encountered in each scenario: Five turned from green

Figure 1. A typical research participant, conversing over a hands-free cell phone while navigating a city driving scenario.

to red upon approach, three stayed green, and two were red upon approach but later turned to green if the participant came to a complete stop. Distracter vehicles were programmed to stay near the participant vehicle, but in no case did they limit the speed at which participants could proceed.

Each city scenario also contained two events that necessitated an immediate braking or steering reaction to avoid a collision. In one scenario, a woman stepped out from behind a parked bus as the participant neared the front of the bus, and later a car backed out of a driveway, stopping just before entering the street. In the other scenario, a dog ran across the road from behind a parked car and a bus merged into traffic without yielding the right of way. After two circumnavigations, the city scenarios automatically terminated (approximately 18 min).

Procedure

On the first day, participants completed a questionnaire assessing their interest in potential topics of cell phone conversation, their driving experience, and their cell phone usage estimates. They were then familiarized with the driving simulator, using a standardized 20-min adaptation sequence, after which commenced the practice portion of the research.

The research used a 2 (real world experience) × 2 (city/highway driving) × 2 (single/dual task) × 3 (day: 1, 4, transfer) mixed within- and between-subject design. Practice scenarios were run on Days 1 through 4 and began and ended with both single- and dual-task driving; Days 2 and 3 of practice consisted exclusively of dual-task driving. (A schematic of the study design is presented in Figure 2.) The two transfer scenarios began on the last half of Day 4. Scenario order and conditions were counterbalanced using a Latin-square design. This resulted in a balanced presentation of the single- and dual-task conditions for Days 1 and 4 and the transfer condition as well as an even distribution of the two city and highway scenario variants for each day.

The phone condition involved naturalistic conversation on a hands-free cell phone with a confederate (see Figure 1). Once initiated, conversation was allowed to progress and develop naturally. In the cases where natural conversation flow was not sufficient to maintain a constant back-and-forth exchange, the research confederate was instructed to generate additional dialogue from the pre-experimental questionnaire. Participants used a hands-free cell phone that was positioned and adjusted before driving began. Additionally, the call was initiated before participants began the dual-task scenarios.

Dependent Variables

Common in both city and highway scenarios were *crashes,* defined as instances in which the participant's vehicle came in contact with objects in the environment. Unique to the highway driving environment were *following distance,* defined

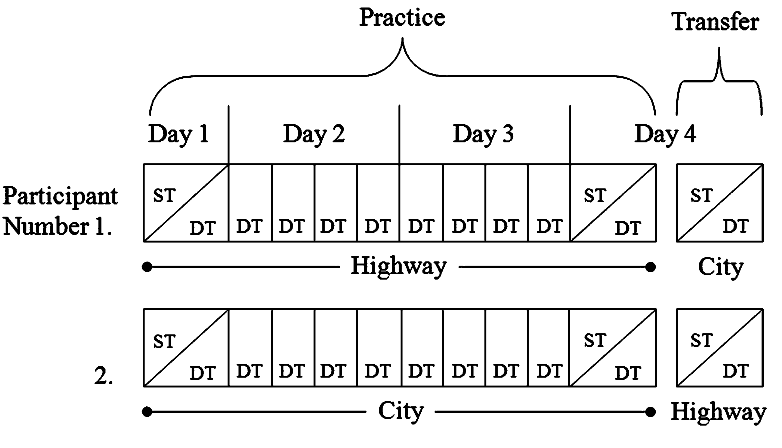

Figure 2. Schematic representation of the temporal layout for practice and transfer conditions in the experiment. Participants drove either city or highway scenarios during practice and drove the unfamiliar city or highway scenarios during the transfer condition. This arrangement provided a between-subject performance baseline to assess transferable learning and a within-subject baseline to assess learning in the repeated scenario practice. The presentation order of single-task (ST) and dual-task (DT) trials during Days 1 and 4 was counterbalanced across participants.

as the mean of following distance in meters from the rear of lead vehicle, and *brake reaction time,* defined as the mean time interval between the onset of the lead vehicle's brake lights and the first detectable brake depression by participants. Unique to the city driving environment was *speed compliance,* defined as the percentage of time that drivers were within 10% of the posted speed limit.

RESULTS

The following paragraphs assess driving performance for Days 1 and 4 of the practice scenarios as well as the transfer condition. Effect size estimates for ANOVA comparisons are given using partial η^2, for which partial $\eta^2 = .1$ is a small effect, partial $\eta^2 = .3$ is a medium effect, and partial $\eta^2 = .5$ is a large effect. Effect size estimates for the *t* test comparisons are given using Cohen's *d,* for which $d = .2$ is a small effect, $d = .5$ is a medium effect, and $d = .8$ is a large effect (Cohen, 1992). Alpha of .05 is used for all comparisons.

Real-World Experience

A MANOVA of the driving variables that proved to be the most sensitive to dual-task interference – mean reaction time, mean following distance, and speed control in the city – failed to reveal any significant effects of real-world cell phone and driving experience, $F < 1$, whereas the main effect of cell phone conversation on driving performance was highly significant, $F(3, 55) = 10.71, p < .001$, partial $\eta^2 = .507$, power = 1.0. Furthermore, univariate ANOVA comparisons of the driving variables considered in this research also failed to find any significant effect of real-world dual-task experience (all *ps* > .10). Because of the negligible impact of real-world experience on dual-task performance, the following analyses are collapsed across the high- and low-experience groups.

Analysis of Repeated Scenario Practice

Practice Day 1. On the first day of practice, drivers using the cell phone were involved in 25 collisions (20 city, 5 highway), compared with 16 collisions in single-task condition (15 city, 1 highway), and McNemar's chi-square analysis found this difference to be significant, $\chi^2(1, N = 60) = 7.12, p < .05$ (see Figure 3). Participants on the cell phone were also significantly slower to apply their brakes in response to the lead vehicle, $t(29) = 2.67, p < .01, d = .5$ (see Figure 4).

Practice Day 4. On the fourth and final day of practice, dual-task performance continued to show significant impairment from cell phone use. Drivers were involved in 12 collisions when conversing on the cell phone (8 city, 4 highway), compared with 6 collisions in the single-task condition (6 city, 0 highway); this 2:1 difference was not, however, statistically significant, $\chi^2(1, N = 60) = 2.27, p > .05$ (see Figure 3).

Consistent with performance differences on Day 1, dual-task highway variables indicated that drivers on the cell phone were significantly slower

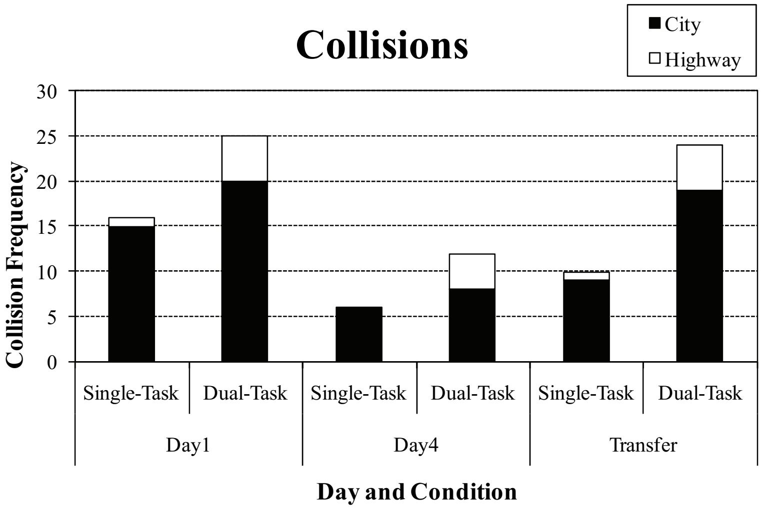

Figure 3. Crash rates for drivers in the single- and dual-task conditions for Days 1 and 4 of the practice condition as well as for the transfer condition.

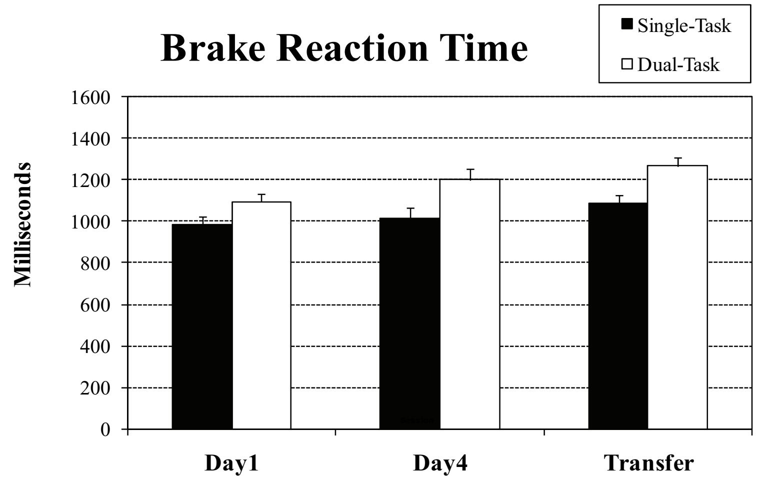

Figure 4. Brake reaction time for drivers in the single- and dual-task conditions is plotted for Practice Days 1 and 4 as well as the transfer driving condition. Error bars indicate the 95% confidence interval of the mean.

to react to the lead braking vehicle, $t(29) = 3.57$, $p < .01$, $d = .7$ (see Figure 4), and maintained a greater following distance, $t(29) = 2.19$, $p < .05$, $d = .3$ (see Figure 5). Whereas speed compliance in the city did not differ on Day 1, performance on Day 4 of practice showed that when drivers conversed on the cell phone, they were significantly less likely to comply with the posted speed limit, $t(29) = 4.41$, $p < .01$, $d = .9$ (see Figure 6). Post hoc distributional analysis indicated that drivers on the cell phone were more likely to drive below the posted speed limit in all three speed conditions.

Practice analysis. Driving variables that were sensitive to the conversation condition on Day 1 or 4 of practice were analyzed for learning effects as a function of practice. Dual-task improvement would be indicated by a reduction in interference, which did not occur for any of the driving variables except collisions. McNemar's chi-square analysis found that drivers on the cell phone were involved in fewer collisions as a result of practice, $\chi^2(1, N = 60) = 9.94$, $p < .01$ (see Figure 3). By contrast, speed compliance in the city scenarios significantly diverged with practice, $F(1, 28) = 8.58$, $p > .05$, partial $\eta^2 = .23$, power = .81 (see Figure 6), indicating that speed compliance degraded as a result of practice in the repeated scenarios.

Additional analysis found no indication of

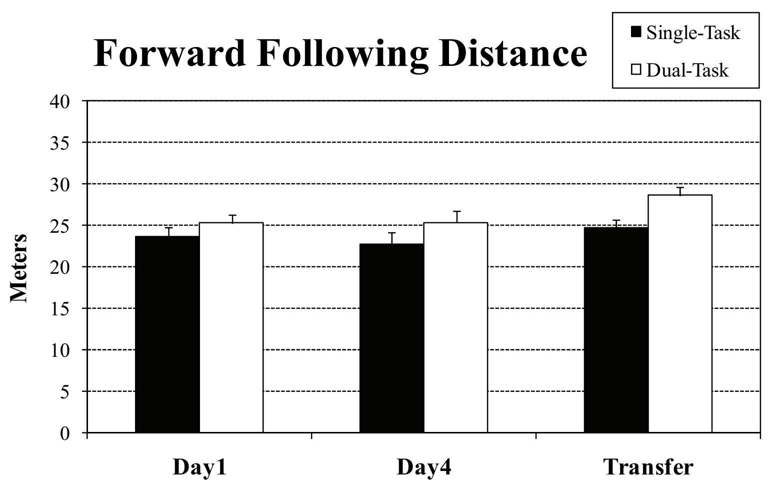

Figure 5. Following distance for drivers in the single- and dual-task conditions is plotted for Practice Days 1 and 4 as well as the transfer driving condition. Error bars indicate the 95% confidence interval of the mean.

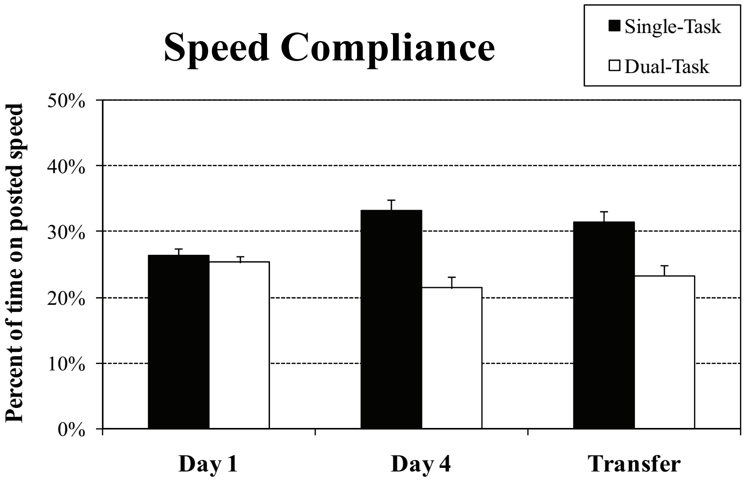

Figure 6. Speed compliance for the single- and dual-task conditions. Error bars indicate the 95% confidence interval of the mean.

improvement with practice (i.e., absence of a significant Day × Single- Versus Dual-Task interaction) in brake reaction time, $F(1, 28) = 2.54$, $p > .05$, partial $\eta^2 = .08$, power = .33 (see Figure 4), or following distance, $F < 1$ (see Figure 5).

Analysis of Transfer Performance and Transferable Learning

Transfer performance. The transfer condition assessed driver performance on the novel city or novel highway scenarios after 4 days of practice in the highway or city scenarios, respectively. This analysis assessed the degree to which any practice improvements carried over to a novel driving condition.

In the transfer condition, when drivers conversed on the cell phone, they were again more likely to be involved in a collision, $\chi^2(1, N = 60) = 6.36$, $p < .05$ (see Figure 3). Analysis of the driver performance variables also revealed that drivers on the cell phone had slower reaction times, $t(29) = 4.18$, $p < .01$, $d = .55$ (see Figure 4), followed farther behind the lead vehicle, $t(29) = 3.81$, $p < .01$, $d = .5$ (see Figure 5), and were less accurate at driving within the posted speed limit, $t(29) = 4.72$, $p < .01$, $d = .9$ (see Figure 6). Post hoc distributional analysis indicated that reductions in speed compliance for drivers on the cell phone were a result of drivers proceeding under the posted speed limit in all three speed conditions.

Analysis of transferable learning. Our final analysis examined between-subjects driving performance on the first day of practice with the final transfer condition. A 2 × 2 between-subjects MANOVA for single- and dual-task performance on Day 1 and the transfer condition examined driving variables that were sensitive to the conversation condition. As with the analyses reported previously, significant dual-task improvement would be indicated by an interaction between the conversation condition and day.

When comparing performance for drivers on the cell phone between Day 1 and the transfer condition, a chi-square analysis of collisions found that the impairment from cell phone conversation did not diminish from Day 1 through the transfer task, $\chi^2(1, N = 60) = 0.43$, $p > .05$ (see Figure 3). Unexpectedly, both reaction time, $F(1, 28) = 4.38$, $p < .05$, partial $\eta^2 = .07$, power = .54, and the standard deviation of reaction time, $F(1, 28) = 6.58$, $p < .05$, partial $\eta^2 = .10$, power = .71, increased in the transfer condition (see Figure 4).

Neither following distance, $F(1, 28) = 1.33$, $p > .05$, partial $\eta^2 = .02$, power = .20, nor standard deviation of following distance, $F < 1$, differed from Day 1 to the transfer condition on Day 4. Additionally, speed compliance did not differ by day, F < 1; however, the Day × Condition interaction was significant, F(1, 28) = 7.39, p < .05, partial $\eta^2 = .11$, power = .76, with drivers on the cell phone proceeding somewhat below the posted speed limits after practice (see Figure 6).

In sum, none of the driving variables assessed in this research indicated a significant reduction in the Day × Condition interaction, and some variables indicated a trend in the opposite direction toward a divergence between single- and dual-task performance after practice (as such, the lack of significance cannot be attributable to inadequate power). In general, effect sizes for the null findings presented in this research were very small; thus it appears that there are no reliable practice effects in this dual-task combination.

DISCUSSION

Consistent with previous driving research, results from the first day of practice indicated that drivers conversing on the cell phone responded more slowly to lead vehicle braking. By Day 4, driving performance differences were also observed on following distance and speed control. Repeated scenario exposure during the practice portion of this research resulted in little overall performance improvement for drivers using a cell phone (with the exception of collision rates), and performance on the transfer task was nearly identical to performance on Day 1. Moreover, differences in real-world cell phone use did not significantly moderate dual-task performance. This latter finding is consistent with the results from the practice and transfer analysis, suggesting that experience, whether gained in the real world or from simulator practice, may not significantly improve the ability to converse on a cell phone while driving.

Overall, our findings are consistent with the established skill acquisition literature, which indicates that the concurrent performance of two unpredictable, attention-demanding tasks will exhibit persistent impairment (Kramer et al., 1995). We hypothesized that driving in the repeated scenarios might increase task predictability and thus lead to localized improvements in performance. We also predicted that any improvement would fail to transfer to a novel condition. Consistent with these hypotheses, collision rates significantly declined during practice but reverted back to initial levels in the unfamiliar transfer condition. Collisions were the exception, however, as other driving performance measures did not converge with practice. This suggests that although participants successfully learned to avoid specific collision-eliciting events (e.g., the pedestrian repeatedly stepping out into traffic at a particular intersection), they never fully automatized the driving + cell phone dual-task combination.

Why was so little learning observed in the current study, whereas Shinar et al. (2005) reported considerably more dual-task learning using a similar task repetition? We suggest that differences in scenario structure and dependent measures can account for the disparate findings. Shinar et al. (2005) assessed the average and variance of speed (where scenario speed limits were given to participants before driving commenced), average and variance of lane position, and steering deviations in a highway driving environment that included few turns and little traffic. With the exception of speed, the current study also found these variables to be insensitive to dual-task interference. We attribute this insensitivity to the performance demands required of these driving measures, which are largely dictated by characteristics of the driver's vehicle and stable aspects of the driving environment.

By contrast, in the current study driving measures included speed adherence (where limits changed throughout scenarios), collisions, reaction time, and following distance, all of which required drivers to interact with dynamic environmental elements. Given these differences in research design, we suggest that the observed dual-task learning reported by Shinar et al. (2005) may have indicated a relearning of the nuances involved in simulated vehicle control rather than generalizable dual-task improvement. The fact that Brookhuis et al. (1991) assessed driver performance using an instrumented vehicle in real traffic and failed to find dual-task learning on measures related to vehicle control provides further support for this hypothesis.

Although practice did not result in a convergence of single- and dual-task performance on any of the driving measures, it did result in a transferable divergence in speed compliance between single- and dual-task driving. Practice also resulted in a relative increase in following distance and brake reaction time in both the single- and dual-task conditions.

One explanation for these findings is that participants may have learned to better regulate the primary task of driving in order to accommodate the added demands of the phone conversation. Nevertheless, the relative success of this compensation appears to have been limited, as collision rates in the transfer condition were nearly identical to those on Day 1. Furthermore, with the comparably vast amount of real-world experience that drivers had, it is not clear why such a strategy of compensation would develop during this brief observation period and not in the many hours of previous cell phone and driving exposure. An alternative account of these findings could be that they indicate learning associated with simulated driving or perhaps reduced inhibition associated with increased familiarity with the research procedures.

Considerations and Limitations

Although it is impossible in a simulated environment to capture all of the real-world dynamics of driving, the current study observed performance in a wide range of driving conditions. In many respects, the city and highway driving environments used in this research portrayed situations that drivers are likely to face in routine real-world driving. Nonetheless, in order to generate reliable collision data, we incorporated a higher density of immediate-response events than is typical of real-world driving. Although collision frequency in this research may have been higher than that in the real world, the observed relative increase in collisions was actually lower than estimates based upon epidemiological research (Laberge-Nadeau et al., 2003; McEvoy et al., 2005; Redelmeier & Tibshirani, 1997).

Participants in this research were exposed to 198 min of dual-task driving, which, although double the 96 min of dual-task driving used by Shinar et al. (2005), falls short of the amount of practice required to develop complex skill (Anderson, 1982). It follows that of the two experience measures considered in this research, we expected real-world usage to be a better barometer of the effects of practice. No significant impact of real-world experience was observed; nonetheless, it remains theoretically possible that additional practice could result in some limited improvement on this dual-task combination.

In addition, it is also possible that real-world practice may modify dual-task performance relationships in ways that were not measured in the current driving experiment. Nonetheless, effect size estimates of real-world experience were on the whole quite small (partial $\eta^2 < .08$). The fact that dual-task costs persisted through practice and transfer suggests that the unpredictable structure of the two tasks likely precludes the development of a cell phone + driving skill.

Additionally, it is worth considering the inclusion criteria for the real-world high- and low-experience groups. The selection process defined groups that reported equivalent general driving experience and either high or low levels of cell phone use during driving. Although self-reported driving and cell phone habits remained consistent during the 3 months prior to research participation, we have no way of gauging historic changes in usage frequency, nor can we be certain that the self-reports accurately reflected actual real-world usage.

Conclusion

This research found similar dual-task driving performance for participants with high and low real-world cell phone and driving experience. Furthermore, repeated-scenario practice yielded only modest changes in dual-task performance, which failed to transfer to the novel driving condition. Effect sizes for the null findings presented in this research were also quite small. Therefore, any generalizable effect of practice would appear to be negligible. Thus, we conclude that the dynamic nature of both driving and conversing on a cell phone precludes the possibility of practicing away the dual-task costs associated with concurrent task performance.

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