Effects of practice, age, and task demands, on interference from a phone task while driving

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Received 17 August 2004; received in revised form 29 September 2004; accepted 30 September 2004

Abstract

Experimental research on the effects of cellular phone conversations on driving indicates that the phone task interferes with many driving-related functions, especially with older drivers. Unfortunately in past research (1) the dual task conditions were not repeated in order to test for learning, (2) the ‘phone tasks’ were not representative of real conversations, and (3) most often both the driving and the phone tasks were experimenter-paced. In real driving drivers learn to time-share various tasks, they can pace their driving to accommodate the demands of a phone conversation, and they can even partially pace the phone conversation to accommodate the driving demands. The present study was designed to better simulate real driving conditions by providing a simulated driving environment with repeated experiences of driving while carrying two different hands-free ‘phone’ tasks with different proximities to real conversations. In the course of five sessions of driving and using the phone, there was a learning effect on most of the driving measures. In addition, the interference from the phone task on many of the driving tasks diminished over time as expected. Finally, the interference effects were greater when the phone task was the often-used artificial math operations task than when it was an emotionally involving conversation, when the driving demands were greater, and when the drivers were older. Thus, the deleterious effects of conversing on the phone are very real initially, but may not be as severe with continued practice at the dual task, especially for drivers who are not old.

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Keywords: Driving distraction; Cell phones and driving; Driving safety; Older drivers

1. Introduction

Innovative in-vehicle technologies increase the scope of activities that drivers can perform while driving. One ubiquitous manifestation of the new technologies is the in-vehicle cellular phone and the use of portable cellular phones while driving. As the number of people with cell phones increases, so does the number of drivers who use in-vehicle cell phones (Royal, 2003). From a cognitive, human-information-processing perspective, the use of the phone while driving constitutes a time-sharing situation in which driving is the primary task (hopefully) and talking on the phone is the secondary task. As such, the phone task can be distracting, disruptive to driving, and potentially dangerous (Goodman, 1997; Goodman et al., 1999). This general conclusion is supported by laboratory and driving simulation studies (McKnight and McKnight, 1993; Alm and Nilsson, 1993; Strayer and Johnston, 2001), closed track road studies (Ishida and Matsura, 2001; Hancock et al., 2003), and open road studies (Brown et al., 1969; Harbluk et al., 2002; Patten et al., 2004).

In the paradigm common to all the experimental studies that have been reviewed (1) both the driving and the distracting ‘phone’ task are experimenter-paced (unless driving speed is one of the measures of driving performance), and (2) the studies compare the performance of one or more control conditions (e.g., no distraction) with one or more distracting conditions (e.g., math operations) in a situation where each condition is presented only once, or for one block of trials.
However, these two features – fixed paced, experimentercontrolled tasks and one trial or block of trials in each condition – are not typical of driving in general, and of driving while performing other tasks in particular. Driving and conversing on the phone are both partially self-paced tasks. Drivers can often adjust their speed to control the rate of information input, and they can often pause in the conversation or postpone a conversation when the driving task is too demanding. In addition, as in other tasks in life, our performance improves with practice and feedback so that the more practiced a task is, the more it (or parts of it) can be automated, and consequently more attentional capacity is left for other tasks. Thus, practice at a task can enable a person to time-share it effectively with other tasks (e.g. Wickens and Hollands, 1999).

In driving, much of the experience-based improvement is based on subtle and gradual changes in information acquisition and processing (Mourant and Rockwell, 1972; Shinar et al., 1991; Ishida and Matsuura, 2001), or by reducing their speed (Ishida and Matsuura, 2001; Waugh et al., 2000). In addition to pacing or modifying the driving, drivers can also pace the phone conversation (Waugh et al., 2000).

In 1938 concerns similar to those that are raised now with respect to cell phones, were raised with respect to allowing drivers to listen to the radio while driving (Goodman, 1997). This perspective raises the issue of whether or not introducing new cognitive tasks to the driving situation necessarily impairs driving significantly, and if so under what conditions and for how long. Like other psychomotor skills, it is possible that sharing the driving task with the listening/talking phone task can be improved with practice.

The objective of this research was to see if, when the driving task is sufficiently difficult or the driver is less capable, there is a learning effect whereby drivers learn to combine the driving task with the phone task. With respect to the distraction, we used two types of tasks: a math operations task (as in many previous studies), and an emotionally involving conversation. The math operations task has been shown to be sufficiently taxing to interfere with driving performance (McKnight and McKnight, 1993; Shinar et al., 2002), but its validity as a surrogate for a phone conversation is questionable. The conversation task has the needed ecological validity but suffers from the fact that it is much less structured and – to be emotionally involving – has to be individually tailored to each subject.

2. Method

2.1. Subjects

Thirty drivers who all own cell phones and have used the phone while driving. The drivers were sampled from three age groups:

1. Ten young/novice drivers (six males, four females), all but one 18-years-old (one was 22), with less than 6 months of driving experience, all reporting ‘never’ or ‘rarely’ using the phone while driving (averaging 3/4 h per week).
2. Ten experienced drivers (eight males, two females), ages 30–33-years-old, with 8–15 years of driving experience, all reported using the phone while driving – from ‘rarely’ to ‘frequently’ (averaging 1.2 h per week).
3. Ten older drivers (seven males, three females), ages 60–71-years-old, with an average of 35 years of driving experience, all reported using the phone while driving – from ‘rarely’ to ‘frequently’ (averaging 3/4 h per week).

2.2. Equipment and measurement devices

The participants drove an STISIM fixed based simulator, installed in a cab of a passenger car. The roadway was projected on an 8 ft x 6 ft screen in front of the car, subtending a 40° horizontal visual field with 1:1 magnification ratio. The roadway consisted of a relatively straight 2-lane highway with few turns and little traffic. There were cars that occasionally came towards the subjects in the opposite lanes, and other cars that passed the subjects. However, except in the car-following task, on no occasion did the driver come up to a car proceeding at a slower speed. An ‘off road’ secondary target detection task was added to the driver’s information processing load in an otherwise easy drive. It consisted of two diamond shapes positioned on the right top and left-top corners of the screen. In a random manner, one of them would change shape from a diamond to a triangle, and would remain in that shape for 5 s. The subject’s task was to move the signal handle in the direction of the diamond that changed shape. A total of 12 signals were given on each session, with 0–3 signals on each of nine 3 min segments.

To simulate the cellular phone demands, two hands-free dual tasks consisting of listening and responding to verbal questions were used. All of the information was given through a dedicated speaker installed on the dashboard to the left of the steering wheel. Two different kinds of distracting ‘phone tasks’ were given:

1. Math operations task – the drivers were presented with a sequence of numbers and operations and asked to provide the final answer. For example: [(3 + 6 + 9 − 2 + 4) × 2 + 6]/2 = ? Answer: 23. This task was identical to the one used by McKnight and McKnight (1993). The numbers were presented at the rate of 1 per 2 s, and the subjects were allowed 5 s for their final response.
2. Emotionally involving conversation – prior to the driving, as part of the background interview, the subject was asked about his/her school, work, social habits, hobbies and interests. Based on these, a series of questions were developed to generate conversations that would be emotionally challenging. For example, if the driver was an avid sports fan of a specific team then one conversation topic would
related measures were evaluated included: related measures and phone-related measures. Performance was evaluated on the basis of driving-

2.4. Design

Each subject participated in five sessions, extending over 14 days with 1–4 days between sessions. The first session lasted close to 1 h and the others lasted slightly over 30 min. In Session 1 the subject was given a brief questionnaire, interviewed about his/her hobbies and interests, and drove the simulator without any distracting tasks for 4 min, and then for three more minutes with each of the two distracting ‘phone’ tasks. This was followed by a short break after which the experimental session began.

Each experimental session consisted of three 9 min blocks of driving – each divided further into three 3 min segments. The three segments consisted of a random order of the three levels of the distracting phone tasks: no distraction, math computations, and an emotionally involving conversation. There were no breaks between the segments within each 9 min driving block, but there was a one-minute break between driving blocks. The three blocks consisted of three ‘speed conditions’: driving while attempting to maintain a constant 50 mph, driving while attempting to maintain a constant 65 mph, and driving while following a car whose speed varied between 50 and 65 mph. The order of the phone conditions (within the blocks) and the speed conditions (between the blocks) were counterbalanced within and between subjects.

All drivers were requested to drive as closely as possible to the center of the lane. In the constant speed conditions, whenever the driver’s speed deviated from the required speed by 10 mph he/she was reminded of the required speed and asked to resume it. This actually happened very rarely, and only on the first session.

At the end of each session the subjects filled out a questionnaire relating to their perceptions of their task that day. There were seven questions, and for each question the subject had to rate his/her feelings on a scale of 1–9, with 1 indicating ‘very little’ and 9 indicating ‘very much’. The seven questions addressed the mental difficulty, the physical difficulty, the pace of work, the perceived success at the task, the level of work involved, the tension/stress involved, and the general load.

2.4. Design

The study design was a within subject repeated measures paradigm. Performance was evaluated on the basis of driving-related measures and phone-related measures.

The independent variables whose effects on driving-related measures were evaluated included:

1. Driving condition/speed: 50 mph (slow speed), 65 mph (fast speed), and car following (with lead vehicle speed varying between 55 and 65 mph).
2. Distracting phone condition: no phone task, arithmetic calculations, and emotionally involving conversation.
3. Practice: sessions 1 through 5.

The driving-related dependent measures included average speed, speed variance, average lane position, lane position variance, steering variability, crashes (including going off the road), and reaction time to distracting peripheral signals. The distraction-related dependent measure was the number of correct responses in the math operations task.

3. Results and discussion

In general we hypothesized that over the 5 days of driving and listening to the phone there would be a gradual improvement in both the driving tasks and the phone tasks. The mere driving of the simulator for 5 days should produce a practice effect. However, the critical issue is whether there is a statistical interaction between the learning effects and the phone conditions, and whether or not that interaction differs for the three different age groups. Such an interaction would be manifested in a diminishing difference in the driving performance as a function of the distracting phone condition from day 1 (with driving performance being significantly poorer with the distraction than without it), to day 5.

This general hypothesis – that the interference from the distracting task diminishes over time – is tested below on each of the driving measures and on the subjective workload experienced by the drivers. To test these effects a four-way partially repeated measures analysis of variance (ANOVA) with age (between subjects), speed, distraction, and day (within subjects) was performed on each of the dependent measures. The results describe below focus on the effects of distraction, and include some – but not all of the effects of the other variables on the different driving measures.

3.1. Effects on average speed

A distracting task should make it more difficult to maintain the desired speed, so that the requirement to perform the distracting phone task should cause drivers to lower their driving-related information processing and drive at a lower speed than required.

All of the ANOVA’s main effects on the average speed and most of the interactions were statistically significant. Actual average speed was – as expected – highest for the 65 mph condition and lowest for the 50 mph condition ($F(2, 54) = 1430.48, p < 0.001$). There was a significant learning effect ($F(4, 108) = 11.14, p < 0.001$), with speed increasing from the first day (mean = 55.1) to the last day (mean = 56.5). Older drivers drove significantly slower than the other driver
Fig. 1. The effects of day, required speed, and age on the drivers’ average speed.

The interaction between speed and day was significant \( F(8, 216) = 11.68, p < 0.001 \), reflecting a fairly constant desired speed for the 50 mph and the car following condition, and an increasing speed over the 5 days for the 65 mph condition (from 58.4 to 61.5 mph – never quite reaching the target speed). These results indicate that the 65 mph requirement was in fact more demanding than the other two lower speeds, especially for the older drivers (day, speed, and age interaction was significant \( F(16, 216) = 1.72, p < 0.05 \)). Fig. 1 illustrates the differential effects of age on speed over the 5 days of practice. It can be seen that the effects of age are restricted to the high speed conditions only.

The effects of practice in diminishing the distraction effects of the phone task are shown in Fig. 2. The significant interaction of day, speed condition, and distraction on the average speed \( F(16, 432) = 16.28, p < 0.001 \) indicates that with the lower speed (50 mph) there is no apparent learning, with a ceiling effect already on day 1 when all groups of drivers are able to maintain the required speed. In contrast, with the required high speed of 65 mph, there is a learning effect – reflected in an increase in speed over the 5 days, and a diminishing effect of the distraction on the speed: initially the math operations cause a significant reduction in speed relative to the no-distraction and the conversation (which do not differ from each other), but by the end of the 5th day the math operations have no impact on the average speed. This is also indicated by the significant four-way interaction that showed that in the 50 mph speed condition there were essentially no effects of practice, age or distraction. In the car-following mode there were also no effects of practice or age, but the average speed with no distraction was very stable at approximately 55 mph, while with the distracting task it was more variable and significantly higher. Only at the most demanding speed of 65 mph, do we see the effects of learning, distraction, and age. All groups show a learning effect under this condition, but the relationship between the learning and the distraction is different for the different age groups, as can be seen in Fig. 3. The youngest drivers do not show any deleterious effects of the distracting task. The middle-aged group initially performs better with no-distraction and conversation than with the distracting math task, but by the fifth session their performance is the same regardless of the presence or absence of distraction. The older drivers show the greatest effect of the distraction initially, but they too are able to combine the two tasks by the fifth session, though their progress is much more variable.

3.2. Effects on speed variance

A distracting task should make it more difficult for the drivers to maintain the desired speed, and consequently the variance around their mean speed should increase with
Fig. 2. The effects of distraction, practice and required speed on the drivers’ average speed.

Fig. 3. The effects of distraction, practice and age on the drivers’ average speed when required to maintain a speed of 65 mph.
increasing distraction. The main effects of age, day, and speed on speed variance were significant. Older drivers exhibited the highest variance \((F(2, 27) = 14.75, p < 0.001)\). Speed variance improved steadily with practice \((F(4, 108) = 26.97, p < 0.001)\), and was highest for the 65 mph condition \((F(2, 54) = 187.52, p < 0.001)\). The main effect of distraction on speed variance was significant \((F(2, 54) = 44.88, p < 0.001)\) with an average variance of 5.2 mph for the no-distraction condition, 4.6 mph for the conversation distraction, and 5.6 mph for the math operations distraction. Thus, the speed variance was significantly higher with distraction than in the control condition only when the phone task required math operations. The requirement to converse, inexplicably actually lowered the variance relative to the control condition. The absence of a significant interaction with age, indicated that this pattern was identical for all age groups.

The interaction of age and practice, shown in Fig. 4, was significant \((F(4, 54) = 6.03, p < 0.001)\). Older drivers had more difficulty at the task, manifesting much greater variance than the two younger groups, which did not differ from each other. Some learning is apparent for all groups, though the younger two groups’ variance nearly levels off after the second day, while the older drivers continue to improve on all days. On their last day all groups perform at about the same level.

The three-way interaction of day, age and speed was significant \((F(16, 216) = 3.31, p < 0.001)\), indicating that the difficulties that drivers had in maintaining average speed were mostly in the 65 mph condition and especially on the first day.

### 3.3. Effects on the average lane position

In the driving simulator, lane position is measured relative to the center of the road. Since the lane width was 8.33 ft, drivers who keep their car closer to the shoulder would have an average lane position greater than 4.16 ft, and those who keep it closer to the median would have an average lane position less than 4.16 ft.

All age groups maintained an average position at the right of the lane (i.e., closer to the shoulder). Still, there was a significant main effect of age on lane position \((F(2, 27) = 7.37, p < 0.01)\), with the oldest drivers being closest to the center of the lane, at an average position of 4.5 ft, the middle age drivers maintaining a position farther to the shoulder at 4.7 ft, and the youngest staying the farthest to the right at an average of 5.2 ft. There was no other significant main effect on average lane position.

The interaction of distraction with practice was highly significant \((F(8, 216) = 8.90, p < 0.001)\), as was its interaction of distraction with speed \((F(4, 108) = 12.44, p < 0.001)\), and the three way interaction with both variables \((F(16, 432) = 10.96, p < 0.001)\) that showed that the practice effect was most consistent in the car following condition, where over the 5 days the drivers steered further away from the centerline towards the shoulder.

### 3.4. Effects on the variance of lane position

The variance in lane position is an indicator of the driver’s stability in maintaining the car within the lane – independently of its average location within the lane. Thus, it was
expected that in the presence of a demanding distracting task, the variance would increase relative to the driving without distractions, and that with practice the variance would decrease.

The ANOVA yielded only one significant main effect: age \( F(2, 27) = 12.77, p < 0.001 \), with the younger drivers being much more stable than the older ones. The youngest drivers’ lane position variance was 0.9 ft, the middle age drivers’ was 1.4 ft, and the older drivers’ was 1.6 ft. All the two-way interactions between day, speed, and distraction were also significant, as was the three-way interaction between them, but they were noisy and difficult to interpret.

### 3.5. Effects on steering variability

Steering variability was measured in terms of the rate and extent of steering wheel corrections. The actual measure was the absolute value of the steering angle deviations in rad/s. As with lane position variance, the rationale behind the use of this measure, is that the greater the load on the driver the greater the extent and rate of steering corrections that the driver has to make in order to retain the desired lane position.

With the exception of one interaction, all main effects and interactions were highly significant, and most of them in the expected direction. Steering variability decreased with practice \((F(4, 108) = 4.92, p < 0.01)\), mean = 0.67, 0.65, 0.64, 0.60, and 0.60 on days 1 through 5, respectively; with speed \((F(2, 54) = 147.85, p < 0.001)\), mean steering variability = 0.70 at 65 mph, 0.66 in car following, and 0.54 at 50 mph; and with age \((F(2, 27) = 7.46, p < 0.001)\), mean steering variability = 0.70 for the older drivers, 0.57 for the middle age drivers, and 0.63 for the young drivers. The effects of distraction were the only counter-intuitive effects; with steering variability of 0.73 rad/s in the absence of distraction, and 0.58 rad/s when either distraction task was used \((F(2, 54) = 261.87, p < 0.001)\).

Fig. 5 reflects the joint effects of speed and practice on the steering wheel deviations. It clearly reflects the improvement with practice and the consistently poorer performance at the higher required speed of 65 mph, than at the lower speed of 50 mph and the car following mode. Practice and speed interacted significantly with age \((F(16, 216) = 3.04, p < 0.001)\), showing that the greatest learning effect was observed for the older drivers whose initial performance was much poorer than that of the other two groups – especially in the 65 mph condition – but by day 5 their performance was similar to that of the two younger age groups.

Distraction had a significant effect on steering wheel deviations both as a main effect and in its interactions with all of the other variables. No consistent pattern was apparent in the absence of distraction or when the distraction was limited to a conversation. However, Fig. 6 shows systematic effects of practice and age on steering wheel deviations during the math operations distraction task \((F(16, 216) = 5.98, p < 0.001)\). This may be due to the fact that doing math while driving was the most novel task for all drivers, and consequently the initial performance was the poorest. More relevant to the central hypothesis of this study, is the fact that initially the older drivers’ performance was significantly poorer than that of the two younger groups, but over time, with practice, all three groups converged so that on Day 5 their performance was essentially the same.
Fig. 7. The effects of age and practice, when required to maintain a speed of 65 mph while being distracted by math operations, on the drivers’ steering wheel deviations (in rad/s).

A detailed examination of the significant 4-way interaction \( F(32, 432) = 4.55, p < 0.001 \) among all the independent variables showed that the source of the consistent effect of the math operations was, as might have been expected, in the 65 mph condition. This is demonstrated in Fig. 7, from which it can be seen that in this most demanding combination of speed and distraction there is a very consistent and large learning process in which drivers of all ages initially start out with deviations of 1.1–1.4 rad/s, and end up with nearly zero rad/s. Furthermore, initially there is a significant age effect in this condition, where the older drivers are the poorest performers and the middle-aged ones are the best.
and eventually all groups perform the same – with close to perfect performance.

3.6. Effects on crashes

The number of crashes – including collisions and driving off the road – was very small: 45 crashes for the 450 combinations of age × day × speed × distraction. Crashes in this study are essentially extreme cases of lane deviations. With only 10 percent of the segments having crashes, it was impossible to analyze that data in a factorial design. However, a Chi Square analysis of the main effects showed a significant effect for speed only. The number of crashes was 26 for 65 mph, 14 for car following, and 5 for 50 mph (Chi square (2 d.f.) = 7.99, p = 0.01), again demonstrating the greater difficulty of driving at 65 mph than car-following at a lower speed or driving at 50 mph.

3.7. Effects on reaction time to peripheral signals

The analysis of reaction times to the peripheral signals was limited because the signals appeared randomly during each session. Since there were 12 signals in each session and nine specific combinations of speed and distraction conditions, in some of the conditions no signals appeared at all. Consequently, only main effects and two-way interactions could be analyzed.

The ANOVA’s yielded a main effect of age (F(2, 26) = 20.75, p < 0.001), indicating longer reaction times for the older drivers (2.38 s) than for the middle age (1.59 s) or younger drivers (1.26 s). Reaction times were also longer at the 65 mph speed requirement (1.90 s) than at the lower speeds (1.74 s for the car-following, and 1.59 s for the 50 mph) (F(2, 52) = 5.37, p = 0.008). The effect of practice was also significant (F(4, 64) = 4.87, p = 0.002), with reaction time generally decreasing over the 5 days (1.89, 1.65, 1.47, 1.51, and 1.32 s on days 1–5). These expected results indicate that whatever effects were observed in the driving measures they were not offset by a speed-accuracy tradeoff in which drivers compensated for the poor driving by paying more attention to the peripheral signals. Interestingly, the effect of distraction was not significant as a main effect, but was significant in its interaction with practice (F(8, 128) = 2.77, p = 0.007). On days 1, 2, and 3 reaction times in the absence of any distraction were greater than with the distraction, while on days 4 and 5 reaction times were faster without a distracting task than with it.

3.8. Effects on performance of math operations as a distraction task

It is necessary to analyze performance on the math operations task, in order to rule out any compensatory behavior in which poorer driving can be accounted for by better performance on the phone task. The best estimate of the magnitude of the effects of distraction on driving can be made when performance on the ‘loading’ distraction task remains the same throughout all conditions. To that end subjects were asked to be as accurate as possible on the math operations task under all driving conditions. Therefore, it is important to look not only at the effects of the distracting task on the driving, but also on the effects of the driving task on performance of the distracting task. There were significant effects of Day (F(4, 108) = 20.17, p < 0.001), Age (F(2, 27) = 4.58, p < 0.05),
and Speed ($F(2, 54) = 9.65, p < 0.001$), and significant interactions of practice with both driver age ($F(8, 108) = 4.88, p < 0.001$) and the required speed condition ($F(8, 216) = 2.05, p < 0.05$).

The effects of practice and age are illustrated in Fig. 8. In addition to the main effect of practice for all age groups, the learning gradient is much greater for the young novice drivers than for the older and middle-aged drivers (which do not differ significantly from each other). The differences between the young drivers and the drivers belonging to the older groups persist only for the first 2 days, after which they are not statistically significantly different from each other. Taken together, the joint improvement in both the driving and the distracting tasks suggests that if performance on the distracting tasks were held constant, the amount of learning observed on the driving task would have been greater. No tradeoffs – in which performance improves on one of the tasks but deteriorates on the other – were observed between the driving tasks and the math operations task that would complicate the understanding of the results of the driving tasks.

3.9. Effects of practice on the subjective estimates of workload and task difficulty

As expected, the subjective evaluation of the workload and related measures decreased significantly over time. Since the estimates were made at the end of each day, they did not distinguish among the speed conditions and the levels of distraction. Separate ANOVAs on each measure shown in Fig. 9 yielded a significant ($p < 0.001$) practice effect for each of the 6 measures of workload.

4. Summary and conclusions

The multivariate results presented above are summarized in Table 1. They portray a more complex, and perhaps more optimistic, picture of the effects of using mobile phones while driving. Clearly, the deleterious effects of new in-vehicle technologies are there initially, but they may decrease considerably with practice. As demonstrated here, the magnitude of the effects also depends on the demands of the driving task, the demands of the conversation, and the driver’s cognitive abilities. Despite the complexity of the results, the following general conclusions can be made:

1. There is a learning process that occurs for both the driving task and the distraction task. Over the course of five sessions there was an improvement in the performance of most of the driving measures and in the math distraction task. In parallel, the subjectively evaluated workload decreased in a fairly monotonic manner.
2. Performance, in general, is poorest for the older drivers. The performance of the other two groups was similar, with a slight advantage to the middle age group over the young group.
3. Performance on the driving task is significantly affected by the required speed, being generally poorer when required to drive at the more demanding 65 mph than when required to drive at 50 mph or follow another vehicle (also at speeds less than 65 mph).
4. Of the two phone distracting tasks used, the math operations – that has been extensively used in previous research to demonstrate the harmful effects of cell phone
use in driving – is a much more difficult task, as reflected in the poorer performance on the driving measures. An emotionally involving conversation is much less disruptive to driving than math operations, and in the case of many driving measures, it appears to be non-disruptive at all (relative to the no distraction condition).

5. The significant interaction of the above conditions shows that the effects of the distracting task on driving are greatest when the distracting task is difficult (math operations), the driving demands are high (65 mph), the driver has no experience in performing the dual tasks (day 1), and the drivers are old (60–71 years-old).

6. In accordance with the main hypothesis of this study, where learning is observed, practice diminishes or completely eliminates the differences in the performance on the driving task, between the no-distraction condition and the two phone distraction conditions.

The data patterns also exhibited significant variance, and this may be explained by at least three factors: (i) the use of multiple dependent measures that allowed drivers to assume different strategic responses to the information overload, (ii) the individual differences in information processing capacities among drivers within each age group, and (iii) the possible onset of boredom with a driving task that is repeated for 5 days, and the likelihood that such effect would start at different times for different drivers.

Yet, despite these limitations, three relatively consistent findings that are critical to the validity of the study were apparent:

1. The three required speed conditions were effective at differentiating the difficulty of the driving task. Performance on most measures was poorest when the drivers were required to maintain a constant speed of 65 mph, and best when the drivers were required to maintain a constant speed of 50 mph.

2. The difficult phone task (math operations) did provide a significant distraction, as manifested in poorer performance on most of the driving measures. Performance was generally best without distraction and worst with the distracting math operations.

3. Older drivers performed, in general, worse than the two groups of younger drivers, and experienced young drivers performed better than novice young drivers.

The results are also consistent with most of the previous research on the effects of distraction, since they clearly show a highly significant main effect of distraction on several of the driving measures (average speed, speed variance, and steering wheel deviations) and a marginally significant effect on the others (lane position and lane position variance). However these results go far beyond the simplistic conclusion that a phone task can impair driving, by showing that these effects can diminish over time and may be less for a more ecologically valid task such as a conversation than for a demanding artificial task such as an experimenter paced math operations. The results of this study also demonstrated another phenomenon that is consistent with the active nature of the driving task: that drivers can and sometimes do adjust their behavior to compensate for information overload. In the present study this was apparent in the driving speed, especially in the high-speed requirement. In the 50 mph and in the car-following condition the demands were not that high, so drivers achieved the desired speed already on

| Table 1 Summary of the effects of practice and distraction on driving performance and other measures |
| Performance measure | Learning/practice effect | Distraction effect | Practice vs distraction interaction | Age related interactions |
| Average speed | Increases for 65 mph requirement | Significant for all age groups but mostly in the 65 mph condition | Effect greatest in the math task at 65 mph, esp. for the older drivers | Most difficult and greatest learning effects for older drivers |
| Speed variance | Decreases, esp. for older drivers and at 65 mph | Possibly but only for math operations | Not consistent, but less on Day 5 than Day 1 | Most difficult and greatest learning at 65 mph, esp. for older drivers |
| Average lane position | In car-following, and 65 mph, older and middle age drivers move closer to shoulder | No significant effect | Significant but inconsistent, since effect of distraction is very small | Oldest drivers closest to center of lane. Youngest closest to shoulder |
| Variance in lane position | None | None as main effect | Significant, consistent reduction with math task at 65 mph | Variance increased with age |
| Steering deviations | Decreased | Greater without distraction than with it | Significant for Math operations but not for emotionally involving conversation | Greatest reduction for older drivers, at end all ages are the same |
| RT to peripheral signals | RT decreases with practice | None | Significant but not systematic RT longer for older drivers | Insufficient data |
| Crashes | Insufficient data | Insufficient data | Older drivers initially better than young drivers and have less room to improve |
| Math operations | Errors decreased, especially for young drivers, and at 65 mph | Not relevant | Not relevant | Not relevant |
| Subjective workload | Decreased on all measures | Not relevant | Not relevant | No age-based differences |
the first session and maintained it throughout the 5 days. In contrast, in the 65 mph condition, there was a typical logarithmic learning curve, and even on the last day the drivers still drove below the desired 65 mph.

Much more research is needed to clarify the conditions under which driving is most susceptible to interference from the use of cell phones. Additional and perhaps finer manipulations of driving conditions (e.g., urban streets versus highways, day versus night, congested versus light traffic) and conversation types may indicate the limitations of practice and automated behavior in preventing or diminishing cell phone distractions. Also, field (as opposed to simulator) studies are required for the validation of our findings. It would also be useful to develop scales of difficulty of driving under different conditions and scales of difficulty of various ‘phone’ tasks. Such scales may facilitate better standards for experimental tasks and should help in creating common ground for future studies, discussions, and decision making not only concerning the use of cell phones but regarding many other innovative in-vehicle information technologies (such as navigation and obstacle detection systems) that are rapidly being introduced without sufficient concern or knowledge of road users safety implications.

Finally, our findings do not imply that hands-free phone conversation during driving is a risk-free activity. The argument that the need to allocate attention resources to the secondary (phone) task can, under certain circumstances, hamper performance in a primary (driving) task is theoretically sound, empirically supported, and intuitively appealing. The range of circumstances examined in this study was quite limited, so generalizations should be made cautiously. Still, one clear implication of this study seems to be that previous research has overestimated the hazards of in-vehicle cell phones by not accounting for three factors: (1) the one-session procedure used in previous research that ignores performance improvement with practice; (2) the method of experimenter-based pacing that ignores the availability of compensation mechanisms employed by drivers to balance driving and conversation demands; and (3) the use of some surrogate distracting tasks (e.g., math operations) that may not be appropriate for simulating conversations. We believe that the diminished hazards associated with phone conversation that were found in this study can be attributed, to a large extent, to the use of more ecologically valid methods and tasks.

Acknowledgements

This study was supported in part by NHTSA, US Department of Transportation contract to the lead author, and in part by the Paul Ivanier Center for Robotics and Production Management.

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