Research Article

DRIVEN TO DISTRACTION: Dual-Task Studies of Simulated Driving and Conversing on a Cellular Telephone

David L. Strayer and William A. Johnston
University of Utah

Abstract—*Dual-task studies assessed the effects of cellular-phone conversations on performance of a simulated driving task. Performance was not disrupted by listening to radio broadcasts or listening to a book on tape. Nor was it disrupted by a continuous shadowing task using a handheld phone, ruling out, in this case, dual-task interpretations associated with holding the phone, listening, or speaking. However, significant interference was observed in a word-generation variant of the shadowing task, and this deficit increased with the difficulty of driving. Moreover, unconstrained conversations using either a handheld or a hands-free cell phone resulted in a twofold increase in the failure to detect simulated traffic signals and slower reactions to those signals that were detected. We suggest that cellular-phone use disrupts performance by diverting attention to an engaging cognitive context other than the one immediately associated with driving.*

The use of cellular telephones has skyrocketed in recent years, with 116 million subscribers in the United States as of June 1, 2001 (Cellular Telecommunications Industry Association, 2001). This increase in cell-phone users has been accompanied by an increase in the number of individuals concurrently driving and talking on the cell phone. For example, recent surveys indicate that 85% of cell-phone owners use their phone at least occasionally while driving, and 27% report using their phones on half of their trips (Goodman, Bents, et al., 1999; Goodman, Tijerina, Bents, & Wierwille, 1999). The precise effects of cell-phone use on public safety are unknown; however, driver inattention and other human error have been linked to as much as 50% of the motor-vehicle accidents on U.S. highways (U.S. Department of Transportation, 1998). Because of the possible increase in risks associated with the use of cell phones while driving, several legislative efforts have been made to restrict cell-phone use on the road. In fact, the use of cellular phones while driving is currently restricted in at least nine countries (Goodman, Bents, et. al., 1999; Goodman, Tijerina, et al., 1999). In most cases, the legislation regarding cell phones and driving makes the tacit assumption that the source of any interference from cell-phone use is due to peripheral factors such as dialing and holding the phone while conversing. Among other things, this report evaluates the validity of this assumption.

One source of evidence concerning the association between cell-phone use and motor-vehicle accidents comes from a report by Redelmeier and Tibshirani (1997). In this study, the cellular-phone records of 699 individuals involved in motor-vehicle accidents were evaluated. It was found that 24% of these individuals were using their cell phone within the 10-min period preceding the accident. The authors claimed that cell-phone use was associated with a fourfold increase in the likelihood of getting into an accident, and that this increased risk was comparable to that found for driving with a blood alcohol level above the legal limit. In addition, these authors found no reliable safety advantages for those individuals who used a hands-free cellular device. The authors concluded that the interference associated with cell-phone use was due to attentional factors rather than to peripheral factors such as holding the phone.

The field studies of Redelmeier and Tibshirani (1997) establish a correlation between cell-phone use and motor-vehicle accidents, but they do not necessarily imply that use of cell phones causes an increase in accident rates. There may be self-selection factors creating an association between cell-phone use and accidents. For example, people who drive and use their cell phone may be more likely to engage in risky behavior, and this increase in risk taking may underlie the correlation. Similarly, being in a highly emotional state may increase one's likelihood of driving erratically and may also increase one's likelihood of talking on the cell phone. In order to assess the possible causal relationship between cell-phone use and automobile accidents, carefully controlled experiments, such as the ones described in this report, are needed.

Prior research has established that the manual manipulation of equipment (e.g., dialing the phone, answering the phone, adjusting the radio) has a negative impact on driving (e.g., Briem & Hedman, 1995; Brookhuis, De Vries, & De Waard, 1991). However, the effects of a phone conversation itself on driving are not as well understood, despite the fact that the duration of a typical phone conversation may be up to two orders of magnitude greater than the time required to dial or answer the phone (Goodman, Bents, et al., 1999; Goodman, Tijerina, et al., 1999). Briem and Hedman (1995) found that simple phone conversations did not adversely affect the ability to maintain road position. However, several studies using cell phones have found that working memory tasks (Alm & Nilsson, 1995; Briem & Hedman, 1995), mental arithmetic tasks (McKnight & McKnight, 1993), and reasoning tasks (Brown, Tickner, & Simmonds, 1969) disrupt simulated-driving performance. Although these earlier studies provide an important piece of the puzzle, the nature of many of these phone tasks differs considerably from the typical cell-phone conversation.[1]

In the current research, we focused on the cell-phone conversation, because it comprises the bulk of the time engaged in this dual-task pairing. We sought to determine the extent to which cell-phone conversations might interfere with driving and, if they do interfere with driving, to determine the precise nature of the interference. In particular, the *peripheral-interference* hypothesis, tacitly endorsed by the majority of legislative initiatives on the topic, attributes any interference from cell phones to peripheral factors such as holding the phone while

Address correspondence to David Strayer, Department of Psychology, 380 S. 1530 E., Room 502, University of Utah, Salt Lake City, UT 84112-0251; e-mail: strayer@psych.utah.edu.

1. Interestingly, Radeborg, Briem, and Hedman (1999) provided evidence that suggests driving is also likely to disrupt the cell-phone conversation, implying that the dual-task interference is bi-directional.

conversing. By contrast, the *attentional* hypothesis attributes any interference to the diversion of attention from driving to the phone conversation itself.

EXPERIMENT 1

Our first study was designed to contrast the effects of handheld and hands-free cell-phone conversations on a simulated-driving task (viz., pursuit tracking). We also included a control group who listened to the radio while performing the simulated-driving task. As participants performed the simulated-driving task, occasional red and green lights flashed on the computer display. If participants saw a green light, they were instructed to continue. However, if a red light was presented, they were to make a braking response as quickly as possible. The red-light/green-light manipulation was included to determine how quickly participants could react to the red light, as well as to determine the probability of failing to detect these simulated traffic signals, under the assumption that slowed reaction time to traffic signals and failure to notice them would contribute significantly to any increase in the risks associated with driving and using a cell phone.

Method

Participants

Forty-eight undergraduates (24 male, 24 female) from the University of Utah participated in the experiment. They ranged in age from 18 to 30, with an average age of 21.3. All had normal or corrected-to-normal vision and received a perfect score on the Ishihara color blindness test (Ishihara, 1993). Participants were randomly assigned to the three groups: radio control, handheld phone, and hands-free phone.

Stimuli and apparatus

Participants performed a pursuit tracking task in which they used a joystick to maneuver the cursor on a computer display to keep it aligned as closely as possible to a moving target. The target position was updated every 33 ms and was determined by the sum of three sine waves (0.07 Hz, 0.15 Hz, and 0.23 Hz). The target movement was smooth and continuous, yet essentially unpredictable. At intervals ranging from 10 to 20 s ($M = 15$ s), the target flashed red or green, and participants were instructed to press a "brake button" located in the thumb position on top of the joystick as rapidly as possible when they detected the red light. Red and green lights were equiprobable and were presented in an unpredictable order.

Procedure

The study consisted of three phases. The first phase was a warm-up interval that lasted 7 min and was used to acquaint participants with the tracking task. The second phase was the single-task portion of the study and comprised the 7.5-min segments immediately preceding and immediately following the dual-task portion of the study. During the single-task phase, participants performed the tracking task by itself. The third phase was the dual-task portion of the study, lasting 15 min. The dual-task condition required the participants to engage in a conversation with a confederate (or listen to a radio broadcast of their choosing) while concurrently performing the tracking task.

Participants in the phone-conversation groups were asked to discuss either the then-ongoing Clinton presidential impeachment or the Salt Lake City Olympic Committee bribery scandal (conversations were counterbalanced across participants). The confederate was seated in a different room than the participant and did not know whether the participant was using a handheld or hands-free phone. The confederate's task was to facilitate the conversation and also to ensure that the participant listened and spoke in approximately equal proportions during the dual-task phase. Throughout the phone conversation, the computer recorded when the participant was talking and when the participant was listening to the confederate. Participants in the radio control group listened to a radio broadcast of their choosing during the dual-task portion of the experiment.

Results and Discussion

Figure 1a presents the probability of missing simulated traffic signals. Overall, miss rates were low; however, the probability of a miss more than doubled when participants were engaged in conversations on the cell phone. In the figure, the data for the two cell-phone groups (hands-free and handheld) are collapsed because a preliminary analysis indicated that there were no reliable differences between these groups, $F(1, 30) = 0.06$, $p > .80$. A one-way analysis of variance

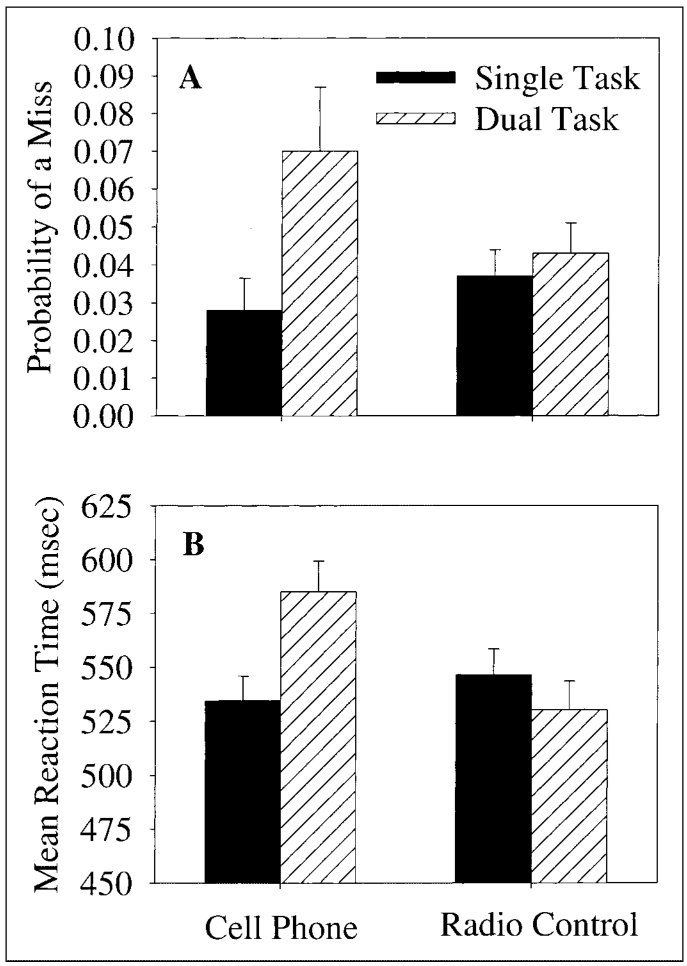

Fig. 1. Probability of missing the simulated traffic signals (a) and mean reaction time to the simulated traffic signals (b) in single- and dual-task conditions in Experiment 1.

(ANOVA) indicated that the probability of missing red lights increased from single- to dual-task conditions for the combined cell-phone group, $F(1, 30) = 8.8$, $p < .01$. By contrast, the difference between single- and dual-task conditions was not reliable for the radio control group, $F(1, 15) = 0.64$, $p > .44$.

The reaction time to the simulated traffic signals is presented in Figure 1b. As with the miss data, the data for the two cell-phone groups (handheld and hands-free) were collapsed because preliminary analyses indicated that there were no reliable differences between these groups, $F(1, 30) = 0.01$, $p > .90$. A one-way ANOVA revealed that participants in the combined cell-phone group responded more slowly in the dual-task condition than in the single-task condition, $F(1, 30) = 28.9$, $p < .01$. A subsidiary analysis of this combined group found that the disruptive effects of the phone conversation were greater when participants were talking than when they were listening to the confederate, although both dual-task deficits were reliable, $F(2, 60) = 19.8$, $p < .01$.[2] There again was no indication of a dual-task decrement for the radio control group. Indeed, there was a tendency for reaction time to decrease in the dual-task condition for this group, $F(1, 15) = 3.2$, $p > .09$.

These data are important because they demonstrate that the phone conversation itself resulted in significant slowing in response to simulated traffic signals, as well as an increase in the probability of missing these signals. Moreover, the fact that handheld and hands-free cell phones resulted in equivalent dual-task deficits indicates that the interference was not due to peripheral factors such as holding the phone while conversing. These data are also consistent with the studies reporting no reliable performance differences between participants using handheld and hands-free cell phones (Redelmeier & Tibshirani, 1997).

Additional Control Condition

There were no dual-task decrements associated with listening to radio broadcasts in Experiment 1. Although this control condition mimicked real-world situations, the broadcasts involved a mixture of music and speech, and we did not assess how well participants attended to this material. Therefore, we ran an additional control condition in which participants listened to a selected passage from a book on tape during the dual-task portion of the study. Participants were informed that at the completion of the study they would be asked a series of questions about the book on tape. Only participants who received scores of at least 90% on this posttest were included in the subsequent analyses. Thus, the book-on-tape control condition was specifically designed to ensure that participants attended to the verbal material in the dual-task portion of the study.

Method

Twenty undergraduates (10 male and 10 female) from the University of Utah participated. They ranged in age from 18 to 30, with a mean age of 20.8. All had normal or corrected-to-normal vision and received a perfect score on the Ishihara color blindness test (Ishihara, 1993).

The procedure was identical to that used for the radio control condition, with the exception that participants listened to selected portions from a book on tape (Brokaw, 1998) during the dual-task phase of the experiment. At the end of the study, participants completed a 10-item multiple-choice questionnaire to assess the degree to which they had attended to the verbal material from the book on tape. Four participants who failed to score at least 90% on the posttest were omitted from subsequent analyses, resulting in a sample of 16 participants who clearly attended to the book on tape.

Results and discussion

Results were similar to those for the radio control condition: There was no difference between the single- and dual-task conditions either in the rate of missing simulated traffic signals (.017 vs. .026, respectively), $F(1, 15) = 0.77$, $p > .39$, or in the reaction time to these signals (541 ms vs. 537 ms, respectively), $F(1, 15) = 0.12$, $p > .73$. Thus, listening to a book on tape did not result in significant impairment on the simulated-driving task. These findings are important because they rule out interpretations that attribute the dual-task deficits associated with a cell-phone conversation to simply attending to verbal material. Active engagement in the cell-phone conversation appears to be necessary to produce the dual-task interference observed in Experiment 1.

Subsidiary analyses were also performed on the dual-task/single-task difference scores for the cell-phone and control groups. In these analyses, the radio and book-on-tape control groups were combined, because preliminary analyses revealed that these groups did not differ significantly from each other (all ps $> .30$). Indeed, the planned comparisons reported earlier indicated that neither control group exhibited reliable dual-task decrements. The aggregated data were analyzed using a 2 (group: cell phone vs. control) $\times$ 2 (task: single vs. dual) split-plot ANOVA. Analysis of the difference scores revealed that the increase in miss rates from single- to dual-task conditions was greater for the cell-phone group than for the control group, $F(1, 62) = 4.97$, $p < .05$, and that the increase in reaction time from single- to dual-task conditions was greater for the cell-phone group than for the control group, $F(1, 62) = 29.9$, $p < .01$. Finally, an analysis of covariance indicated that neither gender nor age contributed to the group differences reported in this experiment (all ps $> .30$).

EXPERIMENT 2

In our second study, we attempted to more specifically localize the source of cell-phone interference on driving. Participants performed the simulated-driving task on both an easy, predictable course and a difficult, unpredictable course. After a warm-up phase acquainting participants with the simulator, they performed each course in single-task mode as well as in two dual-task conditions involving the use of a cell phone. One of the dual-task conditions was a shadowing task in which the participants performed the simulated-driving task while they repeated words that the experimenter read to them over a handheld cell phone. Thus, the shadowing dual-task condition assessed the contribution of holding the phone, listening, and speaking to the dual-task performance deficits. The other dual-task condition was a word-generation task that was identical to the shadowing task with the exception that the participant was required to generate a new word that began with the last letter of the word read by the experimenter. For example, if the experimenter read the word “molar,” the participant was

2. Miss rates were also greater when participants were speaking than when they were listening; however, this trend was not reliable.

required to generate a word that began with the letter *r* (e.g., "robot"). Note that the only difference between the two dual-task conditions was the attentional demands imposed by the word-generation process. In this study, we measured the deviations from the ideal tracking position under the assumption that deviations in tracking would contribute significantly to any increase in the risks associated with driving while using a cell phone.

Method

Participants

Twenty-four undergraduates (12 male and 12 female) from the University of Utah participated in the experiment. They ranged in age from 18 to 26, with an average age of 20.5. All had normal or corrected-to-normal vision and received a perfect score on the Ishihara color blindness test (Ishihara, 1993).

Stimuli and apparatus

In the easy course, the position of the target was determined by a 0.035-Hz sine wave. In the difficult course, the target position was determined using the same algorithm as in Experiment 1; however, the red-light/green-light manipulation from the first study was not included in this variant of the tracking task, because we found that responding to the simulated traffic signals added substantial noise to the tracking data.

Procedure

Participants performed a pursuit tracking task similar to that used in the first study. The easy and difficult conditions were blocked in counterbalanced order, and the order of single- and dual-task conditions was counterbalanced within each level of course difficulty. In both dual-task conditions, the experimenter read four- and five-letter words to the participant at a rate of one word every 3 s. The word lists used in the experiment were counterbalanced across participants and conditions.

Results and Discussion

Figure 2 presents the root mean squared (RMS) tracking error as a function of experimental condition. The data were analyzed using a 2 (tracking difficulty: easy vs. difficult) × 3 (task: single, shadowing, and word generation) repeated measures ANOVA. The analysis revealed that RMS error increased as a function of tracking difficulty, $F(1, 23) = 49.8$, $p < .01$, and task, $F(2, 46) = 13.4$, $p < .01$, and that these two effects interacted, $F(2, 46) = 7.7$, $p < .01$. A series of planned comparisons clarified the nature of this interaction. Single-task tracking error increased from the easy to the difficult condition, $F(1, 23) = 48.8$, $p < .01$. The shadowing dual-task condition did not reliably differ from the single-task control condition, $F(1, 23) = 3.7$, $p > .07$. However, the word-generation task produced significant increases in tracking error, $F(1, 23) = 17.6$, $p < .01$, and this effect was especially pronounced in the difficult driving condition, $F(1, 23) = 10.0$, $p < .01$. The fact that the shadowing task did not reliably elevate tracking error further discredits interpretations that attribute dual-task cell-phone deficits to peripheral factors such as holding the phone while conversing. In addition, these data indicate that the peripheral processes of speaking and listening do not appear to be major sources of interference. However, it is important to caution that our studies do not rule out all peripheral sources of interference. Indeed, there was a trend toward interference in the shadowing task that may have important implications in the real world (cf. Loftus, 1996). Moreover, there is clear evidence that manipulation of a phone while dialing is associated with significant dual-task interference (e.g., Briem & Hedman, 1995; Brookhuis et al., 1991).

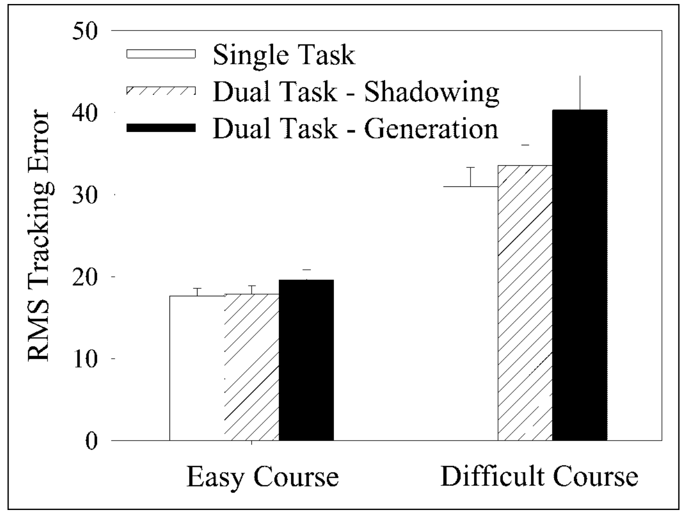

Fig. 2. Root mean squared (RMS) tracking error for the easy and difficult courses in single- and dual-task conditions in Experiment 2.

GENERAL DISCUSSION

The principal findings are that (a) when participants were engaged in cell-phone conversations, they missed twice as many simulated traffic signals as when they were not talking on the cell phone and took longer to react to those signals that they did detect; (b) these deficits were equivalent for handheld and hands-free cell-phone users; and (c) tracking error increased when participants used the cell phone to perform an active, attention-demanding word-generation task but not when they performed a shadowing task.

These data are consistent with an attention-based interpretation in which the disruptive effects of cell-phone conversations on driving are due primarily to the diversion of attention from driving to the phone conversation itself. The largest dual-task performance deficits were obtained in the generative portions of the cell-phone conversations; however, even the listening components were associated with dual-task decrements. Thus, the simulator studies described in this report and the field studies of Redelmeier and Tibshirani (1997) provide converging evidence on the locus of interference. We note that these results are problematic for multiple-resource models of divided attention (e.g., Wickens, 1992). Such models suggest that an auditory-verbal-vocal cell-phone conversation should not interfere substantially with a visual-spatial-manual driving task (see also Briem & Hedman, 1995; Moray, 1999). Indeed, attending to auditory inputs in the radio and book-on-tape control conditions of Experiment 1 and in the shadowing task of Experiment 2 did not lead to dual-task interference; however, conversing using either a handheld or a hands-free cell phone in Experiment 1 and word generation in Experiment 2 resulted in significant interference. Wickens (1999) has suggested that multiple-resource models might be able to account for the interference between cell-phone conversations and driving because there may be an overlap in the stages of processing between the two tasks. But given the similarity of the stages of processing in the shadowing and generation conditions of Experiment 2, this interpretation would seem to erroneously predict similar patterns of dual-task interference for these two conditions.[3]

We suggest that cellular-phone use disrupts performance by diverting attention to an engaging cognitive context other than the one immediately associated with driving. Some aspects of driving are inherently unpredictable (e.g., reacting to a child who darts across the street), and when attention is diverted from the driving context, the appropriate reactions to these unpredictable events will be impaired. Thus, the dual-task decrements described in this article appear to be consistent with the literatures on task and attention switching (e.g., Allport, Styles, & Hsieh, 1994; Gopher, Greenshpan, & Armony, 1996; Rogers & Monsell, 1995).

It is also interesting to consider the potential differences between cell-phone conversations and in-person conversations with other occupants of the vehicle. Although there need not be differences between these two modes of communication, there is evidence that in-person conversations are modulated by driving difficulty, so that as the demands of driving increase, participation by all participants in a conversation decreases (Parks, 1991). By contrast, at least one of the participants in a cellular-phone conversation is unaware of the current driving conditions (and may even be unaware that the cell-phone user is driving). Under such circumstances, it is less likely that the conversation will be modulated as a function of the real-time variations in driving difficulty. Moreover, although other in-car dual-task activities (e.g., dialing the phone, eating a sandwich) are under the direct control of the driver, when the driver engages in a cell-phone conversation, he or she is no longer solely in control of the dynamics of the conversation (i.e., a cell-phone conversation is jointly controlled by the participants).

In sum, we found that conversing on either a handheld or a hands-free cell phone led to significant decrements in simulated-driving performance. Thus, the available evidence indicates that there are at least two sources of interference with driving associated with concurrent cell-phone use: one due to peripheral factors such as manipulating the phone while dialing (e.g., Briem & Hedman, 1995; Brookhuis et al., 1991) and one due to the phone conversation itself. Our data imply that legislative initiatives that restrict handheld devices but permit hands-free devices are not likely to reduce interference from the phone conversation, because the interference is, in this case, due to central attentional processes.

3. Because performance was not measured in single-task shadowing and generation conditions, it is possible that the differences in dual-task interference are due to differences in the difficulty of the two tasks. Even so, the differences in difficulty would be associated with attention-demanding generative components of processing, rather than with peripheral processes associated with holding the phone, listening, and speaking.

REFERENCES

Allport, A., Styles, E.A., & Hsieh, S. (1994). Shifting intentional set: Exploring the dynamic control of tasks. In C. Umilta & M. Moscovitch (Eds.), *Attention and performance IV* (pp. 421–452). Cambridge, MA: MIT Press.

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.

Briem, V., & Hedman, L.R. (1995). Behavioural effects of mobile telephone use during simulated driving. *Ergonomics*, *38*, 2536–2562.

Brokaw, T. (1998). *The greatest generation (sound recording: abridged)* [Cassette]. New York: Random House Audio Books.

Brookhuis, K.A., De Vries, G., & De Waard, D. (1991). The effects of mobile telephoning on driving performance. *Accident Analysis and Prevention*, *23*, 309–316.

Brown, I.D., Tickner, A.H., & Simmonds, D.C.V. (1969). Interference between concurrent tasks of driving and telephoning. *Journal of Applied Psychology*, *53*, 419–424.

Cellular Telecommunications Industry Association. (2001). *CTIA's world of wireless communications* [On-line]. Available: http://www.wow-com.com/

Goodman, M.J., Bents, F.D., Tijerina, L., Wierwille, W., Lerner, N., & Benel, D. (1999). *An investigation of the safety implications of wireless communication in vehicles: Report summary* [On-line]. Available: http://www.nhtsa.dot.gov/people/injury/research/wireless/#rep

Goodman, M.J., Tijerina, L., Bents, F.D., & Wierwille, W.W. (1999). Using cellular telephones in vehicles: Safe or unsafe? *Transportation Human Factors*, *1*, 3–42.

Gopher, D., Greenshpan, Y., & Armony, L. (1996). Switching attention between tasks: Exploration of the components of executive control and their development with training. In *Proceedings of the Human Factors and Ergonomics Society 40th annual meeting* (pp. 1060–1064). Philadelphia: Human Factors and Ergonomics Society.

Ishihara, S. (1993). *Ishihara's tests for colour-blindness*. Tokyo, Japan: Kanehara & Co.

Loftus, G.R. (1996). Psychology will be a much better science when we change the way we analyze data. *Current Directions in Psychological Science*, *5*, 161–171.

McKnight, A., & McKnight, A. (1993). The effect of cellular phone use upon driver attention. *Accident Analysis and Prevention*, *25*, 259–265.

Moray, N. (1999). Commentary on Goodman, Tijerina, Bents, and Wierwille, "Using Cellular Telephones in Vehicles: Safe or Unsafe?" *Transportation Human Factors*, *1*, 43–46.

Parks, A.M. (1991). Drivers business decision making ability whilst using carphones. In E. Lovessey (Ed.), *Contemporary ergonomics: Proceedings of the Ergonomic Society annual conference* (pp. 427–432). London: Taylor & Francis.

Radeborg, K., Briem, V., & Hedman, L.R. (1999). The effect of concurrent task difficulty on working memory during simulated driving. *Ergonomics*, *42*, 767–777.

Redelmeier, D.A., & Tibshirani, R.J. (1997). Association between cellular-telephone calls and motor vehicle collisions. *The New England Journal of Medicine*, *336*, 453–458.

Rogers, R.D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General*, *124*, 207–231.

U.S. Department of Transportation. (1998). *Transportation Statistics Annual Report, 1998: Long-distance travel and freight, chapter 3* [On-line]. Available: http://www.bts.gov/programs/transtu/tsar/tsar98/chap3.pdf

Wickens, C.D. (1992). *Engineering psychology and human performance*. New York: HarperCollins.

Wickens, C.D. (1999). [Letter to the editor]. *Transportation Human Factors*, *1*, 205–206.

(Received 5/29/00; Revision accepted 1/23/01)