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The Impact of Cell Phone Conversations on Driving: A Meta-Analytic Approach

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Abstract

The costs associated with cell phone use while driving were assessed meta-analytically using standardized measures of effect size. Sixteen studies (contributing a total of 37 analysis entries) were included in the meta-analysis—each of which examined driving performance in terms of lane keeping (or tracking) ability or response time to a road event or stimulus. We further identified five moderator variables that were hypothesized to impact the costs associated with cell phone use: measure of driving performance; hand-held versus hands-free phones; conversation tasks versus information processing tasks (e.g., word games, mental arithmetic); in-vehicle (passenger) versus remote conversations; and simulator versus field studies. The overall analysis revealed clear costs to driving performance when drivers are engaged in cell phone conversations. However, further investigations indicated that these costs were primarily a function of reaction time tasks, with far smaller costs associated with tracking performance. Hands-free and hand-held phones revealed similar patterns of results, suggesting that costs are primarily derived from the conversational aspects of cell phone use as opposed to the manual aspects of holding a phone. Conversation tasks tended to show greater costs to performance than did information-processing tasks. Costs in driving performance were roughly equivalent whether the conversation was with a passenger or whether over a cell phone. Finally, the observed effects in simulator and field studies were comparable though there was more variability in the latter.

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Over the past 10 years, there has been accelerated use of cellular or mobile phones. In the US alone, there are an estimated 154 million cell phone subscribers (CTIA, 2004). This increase in usage has been coupled with an acceleration of studies that have attempted to document the negative safety implications of their use while driving (e.g., Alm & Nilsson, 1994; McKnight & McKnight, 1993; Strayer & Johnston, 2001). Such studies have been carried out with a range of methodologies ranging from epidemiological (e.g., Redelmeier & Tibshirani, 1997; Young, 2001) to simulator based (e.g., Strayer, Drews, & Johnston, 2003) to those conducted in basic laboratory settings, emphasizing low fidelity simulations of the drivers information processing demands (e.g., Strayer & Johnston, 2001). Finally, some legislative efforts aimed at banning or restricting the use of cell phones have been seen, based in part upon research cited above.

At present, the issue of how much driving interference cell phone use produces is complicated by conflicting findings. For example, some epidemiological studies point to the very high safety record of cell phones in specialized uses (e.g., ONSTAR assistance calls; Young, 2001), and others raise safety concerns regarding more general use (Redelmeier & Tibshirani, 1997). In controlled experimental research, Brookhuis, de Vries, & de Waard (1991) showed that drivers exhibited *decreased* deviations while engaged in a cell phone task, whereas others have shown the opposite effect for tracking performance (e.g., Strayer & Johnston, 2001). Similarly, numerous studies have shown people exhibit increases in response time on a variety of perceptual and cognitive tasks while they are engaged in cell phone conversations (e.g., Consiglio, Driscoll, Witte, & Berg, 2003; Alm & Nilsson, 1995), whereas others have not shown any significant increases in response latency (e.g., Rakauskas, Gugerty, & Ward, in review). Given these inconsistencies, we decided to integrate the collective wisdom of many of the empirically valid experimental studies, through the technique of *meta-analysis* (Rosenthal, 1991).

Meta-analysis is a technique whereby the results of a number of studies addressing a hypothesis can be combined to provide a single estimate of the reliability and magnitude of the effect supporting (or refuting) that hypothesis. In the current case, the effect we measure is the degradation in driving performance when using a cell phone, compared with a single task, driving control condition. An advantage of meta-analysis is that it allows us to combine data from separate experiments that may have differences in sample characteristics, experimental protocol and dependent measures. In addition, meta-analysis allows the testing of more restricted hypotheses addressed by a subset of research reports. For example, we might wish to ask if the effect of cell phone use was the same on lane keeping performance as on hazard response, or whether the effect was the same for both hands-free and hand-held cellular phones. We can refer to these as *moderating variables* that can modify the main effect of cell phone use.

In carrying out our meta-analysis, we identified five moderating variables that (a) we hypothesized might influence the costs of cell phone use on driving performance and (b) could be important in modeling the effect on the driver's attentional system. These are:

1. Measures of driving performance. Prior research has established that continuous perceptual-motor measures of lane keeping depend on separate attentional resources and are differentially affected by concurrent task demand than are discrete measures of hazard response (Horrey & Wickens, in review; Horrey, Wickens, & Alexander, in review).
2. Hand-held versus hands-free. Some have argued that the primary source of interference for drivers using a cell phone is between the manual dexterity necessary to hold the phone and the manual steering activity—a source of interference that would be evident only in hand-held phones. Others have argued that the primary source of interference is cognitive, related to the information processing activities of listening and selecting vocal responses (e.g., Strayer & Johnston, 2001). Therefore, we consider interference separately in studies using hand-held versus those using hands-free phones.
3. Conversation versus information processing. There have been a number of studies that employ realistic conversation tasks (e.g., Strayer & Johnston, 2001), which may "engage" the driver in varying degrees, depending on their level of interest. In contrast, other researchers employ tasks that simulate the demands of conversation on different aspects of information processing (e.g., Alm & Nilsson, 1994). We have therefore contrasted studies that have used the two types of tasks to simulate cell phone usage.
4. In-vehicle versus remote conversation. It has been argued by some that a major source of distraction in cell phone use is the inability of the non-driving speaker to be aware of the momentary demands on the driver, and hence, the inability to modulate conversation when the driving demands increase. This inability does not characterize the passenger in the vehicle, who may be carrying out the same conversation (e.g., Gugerty, Rando, Rakauskas, Brooks, & Olson, 2003). Hence we contrasted studies that used the two classes of conversation.
5. Simulator versus field studies. Given the frequent citation of cell phone costs in the context of simulator studies, we were interested in whether these findings were consistent with real world in-vehicle field trials, more characteristic of the environments from which epidemiological accident data are drawn (e.g., Redelmeier & Tibshirani, 1997).

Methods

Studies. As shown in Table 1, 16 experiments contributed to the current meta-analysis. In some cases, studies had multiple conditions which allowed us to increase the overall number (to N = 37). For example, some studies examined both hand-held and hands-free cell phones—conditions which were included in the meta-analysis as separate entries. All of the experiments were gathered from online databases (e.g., PSYC INFO) or through backwards referencing and included journal articles, conference proceedings, and technical reports. There were many additional studies, however, that were not included in the analyses for various reasons. For example, meta-analyses require that all findings be presented in terms of single degree-of-freedom (df) main effects, most especially in cases where the raw data are unavailable. Furthermore, we required that all the studies include a common comparison of cell phone use while driving against single-task baseline conditions (e.g., driving alone) and that the results were presented in terms of tracking performance, vehicle control, or response time to a non-cell phone event (e.g., roadside hazard). As such, studies that did not meet these criteria were dropped from this analysis (though many of these are summarized in tabular form in Appendix A). Also, because we were interested in the conversational aspects of cell phone use, we did not include studies that examined driving performance while the driver was dialing or manipulating the cell phone in some way.

Study	Phone Type	Task Type	Location	Measure
Alm, H. & Nilsson, L. (1994). Changes in driver behaviour as a function of handsfree mobile phones—A simulator study. *Accident Analysis and Prevention, 26*(4), 441-451.	Hands-Free	Information Processing	Remote	Tracking
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*(5), 707-715.	Hands-Free	Information Processing	Remote	Tracking, RT
Brookhuis, K.A., de Vries, G., & de Waard, D. (1991). The effects of mobile telephoning on driving performance. *Accident Analysis and Prevention, 23*(4), 309-316.	Hands-Free, Hand-Held	Information Processing	Remote	Tracking, RT
Consiglio W., Driscoll, P., Witte, M., & Berg, W.P. (2003). Effect of cellular telephone conversations and other potential interference on reaction time in a braking response. *Accident Analysis and Prevention, 35*, 495-500.	Hands-Free, Hand-Held	Conversation	Remote, In-Vehicle	RT
Gugerty, L., Rando, C., Rakauskas, M., Brooks, J., & Olson, H. (2003). Differences in remote versus in-person communications while performing a driving task. *Proceedings of the Human Factors and Ergonomics Society 47th Annual Meeting* (pp. 1855-1859). Santa Monica, CA: HFES.	Hands-Free	Information Processing	Remote In-Vehicle	RT
Irwin, M., Fitzgerald, C., & Berg, W.P. (2000). Effect of the intensity of wireless telephone conversations on reaction time in a braking response. *Perceptual and Motor Skills, 90*, 1130-1134.	Hand-Held	Conversation	Remote	RT
Laberge, J., Scialfa, C., White, C., & Caird, J. (2004). The effect of passenger and cellular phone conversations on driver distraction. *83rd Annual Meeting of the Transportation Research Board*. Washington, DC: National Academy of Sciences.	Hands-Free	Information Processing	Remote, In-Vehicle	RT
Lamble, D., Kauranen, T., Laakso, M., & Summala, H. (1999). Cognitive load and detection thresholds in car following situations: Safety implications for using mobile (cellular) telephones while driving. *Accident Analysis and Prevention, 31*, 617-623.	Hands-Free, Hand-Held	Information Processing	In-Vehicle	RT
Parkes, A.M. & Hooijmeijer, V. (2001). Driver situation awareness and carphone use. *Proceedings of the 1st Human-Centered Transportation Simulation Conference* (ISSN 1538-3288). Iowa City, IO: University of Iowa.	Hands-Free	Information Processing	Remote	Tracking, RT
Patten, C.J.D., Kircher, A., Östlund, J., & Nilsson, L. (in press). Using mobile telephones: Cognitive workload and attention resource allocation. *Accident Analysis and Prevention*.	Hands-Free, Hand-Held	Information Processing	Remote	RT
Rakauskas, M., Gugerty, L. & Ward, N.J. (in review). Effects of cell phone conversations on driving performance with naturalistic conversations.	Hands-Free	Conversation	Remote	Tracking, RT
Strayer, D.L. & Drews, F.A. (2003). Effects of cell phone conversations on younger and older drivers. *Proceedings of the Human Factors and Ergonomics Society 47th Annual Meeting* (pp. 1860-1864). Santa Monica, CA: HFES.	Hands-Free	Conversation	Remote	RT
Strayer, D.L., Drews, F.A. & Johnston, W.A. (2003). Cell phone-induced failures of visual attention during simulated driving. *Journal of Experimental Psychology: Applied, 9*(1), 23-32.	Hands-Free	Information Processing, Conversation	Remote	RT
Strayer, D.L., Drews, F.A., Albert, R.W., & Johnston, W.A. (2002). Why do cell phone conversations interfere with driving? *81st Annual Meeting of the Transportation Research Board*. Washington, DC: National Academy of Sciences.	Hands-Free, Hand-Held	Conversation	Remote	RT
Strayer, D.L. & Johnston, W.A. (2001). Driven to distraction: Dual-task studies of simulated driving and conversing on a cellular phone. *Psychological Science, 12*(6), 462-466.	Hands-Free, Hand-Held	Information Processing, Conversation	Remote	Tracking, RT
Waugh, J.D., Glumm, M.M., Kilduff, P.W., Tauson, R.A., Smyth, C.C., & Pillalamarri, R.S. (2000). Cognitive workload while driving and talking on a cellular phone or to a passenger. *Proceedings of the IEA 2000/HFES 2000 Congress* (pp. 6:276-6:279). Santa Monica, CA: HFES.	Hand-Held	Information Processing	Remote, In-Vehicle	Tracking

Table 1. List of studies contributing to the meta-analysis and some of their attributes.

For those studies that met the criteria described, we coded them along each of the five moderator variables. Specifically, we indicated whether the study measured tracking performance or response time (or both). For tracking, performance was typically assessed by absolute error or as an index of RMS error (i.e., variability in tracking performance). Response time tasks, in contrast, involved a speeded response to some stimuli, whether a road hazard or an artificial stimulus presented in the traffic environment.

Second, we coded whether a particular study employed a hands-free or a hand-held cell phone for the conversation task. Third, we categorized the type of phone task that participants performed, that is, whether the task involved a conversation (typically characterized by a free discussion of topics-of-interest or autobiographical information) or an information processing task (e.g., mental arithmetic, word generation games, or the like). Next, we specified those studies that utilized remote (i.e., over a cell phone) conversations and those that incorporated in-vehicle (i.e., passenger) conversations and, finally, those that used simulators (whether low or high fidelity) versus those employing actual field trials.

Meta-Analysis. For the meta-analysis, we converted statistical results into effect sizes and combined these values (Rosenthal, 1991; Rosenthal & Dimatteo, 2001). Effect sizes are advantageous because they focus on how large a particular effect is (as opposed to whether or not it differs from zero) and, when coupled with confidence intervals, they offer estimates for the upper and lower limits of the true effect size in the population.

We used reported test statistics to calculate the effect size for each study, based on the product moment correlation (*r*). In general, we employ *r* as a measure of effect size because it has a number of advantages over other measures (e.g., Cohen's *d*, Hedges' *g*; see Rosenthal, 1991, for details). The effect size can be calculated from *t* statistics or *F* statistics (with 1 df), as shown by Equation (1).

$$r_{ES} = \sqrt{\frac{t^2}{t^2 + df}} = \sqrt{\frac{F}{F + df_{error}}} \quad (1)$$

In situations where the authors indicated no difference between the conditions of interest but failed to provide any statistical details (e.g., $F < 1$), a conservative effect size of zero was assumed for the meta-analysis (see Rosenthal & Dimatteo, 2001).

Following the calculation of the effect size (r_{ES}) for each study, we coded the findings to denote costs or gains in driving performance with the concurrent cell phone task. In the first case, effect sizes were assigned positive values given that this pattern was consistent with the hypotheses (i.e., predicted costs to performance). In cases where the pattern of results was opposite predictions (i.e., gains in performance in dual-task situations), effect sizes were assigned negative values.

In order to combine the effect sizes from multiple studies, we first normalize our effect sizes by converting the r_{ES} scores to z-scores using Fisher's r-to-z transformation (typically offered in tabular form in statistical textbooks, see Rosenthal & Dimatteo, 2001, for details). Next, the unweighted and weighted means of these transformed scores was calculated in which the latter was weighed by the df of the study. The weighted and unweighted z-transformed means were then converted back into *r* values and reported (e.g., see Table 2). Finally, for both the unweighted and weighted means, we estimated the 95% confidence interval, to determine whether the combined effect sizes differ significantly from zero (that is, do not include zero in the interval; following Equation 2).

$$CI_{95\%} = \overline{Z_r} \pm t_{(.05)} S \big/ \sqrt{k} \qquad (2)$$

where $\overline{Z_r}$ is the mean of the transformed r_{ES} values, $t_{(.05)}$ is the appropriate t value for the 0.05 probability level, *S* is the standard deviation of the transformed r_{ES} values, and *k* is the number of studies included in the sample.

While the weighted and unweighted mean results were highly correlated in our analyses, and thus providing an equivalent picture, the former has the advantage of amplifying the greater impact of more reliable (higher N) studies.

After the combined effect sizes were obtained, we conducted a test of heterogeneity (Rosenthal, 1991) to determine whether or not the values contributed to the analysis are consistent (i.e., homogeneous) with one another or inconsistent (i.e., heterogeneous). Heterogeneous results may indicate the presence of moderator variables, such as those described previously, that warrant further investigation.

Results

The results from the meta-analysis are shown in Table 2, including the unweighted and weighted combined effect sizes and corresponding tests of heterogeneity. When we examine all of the studies collectively (without factoring in moderator variables) we find that there is a large, significant cost of cell phone use on driving performance (see **1**, Table 2). We proceeded to break down the set of studies following from the moderator variables outlined previously. (When examining the interactive effects of multiple moderator variables, we did not analyze all possible combinations of variables, instead focusing on those combinations that were of greatest interest to us.)

As shown in row **2** of Table 2, we broke down the overall set of studies into those that examined driving performance in terms of response time to a road event or stimuli or in terms of lane keeping or tracking performance. For those studies examining RT (**2a**), the costs to driving performance were still significant (with a large effect size, which translated to approximately 130 msec in costs). However, for those studies that examined decrements in tracking performance or lane keeping (**2b**), the effect size was substantially smaller and non-significantly different from zero (for the unweighted mean).

An examination of the overall impact of phone type on overall driving performance (hands-free, **3a-i**; hand-held, **3b-i**) showed significant costs. These costs however were moderated by the type of measure of driving performance, offering convergent findings with those results shown in **2**. For measures of reaction time, both hands-free (**3a-ii**) and hand-held (**3b-ii**) phones showed large, significant costs. In contrast, tracking performance showed smaller and non-significant effect sizes (**3a-iii**, **3b-iii**).

			Number of Studies	Combined Effect Size (r)		Test of Heterogeneity	p-value
				Unweighted (95% CI)	Weighted (95% CI)		
1) Overall	-	-	37	0.50 (0.29, 0.60)	0.55 (0.46, 0.64)	198.3	< 0.001
2) Measure	**a)** RT	-	26	0.60 (0.49, 0.69)	0.61 (0.52, 0.69)	123.4	< 0.001
	b) Tracking	-	11	0.22 (-0.10, 0.49)	0.33 (0.08, 0.52)	48.9	< 0.001
3) Phone Type	**a)** Hands Free	**i)** Overall	24	0.47 (0.33, 0.59)	0.51 (0.39, 0.61)	119.4	< 0.001
		ii) RT	18	0.56 (0.43, 0.66)	0.56 (0.45, 0.66)	81.0	< 0.001
		iii) Tracking	6	0.17 (-0.25, 0.53)	0.30 (-0.03, 0.57)	25.5	< 0.001
	b) Hand Held	**i)** Overall	13	0.55 (0.31, 0.73)	0.64 (0.47, 0.76)	71.1	< 0.001
		ii) RT	8	0.68 (0.47, 0.82)	0.72 (0.56, 0.83)	31.9	< 0.001
		iii) Tracking	5	0.27 (-0.35, 0.73)	0.36 (-0.14, 0.71)	23.1	< 0.001
4) Task Type	**a)** Conversation	**i)** Overall	15	0.64 (0.51, 0.74)	0.64 (0.53, 0.73)	52.4	< 0.001
		ii) RT	12	0.67 (0.52, 0.77)	0.67 (0.53, 0.80)	46.9	< 0.001
	b) Info Process	**i)** Overall	22	0.39 (0.22, 0.55)	0.48 (0.34, 0.61)	134.0	< 0.001
		ii) RT	14	0.53 (0.36, 0.66)	0.57 (0.42, 0.69)	72.3	< 0.001
5) Location	**a)** Remote	-	31	0.49 (0.32, 0.57)	0.55 (0.45, 0.64)	173.7	< 0.001
	b) In-Vehicle	-	6	0.55 (0.22, 0.77)	0.54 (0.27, 0.73)	21.5	0.002
6) Study Type	**a)** Simulator	-	25	0.55 (0.43, 0.63)	0.52 (0.42, 0.61)	91.7	< 0.001
	b) Field Test	-	12	0.42 (0.07, 0.68)	0.61 (0.36, 0.78)	103.4	< 0.001

Table 2. Summary table for the meta-analysis and the tests for heterogeneity, including the examination of potential moderating variables. (Underscored results indicate non-significant findings, i.e., confidence interval includes zero)

We broke down the overall set of studies by those employing conversation tasks and those using information processing tasks (**4**). In general, when a conversation task is employed there are high costs to driving performance (**4a-i**), more so than for information processing tasks (**4b-i**), which lies more than the 95% confidence interval below conversation. However, both costs are still significant. This same pattern of differential interference between conversation and information processing is present, though less pronounced, for measures of response time alone (**4a-ii**, **4b-ii**).

In comparison **5**, we note that the distinction of in-vehicle or remote conversations does not appear to have a differential impact on the costs in driving performance. That is, the costs associated with a phone conversation versus a passenger conversation are roughly equivalent. Finally, the costs observed in simulator and field studies was similar (**6**), though we note there were more variable findings for the field work.

Discussion & Conclusions

From the current meta-analysis, we note several important findings. First, there are definite costs associated with cell phone use while driving, however these costs appear to be manifested primarily in measures of response time to critical road hazards or stimuli. In contrast, the costs associated with lane keeping or tracking performance are much smaller (and, in this case, non-significant). Horrey and Wickens (in review) suggest that these tasks (e.g., lane keeping and hazard response) depend on separate resources (ambient and focal vision, respectively) and may be differentially impacted by cell phone conversations. We note that, while the magnitude of the reaction time effect was relatively small (an average delay of 130 ms), this represents a mean value, around which there is considerable variance. Accidents are often caused by "worst case" performers under "worst case" circumstances (Wickens, 2001), at the tail end of the distribution, where reaction time delay can be expected to be considerably longer.

Second, the meta-analysis suggests that costs in driving performance are equivalent across hands-free and hand-held phones, suggesting that the larger part of these costs is due to the cognitive aspects of conversation and not the manual aspects of holding the phone. We note, however, that this does not discount the possibility that the costs associated with hand-held phones could exacerbated in situations requiring significant amounts of manual steering inputs (e.g., intersection turns) and the manual aspects of keyboard entry ("dialing" is not considered here).

Third, conversation tasks, in general, showed greater costs in driving performance than did information processing tasks (though less so for measures of response time alone). This may be due to the greater "engagement" associated with actual conversations. Information processing tasks, although they involve perceptual resources and working memory, do not share the same degree of engagement. We speculate that the costs of engagement may be more pronounced when the conversation is intense, though there was insufficient data along this dimension for the purposes of meta-analysis. Importantly however, information processing tasks do produce substantial influence on interference, and so, should be able to effectively simulate many aspects of the demands of cell phone usage for research purposes.

From our analyses, in-vehicle, passenger conversations were just as costly to driving performance as were remote (cell phone) conversations. This suggests that passengers, at least in those studies explored here, did not moderate their conversation in such a way as to alleviate the costs (compared to remote conversers).

Finally, the costs to driving performance exhibited in simulator studies were similar to those found for field trials, suggesting that the former may be useful in generalizing to real-world driving situations.

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Appendix A. Research summaries of cell phone and driving studies

Author (s), Year	Objectives	Features	Methods				Results / Conclusions
			Participants	Independent variables	Dependent variables	Procedure	
Alm & Nilsson (1994)	Examined the effects of hands-free cell phone conversations on drivers' reaction time, lane position, speed level, and workload in varying driving conditions.	*Hands-free vs. Hand-held:* Hands-Free ***Conversation vs. Info Processing:*** Info Processing *In-Vehicle vs. Remote:* Remote *Straight vs. Curved Roads:* Both *Lane Keeping vs. Hazard Response:* Both	N = 40 (23-61 yrs, M = 32); 20 male, 20 female.	Task Condition: (Phone + Driving; Driving Baseline) Driving Difficulty: (Easy, Difficult)	Speed Lateral position Reaction time (to stimulus) NASA-TLX Phone task accuracy	While driving a simulated route (of varying difficulty), drivers were asked to main lane position and to respond to an occasional red stimulus that appeared on the road ahead. For the concurrent phone task, drivers performed a working memory span task where they listened to short sentences and indicated whether or not they were sensible. Following 5 such sentences, they were asked to recall the last word from each of those 5 sentences.	Reaction time: There was a significant interaction between Task condition and Difficulty ($F(1,26) = 6.4$, $p = .01$) with slower RTs for the phone task on easy roads, but no difference in Task condition on difficult roads. For lateral position, there was increased deviations in the easy phone condition ($F(1,144) = 5.7$, $p = 0.02$), as well as for the difficult condition ($F(1,144) = 22.95$, $p = 0.001$). There were no significant differences in the variability in lane keeping.

Author (s), Year	Objectives	Features	Methods				Results / Conclusions
			Participants	Independent variables	Dependent variables	Procedure	
Alm & Nilsson (1995)	To examine the effects of cell phone conversations on younger and older adult's choice reaction times, headway, lateral position, and workload.	*Hands-free vs. Hand-held:* Hands-Free *Conversation vs. Info Processing:* Info Processing *In-Vehicle vs. Remote:* Remote *Straight vs. Curved Roads:* Straight *Lane Keeping vs. Hazard Response:* Both	N = 40 (30 male, 10 female). Younger (< 60 yrs, M = 29), Older (≥ 60, M = 68). All were licensed and active drivers.	Age: (Young; Old) Task Condition: (Single-; Dual Task)	Brake response time (to lead vehicle) Lateral position Headway distance Workload (NASA-TLX) Accuracy on phone task	In a driving simulator, drivers were forced into a car following situation several times (16) over the course of the experiment. For half of these, they were engaged in a concurrent phone task. Occasionally, they were required to brake in order to avoid a collision with a slowing lead vehicle. The phone task was comprised of a working memory and a decision component. For the decision task, drivers were asked to indicate whether simple sentences were sensible or no. The memory task had drivers repeat the last word of each of the previous 5 simple sentences.	*Response times were 0.56 s slower for younger drivers in dual versus single-task conditions (single: ~1.6 s; dual: ~2.2 s) *Responses were likewise slowed for older adults, however more severely (1.46 s slower) (single: ~2 s; dual: 3.5 s) Main Effect for Task: $F(1,35) = 9.36$, $p = .004$ (no stats for other comparisons are presented) *There were no significant differences across task condition for lane position or for std. dev of lane position (no stats reported)

Author (s), Year	Objectives	Features	Methods				Results / Conclusions
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Briem & Hedman (1995)	Examine the effects of a hands-free cell phone task on pursuit tracking performance.	*Hands-free vs. Hand-held:* Hands-Free *Conversation vs. Info Processing:* Both *In-Vehicle vs. Remote:* Remote *Straight vs. Curved Roads:* None *Lane Keeping vs. Hazard Response:* Hazard Response	N = 20 (10 younger: 19-26 yrs, M = 21; 10 older: 40-51 yrs, M = 46)	Age: (Younger, Older) Gender: (Male; Female) Task Condition: (Radio; Simple Conversation; Difficult Conversation) Driving Difficulty: (Easy-firm surface; Difficult-slippery surface) Task Condition: (Driving Alone; Driving + Obstacles; Driving + Communication; Driving + Manipulation) NOTE: Design was not completely crossed.	Tracking performance (RMS error; percent time off-road and on shoulder) Number of collisions (with obstacles) Speed variability	This experiment was run on a PC based system, which included a steering wheel and pedal mock-up. The driving task was essentially a pursuit tracking task. For the radio task, drivers manipulated and listened to the car radio. The simple conversation involved a discussion on then-current issues whereas the difficult conversation involved a test of working memory span. For this task, they indicated whether or not simple sentences where logical or no and also repeated the first word of the previous set of four sentences.	*Overall, the simple and difficult conversations did not differ from radio tuning in terms of lane deviation (19.7 cm, 20, 21.2, respectively; $F(2,34) = 4$, $p < .05$). Compared to easy driving (17.7), there was little effect of communication task (18.7), however there was degraded performance when manipulation was required (25.2; $F(3,51) = 7.2$, $p < .01$). There was an interaction, such that the effects of the side task were more pronounced in difficult driving conditions ($F(3,51) = 6.1$, $p < .01$). NOTE: no post-hoc comparisons reported here.

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Brookhuis, de Vries, & de Waard (1991)	Examine the impact of hand-held and hands-free cell phones in three different traffic environments (varying in complexity).	*Hands-free vs. Hand-held:* Both *Conversation vs. Info Processing:* Info Processing *In-Vehicle vs. Remote:* Remote *Straight vs. Curved Roads:* Straight *Lane Keeping vs. Hazard Response:* Both	N = 12 (10 male, 2 female, no means reported). All were experienced drivers but without previous experience with cell phones.	Phone type: (Hands-free; Hand-held) Traffic situation: (LIGHT traffic, quiet motorway; HEAVY traffic, four-lane ring road; CITY traffic) Age: (23-35 yrs; 35-50; 50-65)	Effort (Mental Workload) – indexed by heart rate variability Subjective WL ratings Amplitude of steering wheel movements Lane-keeping ability Ability to follow maneuvers of a lead vehicle Mirror checking Paced Serial Addition Task (PASAT) – combination memory and addition task	In a field trial, drivers were tested over the course of three weeks with and without a phone task in each of the traffic conditions described. The phone task consisted of a three-minute PASAT. Half of the drivers used hands-free, the other half, hand-held. Occasionally, the driver of the lead vehicle would use the brakes, in order to assess the participants' braking response times.	**Lane keeping: significant effect of the phone task ($F(1,11) = 7.3$, $p < .02$), with *decreased* lane deviations when engaged in the phone task (for LIGHT: 21.5 cm baseline, 19.5 cm with phone; for HEAVY: 23.5 baseline, 22.5 cm with phone) – no stats for phone type or city traffic Car following: brake RTs were slower in the phone conditions, but the difference (130 ms) was not significant (no stats) *Steering wheel movements: no significant differences between phone and baseline conditions (no stats reported), except for greater variability when the subject needed to manipulate the phone (e.g., dial a number or pick up the phone to receive a call). Mirror checking: no effect of phone task (no stats) Mental WL: heart rate and HR variability increased with phone task ($F(1,10) = 7.8$, $p < .02$; $F(1,10) = 5.5.$, $p < .04$). Subjective WL ratings were consistent, with higher WL for phone tasks ($F(1,11) = 5.3$, $p < .04$). There was no effect of phone type. No performance trade-offs reported for telephone task. No effects of age.

Author (s), Year	Objectives	Features	Methods				Results / Conclusions
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Consiglio, Driscoll, Witte, & Berg (2003)	Examine the impact of cell phone conversations on braking response times.	*Hands-free vs. Hand-held:* Both *Conversation vs. Info Processing:* Converse *In-Vehicle vs. Remote:* Both *Straight vs. Curved Roads:* None *Lane Keeping vs. Hazard Response:* Hazard Response	N = 22 young adults (18-27 yrs, M = 21)	Distraction type: (No distraction; Listening to radio; Conversation with passenger; Conversation over hand-held; Conversation with hands-free)	Response time to brake light stimulus	Participants were seated at a vehicle (i.e., brake and accelerator) mock-up in front of a red lamp. (The red lamp was intended to simulate a lead vehicle's brake lights.) Over the course of the trial, the lamp activated every 10-20 seconds. There were 5 conditions, including a control (no side task), listening to music on the radio, conversation with a passenger (answering basic autobiographical questions), conversation with a hand-held phone (same as above), and conversation with a hands-free phone.	*Compared to baseline measures (392 ms), brake responses were significantly slowed with the passenger conversation (453 ms; t(no df) = 7.84, $p < .0001$), the hand-held (464 ms; t(no df) = 9.28, $p < .0001$), and the hands-free (465 ms; t(no df) = 9.43, $p < .0001$). There was no difference between control and radio listening (408 ms; t(-) = 2.07, $p > .05$), between passenger and cell phone calls (hand-held: t(-) = 1.44, $p > .05$; hands-free: t(-) = 1.59, $p > .05$), nor between cell phone type (t(-) = 0.15, $p > .05$). NOTE: Simple reaction time measure was employed. No side task measures or tracking task.

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Gugerty, Rando, Rakauskas, Brooks, & Olson (2003)	Examine differences in remote cell phone and passenger conversations while driving to determine whether or not there were any modulations of conversation on the part of the passenger. In Exp 2, the verbal task was made more challenging for drivers.	*Hands-free vs. Hand-held:* Hands-Free *Conversation vs. Info Processing:* Info Processing *In-Vehicle vs. Remote:* Both *Straight vs. Curved Roads:* None *Lane Keeping vs. Hazard Response:* Hazard Response	Exp 1 N = 29 pairs of individuals (1 driver and 1 non-driver). Ages ranged from 18-22 yrs. Exp 2 N = 40 pairs (18-43 yrs)	Exp 1+2 Task Condition: (Driving; Driving + Conversation) Interaction Type: (Remote; In-Person) Role: (Driver; Non-Driver)	Exp 1+2 Measures of verbal task performance (multiple) Location-recall error (situation awareness) Percent correct scene interpretations (SA) Percent hazards detected Blocking car detections Hazard response times	Exp 1 Drivers were shown brief animated scenarios depicting different traffic configurations. After each scene, location-recall and scene-interpretation probes queried drivers' knowledge of the traffic situation. Additionally, there were performance probes in which drivers had to respond to hazard events. The verbal task was a word generation game (i.e., say a word that starts with the last letter of the previous word). The non-driver was positioned either in the passenger seat or behind a nearby screen. Exp2 Same as above except non-drivers were given words via computer screen (to speed up the game). Only the driver engaged in the word game (thus, increased load)	Exp1 Hazard RTs were slower in dual-task (1.37 s) versus single-task conditions (1.27 s) for hazards that appeared suddenly ($p < .05$) The type of conversation (Remote, In-Person) did not appear to impact driving performance differentially (no stats). Exp 2 Again, a slowing in response time was observed in dual-task conditions (1.92 s) versus single-task conditions (1.72 s; no stats). No difference between remote and in-vehicle ($F(5,29) = 1.13$, $p = .37$)

Author (s), Year	Objectives	Features	Methods				Results / Conclusions
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Haigney, Taylor, & Westerman (2000)	Examines the effects of cell phone conversations on various performance measures.	*Hands-free vs. Hand-held:* Both *Conversation vs. Info Processing:* Info Processing *In-Vehicle vs. Remote:* Remote *Straight vs. Curved Roads:* Unknown *Lane Keeping vs. Hazard Response:* Lane Keeping	N = 30 (13 male, 17 female, M = 27 yrs)	Transmission Type: (Manual; Automatic) Phone Type: (Hands-free; Hand-held) Task Phase: (Pre-call; During call; Post-call)	Number of lane departures Heart rate Speed variability Phone task performance	Drivers completed four drives in a simulator: two with manual and two with automatic transmission. During each trial there were 3 phases: pre-call, during call, and post-call. (150 s each). Half of the trials involved a hand-held phone while the other half employed a hands-free system. The phone task involved working memory components. Drivers responded 'true' or 'false' to statements regarding the relative ordering of 5 stimulus letters (e.g., "A, F, T, H, E", "F was before H". Ans: True)	*No differences across Task phase (i.e., pre-, during, post-) for number of lane departures (for hand-held: 0.18, 0.32, 0.10, respectively; for hands-free: 0.12, 0.13, 0.10; $F(2,58) = 1.35$) *There were however more lane departures when using the hand-held (0.32), compared to the hands-free (0.13; $F(1,29) = 4.22$, $p < .05$)

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Irwin, Fitzgerald, & Berg (2000)	Examine the impact of conversation intensity on braking reaction times.	*Hands-free vs. Hand-held:* Hand-Held *Conversation vs. Info Processing:* Converse *In-Vehicle vs. Remote:* Remote Straight vs. Curved Roads: None *Lane Keeping vs. Hazard Response:* ~Hazard RT	N = 16 (M = 32 yrs; 8 male, 8 female). All were licensed drivers.	Intensity of phone conversation (see a to e, in Procedure section)	Mean RTs – to stimuli	In a lab trial, participants sat at a mock driving station that included brake and accelerator pedals and were required to brake as quickly as they could to a red stimulus light. Following practice trials, participants completed 5 experimental blocks: (a) baseline, no phone task; (b) listen to weather forecast; (c) simple (1 to 2 word) responses to questions, e.g., do you own a dog? (d) questions requiring more thought and use of memory, e.g., describe the route to your residence from your current location; (e) questions about personal beliefs or feelings regarding potentially emotionally-loaded topics, e.g., what are your views about gun control? Red stimulus light was activated at random 10- to 20-second intervals.	*Results showed that there was significant slowing of RTs for all phone conditions (b – 481 ms, c – 485 ms, d – 516 ms, e – 513 ms) compared to baseline (a – 401 ms; $F(4,12) = 22$, $p < .001$, with post hoc comparisons ranging from $p < .05$ to $< .001$). **There were, however, no significant differences between each of the phone conditions (no p reported), suggesting that the intensity of a conversation does not impact simple RT performance. NOTE: The task used in the current study is a simple reaction time task, which is significantly different than driving. Additionally, there were no measures of secondary task performance, no continuous control task, and no description of the coupling of phone tasks to the light stimulus.

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Laberge, Scialfa, White, & Caird (2004)	Examine whether or not passenger conversations are modulated versus cell phone conversations and the relative impact on driving performance.	*Hands-free vs. Hand-held:* Hands-Free *Conversation vs. Info Processing:* Info Processing *In-Vehicle vs. Remote:* Both *Straight vs. Curved Roads:* Both *Lane Keeping vs. Hazard Response:* Both	N = 40 pairs (18-27 yrs, M = 21 yrs)	Task Condition: (Driving Alone; Cell Phone Conversation; Passenger Conversation) Driving Difficulty: (Easy; Difficult) Role: (Driver; Non-Driver)	Lane position Speed variability Response times to driving events (PRTs) Phone task performance (speech rate, word complexity, errors, and linguistic frequency) Modified NASA-TLX (workload assessment)	In this simulator study, drivers drove through varied traffic environments while engaged in a simulated conversation. There were two discrete traffic events (traffic light change, pedestrian incursion) that required an overt response by drivers. In the conversation conditions, drivers were paired with non-drivers and were engaged in a word-game task. This task involved the generation of new words starting with the last letter of the previously spoken word (thus simulating turn-taking in conversations). The non-driver was either seated in the passenger seat or behind a screen (using a head set).	*There were no significant differences in lane position ($p > 0.69$) or lane variability ($p > 0.12$) across Task condition, nor was there an interaction with Difficulty. *For the pedestrian event, PRTs were slower when talking to the passenger (1.40 s) than when driving alone (1.2 s; $t(42) = 2.48$, $p = .009$). PRT was also slower when talking on the cell phone (1.34 s; $t(42) = 1.75$, $p = .04$).

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Lamble, Kauranen, Laakso, & Summala (1999)	Investigates drivers' ability to detect deceleration from lead vehicle while doing cell phone-related tasks.	*Hands-free vs. Hand-held:* Both *Conversation vs. Info Processing:* Info Processing *In-Vehicle vs. Remote:* In-vehicle *Straight vs. Curved Roads:* Straight *Lane Keeping vs. Hazard Response:* Hazard Response	N = 19 (20-29 yrs, M = 23, 10 male, 9 female)	Task Condition: (Control, Phone Dialing; Cognitive Task)	Brake response time (RT) to lead vehicle Detection thresholds (time-to-collision, TTC) Variability in lane position	During each trial in this field study, drivers were required to follow and brake when necessary to a lead vehicle. In this conditions, drivers were either looking at the lead vehicle (control), dialing numbers on a keypad, or performing a mental memory or addition task presented by the experimenter (i.e., drivers were required to add the last two digits of a string presented to them).	*There were overall differences in RTs ($F(2,36) = 12.63$, $p < .001$), with slower responses with the dialing task (0.48 s slower; $F(1,18) = 17.7$, $p < .001$) and the cognitive task (0.50 s slower; $F(1,18) = 17.6$, p , .001) compared to baseline. *There was no effect of Task type on variability in lane position ($F(2,36) = 2.16$, $p = .13$)

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McKnight & McKnight (1993)	Examine the impact of cell phones, complexity of conversation, and age on driving performance.	*Hands-free vs. Hand-held:* Hands-Free *Conversation vs. Info Processing:* Both *In-Vehicle vs. Remote:* Remote *Straight vs. Curved Roads:* Straight *Lane Keeping vs. Hazard Response:* ~Hazard Response	N = 150 (45 young (17-25 yrs), 56 mid-age (26-49), and 49 older (50-80); no means reported).	Distraction type: (No distraction; Placing a call (dialing); Casual conversation; Intense conversation; Tuning a radio) Age (Young; Mid-aged; Older)	Event response accuracy – appropriate responses (e.g., steering, braking) or no	Drivers, in this study, were presented with videos of driving scenarios and instructed to pretend they were controlling the vehicle. In the experimental trials, drivers completed each of the 5 task conditions. For the casual conversation, drivers talked about largely inconsequential topics. The intense conversation involved a set of problem-solving exercises (e.g., math or memory problems). Throughout the 25 min session, there were 45 events that required a response, such as traffic control devices, pedestrians, or vehicles)	*There was a greater mean proportion of drivers who failed to respond to traffic events in the 4 distractor conditions (0.43), relative to baseline (0.34; $F(1,136) = 36$, $p < .01$). Radio tuning and intense conversations had slightly higher proportions than dialing and casual conversations (0.44 vs. 0.41; $F(3,134) = 2.1$, $p = .10$) There were some effects of age, with older drivers responding to fewer traffic events overall (see paper for further details). NOTE: There is no description of how accuracy of event responses was determined (e.g., a set of independent raters, etc.). In light of this, failing to respond in certain situations may not be very telling.

Author (s), Year	Objectives	Features	Methods				Results / Conclusions
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Parkes & Hooijmeijer (2001)	Examined the impact of hands-free conversation on driver performance and situation awaremess.	*Hands-free vs. Hand-held:* Hands-Free *Conversation vs. Info Processing:* Info Processing *In-Vehicle vs. Remote:* Remote *Straight vs. Curved Roads:* Both *Lane Keeping vs. Hazard Response:* Both	N = 15 (22-31 yrs, M = 24)	Task Condition: (Driving Alone; Driving + Conversation)	Reaction time (RT) to stimuli Lateral position and variability Speed Situation awareness (all levels) NOTE: No measures of phone task performance.	In a fixed-base simulator, drivers drove in a freeway environment while performing a phone task. The phone task had drivers respond to a series of questions that tapped numerical and verbal memory as well as arithmetic and verbal reasoning. During the drive, participants were forced to respond to a green or a red stimulus, either by manipulating the headlights or by pressing the brakes (choice reaction time task)	There was a significant slowing in RT to the first green stimulus for drivers with the cell phone task (1.13 s) versus those without (1.01 s; $t(14) = 2.6$, $p < .05$). There were, however, no differences across Task condition for the 2nd green stimulus (single task = 1.12 s; dual-task = 1.19 s) or for the red stimulus (s = 1.37 s; d = 1.42 s). For lane keeping, there were no differences across task conditions, even during two simulated wind gusts ($t(14) = 0.48$ & 0.73, respectively)

Author (s), Year	Objectives	Features	Methods				Results / Conclusions
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Patten, Kircher, Östlund, & Nilsson (2003)	Examined the effects of simple and complex phone conversations on driving performance.	*Hands-free vs. Hand-held:* Both *Conversation vs. Info Processing:* Info Processing *In-Vehicle vs. Remote:* Remote *Straight vs. Curved Roads:* Unknown *Lane Keeping vs. Hazard Response:* ~Hazard Response	N = 40 professional drivers (21-60 yrs, M = 40)	Task Condition: (No Conversation; Simple Conversation; Complex Conversation) Phone Type: (Hands-Free, HF; Hand-held, HH)	RT to peripheral detection task Correct detection Mean velocity	In a field study, drivers were asked to perform a concurrent peripheral detection task (PDT). The PDT involved a set of LED lights which flashed periodically (centrally located). The complex conversation task had participants add two given digits, whereas the simple task was a shadowing task for the given digit strings.	Response times for the PDT were the same across Phone type for both the simple (HH = 662 ms; HF = 650 ms) and complex conversations (HH = 849 ms; HF = 841 ms). Both simple conversations resulted in significantly slower responses than baseline (584 ms; HH: $t(39) = 3.96$, $p < .001$; HF: $t(39) = 4.6$, $p < .001$) as were the complex conversations (HH: $t(35) = 12$, $p < .001$; HF: $t(39) = 11.9$, $p < .001$).

Author (s), Year	Objectives	Features	Methods				Results / Conclusions
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Rakauskas, Gugerty, & Ward (in review)	Explored naturalistic conversations in driving context.	*Hands-free vs. Hand-held:* Hands-Free *Conversation vs. Info Processing:* Converse *In-Vehicle vs. Remote:* Remote *Straight vs. Curved Roads:* Straight *Lane Keeping vs. Hazard Response:* Both	N = 24 (12 male, 12 female, 18-32 yrs, M = 20)	Task Condition: (No Conversation; Easy Conversation; Difficult Conversation)	Lane keeping (steering wheel offsets, mean lateral speed) Hazard RT (3 types of incursion events) Mental workload	In this simulator study, drivers drove a closed circuit road. For the phone task, drivers were asked questions that were easy (e.g., what's your major?) or difficult (e.g., would you prefer to be blind or deaf? Why?). There were 3 hazard events embedded within the experimental blocks, which required an overt response from drivers.	For lane keeping, there was greater variability in steering for the easy (2.22) and difficult (2.16) conversation conditions, relative to baseline (1.86; $t(23) = 2.4$, $p = .01$), but no difference across the two conversations themselves ($t(23) = 0.72$, $p = .24$). For hazard RTs, however, there were no differences between the two conversation types (Easy = -.04, Difficult = -.17, standardized) and baseline conditions (0.22; $t(23) = 0.53$, $p = .30$), nor between the two conversations ($t(23) = 0.37$, $p = .36$)

Author (s), Year	Objectives	Features	Methods				Results / Conclusions
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Serafin, Wen, Paelke, & Green (1993)	Examined different aspects of dialing and conversing on driving performance.	*Hands-free vs. Hand-held:* Both *Conversation vs. Info Processing:* Info Processing *In-Vehicle vs. Remote:* Remote *Straight vs. Curved Roads:* Curved *Lane Keeping vs. Hazard Response:* Lane Keeping	N = 12 (6 male, 6 female). 6 Younger (20-35 yrs, M = 24). 6 Older (> 60 yrs, M = 70)	Phone Type: (Manual; Voice-Operated) Display Type: (Instrument Panel, Head-Up Display, HUD) Number Length: (7; 11 digits) Number Familiarity: (Novel; Memorized) Task Combination: (Driving Alone; Driving + Dialing; Driving + Task) Task Type: (Loose-ends; Listing; Talking; Listening) Age: (Younger; Older) Gender: (Male; Female)	Lane position variability Dialing times for the phone tasks	In a low-fidelity simulator, driver drove on a single lane road in nighttime conditions. During driving blocks, participants engaged in several phone tasks involving dialing (see paper for details) and conversing. There were 4 different conversation types, including loose-ends (determine how many loose ends there were in a given capital letter, e.g., A = 2, B = 0); listing (name as many items belonging in a given category); Talking (answering simple questions); and listening (answering questions following a description of a hypothetical situation).	For driving performance, there was a significant effects of performing a concurrent phone task ($F(1,493) = 11.2$, $p < .001$), however this appeared to be a function of performing the dialing task (16.8 cm) as opposed to the conversation task (13.2 cm; baseline = 14.2 cm). (No post hoc comparisons reported) The voice operated system (14.5) led to slightly better performance than the manual system (15.5; $F(1,493) = 8.34$, $p = .004$)

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Siebert, Mouloua, Burns, Marino, Scagliola, Winters, Hancock, & Agliata (2002)	Examine driver distraction in conjunction with cell phone and analogue radio use.	*Hands-free vs. Hand-held:* Hand-Held *Conversation vs. Info Processing:* Info Processing *In-Vehicle vs. Remote:* Remote *Straight vs. Curved Roads:* Unknown *Lane Keeping vs. Hazard Response:* Lane Keeping	N = 34 (M = 21 yrs; 9 male, 25 female).	Device type: (Cell phone, Analogue radio) Phase: (Pre-, During, and Post-allocation phases)	Lane deviations Speed control Number of collisions Secondary task performance Errors on secondary task	Using a low-fidelity driving simulator, drivers were required to complete a concurrent secondary counting task, which was presented on an LCD screen (i.e., detect every fourth visual stimuli). Drivers first completed the pre-allocation phase, which involved the driving and secondary tasks. During the allocation phase, drivers performed both tasks while talking on a cell phone or continuously adjusting the radio. The post-allocation phase was the same as the pre- phase. NOTE: details regarding the cell phone and radio tasks are lacking.	Lane keeping: there were increased lane deviations during the allocation phase (9.1) compared to the pre- and post- phases (4.1, 5.9, respectively; $F(2,64) = 10.6$, $p < .001$) – measurement units are NOT specified. Secondary task performance: more errors were made during the allocation phase (6.5) that pre- and post- (4.5, 3.4; $F(2,64) = 5.7$, $p < .01$). No reported comparisons of cell phone versus radio tuning. NOTE: Lack of statistical and methodological details severely limits the quality and generalizability of results.

Author (s), Year	Objectives	Features	Methods				Results / Conclusions
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Strayer & Drews (2003)	Examined the differential effects of hands-free cell phone conversations on younger and older adults.	*Hands-free vs. Hand-held:* Hands-Free *Conversation vs. Info Processing:* Converse *In-Vehicle vs. Remote:* Remote *Straight vs. Curved Roads:* Unknown *Lane Keeping vs. Hazard Response:* Hazard Response	N = 40. Twenty younger (18-25, M = 20). Twenty older (65-74 yrs, M = 70)	Age: (Younger; Older) Task Conditions: (Driving Alone; Driving + Cell Phone)	Brake RT to lead vehicle Following distance Speed Half-recovery time (time to recover 50% of speed following a braking response)	In a driving simulator, drivers traveled through varied environments while sometimes engaged in a cell phone conversation. The conversations were tailored to the interests of the driver. The drivers were instructed to follow a lead vehicle throughout the drives. At random intervals, this vehicle would brake, requiring a response from the driver in order to avoid a collision.	There was a significant slowing in brake RT for dual-task versus single task conditions (153 ms slower; $F(1,38) = 12.96$, $p < .01$). There was no interaction with Age, however ($F(1,38) = 0.26$, $p > .64$)

Author (s), Year	Objectives	Features	Methods				Results / Conclusions
			Participants	Independent variables	Dependent variables	Procedure	
Strayer, Drews & Johnston (2003)	Examined the effects of hands-free phone conversations on driver response times, recognition of roadside features, and visual attention. NOTE: We do not report findings form Exp 2 (memory for roadside billboards), Exp 3 (eye scans towards billboards), or Exp 4 (implicit perceptual memory)	*Hands-free vs. Hand-held:* Hands-Free *Conversation vs. Info Processing:* Both *In-Vehicle vs. Remote:* Remote *Straight vs. Curved Roads:* Straight (?) *Lane Keeping vs. Hazard Response:* Hazard Response	Exp 1 N = 40 (M = 24 yrs, 18 male, 22 female).	Exp 1 Task condition: (No secondary task; Hands-free conversation) Traffic density (Low; High)	Exp 1 Brake response times (to lead vehicle) (Others: brake-offset time, time to minimum speed, following distance)	Exp 1 In a simulator, drivers drove on freeways in high or low traffic densities, while following a pace car. The pace car would slow frequently, requiring that drivers make the appropriate brake response. For half the trials, participants engaged in a hands-free phone conversation on issues of interest to the participant.	Exp 1 *There were small dual-task costs in brake response times for the low traffic (957 ms versus 928 ms, single task; $t(19) = 0.8$, effect size = 0.1) but more substantial in the high traffic condition (1112 ms vs. 933 ms single; $t(19) = 2.6$, $p > .01$; ES = 0.6

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Strayer, Drews, Albert, & Johnston (2002) Note: Exp 2 data is the same as reported in Strayer, Drews & Johnston (2003), so will not be reported again.	In two studies, examined the effects of cell phone conversation on driver performance in a laboratory (Exp 1) and simulator (Exp 2) environment.	*Hands-free vs. Hand-held:* Both *Conversation vs. Info Processing:* Converse *In-Vehicle vs. Remote:* Remote *Straight vs. Curved Roads:* Unknown *Lane Keeping vs. Hazard Response:* Hazard Response	N = 64 (32 male, 32 female, 19-30 yrs, M = 21)	Task Condition: (Hands-Free Conversation; Hand-Held Conversation; Radio Listening; Book-on-Tape Listening; No Secondary Task)	RT to traffic light stimulus Traffic light misses	Drivers performed a pursuit-tracking task while monitoring for red or green stimuli. When a red light appeared, they were instructed to brake as quickly as possible. The conversation tasks involved a discussion of a then-current news issue.	There were no differences between hands-free and hand-held conversations in RT to the red light ($p > .80$; no further stats presented. These conditions were aggregated in the following). With cell phones, drivers were slower to respond (585 ms) than when driving alone (534 ms; $F(1,31) = 29.8$, $p < .01$). There was no decrement when listening to the radio or a book-on-tape (533 ms; $F(1,31) = 2.7$, $p > .11$)

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Strayer & Johnston (2001)	Use a dual-task paradigm to examine the impact of hand-held and hands-free cell phones on driving performance and to explore the source of interference observed.	*Hands-free vs. Hand-held:* Both *Conversation vs. Info Processing:* Both *In-Vehicle vs. Remote:* Remote *Straight vs. Curved Roads:* None *Lane Keeping vs. Hazard Response:* ~Both	Exp 1 N = 48 (M = 21 yrs, 24 male, 24 female). Extra control: N = 20 (M = 21 yrs, 10 male, 10 female). Exp 2 N = 24 (M = 21 yrs, 12 male, 12 female).	Exp 1 Task condition: (No secondary task; Hand-held; Hands-free; Radio) Additional condition: (Book-on-tape) Exp 2 Tracking difficulty: (Easy; Hard) Task condition: (No task; Shadowing; Generation)	Exp 1 Number of missed events – light stimuli Reaction time to red light stimuli NOTE: No measures of primary tracking performance reported. Exp 2 RMS tracking error	Exp 1 Participants completed a pursuit tracking task while monitoring light stimuli. When a red light appeared, they were instructed to make a button response. The participants completed either a hand-held or a hands-free phone conversation condition, or a radio listening condition. The conversations involved then-current news topics. (In the extra control condition, participants listened to a book-on-tape.) Before and after the dual-task block, participants completed a baseline block for the tracking task. Exp 2 Similar to Exp 1, however the phone tasks were both done with a hand-held. For shadowing, participants repeated words spoken by the experimenter. For the generation task, they generated new words based on the last letter of the previously spoken word.	Exp 1 **There were no differences between hands-free and hand-held in terms of the probability of missing an event and RTs ($F(1,30) = .06$, $p > .80$; $F(1,30) = .01$, $p > .90$, respectively). *The p(miss) was more than double in the dual-task cell phone conditions (.07) compared to single-task (.03; $F(1,30) = 8.8$, $p < .01$). There were no differences between single- and dual-task conditions for the radio task. *RT to the light event followed similar patterns, with slower responses for the dual cell phone conditions (~585 ms) vs. baseline (533 ms; $F(1,30) = 28.9$, $p < .01$), and that these effects were more pronounced when the participant was talking as opposed to listening. The results from the book-on-tape condition closely paralleled those for the radio condition. Exp 2 *The Tracking x Task interaction showed that the shadowing condition did not differ from baseline tracking, however there was poorer tracking with the generation task ($F(1,23) = 17.6$, $p < .01$) and this decrement was especially pronounced in the difficult condition ($F(1,23) = 10$, $p < .01$).

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Waugh, Glumm, Kilduff, Tauson, Smyth, & Pillalamarri (2000)	Examine differences in cognitive workload and performance while completing a concurrent cognitive test battery administered by a passenger or via cell phone.	*Hands-free vs. Hand-held:* Hand-Held *Conversation vs. Info Processing:* Info Processing *In-Vehicle vs. Remote:* Both *Straight vs. Curved Roads:* Curved *Lane Keeping vs. Hazard Response:* Lane Keeping	N = 12 (M = 38 yrs; 7 male, 5 female). All had experience with cell phones (0.7 to 5 yrs).	Source of input: (Passenger; Cell Phone)	Mean Lap Time – driver velocity Driver Error – traffic cone hit Rosenbaum Verbal Cognitive Battery (RVCB) – measures judgment, “flexible thinking”, and speed of info processing through remembering sentences and verbal puzzles Subjective Workload Assessment Technique (SWAT)	In a field trial, drivers navigated a highly curved course (marked by traffic cones). Drivers were instructed to drive the course as quickly as they could without hitting any of the cones. The 4 experimental conditions, which were fully counterbalanced, were: baseline driving (no side task); baseline RVCB (no driving); driving with passenger-spoken RVCB; driving with cell phone RVCB.	Drivers were slower in the passenger (43 s, mean lap time) and phone conditions (47 s), relative to baseline (41 s; $F(1,11) = 14$, $p < .001$). Post hoc test showed that the baseline and passenger conditions did not differ from one another. **The number of driver errors was relatively constant across baseline, passenger, and phone conditions (19, 22, 18, respectively; $F(2,22) = 0.3$, no p). For remembering sentences: There was a significant difference in response latencies ($F(1,11) = 42$, $p < .001$), with slower times in the phone condition (2.3 s) compared to the passenger (0.25 s) and baseline conditions (0.27 s). There were no differences for measures of response duration or errors. For verbal puzzles: There was a significant increase in response durations for the phone condition (3.6 s), relative to passenger (1.1 s) and baseline conditions (1 s; $F(1,11) = 9$, $p < .025$). For SWAT ratings: the phone condition had higher workload ratings than the two baseline conditions. The passenger was rated higher WL than driving but not RVCB baseline.