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A meta-analysis of driving performance associated with the use of cellular telephones while driving: Results and methodological implications

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Study Objectives

Currently, 45 countries have implemented bans on using cell phones while driving. Policy makers must weigh the benefits of using cell phones while driving against the growing literature suggesting negative impacts for a variety of activities. A synthesis of the research in this area can provide useful guidance for those who seek to base their policies on available science.

This paper addresses the effects of cell phones on driving performance by means of a review of the literature and an analysis of scientifically credible epidemiological and driver performance studies. A total of 69 articles were obtained covering the period 1969–2005 that measured driving performance while using a cell phone.

Based on an initial review of this literature, the analysis focused on twenty two performance studies of sufficient quality which were used to answer four questions.

1. Does conversation on cell phones, whether hand-held or hands-free, influence driving performance?
2. Are there differences in findings among computer-based studies, driving simulator studies and on-road studies?
3. Does performance differ between hand-held and hands-free cell phones?
4. Are some age groups more susceptible to negative influences of cell phone use on driving?

Each question is briefly discussed either here or in the presentation, whereas the full technical report can be found at the url listed in the reference section (Caird et al., 2004).

The discussion about methods is expanded to address gaps in existing cellular telephone research and to anticipate analogous issues that face the integration of other technologies into the automobile.

Methods

The methodological approach was as follows. Where there were sufficient studies, meta-analyses were carried out to combine study results to answer the above questions (Rosenthal & Diamatto, 1991). Where there were not sufficient studies, the results of performance (i.e., reaction time and driving variables) studies were reviewed. In addition, because of the availability of a large number of studies, a quantitative analysis of reaction time, as affected by cell phone characteristics, cell phone tasks, driving tasks and driver age was carried out. Studies that were included in the meta-analysis and RT analyses respectively are indicated as such in thre reference section.

Two meta-analyses were carried out to address the influence of cell phones on driving performance. The first analysis was done to determine the effects of cell phone use on performance. Three categories of performance were considered: RT to critical events (e.g., a vehicular incursion), driving control variability variables (i.e., lane position, headway and speed variability) and speed (i.e., mean speed).

The second analysis compared cell phone effects as a function of whether the experiment was carried out on a desktop computer (e.g., a search task executed while engaged in conversation), a simulator, or on the road. As discussed in the section on methodology, each meta-analysis dealt with unknown effects. Two approaches were used, one more conservative and the other less conservative, to determine the maximum and minimum likely effects.

Results

The meta-analysis of the performance studies showed moderate-to-large negative effects of the use of cell phones on driving performance, which was also found by Horrey and Wickens (2004). The largest negative effects were found for reaction time (an increase of 0.23 of a second on average and for older drivers, in particular, about 1/2 second). There were lesser size effects for lateral and longitudinal (headway) control, and speed control.

Differences in findings were evident among computer-based studies, driving simulator studies and on-road studies (see Table 1). A meta-analysis of the performance studies showed the strongest effects for laboratory studies, in comparison to on-road or driving simulator studies. Nonetheless, even using the most conservative analysis, on-road studies showed moderate impacts of cell phone use on performance.

Based on the RT analyses, performance did not differ between hand-held and hands-free cell phones. There were insufficient studies to carry out a meta-analysis. Most driving performance studies found no difference between hands-free and hand-held phones. However, the comparisons made have not focused on those situations in which hand-held phones are likely to be more of a liability with respect to physical demands of driving – for example, while merging into traffic, or while dialling or answering a call.

Table 1. Effects of cell phone vs. no cell phone across study types.

Statistic	Lab Studies	Simulator Studies	On-Road Studies
Ignoring Data Reported as Non-Significant			
Average Effect	0.89	0.36	0.64
Standard Deviation	0.40	0.20	0.42
Median	0.87	0.35	0.59
N of Data Points	9	21	11
Setting to Zero Non-Significant Effects and Averaging across Measures			
Average Effect	0.57	0.26	0.38
Standard Deviation	0.54	0.18	0.36
Median	0.59	0.26	0.28
N of Data Points	5	12	6

Reaction time (RT) is a dependent variable category that includes simple reaction time, choice reaction time, perception reaction time and brake reaction time (Olson & Farber, 2003). When the stimulus and response characteristics of the RT category are logically grouped and analyzed, Table 2 results. The RT increase is greatest for lead vehicle braking (0.43 s) and least when responding to a simple stimulus such as the onset of a single LED (0.06 s). BRT/RT to an abstract stimulus response (S-R) includes responses or stimuli that are not usually encountered by drivers. For example, braking to a red square that appears on the left-hand side of the road or flashing a car's warning lights to traffic lights are not typical driver actions. The authors of these studies argue that these manipulations approximate surprise events, but the novelty of these events may speed responses and/or confuse participants if they cannot remember how to respond (e.g., older adults).

Table 2. Mean reaction time increase (i.e., drive with distraction – baseline drive), standard deviation of study means, number of studies and number of participants.

Condition	Mean Increase in Reaction Time (seconds)	Standard Deviation	Number of Studies	Number of Participants
All Distraction Tasks	0.23	0.31	18	532
BRT, Lead Vehicle Brakes	0.43	0.46	6	230
BRT, Light Change at Intersection	0.12	0.18	3	78
BRT/RT, Abstract S-R	0.17	0.17	4	104
RT, Simple	0.06	0.19	5	147

A number of individual studies, not listed in Table 2, used unique scenarios that were quite relevant to the impact of cell phone distractions on driver performance. The sudden appearance of a pedestrian on the right while the driver was talking on a hands-free phone produced a 0.14 s increment (LaBerge et al., 2004), whereas when a lead vehicle cut in while talking, a 0.77 s increment was found (Ranney, Watson, Mazzae, Papelis, Ahmad, & Wightman, 2004).

Conclusions

Our conclusions were similar to those of other reviews of the cell phone and driving literature. Additional findings of interest, not included in the meta-analyses, were that the reaction time increase was greater for lead vehicle braking as compared to other reaction time situations, and that use of a cell-phone while driving reduced the eyes-on-road time while driving, and narrowed the areas to which drivers attended.

A number of gaps in research were identified. These include:

- Insufficient study of hand-held as compared to hands-free cell phones
- Cell phone use while driving and strategic use as unknown moderators
- Lack of clarity concerning the timing of the cell phone task and a critical driving event and the performance of the cell phone task
- Lack of clarity regarding the meaning of reported driving performance independent and dependent variables (e.g., eye movements)

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References

Studies that are preceded by an asterisk (*) were included in the meta-analysis, whereas studies included in the quantitative RT analysis are denoted by a number sign (#).

#*Ålm, H., & Nilsson, L. (1994). Changes in driver behaviour as a function of handsfree mobile phones: A simulator study. *Accident Analysis & Prevention, 26*(4), 441-451.

#*Ålm, H., & Nilsson, L. (1995). The effects of mobile telephone task on driver behaviour in a car following situation. *Accident Analysis & Prevention, 27*(5), 707-715.

*Brookhuis, K.A., de Vries, G., & de Waard, D. (1991). The effect of mobile telephoning on driving performance. *Accident Analysis & Prevention, 23*(4), 309-316.

#Burns, P.C., Parkes, A., Burton, S., Smith, R.K., & Burch, D. (2002). *How dangerous is driving with a mobile phone? Benchmarking the impairment to alcohol* (Tech. Rep. TRL 547). Crowthorne, U.K.: Transport Research Laboratory.

#Burns, P.C., Parkes, A.M., & Lansdown, T.C. (2003). Conversations in cars: The relative hazards of mobile phones. *Proceedings of the International Ergonomics Association Meeting [CD-ROM].* Seoul, Korea: IEA.

Caird, J.K., Lees, M., & Edwards, C. (2004). *The naturalistic driver model: A review of distraction, impairment and emergency factors*. Richmond, CA: California PATH/U. of California at Berkeley.

Caird, J.K., Scialfa, C., Ho, G., & Smiley, A., (2004). *The Effects of Cellular Telephones on Driving Behaviour and Accident Risk: Results of a Meta-Anlaysis*. Edmonton, AB: AMA/CAA. www.ama.ab.ca/advocacy/traffic_safety/FinalReport_CellPhones4.pdf

#*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 & Prevention, 325*, 495–500.

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

Goodman, M.J., Bents, F.D., Tijerena, L., Wierwille, W., Lerner, N., & Benel, D. (1997). *An investigation of the safety implications of wireless communications in vehicles* (DOT HS 806-635). Washington, D.C.: National Highway Transportation Safety Administration. http://www.nhtsa.dot.gov/people/injury/research/wireless/

*Gugerty, L., Rando, C., & Rakauskas, 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.

#Hancock, P.A., Hashemi, L., Howarth, H., & Ranney, T. (1999). The effects of in-vehicle distraction on driver response during a critical driving maneuver. *Transportation Human Factors, 1*(4) 295-309.

#Hancock, P.A., Lesch, M., & Simmons, L. (2003). The distraction effects of phone use during a crucial driving maneuver. *Accident Analysis & Prevention, 35*, 510–514.

Horrey, W., & Wickens, C. (2004). *The impact of cell phone conversations on driving: A meta-analytic approach* (Tech. Rep. No. AHFD-04-2/GM-04-1). Savoy, Illinois: Institute of Aviation.

*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.

*Ishida, T., & Matsuura, T. (2001). The effect of cellular phone use on driving performance. *IATSS Research, 25*(2), 6-14.

#* Laberge, J., Scialfa, C., White, C., & Caird, J. (2004). The effect of passenger and cellular-phone conversations on driver distraction. *Transportation Research Record, 1899*, 109-116.

#*Lamble, D., Kauranen, T., Laakso, M., & Summala, H. (1999). Cognitive load and detection thresholds in car following situations: Safety implications for using mobile telephone (cellular) telephones while driving. *Accident Analysis & Prevention, 31*, 617-623.

*McCarley, J., Vais, M., Pringle, H., Kramers, A.F., Irwing, D.E., & Strayer, D.L. (2001). Conversation disrupts visual scanning of traffic scenes. *Vision in Vehicles*. Australia.

*McPhee, L., Scialfa, C., Dennis, W., Ho, G. & Caird, J.K. (2004). Age differences in visual search for traffic signs during a simulated conversation. *Human Factors*, *46*(4), 674-685.

*Nilsson, L., & Ålm, H. (1991). *Elderly people and mobile telephone use– including comparisons to younger drivers' behaviour.* (Rep. No. 176, DRIVE Project V1017, BERTIE). Gothenburg, Sweden: Swedish Road and Traffic Research Institute.

#*Parkes, A.M., & Hooijmeijer, V. (2001). Driver situation awareness and car phone use. *Proceedings of the 1st Human-Centered Transportation Simulation Conference* (ISSN 1538-3288). Iowa City, IA: University of Iowa.

#*Patten, C.J.D., Kircher, A., Ostlund, J., & Nilsson, L. (2004). Using mobile telephones: Cognitive workload and attention research allocation. *Accident Analysis & Prevention*, *36*, 341–350.

*Rakauskas, M., Gugerty, L., & Ward, N.J. (2004). Effects of naturalistic cell phone conversations on driving performance. *Journal of Safety Research, 35*, 453–464.

#*Ranney, T., Watson, G., Mazzae, E.N., Papelis, Y.E., Ahmad, O., & Wightman, J.R. (2004). *Examination of the distraction effects of wireless phone interfaces using the National Advanced Driving Simulator-Preliminary report on freeway pilot study (Pre. No. DOT 809 737).* National Highway Transportation Safety Administration: East Liberty, OH.

Rosenthal, R., & DiMatteo, M.R. (2001). Meta-analysis: Recent developments in quantitative methods for literature reviews. *Annual Review of Psychology, 52*, 59–82.

#*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.

*Strayer, D.L., Drews, F.A., Albert, & Johnston, W.A. (2002). Why do cell phone conversations interfere with driving? *Proceedings of the 81st Annual Transportation Research Board Meeting* [CD-ROM]. Washington, D.C.: TRB.

#Strayer, D.L., Drews, F.A., & Crouch, D.J. (2003). Fatal attraction? A comparison of the cell-phone driver and the drunk driver. *Proceedings of the Second International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design* (pp. 25-30). Park City, Utah.

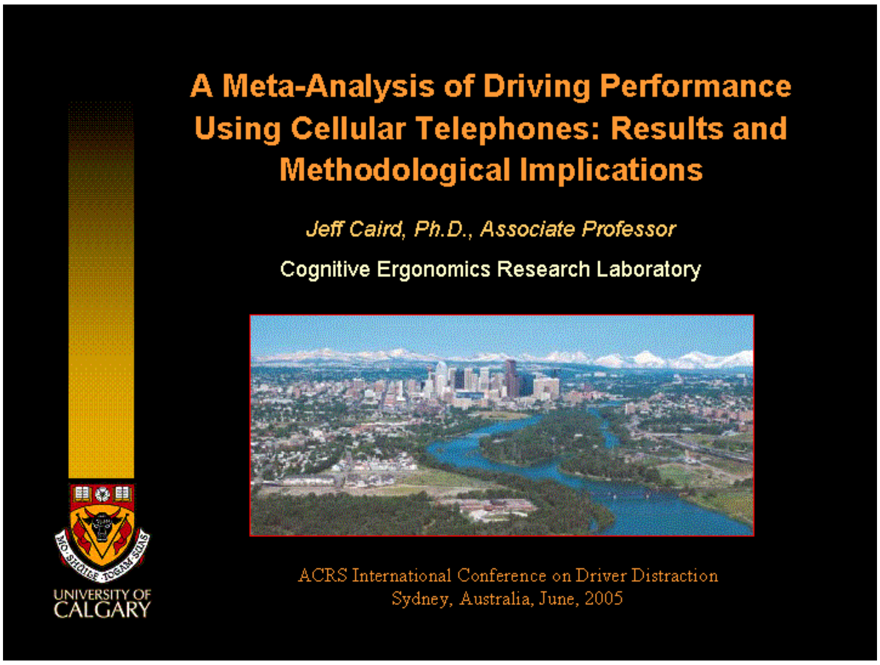
#*Strayer, D.L., Drews, F.A., & Johnston, W.A. (2003). Cell phone-induced failures of attention during simulated driving. *Journal of Experimental Psychology: Applied, 9*(1), 23-32.

*Strayer, D.L., & Johnston, W.A. (2001). Driven to distraction: Dual-task studies of simulated driving and conversing on a cellular telephone. *Psychological Science, 12*(6), 1-5.

*Tijerina, L., Kiger, S., Rockwell, T., & Tornow, C. (1996). *Heavy vehicle driver workload assessment, Task 7A: In-car text message system and cellular phone use by heavy vehicle drivers on the road* (Rep. No. DOT HS 808 467 7A). Washington, D.C.: NHTSA.

#Tokunaga, R.A., Hagiwara, T., Kagaya, S., & Shimojyo, A. (2000). Cellular telephone conversation while driving: Effects on driver reaction time and subjective mental workload. *Transportation Research Record, 1724*, 1–6.

PRESENTATION SLIDES



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What Cell Phone Tasks Affect Driving?

1. Finding the phone.
2. Dialing the phone.
3. Talking on the phone.
4. Hanging up the phone.

Goodman, Bents, Tijerena, Wierwille, Lerner & Benel (1997)

What is the Contribution of Distraction to Crashes, Injuries and Fatalities?

About 20 to 30 percent of all crashes in the U.S. have distraction as a contributor.

About 25 to 30 percent of PDO and injury crashes are the result of driver distraction as a contributing factor.

Eleven percent of fatalities in the U.S. have driver distraction as a contributing factor.

NHTSA (2001)

Driver Distraction Categories

Driver Distraction	Overall (N = 1,420K)
Outside person, object, or event (e.g., vehicle, police, animal, novel events, people or objects in the road, etc.)	**29.4** (2.4)
Adjusting radio/cassette/CD	**11.4** (3.7)
Other occupant (e.g., talking, yelling, fighting, child, infant)	**10.9** (1.7)
Moving object in vehicle (e.g., insects, animals, objects)	**4.3** (1.6)
Other device/object (e.g., purse, water bottle, etc.)	**2.9** (0.8)
Adjusting vehicle/climate controls	**2.8** (0.6)
Eating/drinking (e.g., burger, tea, coffee, soda, alcohol, etc.)	**1.7** (0.3)
Talking/listening/dialing cell phone (e.g., answer, initiate call)	**1.5** (0.5)
Smoking related (e.g., reaching for, lighting, dropping, etc.)	**0.9** (0.2)
Other distraction (e.g., medical, other inside or outside events or objects, intoxicated, depressed, etc.)	**25.6** (3.1)
Unknown distraction	**8.6** (2.7)

Stutts, Reinfurt, Staplin & Rodgman (2001)

Cell Phone Legislation (and Enforcement)

- Forty-five countries have implemented bans on driving with cell phones (Cellular News, 2004),
- Including U.K., Germany, France, Japan, the Netherlands and Australia.
- In Canada, only New Foundland and Labrador have introduced a ban (Transport Canada, 2004).
- In the U.S., New York, New Jersey and D.C. have full bans and other states are currently debating legislation (Cellular News, 2004).

Meta-Analysis Methods

1. Meta-analysis combines results across studies to yield an overall estimate of effect size and compares effects between studies to understand moderating factors.

2. Examined 89 epidemiological and driver performance studies from 1969 to 2005 for methodological and statistical fit with our primary research questions.

3. A total of 27 performance studies were combined to yield effect sizes for the dependent variables of reaction time, lateral control, longitudinal control, and speed.

Caird, Scialfa, Ho & Smiley (2004)

Primary Research Questions

1. Does conversation on cell phones, whether hand-held or hands-free, influence driving performance?

2. Are some age groups more susceptible to negative influences of cell phone use on driving?

3. Are there differences in findings among computer-based studies, driving simulator studies and on-road studies?

4. What are the gaps in literature and research methods?

Statistical Limitations

1. Deficiencies of statistical reporting.
2. Heterogeneity testing for moderating variables.
3. Fixed versus random effects models.
4. Drivers or studies as the unit of analysis.

Driving Performance with Cell Phones

TABLE 2. Summary statistics for effects of cell phone use on RT and driving variable studies

Statistic	RT	Driving Variables
Ignoring Data Reported as Non-Significant		
Average	0.64	0.31
Standard Deviation	0.41	0.18
Median	0.59	0.30
N of Data Points	28	16
Setting to Zero Non-Significant Effects and Averaging Across Measures		
Average	0.44	0.23
Standard Deviation	0.40	0.23
Median	0.42	0.20
N of Data Points	21	12

How Does Cell Phone Use Affect Driving?

1. Lateral control.
2. Longitudinal control.
3. Reaction time.
4. Hazard detection.

Caird et al. (2004)

Comparison of Methods

Statistic	Lab Studies	Simulator Studies	On-Road Studies
Ignoring Data Reported as Non-Significant			
Average Effect	0.89	0.36	0.64
Standard Deviation	0.40	0.20	0.42
Median	0.87	0.35	0.59
N of Data Points	9	21	11
Setting to Zero Non-Significant Effects and Averaging across Measures			
Average Effect	0.57	0.26	0.38
Standard Deviation	0.54	0.18	0.36
Median	0.59	0.26	0.28
N of Data Points	5	12	6

1. Laboratory studies were most sensitive.
2. Relevance of distraction tasks to driving.

Differences in Reaction Time Measures

Condition	Mean Increase in Reaction Time (seconds)	Standard Deviation	Number of Studies	Number of Participants
All Distraction Tasks	0.23	0.31	18	532
BRT, Lead Vehicle Brakes	0.43	0.46	6	230
BRT, Light Change at Intersection	0.12	0.18	3	78
BRT/RT, Abstract S-R	0.17	0.17	4	104
RT, Simple	0.06	0.19	5	147

1. Relevance of task to safety.
2. Expected versus unexpected events.

Which is Worse, Hands-Free or Hand Held?

Condition	Mean Increase in RT (seconds)	Standard Deviation (seconds)	Number of Studies	Number of Participants
All Distraction Tasks	0.23	0.31	18	532
Hand Held Phone	0.20	0.17	4	132
Hands Free Phone	0.21	0.30	14	430

Does Cell Phone Use and Age Matter?

Condition	Mean Increase in RT (seconds)	Standard Deviation	Number of Studies	Number of Participants
All Distraction Tasks	0.23	0.31	18	532
Younger Drivers	0.19	0.26	5	83
Older Drivers	0.46	0.56	5	59

How Do Different Cell Phone Tasks Affect Driver Response Time?

Condition	Mean Increase in Reaction Time (seconds)	Standard Deviation	Number of Studies	Number of Participants
All Distraction Tasks	0.23	0.31	18	532
Cognitive Task	0.34	0.40	9	274
Conversation	0.15	0.13	7	65
Dial/Enter Number	0.30	0.16	3	65
Converse with Passenger	0.20	0.13	3	84
Listen to Radio/Other	0.05	0.03	3	88
In-Vehicle Device Operation	0.35	0.36	1	19

Caird & Hancock (2005)

Research Gaps

1. Hand held versus hands free.

2. Cell phone use while driving experience and strategic use as unknown moderators.

3. Reporting of secondary task performance and experimental checks for task shedding.

4. Ambiguous definitions and imprecise reporting of independent and dependent variables (e.g., eye movements).

Discussion and Conclusions

- Interaction with and conversation on a mobile phone delays recognition and response to important traffic events.

- The issues of driver distraction from mobile phones will also be problematic for other in-vehicle technologies.

- Legislation that bans younger drivers use of technology and travel with passengers is likely to reduce traffic fatalities.

- Another solution to the problem of driver distraction is to make driving and attending to *any* distracting device socially unacceptable.