The New England
Journal of Medicine

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VOLUME 336 FEBRUARY 13, 1997 NUMBER 7

ASSOCIATION BETWEEN CELLULAR-TELEPHONE CALLS AND MOTOR VEHICLE COLLISIONS

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ABSTRACT

Background Because of a belief that the use of cellular telephones while driving may cause collisions, several countries have restricted their use in motor vehicles, and others are considering such regulations. We used an epidemiologic method, the case–crossover design, to study whether using a cellular telephone while driving increases the risk of a motor vehicle collision.

Methods We studied 699 drivers who had cellular telephones and who were involved in motor vehicle collisions resulting in substantial property damage but no personal injury. Each person's cellular-telephone calls on the day of the collision and during the previous week were analyzed through the use of detailed billing records.

Results A total of 26,798 cellular-telephone calls were made during the 14-month study period. The risk of a collision when using a cellular telephone was four times higher than the risk when a cellular telephone was not being used (relative risk, 4.3; 95 percent confidence interval, 3.0 to 6.5). The relative risk was similar for drivers who differed in personal characteristics such as age and driving experience; calls close to the time of the collision were particularly hazardous (relative risk, 4.8 for calls placed within 5 minutes of the collision, as compared with 1.3 for calls placed more than 15 minutes before the collision; $P<0.001$); and units that allowed the hands to be free (relative risk, 5.9) offered no safety advantage over hand-held units (relative risk, 3.9; P not significant). Thirty-nine percent of the drivers called emergency services after the collision, suggesting that having a cellular telephone may have had advantages in the aftermath of an event.

Conclusions The use of cellular telephones in motor vehicles is associated with a quadrupling of the risk of a collision during the brief period of a call. Decisions about regulation of such telephones, however, need to take into account the benefits of the technology and the role of individual responsibility. (N Engl J Med 1997;336:453-8.)

MOTOR vehicle collisions are a leading cause of death in North America; they are the single most frequent cause of death among children and young adults and account for one fatality every 10 minutes.[1-3] During an average year, about 1 person in 50 will be involved in a motor vehicle collision; 1 percent of them will die, 10 percent will be hospitalized, and 25 percent will be temporarily disabled.[4,5] Motor vehicle collisions often injure persons who are otherwise in good health. The causes of motor vehicle collisions are complicated, but error on the part of drivers contributes to over 90 percent of events.[6]

Cellular telephones can be used for placing and receiving telephone calls while in a motor vehicle. North American sales are enormous; for example, in 1995 the number of new subscribers in the United States exceeded the birth rate.[7,8] Many believe that telephones may contribute to collisions by distracting drivers,[9] and a few countries (such as Brazil, Israel, and Australia) have laws against using a cellular telephone while driving. Research with simulators suggests that use of the telephone can impair some aspects of driving performance.[10-14] However, industry-sponsored surveys have found no increased risk associated with car telephones.[15,16]

The most rigorous experimental method for testing the effects of cellular telephones on motor vehicle collisions is to assess outcomes for persons randomly assigned to use or not use the devices, but such a study would be very difficult to perform and possibly unethical. Instead, we used an epidemiolog-

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ic method, the case–crossover design, to evaluate potential associations between the use of a cellular telephone and the risk of a motor vehicle collision in real-world circumstances.

METHODS

The study was conducted in Toronto, an urban region of 3 million people with no regulations against using a cellular telephone while driving. Persons who came to the North York Collision Reporting Centre between July 1, 1994, and August 31, 1995, during peak hours (10 a.m. to 6 p.m.) on Monday through Friday were included in the study if they had been in a collision with substantial property damage (as judged by the police). Drivers do not report to the center if the collisions involve injury, criminal activity, or the transport of dangerous goods. Drivers were excluded if they said they did not have a cellular telephone or if their billing records could not be located by May 1, 1996.

Use of Cellular Telephones

Consenting subjects completed a brief questionnaire about their personal characteristics and the features of the collision. We collected telephone records through each person's cellular-telephone number and verified each invoice by checking the subject's full name, mailing address, and calls made to his or her home telephone number. For each record, we analyzed all telephone activity on both the day of collision and the preceding seven days, with particular attention to the time, duration, and direction (incoming or outgoing) of each call. Special note was made of contact with ambulance personnel, police, or other emergency services.

Time of the Motor Vehicle Collision

The time of each collision was estimated from the subject's statement, police records, and telephone listings of calls to emergency services. We classified the times of collisions as "exact" when information from all three sources was available and consistent or when one source supplied no data but the remaining two agreed. Otherwise, we classified the times as "inexact" and used the earliest of the available two or three times to avoid misclassifying calls made after the collision as contributing to the event. Selecting the earliest listed time reduced the chance of finding spurious associations between telephone use and collisions. However, selecting an excessively early time could lead to the underestimation of the magnitude of any association.

Analytic Method

We used case–crossover analysis, a technique for assessing the brief change in risk associated with a transient exposure. According to this method, each person serves as his or her own control; confounding due to age, sex, visual acuity, training, personality, driving record, and other fixed characteristics is thereby eliminated.[17] We used the pair-matched analytic approach to contrast a time period on the day of the collision with a comparable period on a day preceding the collision.[18] In this instance, case–crossover analysis would identify an increase in risk if there were more telephone calls immediately before the collision than would be expected solely as a result of chance.

Definitions of Time Periods

We defined the hazard interval to include any telephone calls occurring during the 10 minutes before the estimated time of the collision, and tested the robustness of our results by analyzing intervals of 1, 5, and 15 minutes.[19] In the primary analysis, we compared each person's telephone activity immediately before the collision (case) to his or her activity during a control period at the same time as the hazard interval on the day before the collision (crossover). In supplementary analyses we evaluated alternative comparison days and considered intervals of an hour leading up to the collision.

Alternative Comparison Days

We checked our estimates by repeating the calculations using four other control intervals. In the workday comparison we selected the day of the workweek preceding the collision; for example, the period just before a collision on Monday was compared with the same period on the preceding Friday. In the weekday comparison, we selected the same day one week before the collision; for example, Monday was compared with the preceding Monday. In the matching-day comparison, we selected the nearest day of the preceding week on which there was cellular-telephone activity in the predefined lead-up period before the collision. For the maximal-use-day comparison, we used the control interval from the preceding three days in which there was the greatest amount of cellular-telephone activity.

Accounting for Intermittency of Driving

Evaluating telephone activity on the day before a collision is appropriate only if driving occurred during the control interval on that day. A pilot survey involving 100 subjects indicated that 35 percent of them did not drive during the selected period; the rules of conditional probability suggested that this degree of intermittency of driving would inflate the apparent relation between cellular-telephone use and motor vehicle collisions by a factor of 1.5 ($1 \div 0.65$).[20,21] Our estimates of relative risk were therefore divided by this factor as one way of adjusting for the intermittency of driving.

To examine the robustness of our analysis, we also tested a different adjustment that relied on individual driving patterns. To do so, between October 25 and November 28, 1996, we attempted to contact all subjects who had used their cellular telephones in the 10 minutes before the collision or the 10-minute control period. We asked each person to remember his or her driving pattern on both the day of the collision and the day before the collision. We then recalculated relative risks by limiting the analysis to subjects who were confident that they had driven a motor vehicle during both periods on both days.

Ethical Issues

The protocol was approved by the University of Toronto Human Ethics Committee, and all participants provided informed consent. Private industry supplied telephone records but otherwise had no involvement in data collection or analysis or funding the study. Individual billing records were obtained directly from cellular-telephone carriers who provided records for 100 consecutive days of telephone use for each person and who were not told which particular date was the day of the collision. Police reports were obtained directly from police departments; they, in turn, were not provided copies of the drivers' cellular-telephone records.

Statistical Analysis

The sample size was calculated to provide an 80 percent chance of detecting a doubling or halving of collision rates. Relative risks were estimated with methods for matched-pairs studies on the basis of exact binomial tests and conditional logistic-regression analyses.[22] Confidence intervals for the relative risks were derived with the bootstrap bias-corrected method and accounted for the uncertainty in the adjustment for intermittency of driving.[23,24] Modifications of the relative risks were assessed by comparing different subgroups, with particular attention to the prespecified contrast between hand-held cellular telephones and models that leave the hands free. All P values were two-tailed, and all relative risks were computed with 95 percent confidence intervals.

RESULTS

We approached 5890 drivers, of whom 1064 acknowledged having a cellular telephone and 742 consented to participate in the study; the billing records of 699 of these drivers were located (Table 1). The collision times were exact for 231 subjects and inexact for 468. The group placed a total of 16,870 cellular-telephone calls and received 3643 calls during the week before the collisions (average, 3.4 calls placed and 0.7 call received per person each day). The average duration of the calls was 2.3 minutes, and 76 percent lasted 2 minutes or less (similar to cellular-telephone calling patterns elsewhere[25]). The monthly bill in U.S. currency for the average participant was $72, which was greater than that for the average subscriber in Toronto or the average subscriber in North America ($53 and $51, respectively).[26-28]

Overall, 170 subjects (24 percent) had used a cellular telephone during the 10-minute period immediately before the collision, 37 (5 percent) had used the telephone during the same period on the day before the collision, and 13 (2 percent) had used the telephone during both periods. The crude analysis indicated that cellular-telephone activity was associated with a relative risk of a motor vehicle collision of 6.5 (95 percent confidence interval, 4.5 to 9.9). The primary analysis, adjusted for intermittent driving, indicated that cellular-telephone activity was associated with a quadrupling of the risk of a motor vehicle collision (relative risk, 4.3; 95 percent confidence interval, 3.0 to 6.5).

At follow-up in 1996, we located 145 subjects, of whom 72 (50 percent) were confident that they had driven during both the hazard period and the control period. Restricting our analysis to this subgroup yielded an estimated relative risk of 7.0 (95 percent confidence interval, 3.7 to 15.5) associated with cellular-telephone use. An analysis that included the entire cohort of 699 drivers and used alternative comparison days yielded similar estimates of the relative risk of a collision (Fig. 1). All the alternative estimates of relative risk were adjusted for intermittent driving, and all were statistically significant ($P<0.001$).

The relative risk of a collision associated with using a cellular telephone was consistent among subgroups with different characteristics (Table 2). Younger drivers were at a somewhat higher relative risk when using a cellular telephone than older drivers, although the trend was not significant. In no group did cellular-telephone use have a protective effect. In particular, subjects with many years of experience in using a cellular telephone still had a significant increase in risk. The highest relative risk was found among subjects who had not graduated from high school. Telephones that allowed the hands to be free did not appear to be safer than hand-held telephones.

The increase in risk appeared to be greatest for calls made near the time of the collision, and was not statistically significant for calls made more than 15 minutes before the event (Fig. 2). The relative risk was 4.8 for calls within 5 minutes before the collision, as compared with 1.3 for calls more than 15 minutes before the collision ($P<0.001$). The risks were similar at different times of the day and of the week (Fig. 3). Estimates appeared robust when calculated with use of hazard intervals of 1, 5, or 15 minutes before the collision (relative risks, 4.7, 4.8, and 4.3, respectively), for data including exact rather than inexact times of collisions (4.0 and 4.5, respectively), and with only incoming calls or only outgoing calls included (3.0 and 3.8, respectively). The association appeared stronger for collisions on high-speed roadways than for collisions in parking lots, at gas stations, or in other low-speed locations (5.4 vs. 1.6, $P=0.014$).

A total of 5325 calls were placed and 960 calls

TABLE 1. CHARACTERISTICS OF 699 DRIVERS AND COLLISIONS.

CHARACTERISTIC	NO. (%)*
Age (yr)	
<25	67 (10)
25–39	346 (49)
40–54	227 (32)
≥55	59 (8)
Sex	
Male	502 (72)
Female	197 (28)
High-school graduation	
Yes	615 (88)
No	84 (12)
Type of job	
Professional	168 (24)
Other	531 (76)
Driving experience (yr)	
0–9	137 (20)
10–19	246 (35)
20–29	188 (27)
≥30	128 (18)
Cellular-telephone experience (yr)	
0 or 1	223 (32)
2 or 3	174 (25)
4 or 5	158 (23)
≥6	144 (21)
Type of cellular telephone	
Hand-held	551 (79)
Hands free	148 (21)
Time of collision	
Dawn	19 (3)
Morning	268 (38)
Afternoon	248 (35)
Evening	145 (21)
Night	18 (3)
Late night	1 (<1)
Day of collision	
Sunday	20 (3)
Monday	133 (19)
Tuesday	126 (18)
Wednesday	159 (23)
Thursday	136 (19)
Friday	113 (16)
Saturday	12 (2)
Location of collision	
High-speed location	597 (85)
Low-speed location	102 (15)

*Because of rounding, percentages do not always total 100.

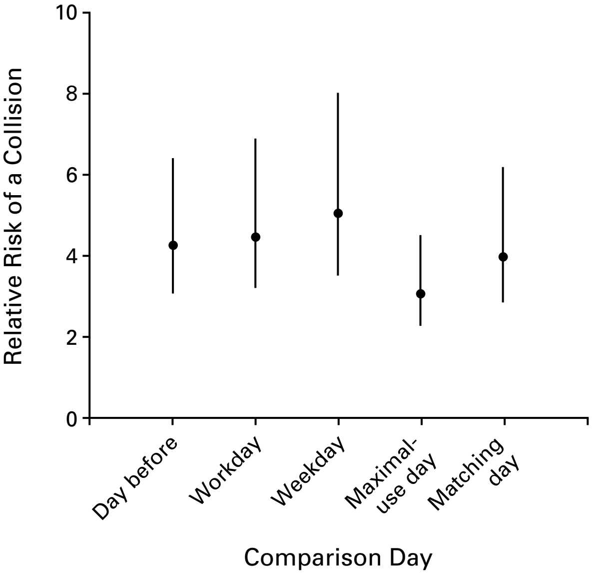

Figure 1. Relative Risk of a Collision for Different Control Periods.

Relative risks were calculated for five different control intervals. In the day-before comparison, we used the control period on the day immediately before the collision; in the workday comparison, the period on the preceding day of the workweek; in the weekday comparison, the period on the day one week before the collision; in the maximal-use-day comparison, the day with the most cellular-telephone activity of the three days preceding the collision; and in the matching-day comparison, the period on the nearest day of the preceding week in which there was cellular-telephone activity in the lead-up period. The vertical lines indicate 95 percent confidence intervals. Bars entirely above 1 indicate statistically significant associations (P<0.05).

Table 2. Relative Risk of a Motor Vehicle Collision in 10-Minute Periods, According to Selected Characteristics.*

Characteristic	No. with Telephone Use in 10 Min before Collision	Relative Risk (95% CI)
All subjects	170	4.3 (3.0–6.5)
Age (yr)		
<25	21	6.5 (2.2–∞)
25–39	95	4.4 (2.8–8.8)
40–54	44	3.6 (2.1–8.7)
≥55	10	3.3 (1.5–∞)
Sex		
Male	123	4.1 (2.8–6.4)
Female	47	4.8 (2.6–14.0)
High-school graduation		
Yes	153	4.0 (2.9–6.2)
No	17	9.8 (3.0–∞)
Type of job		
Professional	34	3.6 (2.0–10.0)
Other	136	4.5 (3.1–7.4)
Driving experience (yr)		
0–9	40	6.2 (2.8–25.0)
10–19	67	4.3 (2.6–10.0)
20–29	36	3.0 (1.7–7.0)
≥30	27	4.4 (2.1–17.0)
Cellular-telephone experience (yr)		
0 or 1	51	7.8 (3.8–32.0)
2 or 3	39	4.0 (2.2–12.0)
4 or 5	36	2.8 (1.7–6.7)
≥6	44	4.1 (2.3–12.0)
Type of cellular telephone		
Hand-held	129	3.9 (2.7–6.1)
Hands free	41	5.9 (2.9–24.0)

*Relative risks indicate the probability of having a collision when using a cellular telephone at any time during a 10-minute interval as compared with the probability of having a collision when not using a cellular telephone at any time during a 10-minute interval. Relative risks have been adjusted to account for the intermittence of driving. CI denotes confidence interval.

were received on the collision days, of which the majority occurred after the event (68 percent and 64 percent, respectively). About 39 percent of the subjects used their cellular telephone at least once to contact emergency services immediately after the collision. The median number of calls made during the remainder of the day after the collision was substantially greater than the median number of calls made during an entire day before the collision (four vs. two, $P<0.001$). Of those who had not used their telephone on any day before the collision, 14 of 39 (36 percent) made at least one call in the aftermath of the event.

DISCUSSION

We found that using a cellular telephone was associated with a risk of having a motor vehicle collision that was about four times as high as that among the same drivers when they were not using their cellular telephones. This relative risk is similar to the hazard associated with driving with a blood alcohol level at the legal limit.[29-31] We also found that cellular telephones have benefits, such as allowing drivers to make emergency calls quickly. A few drivers used their telephones only in the aftermath of a collision, thereby gaining some potential benefits and incurring no potential risks due to telephone use. In general, cellular-telephone calls were brief and infrequent, which explains why the rapid growth of this technology during recent years has not been accompanied by a dramatic increase in motor vehicle collisions.[32]

We observed no safety advantage to hands-free as compared with hand-held telephones. This finding was not explained by imbalances in the subjects' age, education, socioeconomic status, or other demographic characteristics. Nor can it be explained by suggesting that those with units that leave the hands free do more driving. One possibility is that motor vehicle collisions result from a driver's limitations with regard to attention rather than dexterity.[33] Regardless of the explanation, our data do not support the policy followed in some countries of restricting hand-held cellular telephones but not those that leave the hands free.

Three weaknesses of this study should be pointed

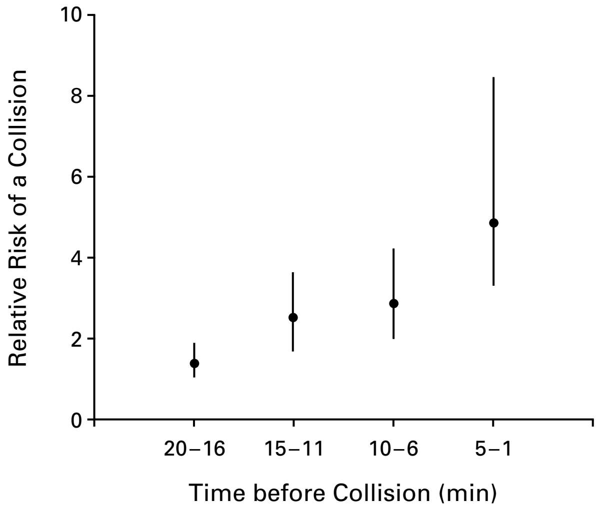

Figure 2. Time of Cellular-Telephone Call in Relation to the Relative Risk of a Collision.

Each minute before the collision was assessed as an independent hazard interval, with these intervals grouped in five-minute periods. Cellular-telephone activity for each hazard interval was evaluated in relation to the same period on the day before the collision. Relative risks greater than 1 indicate an association between telephone use and collisions. The vertical lines indicate 95 percent confidence intervals. Bars entirely above 1 indicate statistically significant associations (P<0.05). Calls made 1 to 5 minutes before the collision were significantly riskier than calls made 16 to 20 minutes before the collision (P<0.001).

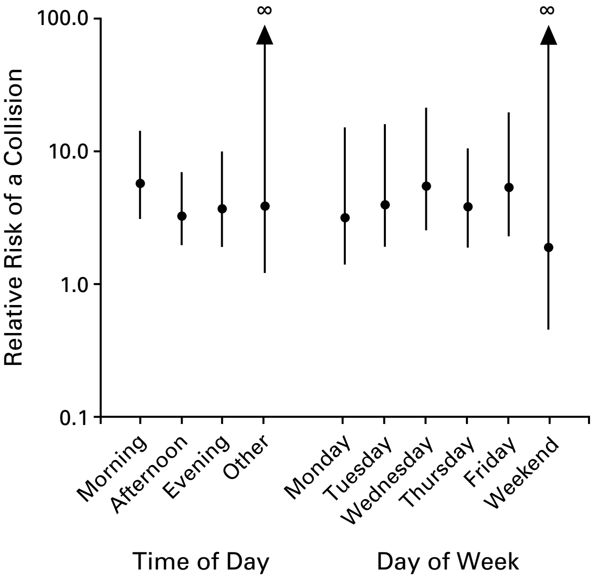

Figure 3. Consistency of Relative Risks Obtained from Different Collision Times.

The graph shows estimates of relative risk for collisions at different times of the day and of the week. Morning was defined as 8 a.m. to 11:59 a.m., afternoon as noon to 3:59 p.m., evening as 4 p.m. to 7:59 p.m., and other as all remaining times. Saturday and Sunday are combined in a single weekend category. The vertical lines indicate 95 percent confidence intervals. Bars entirely above 1 indicate statistically significant associations (P<0.05). The vertical scale is logarithmic.

out. First, we studied only drivers who consented to participate. The fact that some persons chose not to consent might have caused us to underestimate the risks associated with telephone use if these people declined because of concern about personal liability. Second, people vary in their driving behavior from day to day — a fact that makes the selection of a control period problematic. However, it would be difficult to explain all our findings on the basis of different driving patterns, and in particular, this factor would not account for the similar results for those who remembered driving during both periods on both days. Third, case–crossover analysis does not eliminate all forms of confounding. Imbalances in some temporary conditions related to the driver, the vehicle, or the environment are possible, but we believe such factors are not likely to account for the magnitude of the association we observed.

Our study indicates an association but not necessarily a causal relation between the use of cellular telephones while driving and a subsequent motor vehicle collision. For example, emotional stress may lead to both increased use of a cellular telephone and decreased driving ability. If so, individual calls may do nothing to alter the chances of a collision. In addition, our study did not include serious injuries; hence, we do not know how — or whether — cellular-telephone use is associated with motor vehicle fatalities. Finally, the data do not indicate that the drivers were at fault in the collisions; it may be that cellular telephones merely decrease a driver's ability to avoid a collision caused by someone else.

We caution against interpreting our data as showing that cellular telephones are harmful and that their use should be restricted. Even if a causal relation with motor vehicle collisions were to be established, drivers are vulnerable to other distractions that could offset the potential reductions in risk due to restricting the use of cellular telephones. Regulations would also mean reducing benefits; in Canada, for example, half a million calls to 911 emergency services are made from cellular telephones each year.[34] Yet proposals for regulation are not unreasonable, since poor driving imposes risks on others. Public debate is needed, given that cellular telephones contribute to improvements in productivity, the quality of life, and peace of mind for more than 30 million people in North America alone.

The role of regulation is controversial, but the role of individual responsibility is clear. Drivers who use a cellular telephone are at increased risk for a motor vehicle collision and should consider road-safety precautions. For them as for all other drivers, these include abstaining from alcohol, avoiding excessive speed, and minimizing other distractions. Additional strategies might include refraining from placing or receiving unnecessary calls, interrupting telephone conversations if necessary, and keeping calls brief — particularly in hazardous driving situations. Physicians should also learn to recognize patients who are at risk for a collision and who may benefit from advice regarding safety.[35-40] Even limited success in reducing risk may prevent some of the death, disability, and property damage related to motor vehicle collisions.

Supported by a Career Scientist Award from the Ontario Ministry of Health (to Dr. Redelmeier), a grant from the Natural Sciences and Engineering Research Council of Canada (to Dr. Tibshirani), and a grant from the Ontario Ministry of Transportation.

We are indebted to Bell Mobility, Inc., Rogers Cantel, Inc., and the Metropolitan Toronto Police Department for their cooperation; and to the following people for help with specific aspects of the study: Mary Chipman, Ruth Croxford, Allan Detsky, Bradley Efron, Trevor Hastie, Mark Henkelman, Philip Lavori, Barry McLellan, David Naylor, Simon Min, Miriam Shuchman, and Amos Tversky.

REFERENCES

1. Bureau of the Census. Statistical abstract of the United States 1995: the national data book. 115th ed. Washington, D.C.: Government Printing Office, 1995:92.
2. Canada year book 1994. Ottawa, Ont.: Statistics Canada, 1993:149.
3. Instituto Nacional de Estadistica Geografia e Informatica. Anuario Estadístico de los Estados Unidos Mexicanos 1993. Aguascalientes, Mexico: Instituto Nacional de Estadistica, Geografía e Informática 1994:568.
4. Rice DP, MacKenzie EJ, Associates. Cost of injury in the United States: a report to Congress 1989. San Francisco: Institute for Health and Aging, 1989:208.
5. Ontario road safety annual report 1994. Downsview, Ont.: Safety Research Office, Ministry of Transportation, 1996:2-4.
6. McFarland RA, Moore RC. Human factors in highway safety: a review and evaluation. N Engl J Med 1957;256:792-9.
7. U.S. wireless industry survey results: more than 9.6 million customers added in 1995. News release of the Cellular Telecommunications Industry Association, Washington, D.C., March 25, 1996:5.
8. Bureau of the Census. Statistical abstract of the United States 1995: the national data book. 115th ed. Washington, D.C.: Government Printing Office, 1995:849.
9. Violanti JM, Marshall JR. Cellular phones and traffic accidents: an epidemiological approach. Accid Anal Prev 1996;28:265-70.
10. Brown ID, Tickner AH, Simmonds DCV. Interference between concurrent tasks of driving and telephoning. J Appl Psychol 1969;53:419-24.
11. Alm H, Nilsson L. The effects of a mobile telephone task on driver behaviour in a car following situation. Accid Anal Prev 1995;27:707-15.
12. McKnight AJ, McKnight AS. The effect of cellular phone use upon driver attention. Accid Anal Prev 1993;25:259-65.
13. Brookhuis KA, de Vries G, de Waard D. The effects of mobile telephoning on driving performance. Accid Anal Prev 1991;23:309-16.
14. Stein AC, Parseghian Z, Allen RW. A simulator study of the safety implications of cellular mobile phone use. In: Proceedings of the 31st Annual Conference of the American Association for Automotive Medicine, New Orleans, September 28–30, 1987. Des Plaines, Ill.: American Association for Automotive Medicine, 1987:181-200.
15. Smith VJ. What about the customers? A survey of mobile telephone users. In: 28th IEEE Vehicular Technology Conference: conference record of papers presented at the 28th annual conference, Denver, March 22–24, 1978. New York: Institute of Electrical and Electronic Engineers, 1978: 190-3.
16. Canete DW. AT&T cellular phone safety study: a survey of cellular phone owners located in the Baltimore/Washington, D.C., metropolitan area. Parsippany, N.J.: AT&T Consumer Products, 1985:1-62.
17. Maclure M. The case-crossover design: a method for studying transient effects on the risk of acute events. Am J Epidemiol 1991;133:144-53.
18. Mittleman MA, Maclure M, Robins JM. Control sampling strategies for case-crossover studies: an assessment of relative efficiency. Am J Epidemiol 1995;142:91-8.
19. Baker SP. Digit preference in reported time of collision. Accid Anal Prev 1971;3:77-80.
20. Efron B, Tibshirani R. Statistical data analysis in the computer age. Science 1991;253:390-5.
21. Breslow NE, Day NE. Statistical methods in cancer research. Vol. 1. The analysis of case-control studies. Lyon, France: International Agency for Research on Cancer, 1980:162-89. (IARC scientific publications no. 32.)
22. Marshall RJ, Jackson RT. Analysis of case-crossover designs. Stat Med 1993;12:2333-41.
23. Efron B. Bootstrap confidence intervals for a class of parametric problems. Biometrika 1985;72:45-58.
24. Better bootstrap confidence intervals. In: Efron B, Tibshirani R. An introduction to the bootstrap. New York: Chapman & Hall, 1993:178-201.
25. Scientific Advisory Group on Cellular Telephone Research. Assessing real world cellular phone usage patterns. Vol. 2. No. 2. Cellular Telephone Update. Winter 1994:3.
26. 1995 Annual report. Montreal: BCE Mobile Communications, 1996: 53.
27. Annual report 1995. Toronto: Rogers Cantel Mobile Communications, 1996:32.
28. U.S. wireless industry survey results: more than 9.6 million customers added in 1995. News release of the Cellular Telecommunications Industry Association, Washington, D.C., March 25, 1996:4.
29. Smith HW, Popham RE. Blood alcohol levels in relation to driving. Can Med Assoc J 1951;65:325-8.
30. Simpson H. Polydrug effects and traffic safety. J Alcohol Drugs Driving 1985;1:17-44.
31. Vinson DC, Mabe N, Leonard LL, et al. Alcohol and injury: a case-crossover study. Arch Fam Med 1995;4:505-11.
32. Rothman KJ, Loughlin JE, Funch DP, Dreyer NA. Overall mortality of cellular telephone customers. Epidemiology 1996;7:303-5.
33. Kahneman D, Ben-Ishai R. Relation of a test of attention to road accidents. J Appl Psychol 1973;58:113-5.
34. Staying in touch: spring 1996. Etobicoke, Ont.: Bell Mobility, 1996:1.
35. Counseling to prevent motor vehicle injuries. In: Preventive Services Task Force. Guide to clinical preventive services. 2nd ed. Baltimore: Williams & Wilkins, 1996:643-57.
36. Prevention of motor vehicle accident injuries. In: The Canadian Task Force on the Periodic Health Examination. The Canadian guide to clinical preventive health care. Ottawa, Ont.: Canada Communication Group — Publishing, 1994:514-24.
37. Kelly RB. Effect of a brief physician intervention on seat belt use. J Fam Pract 1987;24:630-2.
38. Reisinger KS, Williams AF, Wells JK, John CE, Roberts TR, Podgainy HJ. Effect of pediatricians' counseling on infant restraint use. Pediatrics 1981;67:201-6.
39. Macknin ML, Gustafson C, Gassman J, Barich D. Office education by pediatricians to increase seat belt use. Am J Dis Child 1987;141:1305-7.
40. Redelmeier DA, Blair PJ. Survivors of motor vehicle trauma: an analysis of seat belt use and health care utilization. J Gen Intern Med 1993;8: 199-203.

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March 22, 2001

Dear Drs. Redelmeier and Tibshirani:

We just used your NEJM article on cell phones and collisions in our "practicum" for first year graduate students in epidemiology.

We have two questions about your use of the 0.65 correction factor for intermittency of driving.

First, how exactly was the question on intermittency worded to the 100 persons in the pilot study? What did the "selected period" refer to? Was the question something like "At 8 am are you seldom/often/usually/always driving? Same question in relation to 9 am, 4.30 pm, … Or was it irrespective of time of day, and more to do with how many of the days of the week a person drives (or takes public transport, or someone else had the car, or stays home, or whatever)? Incidentally, we presume that if someone else took the car, that person didn't take the cell phone as well!

Second, It is not obvious to us what assumptions are being made about the statistical correlation (dependence) between "usual" cell phone use (in this period) and driving. This seems to be key to your "conditional probability" argument, but because of lack of space, and the usual short shrift given to statistics and probability, even when it is often key to a paper, we are guessing that the copy editors cut it. (A colleague tells me of dealing right now with a copy editor who -- in a paper dealing where a particularly subtle statistical concept that is the key to the entire paper -- wants to cut out all the "statistical mumbo-jumbo").

We have considered 3 dependency scenarios. They are best described in relation to one large stratum. Later, for completeness, and just in case there is something else we missed, we go through the finely stratified situation.

ONE INDIVIDAUL, A LOT OF EXPERIENCE

Let's start with one individual. In an ideal world, if we could observe this individual in lots of driving occasions ("periods") -- some on and some off the phone -- we would observe numerators (accidents) a[on] and a[off], and record the denominators D[on] and D[off]. It could well be that a[on] and a[off] were both zero, but theoretically [or if we were dealing with a less serious, but more common, occurrence such as "crossing the centre line" or "near misses", a[on] and a[off] would be bigger. Later we will counteract the instability arising from the small amount of observation per individual by aggregating over many individuals.

In any event, let's say that in a certain amount of driving experience, we get to know the two numerators a[on] and a[off], but let's say we cannot document what the two "bases" or denominators, D[on] and D[off], respectively, for these are. If we are content with estimating a rate ratio, (a [on] / D [on]) / (a [off] / D [off]), then all we need to make an unbiased estimate of the rate ratio is how (in relative terms) the total denominator D[on] + D[off] is split up. Then we can estimate the rate ratio,

(a [on] / D [on]) / (a [off] / D [off])

or

(a [on] / a [off]) / (D [on] / D [off])

by

(a [on] / a [off]) / (d [on] / d [off])

where d[on] and d[off] are estimates based on a sample of d (= d[on] + d[off]) driving occasions. [I had initially chosen the letter d and D for "denominator", but as it turns out it is also helpful to think of it as amount (occasions) of "driving"]. Miettinen refers to d[on] and d[off] as "quasi-denominators".

Thus our estimate is

rate ratio = (a [on] / a [off]) / (d [on] / d [off]) = (a[on] * d[off]) / (a[off] * d[on]).

Now to the *real* world, where we are not even able to measure d[on] and d[off] directly. Instead, we can only measure the *larger* "denominators" "on" and "off", where "on" and "off" refer simply to occasions on and off the phone (*whether driving or not!*).

In our study, say that we learned from a sample of 100 occasions, regardless of driving, that the person was on the phone in 5 of the occasions ["on"=5] , and off the phone in 95 occasions ["off" = 95] (We picked 5% because it is the average in your study).

How can we go from these to the d[on] and d[off] we need to estimate our rate ratio?

1. We can ask the person, as you did in the study proper in November 1996.

2. We can make some assumptions, which we label "++" , "0" and "–" for three different levels of dependency between cell phone use and driving. At one extreme, if we posit that

(++) people at "this" [same as the accident] time of the day only use their cell phones if they are driving, and never if they are not driving.

Then a[on] = "on". For example, if the person is driving on 65/100 such occasions , then we have

	On phone	Off phone	All
Driving	5 (= d[on])	60 (= d[off])	65
Not driving	0	35	35
Combined	5 (= "on")	95 (= "off")	100

So d [on]=5 and d[off] = 60, and so we have d[on]/d[off] = 5/60.

If instead we posit that

(0) people use their phones at the same rate whether driving or not

then we have

	On phone	Off phone	All
Driving	65% of 5	65% of 95	65
Not driving	35% of 5	35% of 95	35
Combined	5	95	100

So that the critical d[on]/d[off] ratio is still the same 5/95 that we have in our simple survey of “on” and “off” the phone (*driving or not*).

At the other extreme we could posit that

(—) people are less likely to use the cell phone while driving than when not driving

We can’t say they NEVER use the cell phone while driving [we have lots of personal observations to bear this out – and we have the fact that some 25% of the accidents were while talking on a cell phone while driving!] But let’s say the rate of use of phones is *much* lower while driving than when not driving, so that we might have

	On phone	Off phone	All
Driving	1	64	65
Not driving	4	31	35
Combined	5	95	100

giving a d[on]/d[off] ratio of 1/64.

Thus our estimates of the rate ratio would be, under assumptions (a)-(c)

dependency	estimate
++	(a [on] / a [off]) / (5 / 65) < "crude" RR
0	(a [on] / a [off]) / (5 / 95) = "crude" RR
—	(a [on] / a [off]) / (1 / 64) > "crude" RR

From your division of the odds ratio by 1.5 (or multiplication by 0.65), it would appear that you used ***assumptions closer to (++) i.e., "for this time of day all of the recorded cell phone use is while driving"****.* (This wording is based on what we think you asked in your pilot study (see our first question above).

By the way, some students asked how you established that the cell phone use was generated by the person who was in the collision, and not say by another family member.

AGGREGATION OVER LOTS OF INDIVIDUALS, EACH WITH LIMITED DENOMINATOR DATA
THIS GIVES SAME DIRECTIONS, BUT WE JUST WANTED TO BE CHECK JUST IN CASE

In your study, over 14 months, the population of cell phone users generated a total numerator of > 669 accidents while driving. Presuming that nobody had 2 or more accidents during that time, each one of the 669 distinct persons who volunteered to be in your study generated a total of a[on] +a[off] = 1 each. For each of these persons, we only have a single occasion per person (i.e. "on" + "off" = 1 period the previous day), rather than the 100 (or more!) we could use in our "no-cost" armchair example.

We can "aggregate" the 699 within-in person contributions to the estimation by using the Mantel-Haenszel summary estimator, i.e., summing over the 699 individuals,

Sum { (a[on] * "off" / 2 } / Sum { (a[off] * "on" / 2) }, as in the usual matched pair case control study, giving 157/24=6.5.

If we divided this by your correction factor of 1.5 (=1/0.65), we get the adjusted rate ratio of 4.3 that you report.

But we are dealing with -- for each person -- an "on" + "off" = 1, rather than 100. The configurations are given below for the 3 scenarios.

	++				0				—			
#	13	157	24	505	13	157	24	505	13	157	24	505
a[on]	**1**	**1**	**0**	**0**	**1**	**1**	**0**	**0**	**1**	**1**	**0**	**0**
a[off]	**0**	**0**	**1**	**1**	**0**	**0**	**1**	**1**	**0**	**0**	**1**	**1**
"on"	1	0	1	0	1	0	1	0	1	0	1	0
"off" (*)	0	1	0	1	0	1	0	1	0	1	0	1
d[on]	**1**	**0**	**1**	**0**	**.65**	**0**	**.65**	**0**	**<.65**	**0**	**<.65**	**0**
d[off]	**0**	**.65**	**0**	**.65**	**0**	**.65**	**0**	**.65**	**0**	**>.65**	**0**	**>.65**
a[on]*d[off]	**0**	**.65**	**0**	**0**	**0**	**.65**	**0**	**0**	**0**	**>.65**	**0**	**0**
a[off]*d[on]	**0**	**0**	**1**	**0**	**0**	**0**	**.65**	**0**	**0**	**0**	**<.65**	**0**
ratio of sums**	$\frac{157 \text{ x } 0.65}{24 \text{ x } 1}$				$\frac{157 \text{ x } 0.65}{24 \text{ x } 0.65}$				$\frac{157 \text{ x } > 0.65}{24 \text{ x } < 0.65}$			
	= 4.3				= 6.5				> 6.5			

(*) if not on the phone, the in scenario (a) the negative predictive value for driving (d[off]) may be *slightly* > 0.65, but not very much so;

(**) If we used Mantel and Haenszel's divisor of the crossproduct, then in the ++ scenario, the divisor (what they called T) is 1.65 in the case of the each of the 157 and 2 in the case of each of the 24, giving the estimate

$$\frac{157 \text{ x } 0.65/1.65}{24 \text{ x } 1/2} = 4.3 \text{ x } 2/1.65 = 5.2,$$

closer to the "crude" rate ratio

For the — scenario, the divisor is > 1.65 in the case of the each of the 157 and < 1.65 in the case of the 24, again tending to pull the adjusted value back towards the crude one.

So, just like in the unstratified situation, the adjustment could again go either way, according to the dependency between cell phone use and driving in the period selected.

We wonder if this is how you reasoned this out, or if we are missing something. We realize that the NEJM forces you to remove large amounts, a real pity here as this is such an elegant teaching example, on an important topic, as well as being a study that catches student attention more than any other we had. We also see that you thanked some other high powered numerically nimble people like Efron, Hastie, Henkelman, Lavori, and Tversky, so we expect that this was discussed at some length. Indeed, if you have any technical methodlogical notes on the study, or extended versions of the manuscript that did not survive the statistical-ectomy at the NEJM, we would be happy to receive them.

Again, thanks for a most interesting article, And we hope that you have time to answer us. We would like to share your answers with our students, as some of them raised this issue too, but were afraid to ask you directly!

Sincerely,

James A Hanley

James A. Hanley and Jean-François Boivin

Professors

PS. We run the course by giving 1/3 of the students just the title and intro, 1/3 just the abstract and 1/3 the methods. The 1st group have to design a study, the 2nd have to read the abstract and ask what issues it raises in their minds and what else they will be wanting to check in the methods; the 3rd group answers the second group. If you are interested, you can see our web site

`http://www.epi.mcgill.ca/practicum/`

But don't tell the NEJM that we electronically manipulate your and other papers!

Dear Jim Hanley,

1) I have skimmed your e.mail
2) and can respond to your first issue
3) the second issue is more complicated
4) and I won't address it in this e.mail

5) for the first issue, you ask about our aggregate measure of intermittancy
6) namely, question for determining if driving occured on day prior to collision
7) to do so, we surveyed 100 drivers who had been involved in a collision
8) all of which had significant property damage but no personal injuries
9) and all of which came to the North York Collision Reporting centre
10) thus, the inclusion criteria were similar to the main study
11) except that we did not insist that the driver own a cellular telephone
12) and also did not insist that the driver share telephone records

13) for each individual, we marked the date and time of their collision
14) for example, <Crash occurred on July 13 at 0730h>
15) we then asked them to consider the same time during the weekday before
16) for example, <Were you also driving your car on July 12 at 0730h>
17) notice that this approach required an interview, not a fixed survey
18) because the wording was individualized for each respondent
19) and we wanted them to think about an exact minute on specific day

20) on reflection, I think that this was a reasonable approach
21) but perhaps I am mistaken and missing something important
22) if so, please let me know
23) in the interim, I'll also give some thought to your second question
24) in addition, Rob may have his own thought about your second question too

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Dear Jim Hanley,

1) I have skimmed over the rest of your e.mail
2) focusing now on just the second issue
3) you have made efforts to write clearly
4) but I still might not be fully understanding
5) I'll give you my reactions as best as possible

6) the main focus seems to be the issue of driving intermittancy
7) that is, individuals do not drive every single moment of every day
8) hence, at some times people are relatively protected from collisions
9) thus, behaviors that are specific to vehicles can create faulty correlations
10) for example, consider the behavior of "checking a rear view mirror"
11) clearly, this behavior can only occur while driving a vehicle
12) and sometimes this behavior may be followed by a sudden collision
13) and this behavior does not occur on days when the driver is not driving
14) hence, a case crossover study might incorrect find this behavior is risky
15) when, quite the contrary, we know that checking a rear view mirror is safe

16) now, the same issue arises when assessing the risk of cellular telephones
17) for the same reason: drivers do not drive every single moment of every day
18) your work shows that you are fully aware of this issue
19) and that the main task is to adjust the control comparisons
20) you introduce a big nuance; namely, correlation between calling and driving
21) that is, when drivers don't drive are they less likely to use a phone?
22) now, at this stage I got a bit lost
23) but it seems that you accept our overall measure of driving intermittancy
24) and that you apply this correction at the individual level
25) and generally find that it changes the final estimate of relative risk
26) that is, if the correlation is postive, the final Rel Risk is 4.3
27) if the correlation is zero, the final Rel Risk is 6.5
28) if the correlation is negative, the final Rel Risk exceeds 6.5

29) now, here's where I want to stop
30) and check that I'm correct so far
31) and also check if Rob Tibshirani has any reactions

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Dear Jim Hanley,

1) I have skimmed over the rest of your e.mail
2) focusing now on just the second issue
3) you have made efforts to write clearly
4) but I still might not be fully understanding

sorry i was a bit long-winded -- mainly because i want to show students that the "b/c" estimate we calculate from matched c-c studies is nothing other than the m-h summary estimate..

In fact I don't know why we need a fancy name "case-crossover" when the term "self-matched c-c study" would probably do.. but that too is another story..

5) I'll give you my reactions as best as possible

17) for the same reason: drivers do not drive every single moment of every day
18) your work shows that you are fully aware of this issue
19) and that the main task is to adjust the control comparisons
20) you introduce a big nuance; namely, correlation between calling and driving
21) that is, when drivers don't drive are they less likely to use a phone?

yes that's the crux of it...

22) now, at this stage I got a bit lost
23) but it seems that you accept our overall measure of driving intermittancy

absolutely.. and indeed samy suissa (and Hemelgarn) here did lots of studies on medication use and accidents and he has not able to deal fully with this issue .. he doesn't have access to people only databases..

i think your technique for estimating intermittency could help him a lot..

24) and that you apply this correction at the individual level
25) and generally find that it changes the final estimate of relative risk
26) that is, if the correlation is PERFECTLY postive (i.e. +1)

, the final Rel Risk is 4.3

exactly ..

27) if the correlation is zero, the final Rel Risk is 6.5
28) if the correlation is negative, the final Rel Risk exceeds 6.5

29) now, here's where I want to stop
30) and check that I'm correct so far
31) and also check if Rob Tibshirani has any reactions

Yes that's the gist of my argument.. namely that your correction is compatible with assuming a correlation of +1 b/w driving and cell phone use..

indeed the correlation of +1 (rather than something less) is easiest
to think about and to correct for.. but to me it is a big assumption..
I just wonder how one could check it out..

Rob just e-mailed me to say he is v. busy but that he will talk with me
when he is in Montreal on april 19..

all the best for now...

Jim Hanley

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