A B S T R A C T

Objective: Some countries have regulations against using a cellular telephone while driving. We used ecologic analysis to evaluate cellular telephone use and motor vehicle collisions in a city without such regulations.

Methods: We studied locations in Toronto, Ontario (n=75) that were hazardous (total collisions=3,234) and tested whether increases in collision rates from 1984 to 1993 correlated with increases in telephone usage over the same time interval.

Results: Locations with the largest increases in collision rates tended to have the smallest increases in estimated cellular telephone usage. Yet extreme assumptions about potential protective effects from cellular telephones failed to explain the magnitude observed.

Conclusion: The effects of cellular telephones on driving ability are small relative to the biases in ecologic analysis. Claims from industry, which argue that cellular telephones are not dangerous based on ecologic analysis, can be misleading in the policy debate about whether to regulate cellular telephone use while driving.

A B R É G É

But de l'étude : Dans certains pays, la loi interdit l'utilisation d'un téléphone cellulaire lors de la conduite automobile. Nous avons effectué une analyse écologique pour évaluer l'utilisation de téléphones cellulaires et les collisions d'automobile, dans une ville qui n'a pas de loi à cet effet.

Méthode : Nous avons étudié plusieurs régions de Toronto, Ontario (n=75) à risque élevé (taux de collisions=3,234) et avons vérifié si l'augmentation des taux de collisions de 1984 à 1993 corréle avec une augmentation d'utilisation de téléphones cellulaires durant la même période.

Résultats : Les régions où l'on a observé les plus grandes augmentations de taux de collision tendaient à avoir les plus petites augmentations d'utilisation estimée de téléphone cellulaire. Par contre, des suppositions extrêmes sur les effets potentiellement protecteurs des téléphones cellulaires ne pouvaient pas expliquer l'amplitude observée.

Conclusion : Les effets de l'utilisation de téléphones cellulaires sur l'habileté au volant sont petits en comparaison du biais de l'analyse écologique. Les affirmations provenant de l'industrie, voulant que les téléphones cellulaires ne sont pas dangereux sur la base de l'analyse écologique, peuvent être trompeuses dans le débat politique sur la question s'il faut ou non contrôler l'utilisation de téléphones cellulaires lors de la conduite automobile.

Car Phones and Car Crashes: An Ecologic Analysis

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Motor vehicle injury is a widespread cause of mortality and morbidity. In Toronto during 1995, for example, 1 of every 40 drivers was involved in a collision and thereby contributed a total of 56,000 events, 17,000 injuries, and 73 fatalities.¹ Motor vehicle collisions remain the single most common cause of mortality and morbidity for children, teenagers, and young adults.² The causes of such collisions are complex and multifactorial, but driver error is one of the most frequent contributors.³

The cellular telephone market has grown tremendously during recent years. In Toronto, the number of subscribers amounted to about 9% of the total population in 1995 and may exceed 15% by 1999.⁴⁻⁶ Even higher growth is possible if prices continue to fall and advertising remains enthusiastic. Yet such high popularity might have adverse public health consequences if the technology were associated with injury or illness. Because motor vehicle trauma is prevalent, in particular, a small increase in driver distraction could have substantial consequences.

Some countries, such as Portugal and Australia, have laws against using a cellular telephone while driving. These laws were enacted in response to popular opinion and laboratory simulations which suggested that operating a telephone might be distracting to drivers.⁷⁻¹² Two epidemiologic

studies also found that car telephone usage increased the risk of a collision.^{13,14} Yet industry-sponsored surveys reported no appreciable risk given that drivers who own car telephones had fewer collisions than drivers who did not own car telephones.^{15,16}

Ecologic analysis provides an alternative approach for exploring risk factors for motor vehicle collisions. The design compares exposures and event rates across populations rather than individuals.¹⁷⁻²⁰ Such analysis minimizes errors due to random chance and are particularly useful for assessing phenomena that affect people indirectly, such as when poor driving causes a chain of collisions. This study uses a specific type of ecologic analysis, the multiple group time-trend method, to examine the association between cellular telephones and vehicle collisions.

METHODS

A multiple group time-trend analysis examines numerous populations over a period of time to assess whether changes in event rates are related to changes in exposures. Changes in exposures that are accompanied by similar changes in event rates for all subgroups suggest a positive association between exposure and outcome. Changes in exposures that are accompanied by opposite changes in event rates for all subgroups suggest a negative association between exposure and outcome. Inconsistent changes suggest no association between exposure and outcome.

In this study the exposure of interest was cellular telephone usage. The event of interest was a motor vehicle collision. The setting was Metropolitan Toronto during

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two years: 1984 and 1993. The multiple group time-trend analysis examined the geographic distribution of collisions in 1993 relative to 1984, and the geographic distribution of cellular telephone usage in 1993 relative to 1984. The null hypothesis was that changes in collision rates were unrelated to changes in cellular telephone usage.

Collision data were obtained from the Metro Toronto Traffic Data Centre. This database receives information directly from the police records of collisions and is the official government source for traffic statistics. It details individual collisions with respect to location, amount of damage, and presence of injury. All locations with at least 10 collisions in 1984 were included for analysis. Collisions which occurred on private property, highways not under Toronto police jurisdiction, locations with unknown traffic flow data, or more than 200 metres from an intersection were excluded because of data limitations.

Cellular telephone usage at each location in 1993 was estimated by the density of cellular towers (or antennae) in the surrounding area. This approach assumed that locations with greater levels of usage would tend to have more towers than locations with lower levels of usage, given that local demand is the main determinant for tower construction. Other determinants of cellular tower density include unusual topography and special requests by consumers; however Toronto has a flat topography and special requests are neither frequent nor always granted.²¹

Locations of individual cellular towers were obtained from the licensing agency and verified by contact with private industry. Towers up to 5 km outside Toronto were included because they could potentially relay calls to within Toronto. The change in usage between 1984 and 1993 was assumed to equal the total usage in 1993, given the minimal market in 1984. For baseline analysis, the number of towers within a 2 km radius of a collision was counted.²¹ To account for inexact transmission ranges, subsequent analyses used radii between 2 km and 5 km.

Information on the activity of individual cellular towers was obtained from private industry. One company provided the

TABLE I
Summary of Collision Data

	1984	1993
Total collisions in Toronto	51,925	66,500
Total collisions at study locations	1,265	1,969
Average number of collisions at a study location	17	26
Maximum number of collisions at a study location	47	67
Minimum number of collisions at a study location	10	3
Collisions at location with largest rate increase	21	67
Collisions at location with largest rate decrease	47	28

TABLE II
Relationship Between Telephone Usage and Collision Rates

	Observed Beta Coefficient*		Expected Beta Coefficient†
	Mean	95% Confidence Interval	
Univariate Regression			
Towers within 2 km	-0.065	-0.115 to -0.015	-0.012
Towers within 3 km	-0.047	-0.080 to -0.015	-0.007
Towers within 4 km	-0.038	-0.061 to -0.015	-0.005
Towers within 5 km	-0.029	-0.045 to -0.012	-0.004
Activity within 2 km	-0.052	-0.107 to +0.004	-0.013
Multivariate Regression‡			
Towers within 2 km	-0.044	-0.092 to 0.000	-0.012
Towers within 3 km	-0.033	-0.065 to -0.001	-0.007
Towers within 4 km	-0.029	-0.051 to -0.006	-0.005
Towers within 5 km	-0.021	-0.037 to -0.005	-0.004
Activity within 2 km	-0.036	-0.088 to +0.017	-0.013

* relative change in collision rate = $\alpha + \beta \times [\text{changes in cellular telephone usage}]$

† under the assumption that cellular telephones were perfectly protective

‡ relative change adjusted for changes in traffic flow and pedestrian flow

number of channels for each tower (a crude measure of tower activity given that a greater number of channels allows for a larger number of calls). The other company provided the number of bids made to each tower on one day (one bid represents a telephone attempting to have the tower handle a call). Towers were assigned activity ratings based on a linear scale from 0.00 to 1.00, where the busiest towers for each provider had an activity of 1.00.

Previous analyses have suggested that human factors contribute to 93% of collisions, environmental factors to 34%, and vehicle factors to 12%.³ Our ecologic analysis assumed that vehicle factors remained constant during the time interval. We also assumed that human factors remained unchanged in 1984 and 1993 except for cellular telephone usage. We assumed that only two environmental factors changed; namely pedestrian flow (as a global measure of environmental distractions) and traffic flow (as a general measure of roadway crowding).

We obtained detailed traffic and pedestrian flow rates for all selected locations through the Traffic Data Centre. These

data were originally based on surveys of vehicles and pedestrians passing each location during specified time intervals. However, traffic flow data were not available for all years. In such cases, 1985 data were used in place of 1984 data if the latter were unavailable. If both 1984 and 1985 data were available, the average was used in the analysis. Similarly, 1994 data were used in place of 1993 data when the latter were unavailable, and were averaged with 1993 data when both were available.

For each location, the change in the number of collisions and the change in cellular telephone usage was calculated over the nine-year period. The primary analysis estimated cellular telephone usage at each location by the density of cellular towers within a 2 km radius. The secondary analysis tested transmission radii between 2 km and 5 km. In the sensitivity analysis, cellular telephone usage at each location was estimated by the sum of the activities of towers within a 2 km radius. Linear regression, by estimating beta-coefficients and standard errors, was used to determine the relationship between changes in collision rates and changes in estimated cellular telephone usage.

To interpret beta-coefficients we modelled the relationship expected if cellular telephone usage were the sole determinant of changes in collision rates. The model assumed that 15% of vehicles were equipped with telephones in 1993, that drivers could spend up to 100% of time on the telephone, and that the effect of cellular telephones on collision risk occurred only when an equipped driver was on the telephone. The model also assumed that locations with the greatest number of tow-

ers within a specific radius provided sufficient capacity to allow all drivers to spend 100% of time on the phone. The net effect of these extreme assumptions was to permit even small changes in risk to explain large changes in collision rates.

RESULTS

In 1984 a total of 51,925 collisions were reported in Toronto.²² In 1993 a total of 66,500 collisions were reported.²³ Overall,

75 locations satisfied inclusion criteria (Table I), accounting for 1,265 collisions in 1984 and 1,969 collisions in 1993. Thus, the study sample represented approximately 3% of all collisions in each year and tended to reflect relatively hazardous locations (average about 20 collisions per location per year). Collision rates generally increased over the years and varied substantially across the 75 locations (Figure 1). The average location had 9 more collisions in 1993 than in 1984 (range: -19 to +46).

A total of 183 cellular towers were located in or within 5 km of Toronto in 1993. The number of cellular towers within a 2 km radius for each of the 75 locations also varied substantially (Figure 1). The average location had 5 towers in 1993 (range: 0 to +13). Locations with large increases in collision rates were not necessarily locations with large numbers of nearby cellular towers. The greatest increase in collisions from 1984 to 1993 occurred at a location with 3 nearby cellular telephone towers. The greatest reduction in collisions occurred at a location with 12 nearby cellular telephone towers.

The overall relationship between changes in collision rates and changes in cellular tower density was obtained by analyzing data from all locations. On average, locations with 6 or more towers had a smaller average increase in collision rates than locations with 5 or fewer towers (3 vs 12, $p < 0.001$). Regression analysis also suggested that estimated cellular telephone usage was associated with decreased motor vehicle collision rates (Table II). Analyses based on alternative cellular tower transmission distances also showed a consistent negative relationship between changes in estimated cellular telephone usage and changes in collision rates.

Multivariate analyses evaluated how changes in traffic and pedestrian flow might modify the apparent relation between estimated cellular telephone usage and motor vehicle collision rates. Changes in traffic flow were a significant confounder for all analyses (correlation = +0.4, $p < 0.001$). Changes in pedestrian flow were not a significant confounder (correlation = +0.0, $p > 0.20$). Taking into account the changes in flow diminished the apparent

beta-coefficient between estimated cellular telephone usage and collision rates (Table II). However, the beta-coefficients remained negative and were statistically significant in all but one case.

We next applied the interpretive model to estimate the magnitude of the apparent protective effects related to estimated cellular telephone usage. If cellular telephone usage was perfectly protective, the expected beta-coefficient was less extreme than the observed beta-coefficient for all cases (Table II). Observed beta-coefficients were about five times more extreme than expected beta-coefficients for all cases where the univariate analysis yielded statistically significant results. Observed beta-coefficients were about four times more extreme than the expected beta-coefficients for all cases where the multivariate analysis yielded statistically significant results.

DISCUSSION

We used ecologic analysis to explore the relationship between cellular telephones and motor vehicle collisions. Analysis of 3,234 total collisions suggested a negative association between changes in estimated cellular telephone usage and changes in collision rates. The magnitude of the apparent protective effect of cellular telephones on collision risk was re-evaluated using an interpretive model which indicated that even extreme assumptions had difficulty explaining the magnitude of the observed negative association. Together, these findings suggest that the effects of cellular telephones on collision risk are smaller than the biases of ecologic analysis.

In this study we conducted a sophisticated form of ecologic analysis; namely, a multiple group time-trend analysis. As a hybrid of time-trend and multiple group comparison analyses, this approach represents the most rigorous analytic ecologic design.¹⁷ Advocates for the cellular telephone industry have argued that the declining numbers of motor vehicle fatalities in North America demonstrate that cellular telephones might not be dangerous.²⁴⁻³⁰ Our study calls into question such arguments by showing that biases in ecologic analysis are sufficiently large that they

can dwarf even enormous potential effects from cellular telephones.

There are several reasons why an ecologic analysis can be misleading. First, drivers may reduce their net risk of a collision by preferentially using telephones in relatively safe circumstances. Second, the risks associated with using a cellular telephone may be smaller than other determinants of collision rates, such as alcohol. Third, random errors in measuring exposures tend to bias analyses toward conservative results. Fourth, the ecologic fallacy may lead to erroneous inferences of risks for individual drivers because of specification and aggregation bias. In the next two paragraphs we detail these two fundamental contributors to ecologic fallacy.

Specification bias occurs when locations differ in ways unrelated to the exposure of interest. Typically, specification bias is minimized by using multiple regression or stratification techniques.³¹ In our study, specification bias was addressed by adjusting for changes in traffic flow and changes in pedestrian traffic. Additionally, our multiple group time-trend approach controlled for extraneous factors which remained constant over time, such as roadway layout. However, specification bias is still possible if some factors were differentially distributed by locations and time, such as when a new safety program is targeted at a few locations.

Aggregation bias occurs when important information is lost by grouping exposures and outcomes. For example, our analysis assumed that all drivers at a location had consistent levels of cellular telephone usage. However, perhaps drivers deliberately made calls at times when traffic flow rates were low. More generally, the actual exposure of the individual drivers involved in the individual collisions was unknown and the analysis does not establish that the changes in collision rates were attributable to the drivers who had cellular telephones. Finally, ecologic analyses can be further distorted by complex interactions between aggregation bias and specification bias.³²⁻³⁴

Other problems in ecologic analysis include population migration, multicollinearity, cause and effect ambiguity, sampling bias, and spectrum bias. The first is particularly important in our analysis as

drivers at each location likely differed in 1984 compared to 1993. Changes in driver characteristics and behaviour may account for the changes in collision rates. Moreover, population migration becomes increasingly problematic with smaller units of analysis. One method for adjusting for changes in driver characteristics requires evaluating changes in the socioeconomic level of each location. Ultimately, however, it is difficult to eliminate biases of population migration when an ecologic analysis examines human mobility and transportation.

The principal finding of this study is that the risk or benefit associated with using a cellular telephone while driving cannot be determined by ecologic analysis because of multiple sources of bias. More generally, the results caution against using ecologic analysis for studying other driving behaviours given that most other distractions (such as tuning a radio or drinking coffee) are even more problematic to analyze given the lack of objective measures of exposure. Ecologic analysis might be useful if the underlying effect had enormous magnitude; however, enormous effects can usually be identified without a large scientific study.³⁵ Ecologic analysis is unlikely to be useful in detecting behaviours which contribute in subtle yet important ways to motor vehicle trauma.

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