American Journal of Epidemiology
Vol. 153, No. 11
Printed in U.S.A.

Risk Factors for All-Terrain Vehicle Injuries: A National Case-Control Study

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A case-control study design was used to determine and quantify all-terrain vehicle (ATV) risk factors. The analysis was based on the results of two national probability surveys conducted in 1997: a survey of injured ATV drivers treated in hospital emergency departments and a survey of the general population of ATV users. Cases were drawn from the injury survey; controls (ATV drivers who had not been injured) were drawn from the user survey. Risk factors were quantified by means of a binary logistic regression analysis. After adjustment for covariates, injury risks were systematically related to a number of driver characteristics (age, gender, driving experience), driver use patterns (monthly driving times, recreational vs. nonrecreational use), and vehicle characteristics (number of wheels, engine size). The results of the analysis suggest that future safety efforts should focus on reducing child injuries, getting new drivers to participate in hands-on training programs, and encouraging consumers to dispose of the three-wheel ATVs still in use. *Am J Epidemiol* 2001;153:1112–18.

accidents; case-control studies; logistic models; off-road motor vehicles; risk factors; wounds and injuries

All-terrain vehicles (ATVs) are three- and four-wheel motorized vehicles intended for use on various types of unpaved terrain. They have large low-pressure tires, seats designed to be straddled, handlebars for steering, and motorcycle-type engines. Engine sizes range from 50 to 500 cm^3 of displacement, and vehicle weights range from about 100 to 600 pounds (1 pound = 0.454 kg).

Concern about the safety of ATVs grew during the 1980s as the number of ATV-related injuries and deaths rose. Annual estimates of ATV-related injuries treated in US hospital emergency departments increased from an estimated 32,000 in 1983 to 106,000 in 1985, an increase of about 230 percent in just 2 years (1). There were also an estimated 295 deaths in 1985, the first year in which national estimates were available (2). Given an estimated 1.9 million ATVs in use in 1985, there were about 5,580 injuries treated in emergency departments and 15.5 deaths for every 100,000 ATVs in use.

In 1985, the Consumer Product Safety Commission initiated a regulatory proceeding to evaluate and address ATV hazards and ultimately settled with the industry (3–5). The terms of the settlement were specified in the 1988 consent decrees between the Department of Justice and ATV distributors. The consent decrees, which expired in April 1998, included agreements by the ATV distributors to 1) stop selling new three-wheel ATVs; 2) put into effect more stringent driver age requirements; 3) implement a nationwide training program approved by the Consumer Product Safety Commission and to provide free hands-on training to all new buyers and their immediate families; and 4) develop a voluntary standard to make ATVs safer.

The consent decrees appear to have played an important role in reducing rates of injury and death (6). By 1997, the rate of injuries treated in emergency departments (injury rate) had fallen to about 1,490 injuries per 100,000 ATVs in use, a decline of over 70 percent from the 1985 level. Similarly, the death rate declined to about 8.3 deaths per 100,000 ATVs in use, a decrease of almost 50 percent from the 1985 level (1, 2).

Despite the reduction in the overall injury and death rates, however, the number of injuries and deaths remains high. During 1997, for example, there were an estimated 54,000 injuries treated in emergency departments and 300 deaths involving ATVs; more than 35 percent of these injuries and deaths have involved children aged less than 16 years (1, 2).

Because of the continuing large numbers of ATV-related injuries and deaths, and because the consent decrees were set to expire in April 1998, the Commission sponsored a 1997 study of ATV risk and hazard patterns to determine what, if any, further regulatory actions might be warranted. Central to that effort was a case-control study based on the results of two national probability surveys. This article presents the results of the case-control study.

MATERIALS AND METHODS

Data collection

Injury and user surveys. Cases consisted of a sample of injured ATV drivers treated in hospital emergency departments and reported through the US Consumer Product Safety

Received for publication January 4, 2000, and accepted for publication October 20, 2000.

Abbreviations: ATV, all-terrain vehicle; CI, confidence interval; OR, odds ratio.

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Commission's National Electronic Injury Surveillance System from May 1, 1997, to August 31, 1997.

The National Electronic Injury Surveillance System is a stratified national probability sample of US hospitals; at the time of the ATV survey, it consisted of 101 of the approximately 5,400 US hospitals that had at least six beds and provided 24-hour emergency service (7, 8). The sample, which was updated in January 1997 (9), is stratified by hospital size, based on the annual number of emergency department visits. Additionally, to ensure a wide geographic coverage, hospitals within each stratum were ordered by state and zip codes and selected systematically.

At the time of the survey, National Electronic Injury Surveillance System hospitals identified all injuries involving ATVs, with the exception of injuries that occurred when ATVs were being used for commercial or occupational tasks other than for farming or ranching. Coders at the hospitals collected information on a number of variables, including date of treatment, age and sex of victim, injury diagnosis, body part injured, disposition of the case (i.e., treated and released or admitted), and as many as two products that were involved in the injury. A brief narrative describing the injury was also included. The Consumer Product Safety Commission collected the information each evening electronically.

All reported ATV injuries during the study period were assigned for follow-up in-depth telephone interviews. The in-depth interviews were conducted as soon after the injury as possible, usually within 1 month of the injury.

Controls were drawn from a national telephone survey of ATV users conducted for the Consumer Product Safety Commission by Abt Associates, Inc., from September 15, 1997, to November 18, 1997 (10). Eligible respondents included drivers who had used an ATV owned by the driver's household at least once during the preceding 12-month time period. For households with multiple drivers, the driver who had the most recent birthday was selected to be interviewed. The survey was designed to provide a national probability sample of about 500 respondents.

The user survey used a single stage list-assisted random-digit-dialing sample design. The sample was selected using the GENESYS Sampling System, a system which uses the American Telephone and Telegraph (AT&T) master tape of telephone exchanges as the basis for constructing sampling frames (11, 12). The sample was stratified by census region. The screenings needed to complete approximately 500 interviews were distributed among the strata using Neyman allocation to minimize the variance of the estimated overall eligibility rate (13). Up to eight attempts were made to obtain an answered call for each sampled telephone number.

Questionnaire development and interviewing procedures. Questionnaires for both surveys were developed by Consumer Product Safety Commission staff. The injury survey obtained detailed information about the characteristics and use patterns of injured drivers, the ATVs being used, and the injury scenarios. The user survey collected parallel information on the characteristics and use patterns of the driver population.

Respondents targeted for the risk analysis were the injured drivers from the injury survey and the selected drivers from the user survey. In both surveys, however, parents or guardians were asked to respond on behalf of children under age 16. If respondents were not available, call-backs were scheduled.

Survey weighting procedures. Because the National Electronic Injury Surveillance System is a national probability sample of hospitals, each of the injured drivers was assigned a sample weight based on the inverse of the known probability of selection of the hospitals in each stratum. Weights for the completed interviews were adjusted for unit nonresponse.

The user survey observations were also weighted to provide statistically valid national estimates of ATV drivers from ATV-owning households. Each of the sampled households received a weight that was adjusted for the number of telephones in the household and unit nonresponse. Because only one driver per household was interviewed, the household weight was multiplied by the number of household drivers, yielding a driver population weight that reflected the total number of ATV drivers in the United States (14).

Data adjustments. To avoid the possibility of bias in the comparison of cases and controls, several adjustments to the databases were required prior to analysis. First, because the user survey was limited to drivers from ATV-owning households, the cases were limited to injured drivers who owned, or whose household owned, the ATV involved.

Second, because the sample of controls was intended to represent ATV drivers who had not been injured, user observations were excluded from the analysis if the driver had suffered an ATV injury that required emergency department medical treatment during the overall May to November study period. Finally, user survey respondents who used their ATVs entirely for commercial or occupational tasks other than farming or ranching were excluded from the controls because the National Electronic Injury Surveillance System does not routinely collect data on those types of occupational injuries.

Because of these adjustments, inferences are limited to drivers from ATV-owning households, except for those who use their ATV(s) entirely in nonfarm occupational applications.

Statistical analysis

SUDAAN software (Research Triangle Institute, Research Triangle Park, North Carolina) was used in the statistical analysis because of the complex design of both surveys. In the National Electronic Injury Surveillance System survey, the strata were hospital sizes, the primary sampling units were the hospitals, and the secondary sampling units were the injured drivers. Injured drivers were therefore modeled in SUDAAN software as cluster samples of injured drivers from the hospitals. In the exposure survey, the strata were geographic regions, the primary sampling units were households, and the secondary sampling units were uninjured persons in the household. Uninjured drivers were therefore modeled as cluster samples of uninjured drivers from the household.

Thus, both samples were modeled in SUDAAN software as cluster samples within distinct strata and primary sampling units; the SUDAAN design parameter was "without replacement," a design which was appropriate for each sample. Because both surveys were mutually exclusive in their population of interest, they were appended (i.e., stacked) into a single data set representing all ATV users. Variance estimation was based on Taylor linearization methods (15).

A univariate comparison of the cases and controls was conducted as a preliminary evaluation of possible risk factors. Crude odds ratios, with 95 percent confidence intervals, were calculated.

The principal method of analysis was a binary logistic regression analysis of the case-control data. The explanatory variables included various driver characteristics and use patterns, as well as characteristics of the ATVs driven. Age was included as a polytomous categorical variable, with five discrete age categories. The driver's gender and the ATV's number of wheels (three or four) were included as dichotomous variables. The remaining variables were included as continuous variables. Various scales (i.e., functional forms) of the continuous variables and possible interactions between the risk factors were explored.

In addition to estimating adjusted odds ratios, we estimated annual injury probabilities to illustrate the relation between selected risk variables and risk. Injury probabilities were estimated using an adjustment procedure described by Maddala (16) and by Hosmer and Lemeshow (17) that combined the results of the regression analysis with additional independent information on the number of injured and uninjured ATV drivers to account for the relative sampling proportions within the cases and controls (1, 18).

RESULTS

Survey response

A total of 487 injured riders were identified through National Electronic Injury Surveillance System hospitals during the study period. All were assigned for follow-up telephone interviews. A total of 353 interviews with injured victims (or their representatives) were completed, yielding an overall response rate of 72.5 percent.

After data adjustments, cases were limited to 133 of the 353 completed case interviews. Of the 220 cases dropped from the analysis, 34 were determined to be out-of-scope (e.g., the ATV was not being operated at the time of injury), 92 involved passengers, and 79 involved nonowners. Finally, 15 cases were dropped because the ownership of the vehicle could not be determined.

The user survey completed 464 interviews with drivers (or their parents). The screening response rate, the proportion of numbers successfully screened to determine household eligibility, was 80.4 percent. The interview response rate, the proportion of eligible respondents who completed interviews, was 82.7 percent. The overall response rate, estimated as the product of the screening and interview response rates, was 66.5 percent.

Three user survey observations were excluded from the analysis because the driver had suffered an injury that required emergency department medical treatment, and one was excluded because the driver used the ATV entirely for commercial or occupational tasks. The results of the analysis were not affected by the inclusion or exclusion of these observations.

The denominator degrees of freedom, which equals the number of primary sampling units less the number of strata, was 451 (15, 19). This reasonably large value suggests that the analysis should provide enough power, even after adjusting for a number of explanatory variables, to detect and to test for meaningful differences in risk factors.

Descriptive evaluation

The final database used in the analysis included 133 cases and 460 controls. Table 1 shows the characteristics of driver injuries. Almost 16 percent resulted in hospital admission, compared with only about 4 percent of all injuries reported through the National Electronic Injury Surveillance System. Just over 11 percent of the ATV injuries involved the head.

The characteristics of the cases and controls, along with crude odds ratios for the weighted data, are presented in table 2. With the exception of the gender and wheels variables, information on the variables shown in the table was collected as continuous data. The variable categories shown in table 2 were chosen only for expository purposes. The univariate results indicate that the cases are more likely to involve young drivers and children, males, drivers who use

TABLE 1. Characteristics of injuries, US Consumer Product Safety Commission Nationwide All-Terrain Vehicle Injury Survey, 1997

Characteristic	%*
Type of injury (primary)	
Concussion	1.9
Internal injury	2.6
Contusions/abrasions	25.2
Fracture/dislocation	30.7
Strain/sprain	15.1
Laceration	22.9
Other	1.6
Total	100.0
Body part injured (primary)	
Head	11.1
Neck	1.6
Face	6.2
Upper trunk	5.6
Lower trunk	7.4
Arm/shoulder	39.8
Leg/foot	25.0
Multiple body parts	3.3
Total	100.0
Hospital disposition	
Treated and released	84.2
Admitted	15.8
Total	100.0

* Weighted on the basis of 133 driver injuries treated in hospital emergency departments.

TABLE 2. Selected characteristics of cases and controls, US Consumer Product Safety Commission Nationwide All-Terrain Vehicle Injury and User Surveys, 1997

Variable	Cases		Controls		Crude OR*	95% CI*
	No.	%	No.	%		
Age (years)	133		456			
≤15		33.6		14.3	4.9	1.8, 13.1
16–25		31.2		29.0	2.2	0.8, 6.3
26–35		16.1		20.5	1.6	0.6, 4.7
36–45		10.5		18.5	1.2	0.4, 3.5
≥46		8.5		17.6	1.0	
Gender	133		456			
Male		86.4		65.7	3.3	1.5, 7.4
Female		13.6		34.3	1.0	
Wheels	133		456			
Three wheels		30.5		15.5	2.4	1.3, 4.5
Four wheels		69.5		84.5	1.0	
Engine size (cm^3)	122		438			
<100		5.8		5.5	1.3	0.4, 4.4
101–200		23.9		19.5	1.6	0.6, 4.0
201–300		49.4		48.5	1.3	0.7, 2.6
≥301		20.9		26.5	1.0	
Experience (years)	130		454			
≤1		20.8		8.5	3.7	1.5, 9.0
1.1–4.0		24.5		22.8	1.6	0.8, 3.5
4.1–8.0		15.3		15.8	1.5	0.6, 3.5
8.1–12.0		20.1		24.0	1.3	0.5, 3.1
≥12.1		19.3		28.9	1.0	
Nonrecreational use (hours out of 10)	130		457			
0–2		77.8		53.8	3.2	1.5, 7.1
3–7		14.1		28.0	1.1	0.4, 3.1
8–10		8.1		18.2	1.0	
Hours per month	107		443			
0–10		39.3		42.6	0.7	0.3, 1.7
11–25		17.0		27.7	0.5	0.2, 1.0
26–50		25.3		15.4	1.3	0.4, 4.3
≥51		18.3		14.3	1.0	

* OR, odds ratio; CI, confidence interval.

three-wheel (as opposed to four-wheel) ATVs, and drivers who use their ATVs in recreational (as opposed to nonrecreational) activities a greater proportion of the time.

Logistic regression analysis

The results of the logistic regression analysis are presented in table 3. For the most part, they mirror the univariate findings. Additionally, because emergency department injury risks are small on an absolute scale (i.e., generally under 1 percent per year), the adjusted odds ratios approximate relative risks (20).

The estimated risk was highest for children under age 16 and generally declined with age. Relative to drivers "*over age 45*," the odds ratio for children was 12.0 (95 percent confidence interval (CI): 4.6, 31.3). To compare estimated risks for children under age 16 with all older drivers, the table 3 model was reestimated with age as a dichotomous variable; in this model the odds ratio for children, relative to drivers age 16 or older, was 3.9 (95 percent CI: 1.7, 8.7). The estimated risk was also higher for males (odds ratio (OR) = 3.0; 95 percent CI: 1.6, 5.5) and for riders who drove three-wheel ATVs (OR = 3.1; 95 percent CI: 1.5, 6.4).

With the exception of the nonrecreational use variable, all of the continuous variables were scaled as natural logarithms, transformations that substantially improved the fit of the model. Based on the table 3 results, the estimated risk declined with driving experience, declined with the proportion of time ATVs were used in nonrecreational applications, and rose with engine size. Given the logarithmic scale of the

TABLE 3. Logistic regression results, US Consumer Product Safety Commission Nationwide All-Terrain Vehicle Injury and User Surveys, 1997

Variable*	Coefficient (SE†)	Adjusted OR†,‡	95% CI†
Intercept	–8.892 (1.966)		
Age group (years)			
≤15	2.484 (0.489)	12.00	4.59, 31.34
16–25	1.365 (0.417)	3.92	1.73, 8.89
26–35	1.640 (0.405)	5.16	2.33, 11.42
36–45	1.082 (0.388)	2.95	1.38, 6.32
≥46	0 (0)	1.0	
Gender			
Male	1.087 (0.319)	2.97	1.58, 5.55
Female	0 (0)	1.0	
Wheels			
Three wheels	1.130 (0.369)	3.10	1.50, 6.39
Four wheels	0 (0)	1.0	
ln† (engine)§	0.912 (0.293)	1.39	1.13, 1.71
ln (experience)¶	–0.404 (0.139)	0.96	0.93, 0.99
Nonrecreational hours#	–0.240 (0.039)	0.79	0.73, 0.85
ln (hours)**	–2.572 (0.356)	0.90	0.88, 0.93
$[\ln(\text{hours})]^2$	0.434 (0.061)	1.18	1.08, 1.15

* The analysis is based on 96 cases and 421 controls with complete data.

† SE, standard error; OR, odds ratio; CI, confidence interval; ln, natural logarithm.

‡ The odds ratios of the continuous variables specified as natural logarithms depend upon the level of the variable at which the odds ratios are calculated. In these cases, the odds ratio is calculated at the mean unit value of the variable.

§ The natural logarithm of the engine size in cm^3 of displacement. The odds ratio is calculated per 100 cm^3.

¶ The natural logarithm of the months of driving experience (i.e., months since learned to ride). The odds ratio is calculated per 12 months of riding experience.

The number of hours (of every 10) that the driver uses the all-terrain vehicle for nonrecreational purposes. The odds ratio is calculated per hour of nonrecreational use.

** The natural logarithm of the number of hours the driver rides an all-terrain vehicle in an average month of use. The odds ratio is calculated per hour of monthly riding.

driver experience and engine size variables, it can be shown that a 1 percent increase in driving experience results in an estimated risk reduction of about 0.4 percent and that a 1 percent increase in engine size increases the estimated risk by 0.9 percent (21).

Additionally, the estimated risk exhibited a quadratic relation with hours of use in an average month. The estimated risk was high for those who rode infrequently, declined over a brief range of driving times, and then rose as driving times increased. This relation seems to suggest that, while estimated risk generally rises with driving times, it also tends to be relatively high for infrequent drivers.

A number of interaction variables were also evaluated, including interactions between experience and number of wheels, between experience and hours of monthly driving, and between the age and gender of the driver. None of these interactions significantly improved the fit or predictive ability of the model.

Figure 1 illustrates the types of estimated risk relations that can be generated from the regression model when additional information on the sampling proportions for the cases and controls is available. Figure 1 shows the estimated risk relations between engine size and the number of wheels on ATVs for a *typical* driver, who is assumed to be a male aged 30 years with 8 years of driving experience and who rides for about 25 hours per month and uses the ATV for nonrecreational applications about 10 percent of the time.

DISCUSSION

The results of this study suggest that ATV injury risks are systematically related to a number of driver and vehicle characteristics. Moreover, the relations are substantial as well as statistically significant and help to explain, at least in part, the observed reduction in the ATV-related injury rate during the 1985–1997 time period.

The results of the 1997 user survey (18), when compared with those of a similar survey conducted in 1986 (22), suggest a decrease in the proportion of riders under

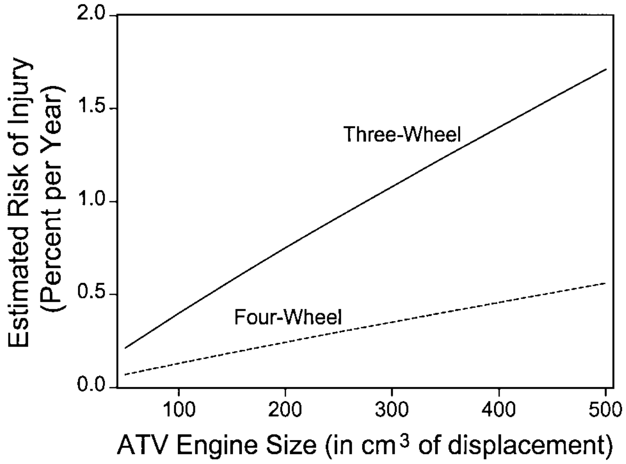

FIGURE 1. Risk of injury by all-terrain vehicle engine size (for both three- and four-wheel all-terrain vehicles), US Consumer Product Safety Commission Nationwide All-Terrain Vehicle Injury and User Surveys, 1997. ATV, all-terrain vehicle.

age 16 (14.3 percent in 1997 vs. 27 percent in 1985), a decrease in the proportion of riders with 1 year or less of experience (8.5 percent vs. 20 percent), a decrease in the proportion of three-wheel ATVs in use (21.5 percent vs. 76 percent), and an increase in the proportion of drivers who use ATVs in nonrecreational activities at least some of the time (73.7 percent vs. 52 percent). Based on the findings of the risk model, each of these population changes would have been expected to reduce the rate of injury. Only increases in engine size, which increased from an average of under 200 cm^3 of displacement in 1985 to about 250 cm^3 in 1997, would have mitigated against the decreasing injury rate.

Possible limitations

The results of this analysis need to be interpreted with some caution. Because the surveys required information on past behavior, responses may be subject to some recall bias. Additionally, because children's ATV use was reported by parents or guardians, there exists the possibility of reporting bias.

However, there is no reason to believe these potential biases had any systematic impact on the statistical results. Most of the variables, such as age, gender, driver experience, engine size, and number of wheels, were factual in nature. Moreover, while reported nonrecreational use and average monthly driving times were undoubtedly approximations, the statistical significance of the remaining relations was not altered when one or both of these variables were excluded from the analysis.

Additionally, the risk findings are plausible. Young children may not have the strength, cognitive abilities, and motor skills to operate large adult-sized ATVs safely (23). With respect to gender, males may be more risk-taking than females, as evidenced by automobile and other injury rates (24, 25).

Higher risks for inexperienced drivers may be explained by the unique dynamic properties of ATVs and the high level of skill needed for safe ATV operation (26). The reasons for lower risks in nonrecreational applications are less clear, but they may be related to differences in nonrecreational driving patterns or terrains.

The finding of higher risks on three-wheel ATVs is consistent with engineering findings that three-wheel ATVs are less stable than are their four-wheel counterparts (26–28). The positive relation between engine size and risk is probably related to the speed and acceleration characteristics of ATVs with larger engines.

Although the findings are plausible, it should also be noted that not all of the potentially important risk factors were evaluated in this analysis. It would have been useful, for example, to explore the relation between the use of alcohol and drugs and the ATV injury risk. Although some information about the use of these products was collected in both surveys, this information could not be evaluated directly in the risk analysis. The user survey asked all drivers about their frequency of alcohol or drug use when riding; in contrast, the injury survey asked only adult riders about alcohol or alcohol use prior to the injury.

The effect of helmet use on risk was not evaluated in this study. In part, this was for theoretical reasons. A driver's decision to use a helmet is arguably interdependent with risk. Thus, while helmet use is expected to affect risk, the risk a rider faces may also affect the likelihood of helmet use; for example, some drivers who ride in more risky environments may be more likely to use helmets. Assuming this to be the case, the decision to use a helmet is not truly a "predetermined" variable eligible for use in a single equation risk model (29). Additionally, helmets are expected to prevent only head injuries. Because head injuries account for only about 11 percent of injuries, most of the outcomes studied would not have been addressed by helmet use.

It should also be reiterated that inferences from the analysis are technically limited to drivers from ATV-owning households. However, there is no reason to believe that the general risk relations are different for nonowners.

Conclusions

The results of this analysis suggest that future safety efforts should focus on reducing injuries and deaths involving children, getting beginning drivers to participate in the existing training programs, and encouraging consumers to dispose of the three-wheel ATVs still in use.

ACKNOWLEDGMENTS

The authors thank Thomas J. Schroeder for assistance in adapting the data sets for analysis and Dr. Michael Greene for helpful comments in the preparation of the article.

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