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Drowsiness, counter-measures to drowsiness, and the risk of a motor vehicle crash

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Abstract

***Objectives*—Knowledge of how different indicators of drowsiness affect crash risk might be useful to drivers. This study sought to estimate how drowsiness related factors, and factors that might counteract drowsiness, are related to the risk of a crash.**

***Methods*—Drivers on major highways in a rural Washington county were studied using a matched case-control design. Control (n=199) drivers were matched to drivers in crashes (n=200) on driving location, travel direction, hour, and day of the week.**

***Results*—Crash risk was greater among drivers who felt they were falling asleep (adjusted relative risk (aRR) 14.2, 95% confidence interval (CI) 1.4 to 147) and those who drove longer distances (aRR 2.2 for each additional 100 miles, 95% CI 1.4 to 3.3). Risk was also greater among drivers who had slept nine or fewer hours in the previous 48 hours, compared with those who had slept 12 hours. Crash risk was less for drivers who used a highway rest stop (aRR 0.5, 95% CI 0.3 to 1.0), drank coffee within the last two hours (aRR 0.5, 95% CI 0.3 to 0.9), or played a radio while driving (aRR 0.6, 95% CI .4 to 1.0).**

***Conclusion*—Drivers may be able to decrease their risk of crashing if they: (1) stop driving if they feel they are falling asleep; (2) use highway rest stops; (3) drink coffee; (4) turn on a radio; (5) get at least nine hours sleep in the 48 hours before a trip; and (6) avoid driving long distances by sharing the driving or interrupting the trip.**

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Keywords: traffic accidents, motor vehicles; sleep deprivation; coffee

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An estimated one fourth to one half of drivers report having fallen asleep at the wheel at least once.[1–3] Studies in the United States have estimated that between 1% and 4% of crashes may be attributed to the driver falling asleep or being drowsy.[4–10] Studies from Norway,[11] Australia,[12] and Britain[13] have given estimates of 4%, 6%, and 16% respectively. These studies have usually been case series in which investigators assumed that drivers or police could determine which crashes were caused by drowsiness. None sampled the prevalence of drowsiness among drivers not in crashes. They also assumed that crashes could be ascribed to just one or two causal factors, rather than a more complex combination.[10]

Admonishing people not to drive while drowsy may be too non-specific to be an effective message. More helpful advice might be generated from knowledge of how crash risk changes in relation to specific measures of drowsiness that drivers can assess and modify. We conducted a case-control study to estimate how drowsiness related factors were related to the risk of a crash.[14]

Methods

STUDY LOCATION

The study location was 106 miles of interstate and 27 miles of state highway in Kittitas County, a rural area in central Washington State with an estimated population of 31 500 in 1997.[15] Washington State Patrol investigated crashes on these roads.

CASE SELECTION

Potential cases were drivers in crashes from 1 January 1997 through 15 November 1998. Only drivers 18 years of age or older in vehicles registered in Washington were eligible. We excluded crashes of motorcycles, vehicle fires not due to a crash, vehicles parked when struck, stolen vehicles, and drivers who died, fled the scene, or did not speak English.

CONTROL SELECTION

We sought to match one control driver to each interviewed case driver. After a case driver was interviewed, a state patrol trooper trained in study procedures returned to the crash site seven days after the crash; if this was not possible, attempts were made 14 or 21 days after the crash. Starting one half hour before the time of the matched crash, the trooper recorded the license numbers of 15 vehicles that drove by in the same direction as the matched case. If traffic was too dense to record consecutive numbers, the trooper recorded the first number, allowed five seconds to elapse, then counted vehicles and recorded the license of the tenth. This was repeated until 15 numbers were recorded. The time that a control license was recorded was the reference time for that driver.

TRACING CASES AND CONTROLS

We were not legally permitted to stop control drivers and we felt that, over time, drivers would have increasing difficulty recalling details regarding sleep and activities. Therefore, we confined the study to eligible drivers who could be interviewed by telephone within 96 hours of crash or reference time.

The license number of each potential control vehicle was used to find the owner's name and address in Department of Licensing files. Interviewers sought a telephone number for each owner, using a computerized directory and directory assistance. The potential control list was randomly sorted and owners called in that order. An interview was sought with the person driving at the reference time. Calls were made in the day and evening until the 96 hour limit. If more than one driver was interviewed, the one highest on the list was retained as the control.

For case drivers, troopers faxed information to us about the crash, including information about the registered owner. To maintain parity with the control selection process, we ignored driver information recorded on the crash report. Instead, we used owner name and address to seek the owner's telephone number, and tried to reach the driver.

We sought to interview at least 200 case-control pairs based on estimates of the sample size needed to detect true relative risks of about 2.0 for most study exposures.

STUDY VARIABLES

Cases and controls were interviewed by telephone using similar questions; for cases we inquired about exposures before the crash and for controls we asked about exposures before the reference time. We assured drivers that responses would be treated in a confidential manner.

We defined a trip as travel by motor vehicle not interrupted by a break of six or more hours, lasting up to the crash or reference time. If, for example, a driver commuted to work at 8:30 am and arrived at 9, left work by car at 5 pm and crashed at 5:15, the trip start time would be 5 pm, not 8:30 am, and the trip duration would be 15 minutes. Drowsiness related exposures included miles driven by the driver, trip distance, trip duration, sleep information for the past 48 hours, breaks during the trip, feelings of falling asleep while driving, yawning, and time of last meal. We inquired about factors that might counteract drowsiness: use of radio or tapes, whether a car window was open, and use of caffeinated beverages. We asked about past episodes of falling asleep while driving and exposures that might indicate sleep disorders, including a history of sleep apnea, weight and height, and the questions on the Epworth sleepiness scale.[16 17]

Potential confounding variables included reason for the trip, presence of passengers, use of a cell phone, and information about the driver: age, sex, education, income, job status, recent work or sports, age at which he or she learned to drive, miles driven in last year, health status, use of medications, use of alcohol, smoking history, and past crash history. Road surface conditions (dry, wet, snow, or ice) were supplied by troopers, and vehicle information came from troopers and the licensing department.

CONSISTENCY OF SLEEP HISTORY

To estimate consistency of history regarding sleep, we reinterviewed 15 cases and 15 controls. We used questions from the initial interview and again asked about the period before the crash or reference time. Within-subject agreement in responses was assessed using the intraclass correlation coefficient.[18] Mean interval from crash or reference time to the first interview was 2.3 days and mean time to the second interview was an additional 1.5 days. Intrasubject correlation coefficients were: (1) for time subject last awoke, 0.98; (2) for time subject last went to sleep, 1.00; (3) for time awake before crash or reference time, 0.99 and; (4) for average hours of sleep per day in previous week, 0.75.

ANALYSIS

Odds ratios from conditional logistic regression were used to approximate relative risks; this accounted for the matched design.[19 20] For each drowsiness related variable we assessed the confounding effects of 49 other variables, some of which were also drowsiness related; in general, a covariate was added to the current model only if including it changed the estimated odds ratio for the exposure of interest by 15% or more in either direction.[21]

We used three methods to examine the possibility that transformations of continuous variables might fit the data better than a linear expression: (1) locally weighted regression[22 23]; (2) additive binomial regression[24]; and (3) fractional polynomial regression.[25–27] Sleep time in the previous 48 hours was modeled best by a linear and quadratic term. To account for the U-shaped association between age and crash risk, we adjusted for age in all models using a quadratic spline with a knot at 40 years.[25]

Procedures were approved by the University of Washington. Informed consent was obtained by telephone.

Results

CASE ASCERTAINMENT

Troopers prepared crash reports on 1521 vehicles during 22.5 months; 367 drivers were not eligible (table 1). In the first two months of the study only a random sample of drivers was selected for interviews; hence, 45 were excluded. The remaining 1109 drivers, in 908 crashes, were potentially eligible. Ultimately (table 1), 200 case drivers were interviewed and used in our analysis.

Using information from patrol troopers, we compared the 200 case drivers included in the analysis with other eligible drivers. Included and not included drivers were similar with regard to sex (67% male *v* 68%), the proportion of crashes on interstate highways (84% *v* 81%), the proportion of crashes involving only one vehicle (51% *v* 53%), the proportion injured (25% *v* 26%), and vehicle model year (median year 1991 for both groups). However, included drivers were somewhat older (median age 38 *v* 35 years) and more likely to have crashed in daylight (71% *v* 63%), to have been the vehicle owner (71% *v*

58%), and to have liability insurance (97% *v* 91%). Included drivers were less likely to have driven a large truck (5% *v* 10%), to have received a traffic citation (28% *v* 36%), or to have been judged by troopers to be under the influence of alcohol (2% *v* 6%).

CONTROL ASCERTAINMENT

We sought controls for 226 interviewed case drivers. Troopers were not able to collect license numbers for seven cases. For 219 case drivers, 3227 control license numbers were collected; 2050 were discarded because a control of higher rank order was interviewed. Other drivers did not meet entry criteria or could not be reached (table 1). Four control interviews were excluded for reasons shown (table 1).

DESCRIPTION OF CASES AND CONTROLS

Compared with controls, case drivers were more likely to have been driving on snowy pavement, less likely to have a child passenger, more often young or old, rather than middle aged, had less education, and had lower incomes (table 2).

Only 4% of case and control drivers gave a history of recent use of alcohol. Troopers judged that four case drivers were impaired by alcohol and one had been drinking but was not impaired; all acknowledged recent drinking in their interview. Among 173 case drivers judged by troopers not to have been drinking, two said they had been drinking when interviewed. The trooper recorded no information about alcohol for 22 case drivers; one reported recent alcohol use.

Table 1 Reasons that potential case and control drivers were excluded from the study and reasons that the remaining potentially eligible case and control drivers were not interviewed or not used in the final analysis

	Potential cases (n=1521)	*Potential controls (n=3227)*
Reason for exclusion		
Control higher in rank interviewed	NA	2050
Vehicle not registered in Washington	258	210
Motorcycle	3	NA
Driver younger than 18 years	55	1
Vehicle fire only	12	NA
Parked vehicle	23	NA
Vehicle fled scene or stolen	6	NA
Driver died	10	NA
Not sampled	45	NA
Total excluded	412	2261
Number potentially still eligible	1109	966
Reason no interview was obtained		
Report received too late from patrol	102	16
Report not sent by patrol	55	NA
Owner name and address not found	2	58
Staff not available or staff error	26	8
No telephone number found	234	187
Unlisted telephone number	81	62
Disconnected telephone	12	11
No answer despite multiple calls	34	48
Answering machine only	85	124
Rental agency refused information	5	10
Commercial owner could not locate driver before deadline	53	36
Other reasons	21	25
Presumed owner denied ownership	0	45
Reached household member, not driver	84	58
Household member refused on behalf of driver	24	8
Driver denied crash or driving at reference time and location	3	31
Driver did not speak English	8	2
Driver refused interview	54	34
Total not interviewed	883	763
Number interviewed	226	203
Reason not used in analysis		
Control license numbers not collected	7	NA
Controls collected at wrong time	2	2
Major errors in control interview	2	2
No control interviewed	15	NA
Included in final analysis	200	199

NA = not applicable.

ADJUSTED RELATIVE RISK ESTIMATES

All estimates were adjusted for age and the matched design. Adjusted relative risk (aRR) estimates thus compared drivers of the same age who were driving at the same location, in the same direction, at the same hour, on the same day of the week.

When we compared drivers who drove the same number of hours, the aRR of a crash more than doubled with every 100 miles driven (table 3). When we compared drivers who drove the same distance, the aRR of a crash was 0.7 for each two hour increment in trip time. Note that the time duration of the trip included breaks and other interruptions, as well as being influenced by vehicle speed while underway.

Drivers reported as few as three and as many as 32 hours of sleep in the 48 hours before their trip. Those with very little or a great deal of sleep in the previous 48 hours had a greater crash risk compared with drivers who had 12 hours of sleep. The differences were statistically significant when total sleep time was nine or fewer hours or 21 or more hours (fig 1). Average hours of sleep in the last week showed little association with crash risk. Crash risk was lower after 12 to 17 hours without sleep, compared with being awake less than six hours: aRR 0.2.

Drivers reported as many as 13 breaks during their trip; 16% reported three or more breaks. We found little difference in crash risk for just one break compared with none (aRR 1.2), but there was a trend for lower risk for each additional break beyond the first: aRR for each additional break 0.9 (table 3). Among drivers who used a highway rest stop, the aRR was 0.5, compared with those who did not use a rest stop. Naps during breaks were uncommon; eight cases and one control reported a nap.

Drivers who felt they were falling asleep at the wheel had a 14-fold increase in risk of a crash. In contrast, drivers who yawned during their journey had an aRR for a crash that was less than half that of drivers who did not yawn.

Drivers with a sound system playing had a lower risk of crashing compared with drivers who had no sound system on: aRR 0.6. There was little association between having the window open and crash risk. Drivers who drank coffee or tea within the last two hours had about half the risk of a crash compared with other drivers; the 95% confidence interval (CI) for tea included 1.

The aRR of a crash was sixfold greater among drivers who had a history of a previous crash due to falling asleep; this history was rare and the 95% CI included 1.

A history of sleep apnea, snoring at night, and higher Epworth sleep scores showed some association with crash risk; none were statistically significant.

Table 2 Tabular comparison of 200 cases and 199 controls in a case-control study of traffic crashes in Kittitas County, Washington, 1997–98. Controls matched to cases on place, time of day, and day of week. Some missing values in most categories

Characteristic	Cases No	Cases %	Controls No	Controls %
Trip characteristics				
Pavement condition				
Dry	99	52.1	154	78.6
Wet	22	11.6	30	15.3
Snow, slush, or ice	69	36.3	12	6.1
Any passenger	102	51.0	114	57.3
Child passenger, 0 to 12 years	13	6.5	35	17.6
Adult passenger, 20 years or older	85	42.5	97	49.0
Driver characteristics				
Driver age (years)				
18–29	74	37.0	36	18.1
30–44	51	25.5	70	35.2
45–64	50	25.0	78	39.2
⩾65	25	12.5	15	7.5
Male driver	134	67.0	141	70.9
Education				
High school or less	66	33.0	53	26.6
Some college	75	37.5	59	29.7
College	59	29.5	87	43.7
Income in thousands of dollars				
<25	69	36.3	39	20.0
25–74	95	50.0	112	57.4
⩾75	26	13.7	44	22.6
Drank alcohol in last 8 hours	8	4.0	8	4.0
Crashes in last 5 years				
0	131	65.5	154	77.8
1	52	25.5	36	18.2
⩾2	18	9.0	8	4.0
Using a cellular phone at crash or reference time	2	3.4	7	7.5
Vehicle characteristics				
Car	148	76.7	152	80.0
Pick-up	35	18.1	33	17.4
Large truck	10	5.2	5	2.6
Vehicle model year				
<1990	77	39.9	59	31.2
1990–93	57	29.5	64	33.9
1994–98	59	30.6	66	34.9
Factors related to drowsiness				
Trip miles driven by driver				
<100	106	54.9	109	56.8
100–199	57	29.5	62	32.3
⩾200	30	15.5	21	10.9
Hours since trip started				
<4	162	81.0	155	77.9
4–7	27	13.5	29	14.0
⩾8	11	5.5	15	7.5
Hours since last sleep				
<6	94	47.0	85	42.7
6–11	81	40.5	73	36.7
12–17	21	10.5	39	19.6
⩾18	4	2.0	2	1.0
Hours of sleep in previous 48 hours				
<12	16	9.2	10	5.5
12–17	106	60.9	136	74.7
⩾18	52	29.9	36	19.8
Average hours slept per day in last week				
<7	31	15.5	35	17.7
7–8	136	68.0	142	71.7
⩾9	33	16.5	21	10.6
Average sleep hours needed per day				
<7	25	12.6	23	11.6
7–8	138	69.7	151	76.3
⩾9	35	17.7	24	12.1
Break taken on trip	117	58.5	119	59.8
Used highway rest stop	29	14.5	44	22.1
Nap during trip	8	4.0	1	0.5
Sensation of falling asleep on trip	11	5.5	1	0.5
Yawned while driving	34	18.4	58	32.4
Ate in last 2 hours	60	30.5	51	25.8
Radio, tape, or compact disk player on	125	63.1	143	71.9
Window open	55	27.8	55	28.2
In last 2 hours, drank				
Coffee	52	26.0	81	40.9
Tea	4	2.0	7	3.5
Soda with caffeine	59	29.5	36	18.2
Any caffeinated beverage	110	55.0	112	60.6
Past crashes due to falling asleep	11	5.5	4	2.0
Ever fell asleep at the wheel	80	40.0	78	39.2
History of sleep apnea diagnosis	3	1.5	3	1.5
Snore most nights	69	36.3	80	42.3
Gasp in sleep	21	10.6	24	12.2
Epworth sleep score				
<5	40	21.7	45	24.1
5–7	53	28.8	58	31.0
8–10	50	27.2	42	22.5
11–22	41	22.3	42	22.5

Discussion

Our study population can be thought of as English speaking adult drivers with listed telephone numbers who could be reached at home with relative ease. Our estimates could be biased if subject selection was influenced by drowsiness related exposures. We tried to minimize this potential bias by applying the same selection scheme to both case and control drivers.

We were probably less likely to sample drivers who spent a great deal of time traveling, because they may have been less accessible for a telephone interview. We had evidence that we were less likely to interview potential case drivers who crashed at night, had been drinking, or were issued a citation; similar information regarding potential control drivers was not available. Furthermore, our findings may not apply to drivers in urban areas or to crashes in which the driver dies.

Differential recall between case and control drivers could have biased some estimates. In particular, case drivers, seeking to explain why they crashed, might be more likely to recall a feeling of falling asleep on their journey, particularly if their crash was related to actually falling asleep. By whatever mechanism, a feeling of falling asleep was associated with a greatly increased risk of a crash. A study of 28 sleep deprived drivers using a driving simulator reported that subjects were always aware of increasing sleepiness before having a simulated crash due to falling asleep.[28]

The aRR of a crash increased exponentially with the distance driven, when we compared trips of equal duration. Once a trip was more than 130 miles, the increase in aRR associated with any further increment in distance was greater than expected if the increase was simply proportional to the distance driven. For example, if we compared a drive of 600 miles with one of 300, the relative risk of a crash increased more than the twofold increase in distance: $2.2^{(6-3)} = 10.6$. This may be consistent with the theory that a driver may become progressively less alert. However, our estimates regarding miles driven, independent of driving time, may also reflect vehicle speed; we had no measure of vehicle speed at crash or reference time.

Naps were uncommon in our study, and were more often taken by the drivers who crashed; a nap may indicate an unsuccessful attempt to fight sleepiness. Using a highway rest stop, however, was associated with a decreased risk of crashing; notably, most of these breaks did not involve napping.

Drivers who had on a radio or tape player, were at less risk for a crash compared with others. This is consistent with a study of 16 sleep deprived subjects in a driving simulator; when they played a radio or tape the subjects had fewer driving errors, although the difference was not statistically significant.[29] The same study found no improvement in performance when cold air was blown in the subject's face; this agrees with our finding that having a window open was not related to the risk of a crash.

Our finding that drinking coffee was associated with a decreased crash risk is consistent

Table 3 Adjusted relative risk estimates for a traffic crash, for factors possibly related to drowsiness. Data from a case-control study in Washington State, 1997–98. Controls matched to cases on time of day, day of week, and location. Estimates adjusted for matching variables and age. Additional adjustments for confounders listed in table

Factors that may be related to drowsiness	*Adjusted relative risk of a crash*	*95% confidence interval*	*Additional confounding variables*
Trip miles driven by driver (100 mile units)	2.2	1.4 to 3.3*	Hours since trip started
Hours since trip started (2 hour units)	0.7	0.5 to 0.9*	Miles driven by driver
Hours since last sleep			
<6	1.0	Reference category	Road surface (dry, wet, snowy)
6–11	0.9	0.3 to 2.3	
12–17	0.2	0.0 to 0.7*	
⩾18	1.3	0.4 to 4.0	
Average hours slept per day in last week	1.1	0.9 to 1.3	None
Average sleep hours needed per day	1.0	0.8 to 1.3	None
Breaks taken on trip			
Any compared with none	1.2	0.7 to 1.9	Number of breaks beyond first
Number of breaks beyond first	0.9	0.7 to 1.0	Any break compared with none
Used highway rest stop	0.5	0.3 to 1.0*	Miles driven by driver
Sensation of falling asleep on trip	14.2	1.4 to 147*	Time awake in last 24 hours
Yawned while driving	0.4	0.2 to 0.7*	None
Time since last ate (6 hour units)	0.8	0.6 to 1.1	None
Radio, tape, or compact disk player on	0.6	0.4 to 1.0*	None
Window open	1.1	0.7 to 1.8	None
In last 2 hours, drank			
Coffee	0.5	0.3 to 0.9*	None
Tea	0.4	0.1 to 1.6	None
Soda with caffeine	1.7	1.0 to 2.8	None
Any caffeinated beverage	0.8	0.5 to 1.3	None
Past crash due to falling asleep	5.9	1.0 to 36	Miles driven by driver Hours since trip started Road surface (dry, wet, snowy)
Ever fell asleep at the wheel	1.6	1.0 to 2.7	Miles driven by driver Hours since trip started
History of sleep apnea diagnosis	2.9	0.2 to 45	Road surface (dry, wet)
Snore most nights	1.7	0.8 to 3.4	Road surface (dry, wet, snowy)
Gasp in sleep	1.0	0.5 to 1.9	None
Epworth sleep score (in units of 6 points)	1.6	0.9 to 2.8	Road surface (dry, wet, snowy) Miles driven by driver Hours since trip started

*95% confidence interval excludes 1.0.

with studies in which 150 mg of caffeine was administered to sleep deprived subjects who were in driving simulators.[30] Coffee contains about 17 mg of caffeine per ounce compared with about 4 mg in soft drinks.[31] This difference could explain our failure to find evidence of a protective effect from sodas.

We expected that yawning might indicate drowsiness; contrary to this expectation, drivers who recalled yawning were at decreased risk of a crash. We were also surprised that the drivers who slept the most during the previous 48 hours had an increased risk of crashing compared with those who slept 12 hours. Perhaps this reflected longer term sleep deficits that were not fully corrected, or it could be a marker for people who need more sleep. Lastly,

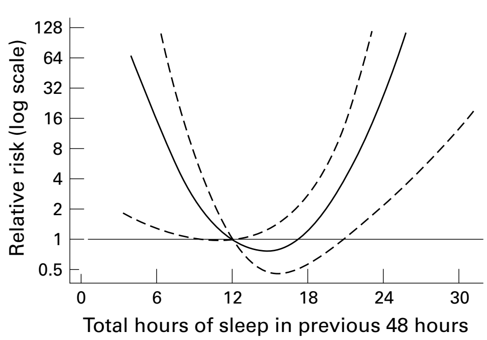

Figure 1 Relative risk of a crash according to the hours the driver slept in the previous 48 hours; adjusted for matching variables, age, and road surface (dry, wet, snowy). Sleep time expressed as linear and quadratic terms. A relative risk of 1 was assigned to drivers who had 12 hours of sleep. Pointwise 95% confidence intervals are shown with dashed lines.

we cannot explain why drivers awake for 12 to 17 hours might have a lower crash risk compared with drivers awake for shorter or longer periods. These unexpected results were not produced by our modeling choices, as different category boundaries and nonparametric regression revealed the same patterns.[24 25] Chance associations in our data or biases in exposure measurement might explain these findings; alternatively, they may offer clues to causal mechanisms that are not apparent to us.

In a previous study, North Carolina drivers in crashes that law officers attributed to sleepiness were compared with drivers in other crashes, and with other drivers not in a recent crash.[32] As the authors noted, this study estimated the relative risk of being in a sleep related crash compared with being in a crash not attributed to sleepiness, or the relative risk of being in a crash classified as sleep related compared with not crashing. These estimates are not comparable with our estimates for the relative risk of crashing compared with not crashing.

A case-control study from Spain examined the association between sleep apnea and the risk of a traffic crash among 102 drivers who crashed and 152 control drivers.[33] Drivers with an apnea-hypopnea index of 10 or higher, compared with those with a lower index, had an aRR for crashing of 7.2 (95% CI 2.4 to 21.8). Case drivers, compared with controls, had slightly higher mean Epworth scores and snoring scores, although these differences were not statistically significant.

Key points

- Risk of a crash was less among drivers who drank coffee, played the radio, and used rest stops.
- Crash risk was much greater among drivers who felt as if they were about to fall asleep.
- Crash risk was greater among drivers who slept fewer than nine hours in the previous 48 hours.
- Crash risk increased with trip distance in an exponential fashion.

Implications for prevention

To our knowledge, this is the first study to provide relative risk estimates for a crash, derived from an actual driving population, for nearly all of the potentially hazardous and protective factors that we examined. Our findings offer some evidence that drivers on rural highways may decrease their risk of a crash if they: (1) stop driving if they feel they are falling asleep; (2) use highway rest stops; (3) drink coffee; (4) turn on a radio; (5) get at least 12 hours sleep in the 48 hours before a trip; and (6) avoid driving long distances, such as 300 miles, by sharing the driving or interrupting the trip. Our data also support the construction of convenient highway rest stops.

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