Cite this article as: BMJ, doi:10.1136/bmj.37984.574757.EE (published 2 February 2004)

Papers

Motorcycle rider conspicuity and crash related injury: case-control study

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Abstract

Objective To investigate whether the risk of motorcycle crash related injuries is associated with the conspicuity of the driver or vehicle.
Design Population based case-control study.
Setting Auckland region of New Zealand from February 1993 to February 1996.
Participants 463 motorcycle drivers (cases) involved in crashes leading to hospital treatment or death; 1233 motorcycle drivers (controls) recruited from randomly selected roadside survey sites.
Main outcome measures Estimates of relative risk of motorcycle crash related injury and population attributable risk associated with conspicuity measures, including the use of reflective or fluorescent clothing, headlight operation, and colour of helmet, clothing, and motorcycle.
Results Crash related injuries occurred mainly in urban zones with 50 km/h speed limit (66%), during the day (63%), and in fine weather (72%). After adjustment for potential confounders, drivers wearing any reflective or fluorescent clothing had a 37% lower risk (multivariate odds ratio 0.63, 95% confidence interval 0.42 to 0.94) than other drivers. Compared with wearing a black helmet, use of a white helmet was associated with a 24% lower risk (multivariate odds ratio 0.76, 0.57 to 0.99). Self reported light coloured helmet versus dark coloured helmet was associated with a 19% lower risk. Three quarters of motorcycle riders had their headlight turned on during the day, and this was associated with a 27% lower risk (multivariate odds ratio 0.73, 0.53 to 1.00). No association occurred between risk and the frontal colour of drivers' clothing or motorcycle. If these odds ratios are unconfounded, the population attributable risks are 33% for wearing no reflective or fluorescent clothing, 18% for a non-white helmet, 11% for a dark coloured helmet, and 7% for no daytime headlight operation.
Conclusions Low conspicuity may increase the risk of motorcycle crash related injury. Increasing the use of reflective or fluorescent clothing, white or light coloured helmets, and daytime headlights are simple, cheap interventions that could considerably reduce motorcycle crash related injury and death.

Introduction

Every day about 3000 people die and 30 000 people are seriously injured on the world's roads.[1] A disproportionate burden is borne by low to middle income countries and vulnerable road users such as pedestrians, cyclists, and riders of motorcycles and scooters.[2] By 2020, road traffic crashes are projected to be the third leading cause of death and disability worldwide.[3]

Low motorcycle conspicuity, or the inability of the motorcyclist to be seen by other road users, is thought to be an important factor associated with risk of motorcycle crashes.[4] This may result from several factors, including size of motorcycle, irregular outline, low luminance or contrast with the background environment, and the ability to travel in unexpected places in the traffic stream. Inexpensive measures can potentially enhance conspicuity—for example, adding a light source and the use of light, bright, reflective, or fluorescent colours.

Much of the epidemiological literature on motorcycle conspicuity comprises historical cohort analyses investigating daytime use of headlights and motorcycle crash rates before and after legislation or ecological studies investigating regions with or without "lights on" laws.[5–12] We are aware of only four previous aetiological studies investigating the association between motorcycle conspicuity and risk of crash related injury.[13–16] All were case-control studies conducted more than 20 years ago, and none used a population based sampling frame.[13–18] In three of these studies, daytime use of headlights was investigated and found to be associated with reduced risk.[13 15 16] Hurt et al found that wearing a high visibility upper torso garment was associated with lower involvement in crashes; however, control data were collected two years after the crash data.[13] No other case-control study has evaluated the effects of colour of helmet or clothing. Despite the limited evidence base, several countries—for example, Malaysia, the United States, and Austria—have made daytime use of headlights mandatory, and riders in other countries have voluntarily adopted this and other strategies.

We investigated the association between a range of conspicuity measures and the risk of motorcycle crash related injury in a country without mandatory daytime headlight laws.

Methods

Study population and setting

We conducted a population based case-control study in Auckland, New Zealand, between February 1993 and February 1996. The study methods and the sociodemographic, behavioural, and vehicle related factors have been described elsewhere.[19 20] At the time of the study, the Auckland region had a population of approximately 950 000, of whom more than 90% lived in urban districts (1991 census). The source population was all motorcycle drivers riding on motorways and principal or arterial roads between 6 am and midnight in the Auckland region. We excluded motorcycle drivers riding on residential roads and riding between midnight and 6 am, as less than 2% of riding occurs in these situations.[21] We defined a motorcycle by using the ICD-9.CM (international classification of diseases, 9th revision, clinical modification) definition of a two wheeled vehicle.[22] We applied the definitions of geographical boundaries, time period, eligible vehicles, and eligible roads in an identical manner to cases and controls. We obtained informed consent from all participants.

Case selection

We included in the study all motorcycle drivers or pillion passengers who were killed, admitted to hospital, or treated in a public hospital emergency department in the Auckland region, and who had an injury severity score of >5 within 24 hours of a motorcycle crash. We conducted case finding prospectively through daily surveillance of the region's four trauma hospitals and single coroner's office. All injured people needing admission to hospital in the Auckland region are admitted to one of these hospitals. We conducted interviews face to face in hospital or by telephone if the participant had already been sent home. For people who died as a result of the crash, we asked next of kin to nominate a proxy respondent who could be interviewed.

Control selection

We obtained a random sample of motorcycle riding by identifying motorcycle drivers from 150 roadside survey sites in the study region and time period. We randomly selected these sites from a list of all non-residential roads in the region, in proportion to their total length. We also randomly assigned time of day, day of week, and direction of travel for each survey site. We photographed motorcyclists as they approached the survey site, stopped them, and invited them to participate in the study. We obtained a name, a telephone number, and a suitable time for a follow up telephone interview. Where survey sites or conditions were too dangerous for motorcyclists to be stopped (for example, motorways, bad weather), we photographed the vehicles and followed them up through their registration plate details. We administered identical questionnaires to both cases and controls, covering circumstances of the crash or current trip and sociodemographic, personal, motorcycle related, and environmental characteristics.

Conspicuity measures

We asked participants if their headlight had been off or on and, if on, whether it had been set to high or low beam. We divided the self identified main colour of clothing worn into two categories: frontal colour from waist up and frontal colour from waist down. We defined motorcycle colour as the main colour of the motorcycle from the front. As well as describing the main colour of their clothing, motorcycle, and helmet, participants nominated the colour as either light or dark. We asked participants if they were wearing any reflective or fluorescent clothing or other articles such as a jacket, vest, apron, sash, ankle or wrist band, or back pack including stripes, decals, or strips.

Potential confounding variables

We considered the following potential confounders suggested by the literature and used in previous analyses of this study[19 20]: age, sex, ethnicity, income, education, motorcycle licence and insurance status, self reported alcohol consumption in the previous 12 hours, years on-road riding experience, kilometres travelled on the specific motorcycle at interview, posted speed limit, ambient illumination, and weather conditions. All data were self reported except for road type and traffic speed zones, which were ascertained by environmental surveys. New Zealand has three main speed limit zones: 50 km/h in most urban areas, 70-80 km/h in restricted speed zones principally on main highways, and 100 km/h on motorways and the open road.

Statistical analysis

We used SAS statistical software to conduct all analyses, and we calculated odds ratios together with 95% confidence intervals by using unconditional logistic regression. As this was a population based study and the outcome of interest is rare, the odds ratios calculated will approximate to relative risks. We fitted a model to examine the independent association of each conspicuity measure and a crash related injury. We assessed each potential confounder in turn and included the variable in the final model if its inclusion changed the odds ratio by 10% or more.[23] We calculated population attributable risk estimates according to methods developed by Greenland and described by Rockwell.[24] The formula uses relative risk estimates and the proportion of cases exposed. We considered pillion passengers to be part of the driver-motorcycle unit and did not include them in the analyses. We stratified the analysis of use of reflective or fluorescent clothing by ambient light conditions (daylight, twilight, night) but did not include an interaction term for this in the logistic regression or multivariate analysis as numbers were small.

Results

The cases were 490 motorcycle drivers (including 32 deaths), and interviews were completed for 463 (95%). Thirteen drivers refused to participate, and 14 could not be contacted. Of the interviews with case drivers, we conducted 293 (63%) by telephone, 164 (35%) face to face, and 6 (1%) by self completed questionnaire.

The controls were 1518 motorcycle drivers: 931 (61%) were identified at sites where motorcyclists were stopped and 587 (39%) from photograph only sites. Interviews were completed with 1233 (81%) drivers, of which 1189 (96%) were conducted by telephone. Most of the drivers not interviewed could not be contacted; only 42 (3%) drivers refused to participate.

Table 1 shows the sociodemographic characteristics of the study participants and the distribution of potential confounding variables. Men accounted for 94% of the motorcycle riding population in Auckland during the study period; most crashes occurred in urban 50 km/h speed limit zones (66%), during the day (64%), and in fine weather (72%).

Young motorcyclists, especially those under 20 years, are at increased risk of injury compared with older riders.[13 14 16 25] Table 2 shows age adjusted and multivariate odds ratios of crash related injury risk associated with conspicuity measures.

Use of reflective or fluorescent clothing

Nearly 20% of control drivers were wearing some type of reflective or fluorescent clothing. Drivers wearing reflective or fluorescent clothing had a 37% lower risk of crash related injury than those who were not wearing such materials (multivariate odds ratio 0.63, 95% confidence interval 0.42 to 0.94). When stratified by ambient illumination (table 3), the protective association seemed to increase with falling light levels, although numbers were small at twilight, reducing the precision of the effect estimate.

Helmet colour

The main colours of helmet reported by control drivers were black (39.8%), white (30.6%), and red (13.8%). Compared with wearing a black helmet, use of a white helmet was associated with a 24% lower risk (multivariate odds ratio 0.76, 0.57 to 0.99). We found similar associations for red and a combined group of yellow and orange helmets, although these did not achieve standard levels of statistical significance. Self nominated description of

Table 1 Sociodemographic, personal, and environmental characteristics of motorcycle crash related injury cases and population controls. Values are numbers (percentages)

	Controls (n=1233)	Cases (n=463)
Age (years)		
15-19	131 (10.6)	86 (18.6)
20-24	322 (26.1)	148 (32.0)
≥25	780 (63.3)	229 (49.5)
Sex		
Female	71 (5.8)	26 (5.6)
Male	1162 (94.2)	437 (94.4)
Type of motorcycle licence		
Learner	198 (16.1)	90 (19.4)
Restricted	97 (7.9)	34 (7.3)
Full	780 (63.3)	224 (48.4)
No licence, lapsed, or lost	125 (10.1)	100 (21.6)
Missing	1 (0.1)	6 (1.3)
Familiarity with specific motorcycle (km)		
<1000	166 (13.5)	99 (21.4)
1000-10 000	477 (38.7)	179 (38.7)
>10 000	570 (46.2)	166 (35.9)
Missing	19 (1.5)	20 (4.3)
Any alcohol ingested in the previous 12 hours		
Yes	129 (10.5)	92 (19.9)
No	1084 (87.9)	365 (78.8)
Missing	20 (1.6)	4 (0.9)
Posted speed limit (km/h)		
50	693 (56.2)	307 (66.3)
70-80	93 (7.5)	40 (8.6)
100	447 (36.3)	111 (24.0)
Missing	0	5 (1.1)
Light conditions		
Daylight	954 (77.4)	294 (63.5)
Dusk or dawn	104 (8.4)	49 (10.6)
Night	175 (14.2)	119 (25.7)
Missing	0	1 (0.2)
Weather conditions		
Fine	804 (65.2)	333 (71.9)
Cloudy	370 (30.0)	76 (16.4)
Rain	59 (4.8)	49 (10.6)
Missing	0	5 (1.1)

"light coloured" helmet compared with "dark coloured" helmet was associated with a 19% lower risk.

Headlight operation

Of the 175 control drivers randomly surveyed at night, 100% were using their headlight. At twilight, 91 (88%) of the 104 control drivers reported having their headlight turned on. Of the 954 control drivers randomly surveyed during the day, 719 (75%) had their headlight turned on—609 (64%) on low beam setting and 92 (10%) on high beam, with 18 (2%) unsure whether high or low beam was used. Overall, voluntary use of headlight in daytime was associated with a 27% lower risk of crash related injury (multivariate odds ratio 0.73, 0.53 to 1.00).

Frontal colour of clothing and motorcycle

Approximately 80% of 1233 control drivers wore either black, blue, or brown clothing on the upper body (955) and black or blue clothing on the lower body (988). Of the main frontal motorcycle colours, 299 (24%) motorcycles were black, 282 were (23%) red, 188 (15%) were white, 183 (15%) were chrome or silver, and 148 (12%) were blue. We observed no association between risk of crash related injury and the frontal colour of drivers' clothing or motorcycle. Similarly, no difference in risk occurred for self nominated light versus dark coloured clothing or motorcycle.

Population attributable risk

The population attributable risk is the estimated proportion by which the incidence of crash related injuries could potentially be averted if a specific risk factor was eliminated from the population. In this population, assuming that the associations described are causal and unconfounded, the population attributable risk associated with not wearing fluorescent or reflective clothing was approximately 33%. Other population attributable risks were 18% for wearing a non-white helmet, 11% for wearing a dark coloured helmet, and 7% for not using headlights during the day.

Discussion

In this large population based case-control study we observed that fluorescent or reflective clothing, wearing a white or light coloured helmet, and voluntary daytime use of headlight were associated with reduced risks of motorcycle crashes resulting in severe injury or death. The protective association for high visibility clothing strengthened with falling light conditions, providing additional support for the validity of the findings. No significant differences in risk occurred with the frontal colour of drivers' clothing or motorcycle.

Strengths and weaknesses of the study

We were able to identify all motorcyclists involved in a crash resulting in moderate to severe injury or death from a large geographically defined base population. The controls were a random sample of motorcyclists from the same study population over the same study period. In this study the prevalence of each characteristic in controls is an estimate of its prevalence in all motorcyclists in the study region.

Most variables investigated were self reported, and recall bias may be a problem. However, exposures such as colour of helmet, colour of clothing, use of high visibility clothing, and operation of headlight are less likely to be influenced by recall bias than other behaviours such as alcohol consumption or speeding. Furthermore, cases may be more inclined than controls to over-report having used conspicuity enhancing measures as they analyse and apportion fault in a multi-vehicle crash. The net effect would be an underestimate of the effects.

The validity of our findings depends on the ability to control for confounding. In this study a wide range of potential confounders were measured and modelled in the multivariate analyses. Riders wearing high visibility clothing and white helmets are likely to be more safety conscious than other riders. However, we were able to adjust for sociodemographic variables, the propensity for risk taking behaviour (such as younger age, alcohol consumption, licence status, and motorcycle riding experience) and environmental characteristics (such as light conditions, weather, and speed limit zones).

Comparison with previous research

Bright colours worn during the day, daytime use of headlight, and reflective or fluorescent clothing are thought to enhance conspicuity by increasing the brightness contrast between the surface or object it is on and the background environment. The finding that helmet colour was associated with injury crash risk whereas frontal colour of clothing was not was unexpected. Hurt et al contended that the principal coloured surfaces with any real potential for contribution to conspicuity are the fairing shield and the rider's upper torso garment.[13] They considered that the

Table 2 Adjusted odds ratios of risk of crash related injury associated with potential conspicuity enhancing measures. Values are numbers (percentages) unless stated otherwise

			Odds ratio (95% confidence interval)	
Measures	**Controls (n=1233)**	**Cases (n=463)**	**Age adjusted**	**Multivariate model**
Wearing high visibility clothing				
No	985 (79.9)	408 (88.1)	1.00	1.00
Yes	242 (19.6)	49 (10.6)	0.50 (0.36 to 0.70)	0.63 (0.42 to 0.94)
Missing	6 (0.5)	6 (1.3)		
Multivariate model: age, white helmet, no licence, alcohol consumption				
Colour of helmet				
Black	491 (39.8)	213 (46.0)	1.00	1.00
White	377 (30.6)	112 (24.2)	0.69 (0.53 to 0.91)	0.76 (0.57 to 0.99)
Yellow or orange	31 (2.5)	8 (1.7)	0.65 (0.29 to 1.43)	0.79 (0.35 to 1.82)
Red	170 (13.8)	55 (11.9)	0.71 (0.50 to 1.01)	0.80 (0.56 to 1.14)
Blue	70 (5.7)	26 (5.6)	0.90 (0.56 to 1.45)	0.96 (0.58 to 1.59)
Other colours (12)	69 (5.6)	41 (8.9)		
Missing	0	8 (1.7)		
Multivariate model: age, no licence				
Self nominated light or dark coloured helmet				
Dark	610 (49.5)	259 (55.9)	1.00	1.00
Light	616 (50.0)	192 (41.5)	0.74 (0.59 to 0.92)	0.81 (0.64 to 1.01)
Missing	7 (0.6)	12 (2.6)		
Multivariate model: age, no licence				
Headlight operation				
Off	216 (17.5)	76 (16.4)	1.00	1.00
On	985 (79.9)	365 (78.8)	0.99 (0.74 to 1.32)	0.74 (0.51 to 1.07)
Missing	22 (1.8)	7 (1.5)		
Multivariate model: age, night, white helmet, alcohol consumption, speed limit 100 km/h, rain				
Daytime headlight operation	(n=954)	(n=294)		
Off	207 (21.7)	72 (24.5)	1.00	1.00
On	719 (75.4)	205 (69.7)	0.77 (0.56 to 1.05)	0.73 (0.53 to 1.00)
Missing	28 (2.9)	17 (5.8)		
Multivariate model: age, alcohol consumption, speed limit 100 km/h, rain				
Self nominated light or dark coloured clothing (waist up)				
Dark	938 (76.1)	365 (78.8)	1.00	1.00
Light	268 (21.7)	92 (19.9)	0.89 (0.68 to 1.16)	0.97 (0.70 to 1.34)
Missing	27 (2.2)	6 (1.3)		
Multivariate model: white helmet				
Self nominated light or dark coloured clothing (waist down)				
Dark	820 (66.5)	302 (65.2)	1.00	
Light	379 (30.7)	149 (32.2)	1.08 (0.85 to 1.36)	1.21 (0.91 to 1.59)
Neither or missing	34 (2.8)	12 (2.6)		
Multivariate model: age, white helmet				
Self nominated light or dark coloured motorcycle				
Dark	609 (49.4)	233 (50.3)	1.00	
Light	599 (48.6)	218 (47.1)	0.94 (0.76 to 1.17)	1.00 (0.77 to 1.29)
Missing	25 (2)	12 (2.6)		
Multivariate model: age, white helmet				

surface presented by even a full face helmet was no more than 20% of that of an upper torso garment and therefore the contribution to conspicuity would be expected to be low. A possible explanation for our findings is that 80% of the controls wore black, blue, or brown top clothing and black or blue clothing from the waist down. Owing to the small numbers wearing light coloured clothing, our study may not have had the power to detect an effect of brightly coloured clothing if it existed. Our study was also limited by the one "catch-all" category for reflective and or fluorescent clothing. These materials offer maximum conspicuity advantage in differing ambient light conditions—fluorescence at twilight and reflective material at night, and we were unable to determine the individual contributions.

Implications for prevention of injuries

This study took place in a predominantly urban area and in a country where motorcycles make up a small percentage of all registered motor vehicles. Factors contributing to poor conspicuity, such as contrast from the background environment and ambient illumination, may differ between settings. The population attributable risks are not generalisable as they depend on the background prevalence of the risk factors in specific populations. However, there is no reason to believe that the relative risk estimates for the conspicuity measures investigated would not be generalisable to other settings.

This seems to be the first population based aetiological study investigating motorcycle conspicuity and risk of crash related injury and death. The study suggests that low physical conspicuity is a contributing factor in a significant proportion of road traffic crashes causing injury. The social costs of motorcycling deaths and disability are high, not only through premature deaths and hospital admissions but also through costs of rehabilitation, lost income, sickness benefits, insurance, property,

Table 3 Use of high visibility clothing stratified by ambient illumination. Values are numbers (percentages) unless stated otherwise

	Controls (n=1233)	Cases (n=463)	Odds ratio (95% confidence interval)	
			Age adjusted	Multivariate model
Reflective or fluorescent clothing during day	(n=954)	(n=294)		
No	767 (80.4)	260 (88.4)	1	
Yes	182 (19.1)	34 (11.6)	0.55 (0.37 to 0.82)	0.62 (0.42 to 0.94)
Missing	5 (0.5)	0		
Multivariate model: age, familiarity, no licence, no insurance				
Reflective or fluorescent clothing at twilight	(n=104)	(n=49)		
No	22 (21.2)	5 (10.2)	1	
Yes	82 (78.8)	43 (87.8)	0.43 (0.15 to 1.22)	0.51 (0.14 to 1.90)
Missing	0	1 (2.0)		
Multivariate model: age, no licence, speed limit 100 km/h, white helmet				
Reflective or fluorescent clothing at night	(n=175)	(n=119)		
No	136 (77.7)	105 (88.2)	1	
Yes	38 (21.7)	10 (8.4)	0.34 (0.16 to 0.72)	0.47 (0.21 to 1.02)
Missing	1 (0.6)	4 (3.4)		
Multivariate model: age, no licence, no insurance, speed limit 100 km/h				

and legal expenses as well as personal costs of grief and suffering. This study supports the introduction of both active and passive injury prevention strategies through laws requiring daytime use of headlights and measures encouraging greater visibility of motorcycle riders on the roads.

We thank the participating motorcyclists; Angela Hursthouse, Kevin Sherlock, Mark McLauchlan, and other staff at the Injury Prevention Research Centre; staff at participating hospitals; and staff at the Land Transport Safety Authority. Special thanks to Shanthi Ameratunga and Joanna Broad for their critical review of the draft papers.

Contributors: SW was mainly responsible for the statistical analysis, interpreting the data, and writing the paper. RJ, RN, BM, and JL were mainly responsible for the study design, and BM was responsible for data collection. RJ, RN, BM, and JL contributed to writing the paper. RJ, JC, and RL-Y contributed to the statistical analysis, interpreting the data, and writing the paper. RJ is the guarantor.

Funding: Health Research Council of New Zealand (HRC) and the Accident Rehabilitation and Compensation Insurance Corporation (ACC). BM was the recipient of an HRC Training Fellowship. The Injury Prevention Research Centre and the Injury Prevention Research Unit were both jointly funded by the HRC and ACC at the time of the study.

Competing interests: None declared.

Ethical approval: The study was approved by the Northern Regional Health Authority Ethics Committee.

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What is already known on this topic

Low conspicuity, or the inability of the motorcycle and rider to be seen by other road users, is thought to be associated with motorcycle crash related injury and death

Previous studies suggest a benefit from daytime use of motorcycle headlights, although the evidence is limited

What this study adds

Wearing reflective or fluorescent clothing and white or light coloured helmets and using headlights in daytime could reduce serious injuries or death from motorcycle crashes by up to one third

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(Accepted 3 December 2003)

doi 10.1136/bmj.37984.574757.EE

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