Brightly coloured motorcycles and brightly coloured motorcycle helmets reduce the odds of a specific category of road accidents: a case-control study

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Summary

Background. Studies suggesting that lack of conspicuity is a major risk factor of motorcycle accidents often use inappropriate exposure groups.

Objectives. This study explores the structural characteristics of a category of accidents caused by poor rider conspicuity and investigates the role of helmet and motorcycle colour in preventing them.

Methods. This case-control study was based on 77 motorcycle accidents and 181 motorcycle controls, drawn from the MAIDS database. Multivariable logistic models are applied to a training and a test sample to estimate and validate the odds ratios of crash for various features of riders and two-wheelers.

Results. Opposite and perpendicular traffic flows, adverse weather conditions, high-displacement engines, and four-wheeler drivers' lack of experience with motorcycles are common features of conspicuity-related crashes. The odds of this category of accidents are reduced by bright colours, of the motorcycle and of the rider's helmet.

Conclusions. Countermeasures modifying the appearance of motorcycles and helmets can reduce the risk of a class of motorcycle crashes.

KEY WORDS: *road accidents, risk factors, motorcycle conspicuity, case-control study, training and test samples*.

Introduction

Background

Previous studies have shown that "the influence of the motorcyclists' behaviour on their risk of accident may be surprisingly small" (1); it is therefore natural to consider the role played in motorcycle crashes by other motorists, and in particular to investigate four-wheeled vehicle drivers' perception of motorcycles in traffic. Some studies point out that many such accidents happen because of the failure of other vehicle drivers to detect the motorcycle in time, and state that inadequate motorcycle conspicuity is an accident risk factor, either in association with other causes (2-4) or as the single identifiable cause (5-8). The term "conspicuity", coined by accident reconstruction experts, means the susceptibility of an entity to be detected by a road user. More precisely, conspicuity refers to the ability of an object to attract attention and to be accurately located, due to its physical properties (5, 9). It has already been shown that the conspicuity of an object is strongly influenced by its size, luminance, contrast and colour (5, 9-15).

Previous studies have helped to outline the problems experienced by motorists when meeting inconspicuous vehicles in traffic, but the ability of these studies

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to identify conspicuity as an accident risk factor is limited by their use, mainly, of surrogate control groups (single vehicle accidents, four-wheeler only crashes, etc.) (7, 8, 16, 17).
MAIDS (the Motorcycle Accidents In Depth Study) (18, 19), on the other hand, is a case-control study that includes a genuine control group of motorcycles/riders circulating in the same area in which the cases were recruited. In particular, the MAIDS database makes it possible to detect appearance dissimilarities between motorcycles/riders involved in accidents and the general population of circulating motorcycles/riders from which the crashes originated.

General goal and rationale

The aim of this study was to investigate the exterior characteristics of motorcycles/riders that, through their negative impact on conspicuity, contribute to causing accidents. We chose, as cases, only accidents in which conspicuity played a possible role. If the motorcycles/riders involved in the cases look different from the normally circulating controls, this suggests that their appearance (colour in particular) plays a role in causing accidents.
The cases in the present study were chosen among the accidents whose primary cause, in the view of reconstruction experts, was a perception error or failure on the part of the driver of a four-wheeler (36% of all the MAIDS accidents). However, not all driver perception errors/failures are due to poor rider/motorcycle conspicuity (e.g. a driver might simply forget to look in the direction from which the rider is coming). Therefore, it was deemed advisable to further restrict the cases to certain accident categories, those in which the perception error or failure was more likely to be related to rider/motorcycle conspicuity. To allow clear inferences to be drawn from this study, the accident cases were defined as objectively as possible, on the basis of statistical models. The conclusions of this study, concerning possible preventive countermeasures, apply to this particular accident category.

Specific objectives

It is necessary to establish, then, the structural characteristics of the accidents included in this study. These had to be accidents caused by a perception error or failure on the part of the driver of a four-wheeled vehicle, probably due to the appearance of the motorcycle/rider. The preliminary objective of this study, therefore, was to identify the structural features of conspicuity-related accidents. This was done using one of the items considered in the MAIDS study, where the reconstruction experts stated whether the motorcyclist's apparel (outfit excluding the helmet) had contributed to causing the accident. This item was taken as the response variable in a model containing the kinematic and human features of the accidents. The accidents thus identified were subsequently used as the cases for the main purpose of the study, i.e. to estimate the accident odds ratios for differently coloured motorcycles and helmets. For the estimation, the cases were contrasted with comparable normally circulating motorcycles/riders (the controls of the MAIDS study). The odds ratios highlight exterior features of the motorcycle/rider that, if appropriately modified, would probably prevent accidents.

Materials and Methods

The database

MAIDS is a multi-centre case-control study conducted in well-defined areas of France, Germany, Holland, Italy and Spain from 1999 to 2001, with the specific aim of investigating the causal factors and the dynamics of motorcycles crashes. The target population included all circulating motorcycles travelling within the predefined areas. The cases were, approximately, all the accidents resulting in injuries between 1999 and 2001, in which the rider died or agreed to be recruited. The controls were motorcycles/riders not involved in accidents and recruited by trained staff during predefined time intervals, at petrol stations. The service stations were sampled in the catchment area of the cases. The control riders received a small recompense for taking the time to be interviewed, and this contributed to a very low refusal rate. The whole MAIDS study included 921 cases and 923 controls.
The accident research form contains more than 1500

variables grouped into three categories: mechanical (vehicles, kinematics), environmental, and human. Each accident was reconstructed and analysed by a team of experts, including qualified engineers, orthopaedic physicians, skilled riders, and data managers. The same variables (except those describing the mechanics and consequences of the accident) were collected for the controls.

Inclusion criterion of accidents used for the preliminary objective of the study

Involvement of at least two vehicles.

Inclusion criteria of cases and controls used in the main analysis of the study

- A priori criteria:
  - *Accidents caused by perception errors/failures on the part of drivers of four-wheeled vehicles*, according to the expert evaluation.
  - *Daylight accidents and controls:* only crashes occurring and controls circulating between 8.30 a.m. and 5 p.m. were selected. Indeed, colours appear to have a complex relationship with conspicuity at night time, but investigation of this relationship was beyond the scope of this study.
- Criteria discriminating conspicuity-related accidents
  - *Perpendicular or opposite traffic collisions*. In perpendicular traffic collisions, the two vehicles were travelling at right angles to one another, or one vehicle executed a right/left angle turn, crossing the path of the other vehicle approaching from the opposite direction. In opposite traffic collisions, the vehicles, travelling in opposite directions, were involved in a head-on crash. This criterion reflects the opinion of the MAIDS reconstruction experts, communicated to the authors prior to the data analysis.
  - *Motorcycles with an engine displacement over 250 cm^3*. Only this category, which emerges as predominantly involved in conspicuity-related accidents, was included in the case and control samples.

The application of these criteria resulted in a sample of 77 cases and 181 controls for this study.

Statistical Analysis

To pursue the preliminary objective of the study (i.e, to identify the structural features of conspicuity-related accidents), logistic models were used to discriminate between the environmental, mechanical and human components of conspicuity-related crashes. The causal role of conspicuity was taken as the response variable. All the variables listed in Table 1 (except motorcycle and helmet colours) were checked alone and in groups as possible predictors, and then excluded if they failed to reach a nominal statistical significance level of 0.05 (Wald test). No automatic variable selection procedure was used: only combinations of variables whose role in the accident was deemed plausible by the accident reconstruction experts were investigated. The predictors finally selected are listed in Table 2. Although the weather conditions and the type of licence held by the driver of the other vehicle appeared to be among the discriminating characteristics of the conspicuity-related accidents, they were not used as inclusion criteria for the subsequent case-control study because they would have been difficult to interpret and would have intolerably reduced the sample size.

For the main purpose of the study (to estimate the accident odds ratios for differently coloured motorcycles and helmets), the sample containing the included cases and the controls was randomly split into two complementary subsets of similar size: the training and the test samples. The training sample was used to select an appropriate logistic model discriminating between cases (accidents) and controls (normally circulating motorcycles). The test sample was to serve for the validation of the final selected model. Among the explicative variables, an indicator called "brightness" was included, specifying that both the helmet and motorcycle itself were brightly coloured. Predominantly white, yellow, red, green, orange, gold and silver colours were considered 'bright', whereas black, blue, grey, brown and purple were considered 'dark'.

The rider's gender and age were evaluated as possi-

Table 1. Environmental, mechanical and human features of the MAIDS accidents versus presumed (expert-assessed) causal role of conspicuity.

Feature		Presumed causal role of conspicuity			
		No (n = 614)		Yes (n = 72)	
		n	(%)[a]	n	(%)[a]
Nation	Holland	151	(96.8%)	5	(3.2%)
	Germany	135	(85.4%)	23	(14.6%)
	French	104	(81.9%)	23	(18.1%)
	Spain	87	(95.6%)	4	(4.4%)
	Italy	137	(89.0%)	17	(11.0%)
Type of area	Urban	469	(89.0%)	58	(11.0%)
	Rural	128	(91.4%)	12	(8.6%)
Roadway alignment	Straight	465	(88.9%)	58	(11.1%)
	Curve/corner	149	(92.0%)	13	(8.0%)
Time of day accident occurred	Daylight	385	(90.6%)	40	(9.4%)
	Not daylight	229	(87.7%)	32	(12.3%)
Traffic density	Light	327	(88.6%)	42	(11.4%)
	Moderate	193	(91.0%)	19	(9.0%)
	Heavy	87	(88.8%)	11	(11.2%)
Weather conditions	No precipitation	566	(90.3%)	61	(9.7%)
	Rain/snow/other precipitation	37	(77.1%)	11	(22.9%)
Accident configuration	Collision with perpendicular traffic	208	(88.5%)	27	(11.5%)
	Collision with opposite traffic	121	(84.0%)	23	(16.0%)
	Collision with traffic in the same direction	154	(95.1%)	8	(4.9%)
Helmet and motorcycle colour	Bright	87	(90.6%)	9	(9.4%)
	Not bright	423	(87.6%)	60	(12.4%)
Engine displacement	Up to 50 cm^3	288	(93.8%)	19	(6.2%)
	50-250 cm^3	81	(88.0%)	11	(12.0%)
	> 250 cm^3	245	(85.4%)	42	(14.6%)
Motorcycle travelling speed (km/h)	0-30	136	(93.8%)	9	(6.2%)
	31-60	314	(87.5%)	45	(12.5%)
	> 60	163	(90.1%)	11	(9.9%)
Other vehicle travelling speed (km/h)	0-30	357	(87.9%)	49	(12.1%)
	31-60	174	(93.0%)	13	(7.0%)
	> 60	60	(90.9%)	6	(9.1%)
Rider's age (years)	Up to 20	198	(93.8%)	13	(6.2%)
	21-50	383	(87.2%)	56	(12.8%)
	> 50	32	(91.4%)	3	(8.6%)
Other vehicle driver's age (years)	Up to 30	222	(89.5%)	26	(10.5%)
	31-50	291	(90.1%)	32	(9.9%)
	> 50	75	(84.3%)	14	(15.7%)
Other vehicle driver's licence ownership	Car licence	433	(87.1%)	64	(12.9%)
	Motorcycle licence + car licence	142	(94.7%)	8	(5.3%)
Fatal consequences	No	556	(90.3%)	60	(9.7%)
	Yes	58	(82.9%)	12	(17.1%)

[a] Row percentages are given.

Table 2. Odds ratios (OR) of causal role of conspicuity for the factors emerging as significant in a logistic model.

Factor		p-value	OR	95% CI Lower	95% CI Upper
Accident configuration	Parallel impact or other type of crash configuration[a]	–	1		
	Collision with perpendicular or opposite traffic	0.034	1.79	1.04	3.07
Weather conditions	No precipitation[a]	–	1		
	Rain/snow/other precipitation	0.010	2.68	1.26	5.67
Engine displacement	Up to 50 cm^3[a]	–	1		
	50-250 cm^3	0.120	1.88	0.84	4.20
	> 250 cm^3	< 0.001	2.99	1.66	5.38
Other vehicle driver's licence ownership	Motorcycle and car licence[a]	–	1		
	Car licence only	0.033	2.31	1.06	5.00

[a] Reference category.

ble confounders or effect modifiers at a 0.05 significance level.

The SPSS 11.5 statistical package was used for all the calculations.

Results

Conspicuity-related accidents

Table 1 summarises the features of the accidents possibly related to conspicuity. Poor rider visibility caused the accident in 72/686 crashes (10.5%).

Environmental aspects. Conspicuity-related crashes were slightly more frequent in straight, urban streets and bad weather conditions. They occurred more often when the direction of the flow of traffic was opposite or perpendicular.

Human aspects. Riders aged 20 to 50, four-wheeled vehicle drivers older than 50, and drivers owning only a car licence were more likely to be involved in conspicuity-related crashes.

Mechanical aspects. High engine displacements (> 250 cm^3) appeared to be associated with conspicuity-related accidents.

Significant factors contained in the discriminating model selected

The descriptive findings summarised in Table 1 were tested using multivariable models. The results of the final model are presented in Table 2. Accident configuration, weather at the time of the accident, engine displacement, and type of driving licence owned by the driver of the four-wheeled vehicle significantly discriminated crashes related to conspicuity.

As expected, conspicuity played a major role in accidents in which motorcycles collided with vehicles travelling in the opposite or perpendicular directions, compared with those in which the vehicles were travelling in the same direction (OR: 1.79, 95% CI: 1.04-3.07).

Conspicuity-related accidents happened more often in bad weather conditions – rain, snow and other types of precipitation (OR: 2.68, 95% CI: 1.26-5.67) – and more frequently involved motorcycles with an engine displacement over 250 cm^3 (OR: 2.99, 95% CI: 1.66-5.38 with respect to mopeds).

To explore the possible role of the high speeds that can be reached by powerful two-wheelers, the speed at which the motorcycle was travelling – both as a quantitative and as a binary variable (cut-offs: 30 km/h, 40 km/h, 50 km/h) – was evaluated in the model, but was not found to be significant. Similarly, the interaction between motorcycle speed and engine power was not found to be relevant.

The licence ownership of the driver of the other vehicle was significantly associated with conspicuity-related accidents, the odds being higher for drivers who hold only a car licence (OR: 2.31, 95% CI: 1.06-5.00).

Causal role of brightness

Only two of the accident features listed in Table 2, frontal or perpendicular collision and engine displacement over 250 cm^3, were used as inclusion criteria for the main analysis (as already mentioned, the analysis included only crashes occurring in the daylight and attributable to a perception error/failure on the part of the driver of the other vehicle, and controls).

Table 3 summarises the characteristics of the subgroup of cases and controls included in the main analysis. A markedly lower percentage of bright helmet and motorcycle colours (6.3%) were found in the cases compared to the control group (24.6%). This result is confirmed in Table 4, which shows similar values of the raw proportions of bright colours in the training and test samples.

The logistic regression results, adjusted for age, are shown in Table 5. There was no adjustment of the estimates for gender, because this was not found to be a significant confounding factor. In the training sample, it emerged that bright motorcycle and helmet colours reduce significantly the risk of accident (OR:

Table 3. Characteristics of cases and controls included in the main analysis.

Variable		Controls n = 181	Cases n = 77[a]
Rider's gender	Male	172 (95.0%)	72 (93.5%)
	Female	9 (5.0%)	5 (6.5%)
Rider's age (years)	Up to 20	7 (3.9%)	2 (2.6%)
	21-50	165 (91.2%)	72 (93.5%)
	> 50	9 (5.0%)	3 (3.9%)
Motorcycle and helmet colour	Bright	44 (24.6%)	4 (6.3%)
	Not bright	135 (75.4%)	60 (93.8%)

[a] The total cases do not coincide with the presumed conspicuity-related accidents of Table 1; they were selected by a logistic model.

Table 4. Frequency distribution of motorcycle and helmet brightness among cases and controls divided between training and test sample.

Motorcycle and helmet colour	Training Sample		Test Sample	
	Controls (n = 102)	Cases (n = 35)	Controls (n = 79)	Cases (n = 42)
Bright	22 (22.0%)	1 (3.2%)	22 (27.8%)	3 (9.1%)
Not bright	78 (78.0%)	30 (96.8%)	57 (72.2%)	30 (90.9%)

Table 5. Odds ratios[a] (OR) of a motorcyclist being involved in a crash, according to "brightness" of helmet and motorcycle.

				95% CI	
Motorcycle and helmet colour	Sample	p-value	OR	Lower	Upper
Not bright[b]			1		
Bright	Training	0.041	0.118	0.015	0.917
	Test	0.038	0.257	0.071	0.935
	Whole	0.004	0.205	0.071	0.599

[a] Adjusted for age.
[b] Reference category.

0.118, 95% CI: 0.015 – 0.917). This result was confirmed in the test sample (OR: 0.257, 95% CI: 0.071 – 0.935). Finally, the significant protective effect (p=0.004) of brightness on the risk of accident was obviously found to be stronger when the whole sample was considered (OR: 0.205, 95% CI: 0.071 – 0.599).

Discussion

This study identified a class of accidents that are caused (concomitantly at least) by the appearance of the motorcycle/rider. Subsequently it investigated the possible features of appearance that are apt to reduce the incidence of those accidents. The two parts of the research are discussed consecutively.

Accidents caused by the conspicuity of the motorcycle/rider

Four characteristics were found, in this study, to be associated with conspicuity-related crashes.

- *Accident configuration:* the motorcycle/rider is likely to be less able to attract conscious attention when it/he remains in the other driver's field of vision for a matter of seconds only. This could explain why crashes involving vehicles travelling in different directions show an association with motorcycle/rider appearance. One suggestion, in view of this finding, could be to equip crossings with road signs that not only inform the driver of the intersection, but that also warn him/her of its particular danger.
- *Bad weather conditions:* poor visibility due to bad weather together with dirt on the windscreen or visor obviously make it difficult to see moving objects. In these conditions, in particular, the conspicuity of the motorcycle/rider needs to be enhanced.
- *Motorcycle engine displacement:* the greater the engine displacement, the higher the proportion of accidents related to poor conspicuity. This association was *not* due to – confounded by – the motorcycle speed, indeed high speed was not found to discriminate conspicuity-related accidents. The different style of equipment used by the riders of powerful motorcycles and the different overall appearance of these two-wheelers versus mopeds could explain the role of engine displacement. The MAIDS experts, when determining the causal role of conspicuity in a crash, apparently judged the appearance of the large motorcycle riders less eye-catching than the more casual appearance of moped riders. Another possible explanation of the role of displacement could be that the motorcycle acceleration interferes with the other vehicle driver's perception process.
- *Type of licence held by the other vehicle driver:* drivers who hold only a car licence have a higher risk of being involved in conspicuity-related accidents than drivers who also hold a motorcycle licence. This result is consistent with the findings of other researchers who have reported that motorcyclists have "better hazard perception" when driving a car than car drivers who have never experienced motorcycle riding (1). Possibly non-motorcyclists, due to their lack of experience of two-wheeler traffic, tend to underestimate the presence these vehicles on the road. It has been shown (5) that an object's conspicuity depends on its characteristics, but also on the attention paid by the observer and thus on his/her training. Some practical conclusions can be drawn from this: it is conceivable that specific training of new drivers, designed to enhance their reactions to the presence of a motorcycle, could help to increase the safety of motorcyclists.

The importance of motorcycle/helmet colour in improving conspicuity

Helmets and motorcycles painted in bright colours were less frequent among the cases (motorcycles involved in accidents) than among the controls (circulating motorcycles). This finding reflects the trend reported in another study (20), where accident risk reductions of 24% and 37% were associated with the use of a white helmet and reflective clothing, respectively. Several laboratory experiments (3, 4, 6, 21-25) have shown that brightly coloured clothes enhance conspicuity and reduce the detection time of the observer. Other authors, such as Deery (26) and Watts (27) reach, on the subject of motorcycle con-

spicuity, conclusions consistent with those of the present study, although in different settings.

Common sense tells us that bright colours catch the eye more than other colours. The question is whether this phenomenon can be of practical use for increasing the safety of motorcyclists. This study provides positive evidence in this regard: bright colours, both of helmets and of the motorcycles themselves, can help. Countermeasures to reduce the incidence of a specific class of accidents (conspicuity-related accidents) can at this point be devised and enacted.

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