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Some factors affecting motorcyclists' conspicuity

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Three experiments examined some of the factors that might affect motorcyclists' conspicuity to other road users. In each case, subjects saw a sequence of slides showing traffic, some of which contained a motorcyclist. A record was taken of their reaction times to decide whether or not a motorcyclist was present in each slide. Experiments 1 and 2 examined the effects on conspicuity of headlight use, type of clothing, distance of motorcyclist from viewer, and driving situation (urban or semi-rural). Experiment 3 looked more closely at environmental influences on motorcyclist conspicuity, systematically varying the level of background 'clutter' behind the motorcyclist. All three experiments indicate that the effectiveness of the conspicuity aids used, especially clothing, may depend on the situation in which the motorcyclist was located: bright clothing and headlight use may not be infallible aids to conspicuity. Brightness contrast between the motorcyclist and the surroundings may be more important as a determinant of conspicuity than the motorcyclist's brightness *per se*. Motorcyclists' conspicuity is a more complex issue than has hitherto been acknowledged.

1. Introduction

In motorcycle accidents involving another vehicle, an important factor seems to be that the other driver fails to detect the oncoming motorcyclist before emerging from a side-turning or before turning across the motorcyclist's path (see reviews in Thomson 1980, 1982). The data of Fulton *et al.* (1980) suggest that about 67% of 150 near-misses and accidents described by their sample of motorcyclists could be subsumed into these two broad categories.

It has been assumed that failure to detect motorcycles is due to their poor visibility compared to other vehicles, although this assumption has been questioned (Olson 1989, Cercarelli *et al.* 1992) and other factors such as drivers' expectancies probably play an important part (Williams 1976, Thomson 1982, Hole and Tyrrell 1995). Consequently, there have been attempts both to assess the conspicuity of motorcyclists and to find ways of enhancing it by methods such as daytime headlight use and fluorescent or reflective clothing (Cassel and Janoff 1971, Fulton *et al.* 1980, Williams and Hoffman 1979, Olson *et al.* 1981).

Diverse techniques, such as accident-statistics analysis (Thomson 1980), field studies (Fulton *et al.* 1980, Olson *et al.* 1981) and laboratory experiments (Williams and Hoffman 1979) have been used to assess the effectiveness of these visibility aids (review in Thomson 1982), but problems with previous work mean that there remains a need for more data on this issue.

First, there are methodological limitations with previous experiments on motorcyclists' conspicuity. Both Fulton *et al.* (1980, section 5) and Williams and Hoffman (1979, experiment 1) used a similar technique to that employed in the present research: subjects were shown photographic slides depicting motorcyclists and asked to press a button as soon as the motorcyclist had been detected. Both of these studies tried to evaluate the relative effectiveness of different kinds of conspicuity aid (e.g. fluorescent jacket, headlamp use, headlamp cover). As such, in both studies the motorcyclist was always in the same position in the scene, and virtually always present in each slide (in the study by Fulton *et al.* (1980), only 9 of the 72 slides showed no motorcyclist at all).

These workers have produced useful data on the relative merits of different kinds of conspicuity aid. However, as Thomson (1982) has pointed out, there may be problems of interpretation because the subject's task in the laboratory is so different from that of drivers in real life: in the studies cited, a subject would know not only that a motorcycle was (almost) always going to be in the scene, but also would have a reasonable idea of where it might be. The present experiments used a detection paradigm, but differed from those just described by requiring subjects to decide as quickly as possible whether or not a motorcyclist was present in a scene. No more than half of the slides presented in any of the present studies contained a motorcyclist; and within these the motorcyclist could be in a variety of locations. In this way, it was hoped to make the subject's task in the laboratory somewhat more equivalent to that of the driver on the road: i.e. subjects were presented with a visual search task, in which the presence of the target for which they were searching could not be taken for granted.

Second, previous research has focused on how motorcyclists' conspicuity might ideally be enhanced, but has generally failed to look at how conspicuous motorcyclists are in real-life conditions. In recent years, multi-coloured patterned clothing has become increasingly popular with motorcyclists. At first sight, one might think that this is all to the good, as far as enhanced conspicuity is concerned. However, such clothing may have the potential to act as disruptive camouflage in certain conditions. By breaking up the rider's contours, brightly patterned clothing might decrease conspicuity, contrary to the rider's expectations.

With these issues in mind, the present research examined how conspicuous motorcyclists were in practice, rather than how well their conspicuity could be enhanced in theory. A number of different variables that might affect conspicuity were examined in the experiments to be described below. While each of these factors has been studied in isolation, no one study has considered them together, yet the conspicuity of motorcyclists is unlikely to be a simple issue. Experiments 1 and 2 examined headlight use, clothing type, and the distance of the motorcyclist from the viewer, in two different types of physical environment: a semi-rural (primary route) setting and an urban situation. These environments differ in the degree of background 'clutter' present, a factor that might well affect motorcyclists' conspicuity. Williams and Hoffman (1979) found that headlight use enhanced visibility more in 'uncluttered' than in 'cluttered' environments. Watts (1980), examining factors affecting the conspicuity of cyclists, found that differences between conspicuity aids were present when they were tested against a dark background, but not when tested against a light background. In the present study, it was thought that if patterned clothing did serve as disruptive camouflage, this would be more likely to occur when there was a visually fragmented background (as in the urban setting), than when the background was relatively homogeneous and uncluttered (as in the semi-rural setting).

Experiment 3 directly compared the conspicuity of lit and unlit motorcycles at different distances, taking background complexity into account. A single location was used, and the degree of background complexity was varied while all other factors were kept constant. The main concern of experiment 3 was to determine whether headlight use offered consistent conspicuity benefits for motorcyclists, or whether the effectiveness of headlight use was altered (for better or worse) by increased background complexity.

2. Experiments 1 and 2: Conspicuity of motorcyclists in semi-rural and urban settings

Experiments 1 and 2 differed mainly in the setting within which conspicuity was assessed, examining conspicuity within 'semi-rural' and 'urban' settings, respectively. Consequently they will be described together, in the interests of brevity.

2.1. *Method*

2.1.1. *Subjects*: A total of 61 volunteer subjects were used, principally Open University students at a summer school at the University of Sussex, and students from the University of Sussex. For the semi-rural experiment, 12 males and 18 females took part, with mean ages of 35 and 34 years, respectively (SD = 8 years in both cases). The males had held a full UK driving licence for a mean of 13 years (SD = 8 years), and the females for a mean of 12 years (SD = 10 years).

Nine males and 22 females participated in the urban experiment. Mean ages were 36 years for the males (SD = 10 years) and 34 years for the females (SD = 9 years). The males had held a full UK driving licence for a mean of 17 years (SD = 9 years), and the females had held a full licence for a mean of 11 years (SD = 8 years).

All subjects, in both experiments, had a minimum of one year's driving experience.

2.1.2. *Stimuli*: Each subject saw 100 colour slides of traffic. For the semi-rural experiment, these were taken on a stretch of the A270 primary route between Brighton and Lewes. The road at this point consists of dual carriageway in both directions, separated by a central grass verge. The view along the road extends uninterruptedly for approximately 3 km, ultimately being blocked by a railway arch on the horizon. On the right-hand side of the road, sloping grass parkland leads to woodland. There is little street furniture except for street lamps along the road's edge.

For the urban study, photographs were taken in a one-way street (Marlborough Place) in the centre of Brighton, East Sussex, UK. The street has three traffic lanes. It is flanked on its left side by trees and a park, and on its right side by buildings. Street furniture on the right side includes bus-stops, litter-bins, signs, etc. The photographer was located on the right side of the road, on the edge of a side-road entering the main road from the right. As one looks down the road, towards the oncoming traffic, the view is ultimately blocked in the distance by buildings with flower-beds in front of them, since the main road deviates sharply to the left (from the photographer's viewpoint).

In both studies, the first seven slides shown were always practice slides. The remaining 93 were test stimuli. Of these, 45 were photographs of traffic (cars, buses and lorries) without a motorcycle present. The other 48 slides were photographs in which a motorcycle was present in the oncoming traffic, as seen from the photographer's viewpoint.

In both the semi-rural and urban studies, there were two photographs for each permutation of the following three independent variables:

(1) *Type of clothing*: The motorcyclist wore a full-face crash helmet, jacket, leather jeans, gloves and boots. The colour and patterning of the helmet and jacket were varied.

The rest of the clothing was always black. There were four different types of clothing:

(a) Plain dark: the helmet and jacket were uniformly black.

(b) Plain bright: the helmet was plain white, and the jacket was a uniform fluorescent deep orange. (Owing to the limitations of colour film, as far as the subjects were concerned the jacket was bright orange.)

(c) Patterned dark: the helmet used for this condition was a 'Wes Cooley Replica', manufactured by Arai Helmets Ltd. This was dark blue, with a wide horizontal black band around it, edged by two thin white bands. The jacket used for this condition was manufactured by Scott Leathers Ltd. The top half of the jacket's torso and sleeves was light blue, and the bottom half was dark blue. In between these halves were horizontal bands of the same colours.

(d) Patterned bright: the helmet for this condition had a similar patterning to the 'Mick Doohan Replica' marketed by Arai Helmets Ltd. This consisted of white as a base colour, overlaid with vertical, ragged-edged stripes of red and blue running from the front to the back of the helmet. The jacket used was manufactured by Scott Leathers Ltd, and was exactly the same style as that in condition (c), except that the top half was white and the bottom half was bright red.

(2) *Headlight use*: The motorcycle's headlight was a rectangular quartz-halogen unit (12 V, 45-W dipped and 60-W main beam). This was either

(a) off, or

(b) on dipped beam.

(3) *Distance of motorcyclist from viewer*: Photographs were taken with the motorcyclist at three different viewing distances. For the semi-rural experiment, the motorcyclist was approximately 225, 113 or 29 m from the photographer. For the urban experiment, the motorcyclist was photographed at distances of 87, 28 and 7 m.

All of the photographs were taken on clear sunny days, with good visibility. The same motorcyclist and motorcycle (a dark blue, unfaired 1989-registered Kawasaki GT550) were used in all photographs in which a motorcycle was present. In selecting photographs for use as stimuli, care was taken to ensure that the motorcycle was the only vehicle with lights; slides were not used if they showed any other vehicle using running lights, headlights or lit indicators.

2.1.3. *Apparatus*: The slides were projected from a Kodak S-AV 1010 150-W bulb slide projector fitted with a Compur Ltd electronic shutter that enabled precise control of exposure onset and offset. The projector was connected to a BBC microcomputer with a second 6502 processor attached. The computer was programmed to open the shutter at the same time as initiating a timer that was stopped by the subject pressing either of two buttons on a hand-held button-box. (The interrupts of the computer were disabled by software means, to obtain a 1-ms measurement accuracy.) Once the subject had made a response (or 4 s had elapsed from the time of the shutter opening, whichever was the longer), the computer closed the electronic shutter and advanced the projector's carousel to the next slide in the sequence. For each subject, all data (reaction times, and which button was pressed on each trial) were written to disc after presentation of the final slide.

2.1.4. *Procedure*: Each subject was tested individually. They were seated in a darkened room, in front and to the left of the screen on which the slides were projected. The line-of-sight distance between the subject and the centre of the screen

Table 1. Summary of ANOVA results for experiments 1 and 2.

Effect	Experiment 1 (semi-rural)	Experiment 2 (urban)
Headlight	$F(1,29) = 15{\cdot}62, p < {\cdot}001$ MSe = 54428	$F(1,30) = 0{\cdot}45$, n.s. MSe = 40812
Clothing	$F(3,87) = 4{\cdot}13, p < {\cdot}01$ MSe = 40546	$F(3,90) = 12{\cdot}22, p < {\cdot}001$ *MSe* = 45729
Distance	$F(2,58) = 84{\cdot}28, p < {\cdot}0001$ MSe = 87940	$F(2,60) = 48{\cdot}56, p < {\cdot}0001$ MSe = 182870
Headlight × clothing	$F(3,87) = 2{\cdot}87, p < {\cdot}05$ MSe = 26717	$F(3,90) = 12{\cdot}76, p < {\cdot}001$ MSe = 34892
Headlight × distance	$F(2,58) = 8{\cdot}56, p < {\cdot}001$ MSe = 35926	$F(2,60) = 3{\cdot}68, p < {\cdot}05$ MSe = 45947
Clothing × distance	$F(6,174) = 7{\cdot}69, p < {\cdot}001$ MSe = 31842	$F(6,180) = 5{\cdot}24, p < {\cdot}001$ MSe = 42310
Headlight × clothing ×distance	$F(6,174) = 0{\cdot}68$, n.s. MSe = 20420	$F(6,180) = 7{\cdot}63, p < {\cdot}001$ MSe = 44200

was approximately 1 m, so that each slide subtended approximately 50° of visual angle. In the semi-rural study, the motorcyclist subtended approximately 0·4, 0·9 or 3·4° of visual angle when positioned at the distances of 225, 113 and 29 m from the photographer. The corresponding figures for the urban study were 1·1, 3·5 and 13·7°, for distances of 87, 28 and 7 m, respectively.

Slides were presented sequentially, under computer control. The subject held a button-box which had two buttons: the left, green button was to be pressed if a motorcycle was present, and the red, right-hand button was to be pressed if no motorcycle was present. Subjects were instructed to make their decisions as quickly but as accurately as they could.

Each subject saw 100 slides, in two blocks of 50. Each block was in a separate carousel, and the blocks were separated by the few seconds that it took to change over the carousels on the projector. Unknown to the subject, the first seven slides were practice slides, whose data was discounted. These were presented in a different random order for each subject. The 93 experimental slides were then shown, also in a different random order for each subject. (Randomization occurred both within and between the two carousels.)

2.2. *Results*

2.2.1. *Reaction time measures*: From each subject in each of the two studies, 48 reaction times were obtained for the slides in which a motorcyclist was present. Since there were two slides for each permutation of variables, the reaction times for each corresponding pair of slides were averaged together to produce 24 mean reaction times (RTs). These constitute the raw data in the following analyses. For each study, the mean RTs were subjected to a 2 × 3 × 4 Analysis of Variance (ANOVA) (light × distance × clothing, with repeated measures on all variables). Table 1 summarizes the results of these two ANOVAs. Figure 1 shows the mean reaction times to detect the motorcyclist for each clothing type in the semi-rural location, considering the headlight-on and -off conditions separately in each case. Figure 2 shows the corresponding mean reaction times for the urban setting.

In both locations, motorcyclists were detected more quickly the nearer they were to the viewer, and in both locations the biggest difference between the headlight-off and headlight-on conditions was at the furthest viewing distance: at the nearest

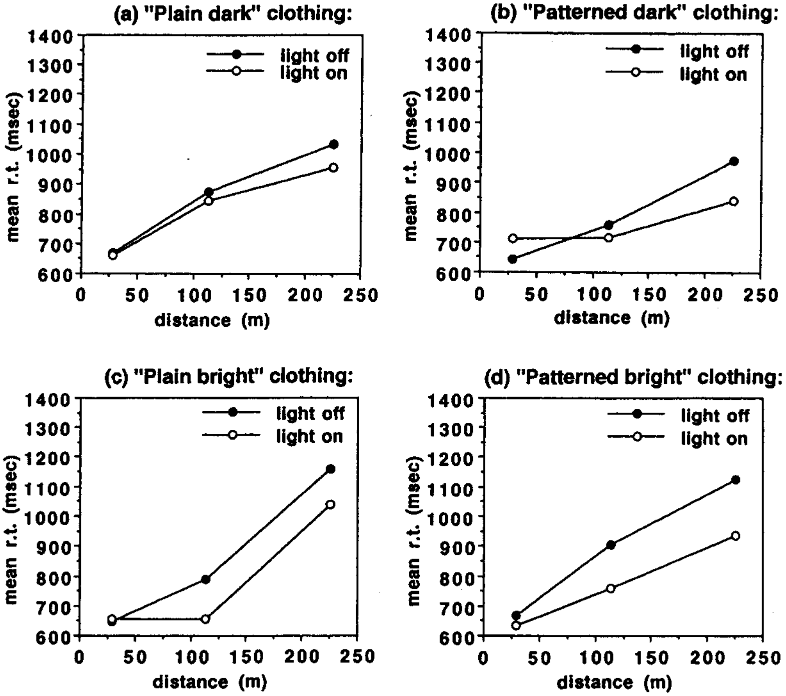

Figure 1. Effects of distance, clothing type and headlight use on motorcyclist conspicuity in a semi-rural setting (experiment 1).

distance, whether or not the motorcyclist had his headlight on made little difference to reaction times. (The one exception to this statement is in the case of the 'patterned-dark' clothing condition in the semi-rural setting, where the mean reaction time to detect the motorcyclist was faster when the headlight was off than when it was on.) However, the effects on conspicuity of headlight use and clothing type varied according to the motorcyclist's setting.

The effectiveness of the headlight as a conspicuity aid was much less clear-cut in the urban setting than in the semi-rural environment. In the latter, subjects were faster to respond when the motorcyclist had his headlight on, regardless of clothing type. This effect was more marked the greater the distance between the rider and photographer. In contrast, headlight use in the urban location enhanced conspicuity only when the motorcyclist was wearing plain bright or patterned dark clothing: when patterned-bright or plain dark clothing were worn, subjects responded faster when the headlight was off than when it was on. In the urban setting, a consistent advantage for headlight use was demonstrated only when the motorcyclist was wearing patterned-dark clothing.

Since the greatest difference between clothing types was at the furthest distance, two separate analyses were conducted on these data for each location. One examined the effects of clothing at the furthest distance, when the motorcyclist had his headlight off. The other examined the effects of clothing at the furthest distance, when the motorcyclist had his headlight on.

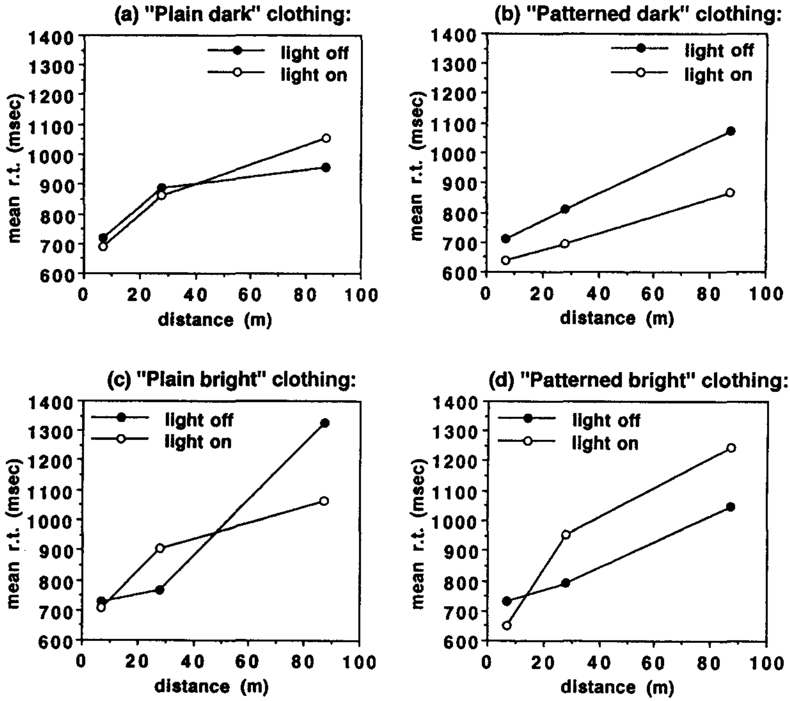

Figure 2. Effects of distance, clothing type and headlight use on motorcyclist conspicuity in an urban setting (experiment 2)

(1) *Effects of clothing at the furthest distance, with headlight off*: Tests for simple effects (Keppel 1982) revealed that in both locations, there was a significant effect of clothing at the furthest distance when the motorcycle's headlight was off (for the semi-rural setting, $F(3, 87) = 3{\cdot}40$, MS error = 60859, $p < {\cdot}02$; for the urban setting, $F(3, 90) = 11{\cdot}87$, MS error = 66158, $p < {\cdot}001$). Planned comparisons showed that in both settings, there was a significant difference between bright and dark clothing overall (semi-rural setting: $F(1, 87) = 9{\cdot}12$, MS error = 60859, $p < {\cdot}01$; urban setting: $F(1, 90) = 13{\cdot}77$, MS error = 66158, $p < {\cdot}001$). However, in both settings, this was in the opposite direction to what one might expect: subjects responded significantly more quickly when the motorcyclist's clothing was dark than when it was bright.

In the semi-rural environment, no significant difference was found between patterned and plain bright clothing, nor between patterned and plain dark clothing ($F(1, 87) =< 1$, MS error = 60859, in both cases). In contrast, for the urban location, a highly significant difference was found between patterned and plain bright clothing ($F(1, 90) = 18{\cdot}55$, MS error = 66158, $p < {\cdot}0001$): subjects responded more quickly to the former than to the latter. In the urban setting, a marginally significant difference was also found between patterned and plain dark clothing, with subjects responding faster to the latter than to the former $F(1, 90) = 3{\cdot}29$, MS error = 66158, $p < {\cdot}06$).

(2) *Effects of clothing at the furthest distance, with headlight on*: Tests for simple effects revealed that in both locations, there was a significant effect of clothing at the

furthest distance when the motorcycle's headlight was on (semi-rural location: $F(3,87) = 4{\cdot}71$, MS error = 41628, $p < {\cdot}005$; urban location: $F(3,90) = 11{\cdot}81$, MS error = 62718, $p < {\cdot}001$). Planned comparisons showed that there was a significant difference between bright and dark clothing overall (semi-rural location: $F(1,87) = 5{\cdot}39$, $p < {\cdot}05$: urban location: $F(1,90) = 16{\cdot}96$, MS error = 62718, $p < {\cdot}0001$), but again in both settings this was in the opposite direction to what one might expect: subjects responded faster to the dark clothing conditions than they did to the bright ones.

Differences between patterned and plain clothing types were inconsistent across the two locations. In the semi-rural setting, the difference between bright-patterned clothing and bright plain clothing (with the former evoking the faster reaction times) was marginally significant ($F(1,87) = 3{\cdot}94$, MS error = 41628, $p = {\cdot}05$) and dark-patterned clothing was responded to significantly faster than dark-plain clothing ($F(1,87) = 4{\cdot}79$, MS error = 41628, $p < {\cdot}05$). In the urban setting, bright plain clothing was responded to faster than bright patterned clothing ($F(1,90) = 8{\cdot}71$, MS error = 62718, $p < {\cdot}001$) and dark-patterned clothing was responded to faster than plain dark clothing ($F(1,90) = 9{\cdot}75$, MS error = 62718, $p < {\cdot}01$).

2.2.2. *The frequency of 'false negative' errors*: An analysis was made of the frequency with which 'false negative' errors occurred. These were instances when subjects mistakenly responded that no motorcyclist was present in a slide.

In the semi-rural setting, the overall mean number of false negative errors made by each subject was 6·7 (out of the 48 slides in which a motorcyclist was present), with a standard deviation of 4·2. The corresponding data for the urban setting were similar (mean 6·0, SD = 2·6). This amounts to a subject making false negative responses on approximately 14% of the slides presented in the semi-rural location, and 12% in the urban setting. For both locations, subjects tended to make more errors the further away the motorcyclist was from the viewer: for the semi-rural location, the mean error-rate per subject was 10·50 (SD = 8·0) for the furthest distance, 1·50 (SD = 1·1) for the medium distance, and 0·63 (SD = 0·89) for the nearest distance. The corresponding data for the urban setting were 10·62 (SD = 9·93) for the furthest distance, 0·69 (SD = 0·70) for the medium distance, and 0·38 (SD = 0·62) for the nearest distance.

Another way to look at these data is to consider the number of errors made for slides of a particular type. Table 2 shows the number of false negative responses made by all 30 subjects in the semi-rural experiment, as a function of the distance of the motorcyclist from the viewer, and whether or not the motorcyclist's headlight was on. Table 3 shows the corresponding data for the 31 subjects in the urban study.

In both locations, many more motorcyclists were undetected at the furthest distance from the viewer than when the motorcyclist was nearby. For the semi-rural location, at all three distances, the error-rate for the slides in which the motorcyclist's headlight was lit was half that for the slides in which the headlight was unlit. For the urban location, at all three distances, the error-rate for the slides in which the motorcyclist's headlight was lit was lower than that for the slides in which the headlight was unlit, but not markedly so.

In both locations, there was little effect of clothing type except possibly at the furthest distance. However, the pattern of errors at the furthest distance differed across locations. In the semi-rural location, at the furthest distance somewhat more errors were made for the plain dark clothing. In the urban location, error-rates were

Table 2. Frequency of 'false negative' errors in experiment 1.†

Distance	Clothing type	Light off	Light on
225 m	Patterned bright	24	11
	Patterned dark	29	9
	Plain bright	26	15
	Plain dark	37	17
	Total	**116**	**52**
113 m	Patterned bright	4	0
	Patterned dark	2	2
	Plain bright	4	3
	Plain dark	6	3
	Total	**16**	**8**
29 m	Patterned bright	2	1
	Patterned dark	1	1
	Plain bright	4	1
	Plain dark	0	0
	Total	**7**	**3**

†Each value in the table in light type represents the total number of errors made by 30 subjects to the two slides used for that particular permutation of distance, clothing and headlight. The bold-type totals represent the total number of errors for the four clothing-types combined, for each permutation of distance and headlight.

highest for the patterned bright clothing, especially when the headlight was on, and the lowest error-rates were for the two dark clothing conditions, when the headlight was on.

This interpretation was confirmed by ANOVAs on the number of errors made for the slides, as a function of what they depicted. A separate ANOVA was conducted for each location. Each permutation of the distance, headlight and clothing variables was represented by two slides, each of which produced an error score across all of the subjects participating in each of the two experiments. The error scores for each corresponding pair of slides were averaged together, to produce a mean error score for each permutation of variables. These error scores were used as the raw data for each of the ANOVAs. Both ANOVAs revealed highly significant main effects of distance (semi-rural location: $F(2,6) = 162{\cdot}37$, $p < {\cdot}0001$, MS error = 1·472; urban location: $F(2,6) = 49{\cdot}78$, $p < {\cdot}001$, MS error = 5·462). In the semi-rural setting, there was a significant main effect of headlight ($F(1,6) = 40{\cdot}87$, $p < {\cdot}001$), plus a significant interaction between distance and headlight ($F(2,6) = 23{\cdot}89$, $p < {\cdot}001$: MS error = 1·472 in all three cases). No other effects were significant, either in isolation or in interaction (all remaining Fs < 3). In the urban location, the main effect of clothing approached significance ($F(3,6) = 3{\cdot}70$, $p < {\cdot}10$), and the interaction between distance and clothing was significant ($(F)6,6) = 4{\cdot}80$, $p < {\cdot}05$; MS error = 5·462 in all three cases). No other effects were significant (all remaining Fs < 2).

2.3. *Discussion*

Taken together, the results of these two studies suggests that motorcyclists' conspicuity is markedly influenced by environmental factors. Both studies showed a strong effect of distance: when motorcyclists were far away from the viewer, subjects were both slower to detect them and more likely to fail to detect them altogether. However, the effects on conspicuity of headlight use and clothing differed according

Table 3. Frequency of 'false negative' errors in experiment 2.†

Distance	Clothing type	Light off	Light on
87 m	Patterned bright	28	42
	Patterned dark	7	5
	Plain bright	25	23
	Plain dark	27	13
	Total	**87**	**83**
113 m	Patterned bright	1	0
	Patterned dark	0	2
	Plain bright	1	2
	Plain dark	4	1
	Total	**6**	**5**
29 m	Patterned bright	0	0
	Patterned dark	2	2
	Plain bright	2	0
	Plain dark	0	0
	Total	**4**	**2**

†Each value in the table in light type represents the total number of errors made by 31 subjects to the two slides used for that particular permutation of distance, clothing and headlight. The bold-type totals represent the total number of errors for the four clothing-types combined, for each permutation of distance and headlight.

to the environment within which the motorcyclist was located. In a semi-rural setting, headlight use improved motorcyclists' conspicuity: the further away the motorcyclist was from the viewer, the greater this effect. When the headlight was on, subjects were both faster to detect motorcyclists and also more likely to detect them. Against a 'cluttered' urban background, headlight use was found to be an inconsistent aid to motorcyclist conspicuity: there was no significant overall effect of headlight use within this setting, and when the motorcyclist was wearing either patterned-bright or plain dark clothing, reaction times and error-rates were worse if the headlight was on.

The effects of clothing were even less clear-cut than those of headlight use: in the semi-rural setting, in both the headlight-on and headlight-off conditions, subjects were slower to detect the motorcyclist when the clothing was bright than when it was dark. The effects on conspicuity of whether the clothing was patterned or plain depended on whether or not the headlight was on: when it was off, patterning had no effect, whereas when it was on, patterned clothing led to marginally faster reaction times than plain clothing. Clothing had little effect on 'false negative' error rates.

The results thus suggest that, in the semi-rural setting, dark clothing was superior in visibility to bright clothing. The fact that patterned clothing was detected slightly faster than plain clothing offers no support for the hypothesis that patterned clothing might act as disruptive camouflage for the rider. However, the environment used for this experiment was relatively 'uncluttered', in Williams and Hoffmann's (1979) terms. In the urban setting, where the background to the rider was much more visually 'fragmented' and hence potentially more conducive to any effects of disruptive camouflage, the effects of clothing were somewhat different. As in the semi-rural setting, dark clothing was responded to faster than bright clothing. Also as in the semi-rural setting, highly significant differences were found between patterned and plain clothing types, but in the urban setting they appear to follow no clearly interpretable pattern. When the headlight was on, patterned bright clothing was responded to faster than plain bright, and plain dark clothing was responded to faster than patterned dark; when the headlight was off, precisely the opposite pattern of effects was found. These results certainly offer no support for claims that patterned clothing is consistently less conspicuous than plain clothing.

3. Experiment 3: Effects of background 'clutter' on motorcyclists' conspicuity

The previous experiments suggest that environmental factors may influence the effectiveness of headlight use and clothing as aids to motorcyclists' conspicuity. However, there are numerous uncontrolled differences between the semi-rural and urban locations used that could produce variations in subjects' performance. The present experiment attempted to examine one of the differences between the two environments previously used—the degree of background 'clutter'—in a more rigorous and controlled manner. The effectiveness of headlight use at different distances was examined in relation to the complexity of the motorcyclist's background. A single location was used, and background complexity was varied by altering the motorcyclist's lateral position within a setting that was 'cluttered' on one side, and relatively 'uncluttered' on the other.

3.1. *Method*

3.1.1. *Subjects*: 40 volunteer subjects were used, principally students at an Open University summer school at the University of Sussex, and students from the University of Sussex. There were 13 males and 27 females. The mean ages were 33 years for the males and 37 years for the females (with SDs of 6 and 9 years respectively). The males had held a full UK driving licence for a mean of 13 years (SD = 7 years), and the females for a mean of 12 years (SD = 9 years). All subjects had a minimum of one year's driving experience.

3.1.2. *Stimuli*: Subjects saw 55 slides. The first seven were practice slides. The remaining 48 consisted of a random mixture of 24 slides in which no motorcyclist was present and 24 slides in which a motorcyclist was present somewhere in the scene.

All of the slides were photographs of a road on the University of Sussex campus. The viewpoint was identical for all slides, and corresponded to the view that would be obtained by a driver waiting to emerge onto a main road, looking right from a side-turning on the right-hand side of the road. Traffic thus appeared to be approaching the subject on the right-hand side of the screen.

On the left side of the road, there was a line of parked cars, whereas the road was empty on the right side. Approximately 56 m from the photographer, the road went under an arch, continuing for some 20 m before turning sharply left.

By varying the motorcycle's position, it was possible to photograph it against different backgrounds: if the motorcyclist was positioned towards the centre of his/her lane (i.e. towards the left of the scene, from the photographer's viewpoint) the background consisted primarily of parked cars and red-brick buildings, a multi-coloured, complex and 'cluttered' background. In contrast, if the motorcyclist was positioned towards the left of his/her lane (i.e. towards the right of the scene from the photographer's viewpoint), the background was 'uncluttered', and much less complicated; owing to perspective, it consisted primarily of the light-grey concrete road surface behind the motorcyclist.

In slides in which a motorcyclist was present, the motor-cycle was the only vehicle present in the scene, other than the parked cars along the left-hand side of the road. In the slides in which no motorcyclist was present, the road was either entirely empty of traffic (except for the parked cars), or contained a single car facing towards the photographer and at varying distances from him. (It was felt that if all of the slides not containing a motorcyclist were always completely empty of vehicles, this in itself might act as a cue by which the subjects could make their decisions. The occasional presentation of a vehicle which was not a motorcycle, but which was presented in similar locations to the motorcycle, meant that subjects had to look at the slides and identify the objects present, rather than being able to base their decisions on the absence *per se* of any objects).

Of the 24 slides containing motorcyclists, there were three different slides for each permutation of the three independent variables of headlight use, distance and level of background clutter.

(1) *Headlight use*: The headlight was either
  (a) lit, on dipped beam, or
  (b) unlit.

(2) *Distance of motorcyclist from viewer*: The motorcyclist was positioned at either approximately 56 or 28 m from the photographer (corresponding to approximately 1·7 and 3·5° of visual angle respectively, at the viewing distance of 1 m).

(3) *Level of background 'clutter'*: The background was either 'cluttered' or 'uncluttered'. As mentioned previously, this was achieved by varying the lateral position of the motorcyclist in the road.

In all photographs containing a motorcyclist, the motorcyclist wore a white full-face helmet, blue jeans, and a leather jacket manufactured by Scott Leathers Ltd. The top half of the jacket's torso and sleeves was dark blue, and the bottom half was red. In between these halves were two horizontal bands, one white and one red.

The motorcycle used for this experiment was an unfaired blue 1976 Honda CB750, with a round quartz-halogen headlamp (12 V, 60 W main beam and 45 W dipped beam), on dipped beam for the headlamp-ON slides.

All slides were taken on the same overcast but bright August afternoon.

3.1.3. *Apparatus*: The remainder of the apparatus (slide-projector, computer and button-box, etc.) was identical to that used in experiments 1 and 2.

3.1.4. *Procedure*: The procedure was similar to that used in experiments 1 and 2, except for the number of slides presented. For each slide, subjects had to press one of two buttons as quickly as possible, according to whether or not they thought a motorcyclist was present in the scene. Unknown to the subject, the first seven slides were practice slides, whose data was discounted. The 48 experimental slides were then shown, in a different random order for each subject.

3.2. *Results*

3.2.1. *Reaction-time measures* Each subject provided 24 reaction-time scores, for the slides in which a motorcyclist was present. The reaction times for each triplet of slides that represented the same permutation of conditions were averaged together, to produce eight means per subject—representing the eight permutations of headlight (on or off), distance (far or near) and clutter (cluttered or uncluttered). These means were used as the raw data in the following analyses. A three-way ANOVA was performed (headlight × distance × clutter, all within-subjects variables with two levels). There were significant main effects of headlight ($F(1, 39) = 11{\cdot}72$, MS

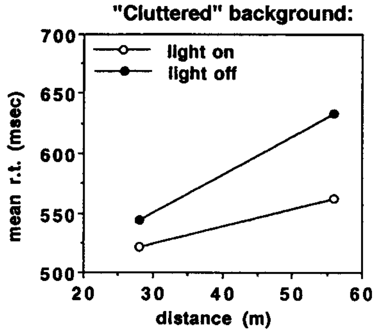

Figure 3. Effects of distance, headlight use and a 'cluttered' background on motorcyclist conspicuity in an urban setting (experiment 3).

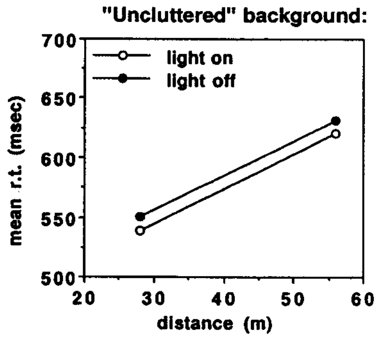

Figure 4. Effects of distance, headlight use and an 'uncluttered' background on motorcyclist conspicuity in an urban setting (experiment 3).

error = 5904, $p < \cdot 001$) distance ($F(1,39) = 54{\cdot}06$, MS error = 7789, $p < \cdot 0001$) and clutter ($F(1,39) = 6.47$, MS error = 5260, $p < \cdot 02$), and a significant interaction between headlight and clutter $F(1,39) = 5{\cdot}46$, MS error = 4650, $p < \cdot 05$). All other higher-order interactions were non-significant ($F < 3$ in all cases).

As can be seen from figures 3 and 4, the most obvious result is that subjects were slower to detect motorcyclists when they were further away: there was a clear and consistent effect of distance on subject's reaction times.

At the near distance, there was no significant difference between the headlight on and off conditions, and no effect of clutter (either in isolation or in interaction with headlight). At the far distance there were two effects. First, when the background was cluttered, subjects were faster to detect motorcyclists with lights on than with lights off ($t = 4{\cdot}20$, 39 df: $p < \cdot 0001$, two-tailed test). Second, subjects were faster to detect the motorcyclist when the headlight was on and the background was cluttered, than when the headlight was on but the background was uncluttered. No other effects were significant. There was no effect of background clutter on time to detect the motorcyclist with headlight off, at either distance. As shown by figure 4, when the background was uncluttered, there was only a small and statistically non-significant advantage for the headlight condition over the no-lights condition, at either the near or the far distance.

3.2.2. *The frequency of 'false negative' errors*: The number of 'false negative' errors made in this experiment was very small: only 11 errors were made in the entire experiment. Of these, eight were failures to detect motorcyclists at the far distance, fairly evenly divided amongst the different permutations of background clutter and headlight use. A total of 32 subjects produced 100% error-free performance. Of the eight subjects who made errors, five made only one error each, and the remaining three made two errors each.

3.3. *Discussion*

Headlight use had a negligible benefit on conspicuity when the background was uncluttered, but did significantly reduce reaction times when the background was cluttered—but only at the far distance. At the near distance, motorcyclists with headlights on were more visible than motorcyclists with headlights off, but not significantly so. Motorcyclists with headlights off were just as readily detected when they were against a cluttered background as when they were against an uncluttered background. When the headlight was on, at the far distance the effect of clutter was to make the motorcyclist easier to detect than when the background was uncluttered: at the near distance, clutter had no effect. Failures to detect motorcyclists (i.e. 'false negative' responses) were few, and showed no effect other than suggesting that motorcyclists at the far distance were possibly harder to detect.

4. Influence of luminance factors in experiments 1, 2 and 3

4.1. *Method*

To determine whether subjects' reaction times in these three experiments were related to the luminance properties of the motorcyclist and/or the background, luminance readings were taken from a variety of locations within each of the test slides used in these experiments. Readings were taken using a 'Macam' L103 Photometer, on its 'candela per square meter × 10' scale. The photometer was placed in front of the projector screen, facing towards the slide projector.

To measure the luminance of sufficiently small patches of the slide, it was necessary to restrict the photometer's angle of acceptance. This was achieved by covering the front of the photometer with a flat mask which was opaque save for a centrally-located 2 mm-diameter hole. Owing to this restriction on the amount of light entering the photometer, the luminance readings probably have little meaning in absolute terms (i.e. in terms of cd/m^2), but the relative differences between readings are meaningful.

For each slide that contained a motorcyclist in experiments 1 and 2, luminance readings were taken from the centre of the motorcycle's headlight, from the centre of the motorcyclist's chest and helmet, and from four points in the background (immediately above, below and to the left and right of the motorcyclist). Additionally, some composite measures were computed; these included the standard deviation of the four background measurements (in an attempt to obtain a quantitative measure of background 'clutter' in terms of variations in background luminance); and the luminance difference between the headlight and the motorcyclist's chest.

For experiment 3, similar measurements were taken, except that eight background luminance measurements were recorded for each slide. These were taken from above and to the left and right of the motorcyclist's head; to the left and right of the centre of the headlight; and from immediately beneath, to the left and to the right of the motorcycle's front wheel.

4.2. *Results and discussion*

For each experiment, stepwise multiple regression was used to examine the relationship between these luminance measurements and the mean reaction time to detect the motorcyclist's presence (averaged across all subjects within each experiment), for each of the slides that contained a motorcyclist. Separate regression analyses were performed for the lights-on and lights-off slides in each experiment. Correlation matrices were produced prior to each regression analysis, showing the Pearson's correlation of each variable with all other variables. These matrices were used to determine which factors were the most useful for inclusion in the regression analyses.

In all three experiments, the factors that showed the highest correlation with mean reaction time were the size of the motorcyclist (measured in terms of visual angle subtended), and the luminance of the motorcyclist's headlight, chest and helmet. The standard deviation of the background luminance measurements (henceforth referred to as 'background SD') was also included in each regression analysis, as a measure of environmental 'clutter': the larger the background SD, the greater the variation in luminance measurements surrounding the motorcyclist.

In the case of the 'lights-on' conditions of experiments 1 and 2, the original intention was to use five predictors in the stepwise multiple regression on these data (motorcyclist's size, headlight luminance, chest luminance, helmet luminance and background SD). However, prior examination of the inter-correlations between these variables showed that headlight luminance and motorcycle size were highly positively correlated with each other. Consequently, for both experiments, two separate stepwise regression analyses were performed, one including motorcycle size as a predictor and the other substituting headlight luminance for motorcycle size. The

Table 4. Summary of regression analyses for experiments 1, 2 and 3 using four predictors of mean reaction time in each case: motorcycle size, headlight luminance, chest luminance and background luminance-variation.†

Conditions	Mean reaction time
Experiment 1 (semi-rural)	
Light on	875 (constant) − 27 (motorcycle size) + 2155 (chest luminance) −223 (helmet luminance) $R^2 = 66{\cdot}54$
Light off	1041 (constant) − 66 (motorcycle size) + 1045 (background SD) $R^2 = 79{\cdot}21$
Experiment 2 (urban)	
Light on	1205 (constant) − 68 (motorcycle size) $R^2 = 53{\cdot}5$
Light off	1233 (constant) − 71 (motorcycle size) $R^2 = 64{\cdot}23$
Experiment 3	
Light on	622 (constant) − 1.6 (motorcycle size) $R^2 = 48{\cdot}78$
Light off	732 (constant) − 2 (motorcycle size) $R^2 = 77{\cdot}36$

†Only predictors that reached statistical significance are shown.

Table 5. Summary of correlational data for experiments 1 to 3.

	Light on	Light off
Experiment 1 (semi-rural location)		
Mean RT and motorcycle size	−·70 (22 df : $p <$ ·01)	−86 (22 df : $p <$ ·01)
Mean RT and chest luminance	+·31 (21 df : $p <$ ·05)	−·007 (21 df : NS)
Mean RT and background luminance variation	−·05 (21 df : NS)	+·43 (21 df : $p <$ ·05)
Mean RT and headlight luminance	−·35 (21 df : $p <$ ·01)	
Mean RT and difference between chest and headlight luminance	−·32 (21 df : $p <$ ·01)	
Experiment 2 (rural location)		
Mean RT and motorcycle size	−·73 (22 df : $p <$ ·01)	−80 (22 df : $p <$ ·01)
Mean RT and chest luminance	+·30 (21 df : NS)	−·03 (21 df : NS)
Mean RT and background luminance variation	−·10 (21 df : NS)	−·01 (21 df : NS)
Mean RT and headlight luminance	−·63 (21 df : $p <$ ·01)	
Mean RT and difference between chest and headlight luminance	−·59 (21 df : $p <$ ·01)	
Experiment 3		
Mean RT and motorcycle size	−·70 (22 df : $p <$ ·02)	−88 (10 df : $p <$ ·01)
Mean RT and chest luminance	+·03 (9 df : NS)	+·43 (9 df : NS)
Mean RT and background luminance variation	+·004 (9 df : NS)	+·20 (9 df : NS)
Mean RT and headlight luminance	−·53 (9 df : $p <$ ·10)	
Mean RT and difference between chest and headlight luminance	−·57 (9 df : $p <$ ·10)	

All correlations except those between mean RT and motorcycle size are partial correlations, eliminating the effects of motorcycle size. See text for full details of the measures correlated.

former are reported here, since they accounted for greater proportions of the variance in mean reaction times (RTs).

The results of the regression analyses, and the principal correlations of interest, are summarized in tables 4 and 5. In all three experiments, it can be seen that the motorcyclist's size is the largest predictor of reaction times: the larger the visual angle subtended by the motorcyclist, the faster the mean RT. Addition of the other predictors into the regression equations accounted for very small additional proportions of the variance in mean RT.

Partialling out the effects of motorcycle size reveals three main points. Firstly, there was a negative partial correlation between mean RT and headlight luminance in the 'lights-on' conditions of all three experiments—possibly reflecting the inverse square law relating brightness to distance. (All other things being equal, headlights that are nearer should appear brighter.)

Second, an initially paradoxical finding is that the correlations between mean RT and chest luminance were either negligible or positive, depending on the experiment and lighting condition: generally, the brighter the chest, the slower the mean RT. However, there were significant negative correlations between mean RT and the difference between headlight and chest luminances in the lights-on conditions of the three experiments. These results are explicable if reaction times are affected by the contrast between the headlight and its immediate surroundings, rather than by the absolute brightness of the headlight—so that the darker the chest, the more the headlight stands out. In short, it appears to be the contrast between the headlight and the motorcyclist's chest that was important for conspicuity, rather than the headlight or clothing in isolation.

Third, table 5 shows that the correlation between variation in background luminance and mean RT varied in strength depending on the experiment and lighting conditions, but was generally negligible (except in the semi-rural/lights off situation, but even then the correlation was small in practical terms).

5. General discussion

Motorcyclists' conspicuity is a complex issue, dependent on a number of factors in interaction. Consideration of each of these factors in isolation may ultimately give a false impression of what is going on. If only one of the three experiments reported here had been performed, different conclusions might have been drawn.

The first study, using a semi-rural environment, would have led the authors to conclude that headlight use consistently enhanced motorcyclist conspicuity. The second study, in the cluttered urban environment, would have led the authors to claim that the advantages of headlight use were much less clear-cut: for two of the four clothing conditions, headlight use enhanced conspicuity, but in the other two conditions the headlight actually reduced it. Experiment 3 would similarly have led to the conclusion that headlight use was a rather limited aid to motorcyclists' conspicuity.

Taken together, these experiments enable one to appreciate that the conspicuity advantages of headlight use and different clothing types may vary depending on the motorcyclist's environment. Previous researchers have also reported environmental influences on the effectiveness of conspicuity aids (Watts 1980, Williams and Hoffman 1979). Although the present results do not entirely support the finding of Williams and Hoffman (1979) that headlight-use enhances visibility more in 'uncluttered' than in 'cluttered' environments, the present experiments do suggest that broad generalizations such as 'bright clothing increases conspicuity' or that 'headlight use improves visibility' may be over-simplistic.

The greater effectiveness of dark as opposed to bright clothing may be explicable in terms of brightness contrast—and this may also explain the discrepancy between the results of the third experiment and those of Williams and Hoffman (1979) mentioned above. In an investigation of the cues used by drivers for detecting oncoming vehicles in rural traffic, Dahlstedt and Rumar (1979), cited in Rumar (1990) found that brightness contrast between a vehicle and its background was by far the most frequently used cue. This contrast was most often provided by headlights, but, importantly for understanding the present results, could also be produced by colour or silhouette.

In the urban setting of experiment 2, the area behind the motorcyclist consisted of brightly coloured flower-beds, street furniture and other vehicles. In this situation, dark clothing may have acted to silhouette the motorcyclist against the background, while bright clothing may well have had a camouflaging effect. Headlight use would tend to have one of two effects, depending on various accidental features such as the precise position and orientation of the motorcyclist with respect to the photographer: it could either fragment the silhouette into a number of small regions that would then be 'lost' in the background clutter, or else the headlight could show up well against the dark backdrop of the rest of the motorcyclist and motorcycle. In the semi-rural condition, at the furthest distance the motorcyclist tended to be against a dark background of woodland and buildings. In this situation, the brightness contrast between the headlight as a point source of light and the surroundings was probably the most salient cue to the motorcyclist's presence.

The key to understanding the results of experiment 3 also probably lies in the contrast relationship between motorcyclist and background. Most British roads are surfaced with asphalt, but the road used in experiment 3 was constructed of concrete. Consequently, it was very light in appearance (as confirmed by luminance readings from the slides). The bottom half of the motorcycle gave consistently low luminance readings. It appears that in experiment 3 (as in experiment 2), a location was found that favoured the detection of dark, unlit motorcycles. At the far distance, in the uncluttered condition, the motorcyclist was readily detectable as a silhouette against the lighter coloured road surface: there was little scope for headlight use to enhance conspicuity further. Even in the cluttered condition, the perspective of the scene meant that the lower half of the motorcyclist was silhouetted against the road surface, providing sufficient information for subjects to detect the motorcyclist relatively quickly. However, in the cluttered condition, there was an opportunity for the lit headlight to be used as an effective cue to the motorcyclist's presence, because it stood out against the relatively dark background for the top half of the motorcyclist.

An interpretation of motorcyclist conspicuity in terms of brightness contrast is also consistent with the authors' attempts to correlate mean reaction times for detecting motorcyclists and the luminance measurements taken from the test slides. There were some indications that conspicuity was related to the contrast between the chest and headlight luminances, when the headlight was on. The somewhat paradoxical finding that dark clothing was more conspicuous than bright clothing in some circumstances, is explicable if one appreciates that dark clothing may serve to enhance the effective contrast of the headlamp.

The generality of these results should obviously be treated with caution. One should be wary of uncritical extrapolations from static slides of street scenes to the information-processing complexities of real-life traffic situations. Thomson (1982) has warned that slides may produce misleading results owing to their limited luminance range in comparison to real life. It is also impossible to examine the efficacy of fluorescent colours by means of slides. The visibility of the fluorescent orange jacket used in the present experiments was probably greatly reduced in these slides. However, it should be noted that motorcycle clothing's fluorescence declines quite rapidly under conditions of everyday use (Fulton *et al.* 1980).

Problems are also caused by the fact that instructing subjects to look for motorcyclists may cause them to process a traffic scene in ways that are different to those used in normal driving (see Hughes and Cole 1988 for an experimental demonstration of the effects of instructions on drivers' fixation patterns). Cole and Hughes (1984, 1990) distinguish between two types of conspicuity. 'Attention conspicuity' refers to the capacity of a stimulus to be noticed when the observer is not actively looking for it. 'Search conspicuity' refers to the capacity of a stimulus to be noticed when the observer is specifically searching for it. The experiments reported here have examined factors affecting motorcyclists' search conspicuity, but in real life, attention conspicuity may also be important.

It should be appreciated that the motorcyclist's size (in terms of visual angle subtended) was the most powerful single determinant of conspicuity in all three experiments. Motorcyclists subtending a large visual angle (i.e. who were effectively nearby) were readily detected regardless of headlight use, type of clothing or type of background. Many motorcycle accidents occur because the motorcyclist's right of way is violated by another road user, at a point when the vehicles concerned are so close that a collision cannot be averted. In these circumstances, the present results lead one to question what 'poor conspicuity' really means.

The experiments reported here show that the conspicuity of motorcyclists at some distance from the viewer may be affected by the motorcyclist's physical properties. However, the fact that there were few differences between conditions when the motorcyclist was nearby implies that motorcyclists' conspicuity *at the close range within which accidents often occur* might be relatively unaffected by such factors: within this range, it is possible that the psychological state of the driver may play a more important role than the physical characteristics of the motorcyclist. Hole and Tyrrell (1995) have shown that subjects will fail to detect unlit motorcyclists who subtend a considerable visual angle (i.e. are effectively nearby), if they are expecting to see motorcyclists using lights. In many cases, similarly inappropriate expectancies may be more important in accident causation than the motorcyclist's physical properties.

If the results from these experiments have relevance to real-life driving conditions, their implications are that motorcyclists should not assume that conspicuity aids such as headlight use and bright clothing will automatically guarantee their detection by other road-users. Although headlight use may often be a powerful aid to conspicuity for motorcyclists, experiments 2 and 3 show that it need not be invariably so. Clothing may be a particularly unpredictable aid to conspicuity: it may be counter-productive to make sweeping recommendations to motorcyclists to wear bright clothing, if the effectiveness of such clothing is situation-specific and lulls the rider into a false sense of security.

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