Journal of Safety Research, Vol. 20, pp. 153-176, 1989

0022-4375/89 $3.00 + .00
Printed in the USA

Motorcycle Conspicuity: An Evaluation and Synthesis of Influential Factors

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Motorcycles are overrepresented in fatal motor vehicle accidents: The death rate for motorcycle riders of about 35 per 100,000,000 miles of travel compares with an overall vehicle death rate of 2.57 per 100,000,000 miles. In the attempt to reduce the frequency of automobile-motorcycle collisions, numerous studies have manipulated motorcycle and motorcyclist characteristics to enhance conspicuity. In this paper, we give a review of studies that examined the effectiveness of these measures. Subsequently, we take a critical look at the methods used in these studies to evaluate the effectiveness of conspicuity treatments. Furthermore, we identify factors yet to be considered in the empirical research in this area that may contribute to collisions with motorcycles. These include information-processing failures at the identification and decision stage, as well as more or less permanent factors potentially responsible for different information-processing failures. Transient factors related to the failure to detect motorcycles might include alcohol, fatigue/lack of sleep, inattention, and information overload, whereas more permanent factors might include "cognitive" conspicuity and field dependence.

To systematically reduce human deaths due to accidental causes it is necessary to identify the most prevalent accident circumstances. Overall, there were over 94,000 accidental deaths in the United States in 1986. More than half of these accidents (47,900, 50.96%) involved motor vehicles.[1] In such events one person died on average every 11 minutes, and one person was injured every 18 seconds. The overall death rate for motor vehicle accidents in 1986 was 19.9 per 100,000 population. This rate varies significantly with age, with a peak at 40 per 100,000 for those between the ages of 15 and 24 years, declining to about 15 per 100,000 for those ages 45 to 64, and increasing again

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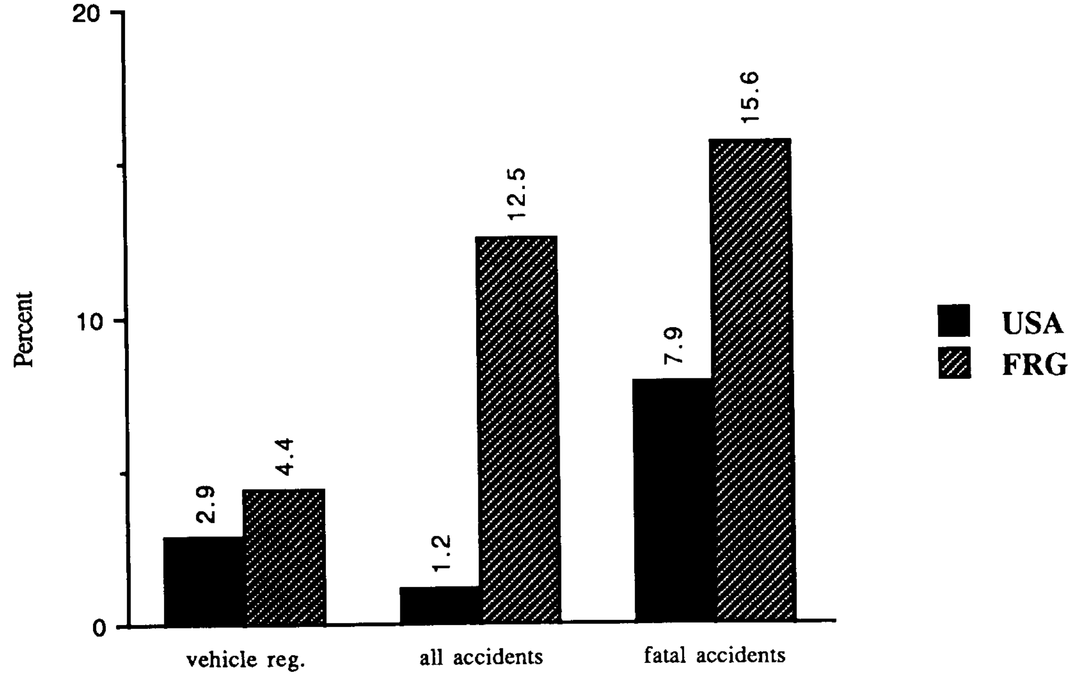
[1] The costs of motor vehicle accidents, including wage loss, medical expenses, insurance administration costs, and property damage, amounted to $57.8 billion (not included are the costs of public agencies, such as police and fire departments, and courts, indirect losses to employers, etc; National Safety Council, 1987).

to a secondary peak of about 29 per 100,000 for the age group of 75 and over (National Safety Council, 1987). In the first age group, the probability of being killed in a road traffic accident is especially high for motorcycle riders. The median age of the motorcyclist population is typically in the mid-20s, and about 70% of the riders fall in the 18 to 34 age bracket (Hurt, Ouellet, & Thom, 1981).

Motorcyclists are the road users who are most vulnerable to injury from collision. Not surprisingly, motorcycles are overrepresented in fatal motor vehicle accidents. Automobiles constituted 74.5% of the total vehicle registrations in 1986 and were involved in 62.4% of the fatal accidents, whereas motorcycles[2] constituted 2.9% of the total vehicle registrations, but were involved in 7.9% of the fatal accidents. This problem is not specific to the United States. In fact, accident data are even less favorable for motorcyclists in other countries. In West Germany, for example, in the same year (1986), 4.4% of all motor vehicle registrations were motorcycles (see Figure 1) and 84.7% of vehicle registrations were automobiles. The overall accident involvement for motorcycles, however, was 12.5% compared to 64.9% for automobiles, and their involvement in fatal accidents was even greater — 15.6% compared to 51.1% for automobiles (Allgemeiner Deutscher Automobil-Club, 1987). The involvement of automobiles and motorcycles in all traffic accidents and in fatal traffic accidents, relative to their number of registrations, is illustrated in Figure 2.

As can be seen, the relative overinvolvement of motorcycles in accidents is particularly high for *fatal* accidents, amounting to 272.4% in the USA and 354.5% in West Germany. Also, 4.3% of all motorcycle accidents, compared to 1.0% of all automobile accidents, resulted in a fatality, and 43.4% of the motorcycle accidents resulted in se-

FIGURE 1
RELATIVE NUMBER OF REGISTRATIONS AND ACCIDENT INVOLVEMENT OF MOTORCYCLES IN THE UNITED STATES AND WEST GERMANY



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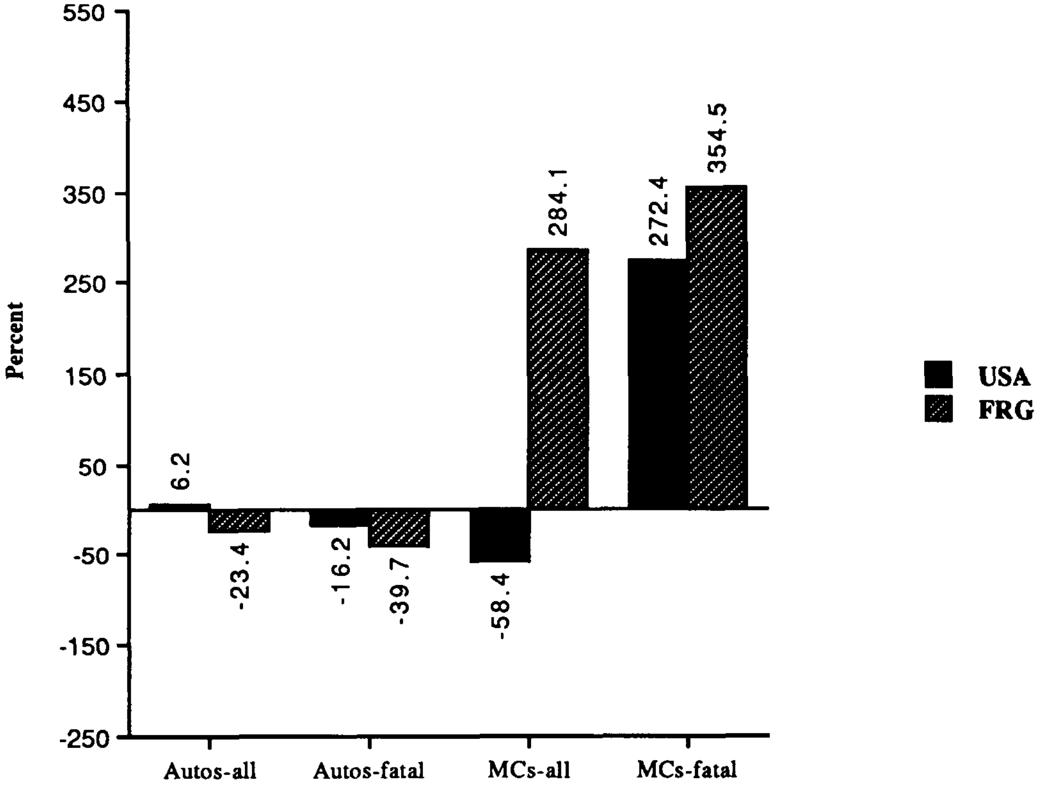
[2] Including motor scooters and motor bikes.

FIGURE 2
ACCIDENT INVOLVEMENT OF AUTOMOBILES AND MOTORCYCLES, RELATIVE TO THEIR NUMBER OF REGISTRATIONS, IN THE UNITED STATES AND WEST GERMANY



vere injuries, as opposed to 14.1% of the automobile accidents (Appel, Otte, & Wüstemann, 1986, p. 97). Taking into account miles of travel, the death rate in the U.S. for motorcycle riders of about 35 per 100,000,000 miles of travel contrasts with an overall motor vehicle death rate of 2.57 per 100,000,000 miles (National Safety Council, 1987). In West Germany, the death rate by kilometers traveled is 44 times higher for motorcyclists than for automobile drivers (Appel et al., 1986). Another illustration of the differing risks involved in riding a motorcycle or driving a car is presented in Table 1, which contains the average times and distances of travel until the occurrence of an accident resulting in an injury or a fatality.

CAUSES OF MOTORCYCLE ACCIDENTS

Accident analyses reveal that the most common cause of motorcycle accidents is the violation of the motorcyclist's right-of-way by another vehicle driver. In West Germany, for example, in 1985, automobile drivers were at fault in 67% of automobile-motorcycle collisions. However, 93% of the persons who were injured or killed in these accidents were motorcycle riders/passengers (Allgemeiner Deutscher Automobil-Club, 1987). The probability of an automobile driver causing an accident with a motorcycle is 80% higher than the probability of a motorcyclist causing an accident with an automobile (Meiszies, 1984).

The most typical automobile-motorcycle

TABLE 1
RISKS OF ACCIDENT-RELATED INJURY AND FATALITY FOR AUTOMOBILE DRIVERS AND MOTORCYCLISTS IN WEST GERMANY

Risk Variable	Automobile Drivers	Motorcyclists
Km (million) until injury	1.8	0.04
Km (million) until fatality	70.6	1.4
Years of driving until injury	3.4	0.1
Years of driving until fatality	134.3	2.6
Years of life until injury	140	16
Years of life until fatality	5,473	560

Note. From Appel & Wuestemann (1986).

accident happens when an automobile turns left into the path of an oncoming motorcycle (e.g., Hurt et al., 1981; Olson, Hallstead-Nussloch, & Sivak, 1979a; Waller, 1972; Weber & Otte, 1980). In postaccident interviews, the driver of the offending automobile often claims not to have seen the motorcycle at all, or not to have seen it until too late to avoid collision (Hurt et al., 1981; Väg-och Trafik-Institutet, 1986, cited in Dahlstedt, 1986). In some instances this failure to see the motorcycle could be attributed to structural limitations, such as view obstructions. However, most frequently the other vehicle driver failed to detect the approaching motorcycle in time. While the phenomenon of "looking without seeing" (Dahlstedt, 1986) is very common not only in everyday life but also in road traffic, it demonstrably has fatal consequences under these circumstances.

From their analysis of 1,508 motorcycle accidents in Victoria, Australia, in 1974, Williams and Hoffmann (1977, 1979a) estimated that inadequate motorcycle visibility was an associated factor in 64.5% of automobile-motorcycle collisions and the sole identifiable cause in 21.0%. Furthermore, Smith (1974) found that, in addition to the other vehicle driver violating the motorcyclist's right-of-way more often than vice versa, the ratio of other drivers' fault to motorcyclists' fault was higher in daytime than at nighttime (5.0 : 1 and 3.6 : 1, respectively). Also, Appel et al. (1986, p. 100) report that motorcycle accidents are underrepresented in nighttime. This suggests that the lack of *conspicuity* of motorcycles, especially in daytime, as compared to nighttime when headlights are in use anyway and provide a strong contrast to the environment, might be a major factor in accident etiology.

Recognition of the specific factors that determine motorcycle conspicuity and how they interact with factors that induce failures in the offending vehicle driver's visual information processing capability can form the basis of strategies to promote effective countermeasures for automobile-motorcycle collisions. In this paper we outline a number of factors associated with these failures to "see" motorcycles and give a review of studies that examine potential countermeasures in terms of both vehicle and operator characteristics and their effectiveness in daytime and at nighttime. Subsequently, we take a critical look at the methods used in these studies to evaluate the different conspicuity treatments. Finally, we identify factors yet to be considered in the empirical research in this area that may contribute to collisions with motorcycles.

INFORMATION-PROCESSING FAILURES AND POTENTIAL COUNTERMEASURES

The causes of failure to "see" a motorcycle can be located at different stages of the driver information-processing sequence, i.e., at the perception (detection/identification) or at the decision level of processing. The following sections outline factors primarily related to these stages and review studies that have examined potential countermeasures.

Perception Stage

Perception is the realization and the detection of an object in an environment. Typically, detection takes place in the periphery of the retina, and an eye saccade is then triggered to examine this object more thoroughly in the fovea. The probability of an object being detected and receiving foveal attention is comparatively high for more *conspicuous* targets.

Visual conspicuity as it is usually understood refers to the ability of an object to attract attention and to be easily located, due to its physical properties (e.g., Engel, 1976). In recent years, research efforts have been directed toward the establishment of factors that determine the conspicuity of an object. It has been shown that the detectability of an object is strongly influenced by its size, luminance,[3] contrast, and color, in relation to the existing background (e.g., Cole & Jenkins, 1984; Connors, 1975; Engel, 1971, 1974, 1977; Gerathewohl, 1953, 1957; Jenkins & Cole, 1979, 1982, 1984; MacDonald & Cole, 1988; Siegel & Federman, 1965). Consequently, numerous studies have focused on these features and have manipulated relevant motorcycle and motorcyclist characteristics to enhance conspicuity. Table 2 gives an overview of studies that have examined the effectiveness of different conspicuity treatments during daytime and nighttime.

Motorcycle characteristics: daytime. Several studies have examined the effectiveness of vehicle characteristics such as daytime running lights, as well as fairings and windshields. In general, running lights during daytime have been shown to increase the noticeability of motorcycles (e.g., Dahlstedt, 1986; Fulton, Kirkby, & Stroud, 1980; Janoff, 1973; Janoff & Cassel, 1971). Specifically, high-beam lights, in both clear and cluttered environments (Williams & Hoffmann, 1979a) and low-beam headlights with auxiliary amber lamps (Mortimer & Schuldt, 1980) enhanced conspicuity, compared to low-beam lamps and headlight-off conditions. Kirkby and Fulton (1978a, 1978b, 1978c) found that dipped headlights on large motorcycles increased the motorcycle's probability of being seen relative to a control motorcycle without lights. Also, pairs of running lights, large dipped headlights (Donne & Fulton, 1985; Donne, Fulton, & Stroud, 1985; Kirkby & Fulton, 1978a), and modulating headlights (Dahlstedt, 1986; Olson, Hallstead-Nussloch, & Sivak, 1979a, 1979b, 1981), as well as special visual warning devices, e.g., a flashing strobe light, a rotating light and reflector, or a continuous light with four rotating prisms (Ramsey & Brinkley, 1977) have been demonstrated to be superior to standard motorcycles. Williams and Hoffmann (1977, 1979a) also found that increasing the frontal area of a motorcycle through the use of a white fairing enhanced its detectability.

Motorcycle characteristics: nighttime. During nighttime, Olson et al. (1979a, 1979b, 1981) did not find substantial advantages for additional running lights. Schuldt (1978, cited in Winn, 1983) showed that a low-beam headlight and auxiliary lamps on the motorcycle were superior in conspicuity to a low-beam headlamp only, but not superior to an automobile with low-beam headlights. Similarly, Donne and Fulton (1987) found that an increase in the power and/or size of the headlamp, as well as additional amber running lights, did not make a motorcycle as detectable as a car. Illuminated legshields or striplights, however, improved the identification of motorcycles compared to a motorcycle using a headlamp only. A modified lighting system tested by Stroud et al. (1980), including amber running lights and a yellow headlight, proved to be of minor benefit compared to a regular headlamp. The *lateral* conspicuity of motorcycles has been shown to be significantly enhanced by the use of reflective sidewall tires (Burg & Beers, 1976, 1978; Internationales Zentrum für Verbrechens- und Verkehrsunfallverhütung, 1977; Kratz, 1978). However, the incidence of accidents in the side-view scenario is very low com-

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[3] An interesting finding in the light of the predominant configuration of automobile-motorcycle collisions (an automobile turning left into the path of an oncoming motorcycle) is implied in the results of a study by Leibowitz and Appelle (1969). They found that the luminance thresholds for peripherally presented stimuli were significantly higher on the right side of the field of view than on the left side. Thus, when the automobile driver turns his or her head to the left during performance of a left turn (that is, in the direction he or she is moving), low-conspicuity targets in the right periphery might have a relatively lower probability of being detected.

TABLE 2
STUDIES EXAMINING THE EFFECTIVENESS OF DIFFERENT CONSPICUITY TREATMENTS DURING DAYTIME AND NIGHTTIME

Study	Conspicuity Devices	Day/ Night	Number of Subjects	Method	Conclusions
Janoff and Callel (1970)	No light; High-beam headlight; at 50, 100, 150, 200, 250, 300 feet	D	1,246	Interview of motorists (motorcycle positioned in cross street)	Motorcycle with headlight on is noticed sooner, at greater distances
Janoff (1973)					
Front-light experiments:					
Experiment 1	No light; Low-beam headlight; High-beam headlight	D	1,369	Interview of motorists (motorcycle traveling in opposing direction)	Headlights increase noticeability of motorcycles, that is, motorcycles are identified with more precision and at greater distances
Experiment 2	No light; Low-beam headlight; High-beam headlight	D	700	Interview of motorists (motorcycle positioned in cross street)	
Experiment 3	No light; High-beam headlight	D	[a]	Interview of motorists (motorcycle waiting at intersection to make left turn)	
Experiment 4	No light; High-beam headlight; Running amber lights	D	[a]	Interview of motorists (motorcycle traveling in opposing direction in nearest lane)	
Distance and headlight condition experiment:	No light; High-beam headlight; at 50, 100, 150, 200, 250, and 300 feet	D	[a]	Interview of motorists (motorcycle positioned in cross street)	

TABLE 2
(CONTINUED)

Study	Conspicuity Devices	Day/ Night	Number of Subjects	Method	Conclusions
Woltman and Austin (1976)	Six colors: fluorescent yellow-orange, fluorescent red-orange, white, yellow, international orange, and red; Three backgrounds: white, tan, olive drab; Four directions: 0°, 45°, 90°, and 135°; Clear and overcast sky	D	19	Determination of distance at which color can be identified	Detection and identification of fluorescent material comparable to conventional pigments under optimum daylight conditions; under overcast or dust, fluorescent materials superior
Stroud and Kirkby (1976)	Motorcycle control; Fluorescent orange legshields; Fluorescent orange headlamp cover; Fluorescent orange sleeves; Fluorescent orange waistcoat; Fluorescent orange jacket; Fluorescent orange helmet	D	100	Slides: time to detect motorcycle	Fluorescent jacket, waistcoat, or helmet produce faster detection times than standard motorcycle
Burg and Beers (1977, 1978)	Reflectorized sidewall tires; Red and amber prismatic side reflectors; Crystal (white) double-faceted prismatic side reflectors	N	89	(1) static target detection (40°, 90°); (2) dynamic target detection (40°, 90°, and 130°)	Reflectorized sidewall tires superior to prismatic reflectors in aiding recognition of motorcycles
Internationales Zentrum fuer Verbrechens- und Verkehrs-unfallverhuetung (1977); Kratz (1978)	Side reflectors; Reflectorized side tires	N	a	Determination of distance at which motorcycle is recognized	Motorcycles with reflectorized sidewall tires recognized earlier than motorcycles with side reflectors

TABLE 2
(CONTINUED)

Study	Conspicuity Devices	Day/ Night	Number of Subjects	Method	Conclusions
Ramsey and Brinkley (1977)					
Phase I	Rotating light and reflector (on/off)	D	1,041	Interview of automobile drivers (motorcycle positioned in cross street)	Larger, higher intensity devices (Prism, Kojak) improve noticeability
Phase II	Rotating light and reflector; Flashing strobe light; Continuous light with four rotating prisms (Prism); Continuous light with rotating reflective shield (Kojak); Continuous light with rotating reflective shield (Cylindrical)	D	425	Rating of noticeability of device	
Phase III	Continuous light with four rotating prisms (Prism); Continuous light with rotating reflective shield (Kojak); Standard motorcycle	D	300	Interview of automobile drivers (motorcycle positioned in cross street)	
Williams and Hoffmann (1977)					
Experiment 1	Low-beam headlamp; High-beam headlamp; Fluorescent jacket; White wind fairing; Standard motorcycle; "Clean" and "cluttered" environments	D	4	Tachistoscopically presented slides: Detection of motorcycle (Y/N)	High-beam headlamp more effective than other devices for improving noticeability in both clean and cluttered environments

TABLE 2
(CONTINUED)

Study	Conspicuity Devices	Day/ Night	Number of Subjects	Method	Conclusions
Williams and Hoffmann (con.)					
Experiment 2	Low-beam headlamp; High-beam headlamp Fluorescent jacket; White wind fairing; Standard motorcycle; Clean and cluttered environments	D	10	Slides: time to identify device	
Experiment 3	Low-beam headlamp; High-beam headlamp; Fluorescent jacket; White wind fairing; Standard motorcycle; No motorcycle; Clean and cluttered environments	D	2	Tachistoscopically presented slides: confidence that motorcycle is present/not present	
Experiment 4	Low-beam headlamp; High-beam headlamp; Fluorescent jacket; White wind fairing; Standard motorcycle	D	10	Tachistoscopically presented slides: confidence that certain device is present/not present	
Kirkby and Fulton (1978a)	Control: Honda C70 without lights; Honda C70, dipped headlamp; Puch 50 cc, dipped headlamp; Yamaha 90, two Lucas running lights	D	1,999	Interview of pedestrians (motorcycle positioned in cross street)	Two Lucas running lights increased probability of motorcycle being seen

TABLE 2
(CONTINUED)

Study	Conspicuity Devices	Day/ Night	Number of Subjects	Method	Conclusions
Kirkby and Fulton (1978b)	Control: Honda C70 without lights; Puch moped, full-beam headlamp; Honda C70, full-beam headlamp; Yamaha 90, dipped headlamp; Yamaha 90, full-beam headlamp	D	3,928	Interview of pedestrians (motorcycle positioned in cross street)	Use of both full and dipped beam headlights increased probability of larger motorcycle (Yamaha 90) being seen
Kirkby and Fulton (1978c)	Control: Honda C70 without lights; Fluorescent orange jacket; Honda C70, dipped headlamp; Yamaha 90, one Lucas running light; Yamaha 90, two Lucas running lights; Yamaha 90, dipped Stanley headlight; at 23 m, 46 m	D	1,894	Interview of pedestrians (motorcycle positioned in cross street)	Yamaha 90 with one or two Lucas headlights or dipped Stanley headlight increased probability of motorcycle being seen at both distances
Williams and Hoffmann (1979a)					
Experiment 1	Low-beam headlamp; High-beam headlamp; Fluorescent jacket; White wind fairing; Standard motorcycle; Clean and cluttered environments	D	10	Slides: time to identify device	High-beam headlamp is superior to other devices both in clean cluttered environments
Experiment 2	Low-beam headlamp; High-beam headlamp Fluorescent jacket; White wind fairing; Standard motorcycle; Clean and cluttered environments	D	10	Tachistoscopically presented slides: confidence that certain device is present/not present	

TABLE 2
(CONTINUED)

Study	Conspicuity Devices	Day/ Night	Number of Subjects	Method	Conclusions
Olson, Hallstead-Nussloch, and Sivak (1979b, 1980, 1981)	Orange fluorescent fairing; Green fluorescent fairing; Headlamp on; Modulated headlight; Reduced-brightness headlight; Orange fluorescent clothing; Green fluorescent clothing; Orange vest; Orange helmet; Car following motorcycle; Modulating headlight plus orange fluorescent clothing	D	15,615	Gap acceptance	Conspicuity most effectively improved by fluorescent garments, modulating lights, or pairs of running lamps
	Retroflective fairing; Additional amber running lamps; Retroflective clothing; Motorcycle control; Car control	N	3,165	Gap acceptance	Conspicuity aided by retroflective garments or additional running lights
Mortimer and Schuldt (1980)	Low-beam headlamp; Low-beam headlamp plus additional yellow lamps; Car control (low beam)	D	900+	Gap acceptance	Additional running lights lead to larger gaps than headlamp only (not as large as automobile, however)
Watts (1980)	Fluorescent orange spacer; Fluorescent yellow panel; Fluorescent orange helmet; Fluorescent orange waistcoat; Fluorescent yellow waistcoat; Fluorescent orange jacket; Nonfluorescent yellow jacket; Nonfluorescent dark blue jacket	D	16	Peripheral detection of approaching motorcycle	Fluorescent and nonfluorescent yellow jacket most readily detectable against dark background; dark blue jacket more detectable against very light background

TABLE 2
(CONTINUED)

Study	Conspicuity Devices	Day/ Night	Number of Subjects	Method	Conclusions
Fulton, Kirkby, and Stroud (1980); Stroud, Kirkby, and Fulton (1980)					
Laboratory Experiment	Motorcycle control; Fluorescent orange legshields; Fluorescent orange headlamp cover; Fluorescent orange sleeves; Fluorescent orange waistcoat; Fluorescent orange jacket; Fluorescent orange helmet	D	100	Slides: time to detect motorcycle	Fluorescent waistcoat, jacket, or helmet lead to shorter detection times than control motorcycle
Field Experiment, Sets 1-3	Motorcycle control;	D	1,615	Interview of pedestrians (motorcycle positioned in cross street)	Large dipped headlights, single running lights, pair of running lights, fluorescent jacket, or waistcoat produce higher detection rate than control motorcycle
	Fluorescent helmet;		619		
	Fluorescent clothing;		1,478		
	Small dipped headlight;		1,264		
	Large dipped headlight;		1,108		
	Single running light;		370		
	Pair of running lights		833		
Field Experiment, Set 4	Motorcycle control;	D	657	Interview of pedestrians (motorcycle positioned in cross street)	
	Small full headlight;		1,369		
	Large dipped headlight;		683		
	Large full headlight		819		
	Motorcycle control (white headlight); Additional pair of amber running lights); Yellow headlight; (6 volt, 12 volt)	N	a	(1) Peripheral detection of approaching motorcycle; (2) Pedestrian interviews; (3) Slides: time to detect motorcycle; (4) Speed judgment	Modified lighting systems do not significantly improve detection or speed judgment

TABLE 2
(CONTINUED)

Study	Conspicuity Devices	Day/ Night	Number of Subjects	Method	Conclusions
Fulton, Kirkby, and Stroud (1980); Stroud, Kirkby, and Fulton (1980) Field Experiment, Set 4 (con.)	Motorcycle control; Fluorescent clothing; Dipped headlight	D	1,854	Gap acceptance	Conspicuity devices do not affect gap acceptance behavior of motorists
Freedman (1982)					
Laboratory Experiment	Horizontally separated tail/brake light over turn signals; Horizontally separated tail/brake light over turn signals with third lamp over center; Enlarged tail/brake lamp and retroreflective license plate border; Side marker lights; Retroreflective rims and strips on fork tubes, rear shocks, and chain guards	D,N	64	Presentation of photographs: paired comparisons	Triangular configuration most preferred rear treatment under all conditions; at night, reflectorization most preferred side treatment
Field Experiment	Rear: Stock tail/brake lamp; Triangular configuration; Horizontally separated config.; Brake lamp modulator, flash rate proportional to deceleration rate; Side: Stock tail/brake lamp; Reflectorization; Triangular configuration; Side marker lights; Horizontally separated config.	D,N	[a]	Sections of rural and urban streets instrumented with Vehicle Trajectory Measurement System; motorcycle entered onto road and completed maneuver (brakeing, turn) to test rear conspicuity; motorcycle remained stationary perpendicular to traffic to test side conspicuity	Separated or triangular tail lamp most effective in rear view conditions; reflectorization most effective in side view conditions

TABLE 2
(CONTINUED)

Study	Conspicuity Devices	Day/ Night	Number of Subjects	Method	Conclusions
Donne and Fulton (1985)					
Experiment 1	Motorcycle control;	D	876	Interview of pedestrians (motorcycle positioned in cross street)	Large headlamps or pairs of running lamps improve conspicuity
	Pair of headlamps (15 watt);		690		
	Pair of headlamps (10 watt);		935		
	Headlamp (15 watt halogen);		935		
	Pair of headlamps (15 watt, tungsten);		1,023		
	Small headlamp (40 watt);		915		
	Small flashing headlamp (40 watt);		885		
	Large flashing headlamp (40 watt);		927		
	Headlamp (55 watt, quartz-halogen);		840		
	Small "parking" light (15 watt);		855		
	Large "parking" light (15 watt);		799		
Experiment 2	Motorcycle control;	D	830	Interview of pedestrians (motorcycle positioned in cross street)	
	Pair of headlamps (15 watt, tungsten festoon);		841		
	Pair of headlamps (6 watt, tungsten festoon);		721		
	Headlamp (10 watt, tungsten festoon);		821		
	Large dipped headlamp (40 watt, tungsten);		799		
	Large dipped headlamp (55 watt, quartz-halogen);		848		
	Headlamp (15 watt, glass-halogen)		874		
Experiment 3	Motorcycle control;	D	197	Glimpses through shutter: report of nearest approaching vehicle	
	Large dipped headlamp (40 watt, tungsten);				
	Headlamp (15 watt, glass-halogen)				
	Pair of headlamps (15 watt, tungsten);				
	Fluorescent orange jacket				

TABLE 2
(CONTINUED)

Study	Conspicuity Devices	Day/ Night	Number of Subjects	Method	Conclusions
Donne, Fulton, and Stroud (1985)					
Experiment 1	Fluorescent legshields; Fluorescent jacket; Fluorescent headlamp cover; Fluorescent helmet; Fluorescent waistcoat; Fluorescent sleeves	D	100	Slides: time to detect motorcycle	Pairs of running lamps, large dipped headlamps, or fluorescent clothing increase conspicuity
Experiment 2	Headlamps of various sizes and powers; Various additional running lamps	D	18,596	Interview of pedestrians	
Experiment 3	Motorcycle control; 40 watt, 180 mm headlamp; 1 x 15 watt running headlamp (glass halogen); 2 x 15 watt running headlamp (tungsten); Fluorescent jacket	D	197	Glimpses through shutter: report of nearest approaching vehicle	
Dahlstedt (1986)	Different combinations of various steady lights, modulated lights, motorcycle colors and sizes, and colors of rider	D	53	Rating of motorcycle visibility relative to automobile	Conspicuity increased by higher headlight intensity, fairing, or fluorescent colors
Donne and Fulton (1987)	Headlights of various powers and sizes, steady and modulated; Yellow filters; Various additional lamps: white, yellow filters, steady, flashing; Strip lights on fork legs; White legshields illuminated by running lamps; Car control	D	[a]	Peripheral detection; glimpses through shutter: identification of leading vehicle; speed judgment	Lighting that helps to define the form of the motorcycle (illuminated legshields, striplights) aids identification in traffic

[a] Number of subjects not reported.

pared to the left-turn configuration which demands frontal conspicuity.

Motorcyclist characteristics: daytime. Manipulations of motorcycle operator characteristics have mainly focused on high-visibility, fluorescent garments (e.g., jacket, waistcoat, helmet) that have the ability to convert invisible radiation to visible radiation. In fact, several studies have demonstrated enhanced conspicuity for fluorescent garments compared to nonretroflective garments (e.g., Dahlstedt, 1986; Donne & Fulton, 1985; Fulton et al., 1980; Olson et al., 1979a, 1979b, 1981; Stroud & Kirkby, 1976; Stroud et al., 1980; Williams & Hoffmann, 1977). In contrast, Woltman and Austin (1974) found no difference between perception of fluorescent and conventional pigments under optimal viewing conditions. However, at dusk, the fluorescent garments were superior. The generally beneficial effects of wearing fluorescent clothing must therefore be qualified with respect to background viewing characteristics. As shown by Watts (1980), a dark blue jacket against a very light background was superior to a fluorescent yellow jacket. This again emphasizes the *relative* nature of conspicuity manipulations.

Motorcyclist characteristics: nighttime. In contrast to daytime findings, there is only limited support for the effectiveness of retroflective garments during nighttime. Olson et al. (1979a, 1979b, 1980, 1981) found some advantage for retroflective clothing for one automobile maneuver only (right turn into the lane occupied by the motorcycle). Stroud et al. (1980) also reported only negligible benefits for retroflective garments at night.

Evaluation methods for conspicuity-enhancing treatments. A number of different methods have been used to evaluate the effectiveness of conspicuity-enhancing measures of motorcycles. In several studies, pedestrians or motorists were asked whether they had seen a stationary motorcycle positioned in a side street that they had just crossed (e.g., Fulton et al., 1980; Janoff, 1973; Janoff & Cassel, 1971b; Kirkby & Fulton, 1978a, 1978b, 1978c; Ramsey & Brinkley, 1977; Stroud & Kirkby, 1976). The advantage of this procedure is that the subjects' visual search behavior is not influenced by their knowledge of being in a test situation. However, its validity is questionable in that the recall rate might be influenced, for example, by novelty factors of the stimulus or by memory capabilities; that is, factors that affect storage and/or retrieval processes may not be relevant in terms of accident causation.

In other studies, slides of traffic scenes were presented (tachistoscopically) to subjects. Several measures of conspicuity have been employed using this procedure. Stroud and Kirkby (1976), Williams and Hoffmann (1977, Experiment 1), and Fulton et al. (1980) measured the time from presentation of the slide to the detection of a motorcycle in the scene. Other measures used are the time required to identify certain conspicuity-improving devices, e.g., fluorescent jacket, headlight, fairing (Williams & Hoffmann, 1977, Experiment 2; 1979a, Experiment 1), or the subject's confidence that a certain device had or had not been shown (Williams & Hoffmann, 1977, Experiments 3 and 4; 1979a, Experiment 2). Freedman (1982) employed the method of paired comparisons, that is, the subject was forced to choose the more conspicuous of any two treatments that were displayed simultaneously.

The validity of these methods, especially of the last three, seems rather dubious, however. It appears questionable to what extent relative judgment, as in the latter case, or the discrimination of different conspicuity measures, as in the experiments by Williams and Hoffmann (1979a), can predict driver detection of motorcycles in real traffic situations. A drawback with the first method is that—contrary to normal driving situations—subjects concentrate on detecting a motorcycle, and may even develop certain detection strategies, such as searching for fluorescent material (Thomson, 1982). Therefore, unless this strategy is widely employed in real driving situations, shorter detection times for fluorescent clothing, for example, might prove meaningless in real traffic. Other problems with the use of slides in general include the nonmovement of the objects, limited luminance contrast, and color rendition, which leave their applicability to the real world somewhat questionable. Dahlstedt (1986) used an "estimation technique," where observers were asked to give a numerical rating for the visibility of different motorcycles relative to a car, the score of which was set at 100. Problems associated with this method are interindividual differences in the "calculation" of the visibility scores and, again, the question of validity with regard to the detection of motorcycles in traffic.

Watts (1980) evaluated subjects who were seated in a (stationary) car, and—while engaged in a secondary task that ensured that their eyes were on a display in front of them—had to give a signal as soon as they detected a motorcyclist (or bicyclist) approaching from a 30° angle. A peripheral detection test was also used by Donne and Fulton (1987). Here, subjects whose central visual field was occupied by another task, had to indicate when they became aware of a vehicle approaching from a 60° angle. The use of moving test objects and subjects' peripheral vision is probably a more realistic representation of many pre-accident situations. Again, however, subjects were aware that the purpose of the study was the detection of an approaching vehicle; also, no active visual search was involved.

An apparently more valid method to evaluate the effects of different conspicuity measures was used by Donne and colleagues (Donne & Fulton, 1985, 1987; Donne et al., 1985). In their experiment the subject was seated in the driving seat of a car parked facing oncoming traffic. A screen that incorporated a shutter obscured the view through the windscreen. While the subject was engaged in a secondary task (differentiating and counting private and commercial vehicles in the traffic approaching from the rear, as seen in the rearview mirror), the shutter was opened sporadically to allow the subject a glimpse of the road scene ahead. Subjects were asked to report anything they had seen of the leading vehicle in oncoming traffic. Among the advantages of this method are a more natural testing environment and the fact that subjects were not aware that the experiment was concerned with the detection of motorcycles. Further, their responses did not depend on (long-term) memory capabilities. A concern here, however, is that the shutter-opening times were adjusted for each subject individually, with glimpse times ranging from 50 to 200 msec for the majority of subjects. Also, motorcycles were overrepresented, with their exposure being about 10%, as compared to less than 1% in normal traffic. Another consideration is the static nature of the test vehicle. Essentially, subjects were engaged in a task not requiring the active responses associated with normal driving.

Olson and his colleagues (1979a, 1979b, 1980, 1981) employed a gap-acceptance technique to assess the effects of conspicuity-increasing treatments. Here, a gap was created in the traffic stream between a lead vehicle and a test vehicle (a motorcycle). The size of the gap that was accepted by subjects as adequate to execute a maneuver (e.g., a turn) in front of the motorcycle was measured. The validity of gap-acceptance techniques seem questionable in that they do not necessarily measure the detectability of motorcycles. Fluorescent clothing, for example, may be considered unusual and may therefore induce drivers to allow larger gaps, that is, it may affect the decision rather than the detection process.

Overall, even though some measures—especially daytime use of headlights—have been demonstrated to enhance the conspicuity of motorcycles, it remains questionable whether they actually increase automobile drivers' detection of motorcycles in real traffic settings to reduce collisions. (For a criticism of studies on conspicuity-enhancing measures, see also Thomson, 1982). In fact, the results of studies investigating the effectiveness of headlight-on laws, or campaigns to promote voluntary headlight use, in terms of a change in motorcycle accident rates, are inconclusive. Several studies compared accident data before and after the enactment of headlight-on laws (e.g., Janoff & Cassel, 1971a; Janoff, Cassel, Fertner, & Smierciak, 1970; Muller, 1984; Robertson, 1976; Waller & Griffin, 1977) and campaigns (Huebner, 1980; Lalani & Holden, 1978), whereas others compared accident data between states with and without headlight-on laws (Olson et al., 1981; Zador, 1985). If any reductions in motorcycle accidents were found in association with increased headlight use, they were minor (for a review, see Henderson, Ziedman, Burger, & Cavey, 1983; Prower, 1985; Winn, 1983). Also, methodological problems of before-and-after studies (e.g., fluctuation in nighttime driving or in the proportion of young drivers), as well as those of between-state studies (e.g., differences in age distribution, or nighttime riding), have to be considered when evaluating the reliability of these studies (see Prower, 1985, for an extensive analysis and criticism of these studies).

A stimulus might impinge upon an individual's senses, but might not be recognized, or identified, as relevant or useful to the situation. Information-processing failures related to the stimulus-identification stage might include the misidentification of a motorcycle, or the incorrect judgment of its speed. It has been shown, for example, that the estimated speed of a motorcycle with headlights *off* is *higher* compared to that of a motorcycle with headlights on (Shew, DaPolito, & Winn, 1977, cited in Winn, 1983). Thus, this effect seems to counteract the conspicuity-enhancing effects of running headlights. Furthermore, Stroud et al. (1980, Experiment 4) found that the speed of both a car and a motorcycle (with different lighting options) were underestimated by subjects. However, the estimation of the car's speed was significantly more accurate than that of the motorcycle with any of the options.

Other variables that have to be considered in this context are the perception of *motion in depth*, or relative closure, the effects of expanding optic arrays (Gibson, 1979), and a time-to-contact variable identified as a powerful information source for both perception and action (Lee, 1980). One conclusion that can be drawn from the research in this area is that, due to its size, a motorcycle has to travel farther than an automobile at the same speed before a comparable change in image size on the viewer's retina is achieved (e.g., Olson et al., 1979a).

Decision Stage

The driver's decision on the appropriate course of action is partially based on the information used in the detection and identification stages. As Nagayama, Morita, Watanabe, and Murakami (1979) have shown, however, even though speed estimation is similarly accurate for trucks, automobiles, and motorcycles, the gap sizes accepted for motorcycles are significantly smaller than those accepted for other vehicles. Thus, automobile drivers seem to apply different standards in their interaction with motorcycles compared to other vehicles capable of the same speed. In terms of automobile drivers' general gap-acceptance decisions when making turns, Shoptaugh (1988) found that drivers adopted a safer criterion than the normative model for left-turn gaps – independent of the speed of the oncoming vehicles; for right-turn stimuli, however, subjects perceived more gaps as safe (even when it was "unsafe" to turn), particularly at higher speeds. This finding seems to imply that the reason for the left-turn situation being the predominant configuration in automobile-motorcycle collisions is not primarily due to failures in automobile drivers' decision-making but to failures in other information-processing stages.

FACTORS INFLUENCING DIFFERENT INFORMATION-PROCESSING STAGES

Motor vehicle drivers do not always perform under optimal conditions for information processing. Factors that can be related to failures in more than one stage of information processing can be divided into static (trait) and dynamic (state) characteristics. Transient factors potentially responsible for different information processing failures that may lead to accidents include, among others, *alcohol*, *fatigue/lack of sleep*, *inattention*, and *information overload.* More permanent factors related to the failure to detect motorcycles may include *cognitive/search conspicuity*, *motorcycle experience* and *field dependence.*

Under the influence of alcohol, visual behavior changes in different ways. The visual field is reduced and the area of visual search is limited (e.g., Cohen, 1984). Also, the average duration of eye fixations is shorter, accompanied by a shortened distance of fixation. The effect of fatigue and lack of sleep are similar to those of alcohol. In addition to increased fixation durations, the average point of fixation is closer, and the effectiveness of peripheral vision is reduced (Cohen, 1987). Overall, driving under the influence of alcohol or fatigue is characterized by limited processing of visual information, conceivably increasing the likelihood that low-conspicuity objects, such as motorcycles, might not be detected.

Important functional limits that reduce the detection of motorcycles seem to be *attentional* failures (Hancock & Hurt, 1985). A correlation between overall accident involvement and performance on a selective-attention test has been demonstrated by Kahnemen, Ben-Ishai, and Lotan (1983). They suggest that subjects' capability to reorient their attention rapidly to relevant stimuli is important for driving performance, especially under conditions of high workload. A critical factor in sustained attention, or vigilance, is the event rate. The infrequency with which motorcycles are encountered in traffic might therefore also contribute to them not being perceived ("expectancy phenomenon," see Australian Motorcycle Council, 1984; Fulton et al., 1980; Nagayama et al., 1975). That is, road users may be conditioned to respond to large stimuli (automobiles), which they encounter more often; thus, they may find it more difficult to notice motorcycles which average about 1 per 175 vehicles in traffic. A second and important consideration is the *cost* of detection failures. While the cost to a car driver for failure to detect a motorcycle is relatively low, in terms of the chance of injury to himself or herself, the cost associated with missing a larger vehicle is substantially higher (i.e., potentially fatal). Therefore, from a pragmatic perspective it is reasonable to suggest that the detection of motorcycles by drivers is of lower priority than for larger vehicle road users. This rank ordering of importance may influence driver trait detection efficiency for motorcycles in traffic.

In addition, an increase in sensory workload, e.g., driving in urban traffic, requires greater effort to extract relevant information. As a result, the average eye-fixation time is prolonged, and therefore the total number of fixations per time interval is reduced. As Cohen (1980) points out, this increases the probability of overlooking essential targets. At the same time, the increased occupation of foveal vision with relevant information decreases the effectiveness of peripheral vision, that is, the amount of information picked up by peripheral vision is reduced (Ikeda & Takeuchi, 1975). This decrease in the functional visual field, caused by *information overload*, has been termed *tunnel vision* by Mackworth (1965). Even though the physiological effectiveness of light receptors in the retina does not change, the useful visual field varies due to limitations in information processing. In an information-overload situation, only selected, i.e., fixated, targets will be processed further. Thus, in competition for the limited resources, foveal vision has priority at the cost of peripheral vision (Cohen, 1986). In a field study, Miura (1987) found that automobile drivers' response eccentricity was reduced with increases in situational demands, indicating a narrowing in the functional field of view. Also, reaction time to peripherally presented stimuli was longer as the complexity of the traffic environment increased. Furthermore, the criterion for the initiation of a saccade might be increased under complex traffic conditions because the frequency limit of fixations is reached. As the number of distractors in the visual scene increases, the eye tends to fixate on the target. This can lead to the rejection of targets that would not be rejected in light traffic (i.e., motorcycles).

Studies examining the effectiveness of measures to enhance the conspicuity of motorcycles mainly focused on conspicuity as a factor inherent to the object. Yet, an object may have physical characteristics that render it conspicuous, but may still be overlooked because it has no relevance to the observer. Engel (1976), therefore, distinguishes between sensory and cognitive conspicuity.

Whereas *sensory conspicuity* refers to conspicuity in the sense mentioned above, that is, the visual prominence of an object due to its physical characteristics, *cognitive conspicuity* depends on the interests and experiences of the observer, i.e., the meaning the stimulus has to him or her. In a similar vein, Hughes and Cole (1984) pointed out that conspicuity cannot be regarded only as an object characteristic because it involves the attraction of attention. Attention level, however, is not stable, but varies due to multiple factors. Thus, whether or not an object attracts attention depends strongly on the observer's state. Whereas one object may be sufficiently conspicuous to attract attention merely by its physical properties, another object without these properties might not be seen even though it is clearly delineated and visible.

However, when attention is directed to the possible occurrence of this object, the observer will readily locate it. Hughes and Cole (1984), therefore, distinguish between attention conspicuity and search conspicuity. *Attention conspicuity* refers to the potential of an object to attract attention when the observer's attention is not specifically directed to its possible occurrence. It might be measured by the probability of an object being noticed without the observer expecting its occurrence. *Search conspicuity*, on the other hand, is defined as the characteristics of an object that enable it to be quickly and reliably located by search, that is, when the observer's attention is directed to its occurrence. Search conspicuity strongly depends on the instructions given to the observer and thus on the observational strategy adopted by the subject. As Hughes and Cole (1984) have shown, the observer's state of attention has a profound influence on the likelihood of a target object being noticed. In particular, they found that the gains of search conspicuity are greater in visual clutter, and that they are also greater for objects with low attention conspicuity than for objects with high attention conspicuity.

These findings might have implications for failures to detect motorcycles in traffic. If the detectability of a target depends on the psychological state of the observer, that is, interests, experience, and attention, it is conceivable that the average automobile driver's lack of experience with motorcycles interacts with the motorcycles' low attention (or sensory) conspicuity and results in synergy in detection failure. In fact, postaccident interviews by Hurt et al. (1981) indicate that automobile drivers involved in collisions with motorcycles were generally unfamiliar with motorcycles. Also, Weber and Otte (1980) report that in West Germany 12.4% of the automobile drivers involved in a collision with a motorcycle had a driver's license for a motorcycle, whereas 42% of driver's license holders in West Germany possess driver's licenses for both passenger cars/trucks *and* motorcycles. This finding suggests that experience with motorcycles might play a role in the detection of motorcycles in traffic. Furthermore, Mortimer and Jorgeson (1975) found that motorcycle riders driving a car attended more to oncoming traffic than did other automobile drivers. Thus, it seems that "familiarity with motorcycles" might be an important factor in the context of automobile-motorcycle collisions.

Individual differences in *field dependence* (Witkin, Dyk, Faterson, Goodenough, & Karp, 1962; Witkin, Lewis, Hertzman, Machover, Meissner, & Wapner, 1954) might also affect the perception of motorcycles. Field dependence refers to a person's ability to extract relevant information from a confusing context. Field-independent persons tend to experience their surroundings analytically, that is, objects are experienced as discrete from their background. Field-dependent persons, on the other hand, have a tendency to experience their surroundings in a relatively global fashion and are more influenced by the prevailing field or context (Witkin et al., 1962). They must make greater efforts to disembed, i.e., to detect, a relevant target. As previous research has shown, field dependence is related to different aspects of driving performance, such as skid control of a vehicle, the use of information from vehicles ahead of a lead vehicle (Olson, 1974), reaction time in emergency situations (Barrett & Thornton, 1968; Barrett, Thornton, & Cabe, 1969), the ability to detect traffic signs (Loo, 1978), as well as the number of traffic accidents and violations (Harano, 1970; Mihal & Barrett, 1976). Furthermore, the results of Shinar, McDowell, Rackoff, and Rockwell (1978) indicate that field-dependent subjects require more time to process visual information, and that they are less effective in their visual search behavior when driving. Also, Cohen (1980) found that field-dependent drivers had a smaller variability in eye-fixation times than field-independent drivers, indicating that the former group was only slightly influenced by the target being fixated. These findings suggest that field-dependent persons possess a reduced capability to adapt their visual-search behavior to the environmental conditions. It is conceivable, therefore, that field dependence is also an important factor in the detection of motorcycles in traffic. However, apparently no studies have yet examined the role this factor plays in automobile-motorcycle collisions.

SUMMARY AND CONCLUSIONS

Descriptive analyses of motorcycle accidents have shown that a major cause for automobile-motorcycle collisions is the lack of conspicuity of motorcycles. In attempts to reduce the frequency of such collisions, much effort has been directed toward manipulations of the motorcycle and its rider's clothing in order to increase conspicuity. However, even though several studies have shown that some measures, e.g., running headlights at daytime, can enhance conspicuity, the methods used in these studies do not allow us to conclude that these measures actually increase automobile drivers' detection of motorcycles in real traffic settings. Also, the results of studies investigating the effectiveness of headlight-on laws are rather inconclusive.

Relatively little concern has been directed to the behavior of the offending vehicle driver and to questions as to why such detection failures might occur. Some evidence suggests that even though automobile drivers "look," they do not "see" motorcycles because—due to the infrequency with which motorcycles occur in traffic—they do not expect to see them. Furthermore, motorcycles by nature have a low sensory or attention conspicuity compared to other road vehicles, e.g., automobiles or trucks. This reduces the likelihood that they are being detected by peripheral vision and will trigger a saccade so that they can be identified through foveal vision—especially in situations where heavy traffic might cause an information overload. In addition, the lack of experience of most automobile drivers with motorcycles reduces cognitive conspicuity, which is based on the interest and experience of an observer and the meaning an object has to him or her. Another factor that might play a role in failures to detect motorcycles in traffic, but that has not yet received much consideration in research on motorcycle accidents is field dependence. Evidence showing the relatedness of field dependence to the ability to detect traffic signs, the effectiveness of visual search behavior when driving, and the number of traffic accidents in general suggests that this factor might be related to automobile-motorcycle collisions as well.

A critical component in future research methods is the evaluation of the dynamics of the automobile driver's visual display. Approaches that present static stimuli to evaluate detection capability should be used as exploratory strategies through which to identify factors that should be more thoroughly investigated in the dynamic realm. Although off-road evaluations and computer-based simulations give the experimenter the chance to control the driving environment, their use without comparable on-road testing generates impoverished information from which to postulate effective countermeasures. In our laboratory, each of these approaches is used simultaneously so that cross-paradigm evaluation renders the most complete picture possible (Hancock, Chu, Damos, & Hansen, 1989; Hancock, Rahimi, & Wulf, 1989; Rahimi & Hancock, 1989). Although a number of factors influencing motorcycle conspicuity have been identified, their interaction under differing driving conditions, and their relationship with individual differences in driving behavior, remains to be elucidated. Further research is needed to determine the relative contribution of these factors to the failures to detect motorcycles and to develop potential countermeasures to enhance automobile drivers' awareness of motorcycles, as well as their consciousness of this problem.

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