

COST Action 357

accident prevention options with motorcycle helmets

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Accident Prevention Options with Motorcycle Helmets

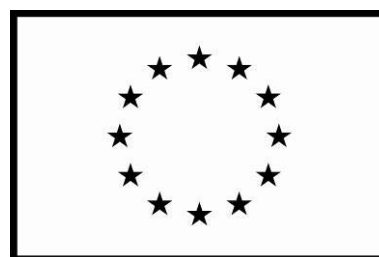
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Preface – COST

The meetings of the COST Action 357 have been funded by COST. COST- the acronym for European COoperation in the field of Scientific and Technical Research- is the oldest and widest European intergovernmental network for cooperation in research. Established by the Ministerial Conference in November 1971, COST is presently used by the scientific communities of 35 European countries to cooperate in common research projects supported by national funds.

The funds provided by COST - less than 1% of the total value of the projects - support the COST cooperation networks (COST Actions) through which, with EUR 30 million per year, more than 30.000 European scientists are involved in research having a total value which exceeds EUR 2 billion per year. This is the financial worth of the European added value which COST achieves.

A “bottom up approach” (the initiative of launching a COST Action comes from the European scientists themselves), “à la carte participation” (only countries interested in the Action participate), “equality of access” (participation is open also to the scientific communities of countries not belonging to the European Union) and “flexible structure” (easy implementation and light management of the research initiatives) are the main characteristics of COST.

As precursor of advanced multidisciplinary research COST has a very important role for the realisation of the European Research Area (ERA) anticipating and complementing the activities of the Framework Programmes, constituting a “bridge” towards the scientific communities of emerging countries, increasing the mobility of researchers across Europe and fostering the establishment of “Networks of Excellence” in many key scientific domains such as: Biomedicine and Molecular Biosciences; Food and Agriculture; Forests, their Products and Services; Materials, Physical and Nanosciences; Chemistry and Molecular Sciences and Technologies; Earth System Science and Environmental Management; Information and Communication Technologies; Transport and Urban Development; Individuals, Societies, Cultures and Health. It covers basic and more applied research and also addresses issues of pre-normative nature or of societal importance.

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Summary

Powered two-wheelers (PTW), such as mopeds and motorcycles, are over-represented in traffic fatalities, accounting for 18% of all European traffic fatalities. Even more disturbing is that PTW are the only mode of transport for which the annual European fatalities are consistently increasing. One of the most effective protection products for PTW riders is the motorcycle helmet. Although understanding and optimizing motorcycle helmets' impact protection has been covered by numerous studies, very little is known about how the motorcycle helmet affects its wearer's riding behaviour, or the behaviour of other traffic participants. Therefore, the objective of the COST Action 357 is to increase knowledge on how motorcycle helmets and their design could be improved in aspects other than impact protection to help facilitate the avoidance of accidents. The Action addresses this objective from two directions - motorcyclists and other road users. The Action focuses on: i) Providing better understanding of the physical and physiological effects of wearing a motorcycle helmet; ii) Providing better understanding of the links between these physical and physiological effects and their impact on the cognitive abilities relevant to the PTW rider; iii) Provide better understanding of how the PTW-rider-helmet systems affect cognitive faculty of other road users perception of PTW riders; and iv) Providing knowledge of how motorcycle helmets should be improved to reduce their negative impact on physiological and cognitive parameters for the rider as well as other traffic participants.

Physical and physiological effect of the helmet on a PTW rider: A study established that the useful-visual-field reduces with age and with increasing PTW speed. At the same time a survey of helmets in use found no difference between the field-of-view provided by helmets involved in accident cases and controls not so involved. This suggests that the simple field-of-view parameter might not play a large role in PTW traffic safety. The same study found that the status of light transmission of helmet visors is not different between PTW riders involved in an accident, compared to controls. One study has assessed perception thresholds for transmission changes of visors. This information is useful in designing effective visors with different transmission states which are perceptually different from one another, and in assessing whether a used visor's transmission has changed from its "as new" condition by a perceptible amount. Other work found that motorcycle helmets are excellent thermal insulators causing relatively warm microclimates around the head, which are unfavourable for thermal comfort; while their ventilation systems are mostly ineffective in providing a perceivable effect on the rider's temperature perception. Carbon dioxide levels can reach at least 2% which rapidly drops with the presence of airflow around the helmet. Although only occurring at stand-still these elevated carbon dioxide levels are relevant since they have been shown to negatively affect cognitive performance. Finally, noise was evaluated on the shell of the helmet as well as in the ear, providing initial understanding of the underlying mechanisms responsible for noise experienced by PTW riders. This understanding will allow better noise reduction methods in helmet design.

Cognitive effects: A test battery was developed for the cognitive assessment of wearing a motorcycle helmet. It was established that, under well controlled laboratory conditions, wearing a motorcycle helmet causes a subtle cognitive impairment when compared to not wearing any headgear. Numerous studies have focused on the ability of other road users to spot approaching PTW riders. Brighter coloured helmets are associated with a reduced accident risk relative to less brightly coloured helmets. A pattern of many different colours as perceived by another road user (referred to as a high spatial frequency) is also considered to play an important role in "looked-but-failed-to-see" accidents, or in misinterpretations the speed of an approaching PTW. A survey was developed to evaluate

attitudes of automobile drivers towards PTW riders. It appeared that automobile drivers have little empathy for the safety needs of PTW riders. Additional results indicated that the empathy of automobile drivers toward PTW riders can be improved through demonstrating the vulnerability of PTWs in traffic, such as through video-clips. Such training could lead to a better appraisal of PTW riders by automobile drivers. Finally, besides the cognitive test battery and the attitudes survey, riding simulators have been developed allowing future studies to be conducted under more realistic, but still well-controlled, laboratory conditions.

During the lifetime of the COST Action 357, the members produced over 25 peer-reviewed publications, two books, a multitude of conference contributions, the organization of a new conference for vulnerable road users (VRU), and two Ph.D. theses, all in the framework of this Action. Many of these scientific contributions advanced the world-wide state-of-the-art, and several projects are still underway. In this timely Action long-lasting European interdisciplinary collaborations have been formed among psychologists, physiologists, and engineers. Young researchers have been greatly supported, producing a total of 13 peer-reviewed accepted publications of which a young researcher was the first author, with an additional 12 manuscript currently under review, and 24 oral presentations at relevant international conferences. Helmet manufacturers have kindly provided helmets for this Action, and the general transport industry has been informed about the results of this Action through a workshop and a symposium, and have been directly provided with published studies. The multidisciplinary approach focussing on both separate and linked physical and physiological effects and their impact on cognition as initiated by this Action should be continued, and new optimized motorcycle helmet concepts should be developed. In such future work helmet manufacturers should play a more active role. The multidisciplinary approach should ensure that one parameter will not be optimized at the cost of another; and especially that the mechanical impact protection characteristics should not be reduced from their current level. Finally, many aspects of the work carried out in this Action are relevant for other types of protective headgear, especially bicycle helmets, for which we hope that the structure of the present Action will serve as an example.

1. Introduction

1.1. Background

Motorcyclists and moped riders accounted for $18 \pm 2\%$ of all traffic accidents on European roads from 1996 to 2005 (ERSO, 2007). These statistics are even more dramatic if expressed in deaths per 100 million person travelling hours (Figure 1.1), which is by far the highest for motorcyclist and mopeds with 440. For comparison, car passengers on average show 25 fatalities for the same time unit, based on EU statistics collected in 2001 and 2002 (Koornstra et al., 2003; WHO, 2004). Moreover, motorcycles and mopeds, collectively referred to as powered two-wheelers (PTW), are the only mode of transport showing a consistent increase of fatalities (ERSO, 2007). Thus, PTWs are overrepresented in traffic fatalities and show a consistent increase over multiple years.

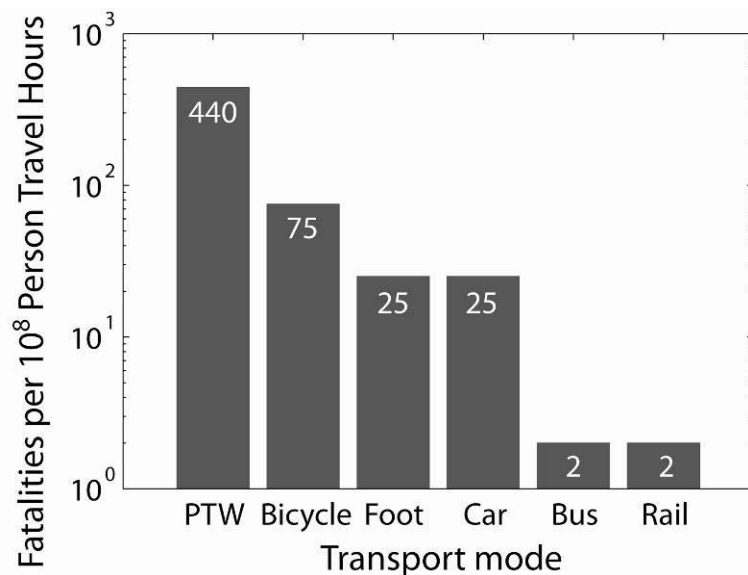
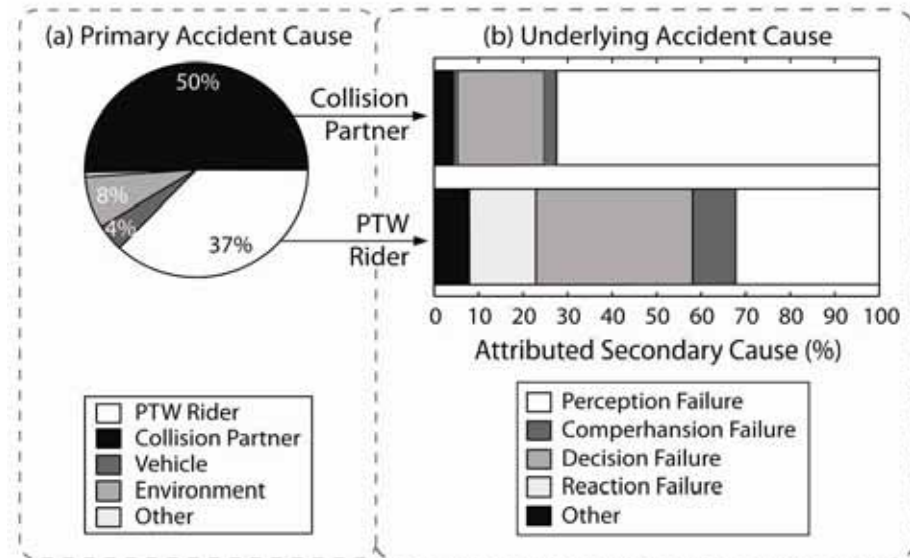


Figure 1.1: Fatalities per 100 million person travel hour, statistics obtained from 2001 and 2002 in Europe. PTW are powered two-wheelers including motorcycles and mopeds; data taken from Koornstra et al. (2003).

Between 1999 and 2000 a large European effort (MAIDS) was carried out, in which PTW accident sites were visited, usually allowing the experimenters access to all involved parties and witnesses (ACEM, 2004). In this study 921 cases were evaluated and, for each case, approximately 2000 variables were recorded. They found that 50% of all accidents were attributed to the collision partner, 37% to the PTW rider, and the remaining were explained by roadway and vehicle defects, and others, summarized in Figure 1.2a. Similar results have been found in a study carried out in Los Angeles (California) from 1975 through 1980 (Hurt et al., 1981). They attributed the accident cause in 51% of cases to the collision partner and in 41% to the PTW rider. The MAIDS study also evaluated the underlying accident cause (Figure 1.2b). From the collision partner they found perception to be the cause of 72% of the accidents in which the collision partner was the primary factor. The low conspicuity of PTW riders and their vehicles play a large role in this (ACEM, 2004; Wells et al., 2004). However, when the PTW rider was found to be at fault, 92% of the cases were explained by some sort of cognitive failure. Thus, perception failure of the collision partner is the major cause of PTW accident. In addition, for cases in which the PTW rider is the cause, cognitive failure is the source.

Figure 1.2: (a) Primary accident causes of powered two-wheeler (PTW) accidents. (b) For the collision partner (which was most often a passenger car) and the PTW rider, the underlying accident causes are indicated. Data for both figures are obtained from ACEM (2004).



The most efficient means of reducing PTW fatalities is by wearing a certified motorcycle helmet (Shinar, 2007). Reported effectiveness of helmet use on PTW accident survival range from 22% to 50% (Deutermann, 2004; Keng, 2005; Ouellet & Kasantikul, 2006; Houston & Richardson, 2008; Liu et al., 2008). In addition, the use of such helmets reduces injury severity and medical cost associated with such accidents (Johnson et al., 1995; Rowland et al., 1996; Max et al., 1998; Chinn et al., 2003; Liu et al., 2008). This motivated the numerous efforts on optimizing motorcycle helmets for reducing injury severity during an accident (Mills & Gilchrist, 1991; Richter et al., 2001; Chinn et al., 2003; Van Den Bosch, 2006). However, little attention has gone to the role of helmets on other factors affecting the likelihood of getting involved into a traffic accident. Analysis in the COST Action 327 suggests that helmet related factors, could be important in many PTW accidents (Chinn et al., 2003).

The research in the present COST Action 357 has examined the problem of PTW accident prevention from several perspectives. The main emphasises is on understanding motorcycle helmet factors with a potential importance for traffic safety. These factors excluded impact protection, and can be grouped into the three following categories: physical boundary conditions, physiological effects, and cognitive effects. In what follows an overview will be given of the research carried out before the COST Action 357, grouped in the defined categories.

1.1.1. Physical boundary conditions

1.1.1.1. Microclimate carbon dioxide concentration

Ambient carbon dioxide concentrations are of the order of 0.04%, whereas the carbon dioxide concentrations of exhaled air range between 4% and 5%. Since full-face motorcycle helmets encapsulate the entire head, it is not unlikely that the microclimate carbon dioxide increases over ambient conditions. Two studies have evaluated microclimate carbon dioxide concentrations of different motorcycle helmets while worn by subjects (Iho et al., 1980; Aldman et al., 1981). Iho et al. (1980) found carbon dioxide concentrations ranging between 1% and 2% for wind-still conditions, others found slightly higher values for similar conditions (Aldman et al., 1981). However, as soon as an airflow is provided, such as mostly the case during PTW riding, carbon dioxide concentrations drop

below 0.5%. Cognitive faculty has been evaluated as a function of carbon dioxide concentrations, with the lowest concentrations being 2.5%. At these concentrations two published pilot studies found reductions in performance on visual tasks (Sun et al., 1996; Yang et al., 1997). However, it is difficult to translate this to traffic safety, since the exposure time to the elevated carbon dioxide concentrations before the performance was assessed was relatively long (~1.5 h). In addition, it remains unclear how the employed cognitive tests relate to traffic situations.

1.1.1.2. Noise

Motorcycle helmets are found to exceed 90 dB at speeds higher than 60 km·h⁻¹ (McCombe et al., 1994); which at the time of publishing was the recommended 8 hour maximum. The same authors concluded that the attenuation is not similar over the audible spectrum. In fact, attenuation is negligible at frequencies smaller than 2000 Hz (McCombe et al., 1994). Others have assessed how these physical boundary conditions influence subject perception (Purswell & Dorris, 1977; McKnight & McKnight, 1995). McKnight and McKnight (1995) produced a tone of 700 Hz which was played at increasing sound pressure levels. Their subjects drove a motorcycle outdoors with three different helmet conditions. No differences were found among the helmet condition, one of which was no helmet. However, an earlier study did not find differences in perception thresholds among helmet conditions (of which one without a helmet) (Purswell & Dorris, 1977). Thus, these studies indicate the relatively high noise levels during PTW riding, and a possible importance of the attenuation of external signals. It remains unclear if the auditory conditions created while riding a PTW are related to traffic safety, and how this might be improved.

1.1.1.3. Vision

While wearing a motorcycle helmet the horizontal and vertical field-of-view are reduced if one does not allow the subject to move the head (Gordon & Prince, 1975). This study reported reduction of the field-of-view up to 6.5° (~3%) and 57.7° (~22%) for the horizontal and vertical plane, respectively. However, head movement could compensate for this reduction. One study evaluate head rotation during lane changes in traffic with three different helmet conditions, of which one without helmet (McKnight & McKnight, 1995). The results indicate that head rotations increases with decreasing field-of-view. Interestingly, the time needed to complete the lane change was indifferent among helmet conditions. This tends to indicate that if the reduction in field-of-view by motorcycle helmets is relevant to traffic safety, the visual restriction caused is compensated for my head movement. Finally, another relevant factor is the useful-visual-field, which is the region of the field-of-view in which visual input results in a response if required. This useful-visual-field is smaller than the field-of-view under riding conditions, and thus indicates that restrictions of the field-of-view might be less important during riding.

1.1.1.4. Thermal insulation

Brühwiler (2003) examined heat loss from a head while wearing a motorcycle helmet. He measured heat loss from the scalp and face using a non-sweating thermal manikin headform under standardized conditions. The two helmets examined in this study yielded heat losses of roughly 0.5 W and 10 W, for the scalp and face sections, respectively. The sum of about 10.5 W is slightly lower than results from the nude human head estimated at 14 W, under comparable (comfortable) conditions (Froese & Burton, 1957; Clark & Toy, 1975; Rasch et al., 1991). However, striking is the low contribution of the scalp section to the total heat loss, indicating that the thermal insulation of these

helmets mainly affects the scalp section. In contrast, relatively high levels of heat loss were obtained from the face, suggesting a larger air movement in this area.

1.1.2. Physiological effects

The effect of motorcycle helmets on human physiology has previously been reported in one study (D'Artibale et al., 2008). They measured heart rate and blood lactate levels of competitors of road-race motorcycling competitions. The results indicate relatively high heart rates of the order of 90% of the maximum. Lactate levels were also increased above baseline levels. These results indicate the metabolic rate is relatively high during competitions. However, it is unlikely that regular PTW riders experience similar physiological conditions during traffic participation. Several studies have monitored the effects of other types of headgear on multiple physiological parameters, for bicycle helmets (Gisolfi et al., 1988; John & Dawson, 1989; Sheffield-Moore et al., 1997; De Bruyne et al., 2008; De Bruyne et al., in press), equestrian helmets (Taylor et al., 2008), cricket helmets (Neave et al., 2004), football helmets (Coleman & Mortagy, 1973), and industrial protective headgear (Davis et al., 2001; Holland et al., 2002). None of these studies found a helmet-mediated effect on core temperature or heart rate, but did find an increased local skin temperature where covered by the headgear. The reported minimum temperatures underneath headgear range from 26 °C to 36 °C, with maximum temperatures ranging from 30.5 to 36.5 °C. The variation within these lower and upper limits seems mainly due to differences in ambient temperature and assumed airflow over the skin under the headgear, possibly in combination with sweating. Recently, a set of observations have been reported for motorcycle helmets indicating microclimate temperatures of the similar order (Schueler et al., 2007). It can be speculated that the body core temperature is left unaffected, as well as heart rate.

1.1.3. Cognitive effects

1.1.3.1. Cognitive effects of wearing a motorcycle helmet

Above it is described to which condition the wearer of a motorcycle helmet is exposed. These boundary conditions might directly affect the cognitive performance of the wearer, and/or they might decrease the willingness to wear such helmets due to discomfort. Below both factors will be reviewed.

Even though the head only makes up a small part of the total skin area, for a similar stimulated skin area it ranks among the body parts that exhibit the largest influence on whole body temperature perception (Hardy & Oppel, 1937; Stevens et al., 1974; Crawshaw et al., 1975; Zhang, 2003; Arens et al., 2006a; b) and whole body thermal comfort (Zhang, 2003; Pellerin et al., 2004; Cotter & Taylor, 2005; Arens et al., 2006a; b). Cotter and Taylor (2005) found that the sensitivity was a factor 1.5 larger than the next most sensitive body part (the back). The sensitivity of the face was 2.5 times larger compared to the average sensitivity among all other evaluated body parts, although not all body parts showed significantly different sensitivities compared to the face. In another extensive study, it was concluded that, in addition to a relatively high sensitivity of the head, the rate of skin temperature change has a large influence on temperature perception and thermal comfort (Zhang, 2003; Arens et al., 2006a; b). Motorcycle helmets are expected to cause increased skin temperature of the head, especially of the scalp. It is therefore not surprising that thermal discomfort is often given as a reason for not wearing a motorcycle helmet (Patel & Mohan, 1993; Skalkidou et al., 1999; Li et al., 2008), which is supported by field observations (Gkritza, 2009). The ventilation systems of motorcycle helmets suggest that they might also cause local temperature changes in the microclimate by opening or

closing vents. However, it remains unclear how efficient these ventilation systems are in relieving discomfort.

Several studies have warmed the head of resting subjects in a thermal neutral environment, with and without manipulating the thermal state of the rest of the body (Holt & Brainard, 1976; Hancock & Dirkin, 1982; Hancock, 1983). These studies used the same helmet instrumented with electrical heaters on its inner surface, achieving an increase in tympanic temperature of the order of 1 °C (Holt & Brainard, 1976). One study reported a shortening of reaction time by heating the head, reported on the $p < 0.1$ level (Holt & Brainard, 1976). Hancock and Dirkin (1982) found increased reaction times and a decrease in errors on a choice reaction test. Such an effect could simply indicate an attention shift from one task to the other; a follow-up study was therefore carried out. In that study, subjects completed significantly more mathematical problems in a given period while wearing the heated helmet (Hancock, 1983). These three studies also evaluated cognitive performance while wearing the helmet without the heating elements turned on. However, only one found an effect, in the form of an increased reaction time (Hancock & Dirkin, 1982). Thus, two studies found an effect of passive (non-heating) headgear on cognitive performance (Hancock & Dirkin, 1982; Neave et al., 2004); in contrast, two other studies did not find such an effect (Holt & Brainard, 1976; Hancock, 1983). Thus, the relation between headgear and cognitive performance as found in previous work is unclear. In addition, also other factors than warmth might influence the cognitive performance of a person wearing a motorcycle helmets, e.g., increased carbon dioxide concentrations as summarized under physical boundary conditions.

1.1.3.2. Conspicuity

Perception failures of car drivers is a major cause of PTW accidents (Hurt et al., 1981; ACEM, 2004), especially occurring at crossings where automobile drivers fail to yield the right of way to the PTW (Vis, 1995; Clarke et al., 2007). Following many such crashes the automobile drivers in fault report having failed to see the PTW in spite looking in its direction. The ease, with which an object can be detected, or conspicuity, is thought to play a major role in this type of accidents.

Conspicuity of motorcycles is influenced by a wide range of factors (for reviews, see Wulf et al., 1989; Crundall et al., 2008b). Some, such as colour and brightness, relate to the characteristics of the perceived object that together determine its saliency (which is the extent to which this object stands out relative to its background). One disadvantage of PTWs and their riders is that they travel at similar speeds as automobile, but have a much smaller frontal area. This is one example for PTW characteristics that make it more difficult for automobile drivers to spot them. Besides the size of the frontal area, the contrast with their background is yet another important factor that affects saliency and conspicuity.

Finally, some of the influences on conspicuity of PTW relate to the perceiver (rather than to the perceived object), hence to other road users. Typically referred to as top-down factors these influences also include a variety of factors, such as fatigue and expectations to see PTWs. This implies that looking for a PTW increases the chances of spotting it when present, compared to when one is not looking for a PTW (Hancock et al., 1990). As more conspicuous PTWs and riders are less likely to get involved in a traffic accident (Hurt et al., 1981; ACEM, 2004), much of the research about PTW safety focuses on how conspicuity of PTWs and their riders are most optimally improved.

1.2. Objectives

The objective of this COST Action was to increase knowledge on how motorcycle helmets could be improved to help facilitate the avoidance of accidents. The Action addressed this objective from two directions: motorcyclists and other road users. The following goals were pursued:

- Providing better understanding of the physical and physiological effects of wearing a motorcycle helmet;
- Providing better understanding of the links between these physical and physiological effects and their impact on the cognitive abilities relevant to the PTW rider;
- Provide better understanding of how the PTW-rider-helmet systems affect cognitive faculty of other road users perception of PTW riders
- Providing knowledge of how motorcycle helmets should be improved to reduce their negative impact on physiological and cognitive parameters of the rider as well as other traffic participants. In addition to the development of methods facilitating such studies, e.g., sensitive cognitive tests and motorcycle riding simulators.

Concerning conspicuity and saliency not only the motorcycle helmet is considered, but also the entire PTW including the rider. This is motivated by the importance of surface area for these factors. The COST Action 357 has been divided into four Working Groups (WG), all with a separate theme and multiple tasks, which are visualized in Figure 1.3. In what follows the most relevant work carried out within each WG is summarized. More extensive summaries for each individual study discussed in the WG summary can be found in the Appendix. This publication is supported by COST.

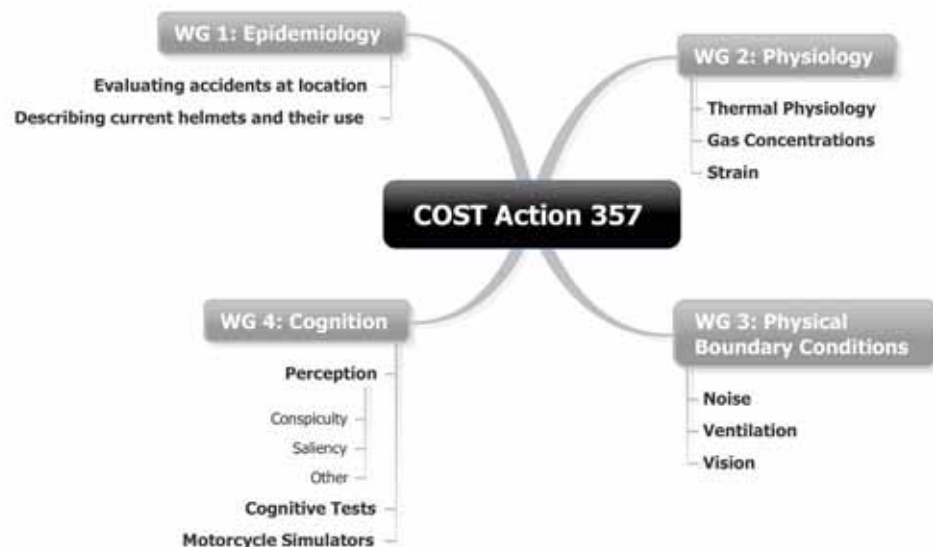


Figure 1.3: The different tasks of the COST 357 Action with responsible Working Groups.

2. Working Group 1: A European Perspective on In-Depth Data Sampling on Cognitive Aspects of Motorcycle Helmets

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The full Working Group 1 report is an electronic supplement to this report and can be downloaded from www.cost357.org.

The task of Working Group 1 has been to analyse accident events, and to identify helmet properties associated with traffic accidents. Several properties have been evaluated, e.g., thermal conditions, visibility of the rider to other traffic participants, acoustical impairments of the PTW rider, and visibility limitations experienced by the PTW rider caused by the visor. These factors were studied using field-surveys. Six European countries took part in this study (Germany, Greece, Italy, Ireland, Portugal and Turkey). Two practical approaches were followed to obtain information. Firstly, accidents-sites were visited just after the occurrence of a PTW accident by a specialized team, who registered a large range of parameters in the form of a survey. Secondly, PTW riders, not involved in an accident at the time of contact, were submitted to the same survey. The latter acted as a control group for the former. The survey registered more than 100 parameters, involving interviews and helmet inspections. In order to measure the horizontal field-of-view of PTW riders wearing a helmet, a goniometer was developed. Using this device, the participant fixes his/her eyes on a pin at the midpoint of the goniometer's semicircle while the experimenter moved a pin to identify the limits of the subject's vision. Furthermore, the light transmission and the light diffusion of the visors were measured by using validated lenses of different transmission and diffusion values and comparing them with the visors of the helmets. The control group included 390 PTW riders, whereas 208 accident cases (Table 2.1).

Table 2.1: Collected cases per country.

Country	Cases	
	Control	Accident
Germany	85	7
Greece	52	48
Ireland	43	11
Italy	101	91
Portugal	26	14
Turkey	83	37

The female rides accounted for 12% in the whole data-set. 40% of all PTW riders had been riding for 10 years or longer and some 20% of all had been riding for 20 years or longer. One-third rode over 10.000 km per year, while this share is significantly higher in Portugal and significantly lower in Germany. Among these frequent riders the share of motorcyclists with large engine sizes was exceptionally high with 56%. In addition it was found, that more than half of the investigated PTW riders had already been involved in a traffic accident before participating in the present study. Full-face helmets were predominantly used across Europe ranging from 20% in Italy to 80% in Ireland. Open-face helmets, were in general more often worn by riders of PTW with small engines (e.g. mopeds). However, the riders of PTW with an engine capacity larger than 400 ccm, prefer to use full-face helmets (e.g., integral helmets and motocross helmets) in over 85% of the cases. Helmet usage in Germany and Ireland was larger than 96%. Helmet usage is considerably lower ranging between 86% and 92% for Italy, Portugal, and Turkey. Greece strikingly forms an outlier with 59% helmet usage. Riders that tend not to use a helmet are typically young males, owners of PTW with a small engine size, with a riding experience of more than 3 years, and these riders often live in warm countries.

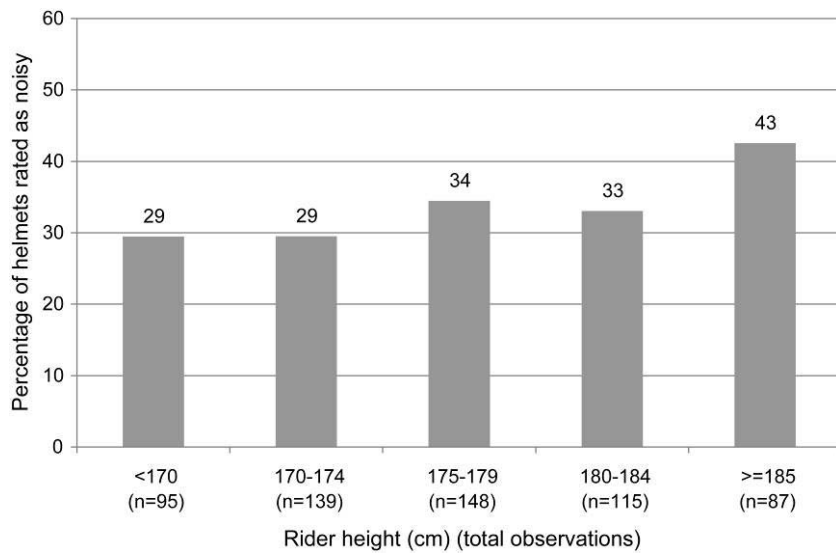
A large part of the data assessed by the questionnaire dealt with the rider's subjective feeling of discomfort when using the helmet. For instance, 18% of those PTW riders questioned indicated that the helmet limits their field-of-view, 27% reported that visors frequently opened of their own and more than one-third of the riders considered their helmet to be too noisy (Table 2.2). Additionally, over 14% regarded the chin-strap as being uncomfortable. Finally, helmet noise seemed to be one of the main factors of discomfort. When comparing the riders complaining about helmet noise within different types of helmets, it was observed that 48%, 40%, and 21% coincided with the use of a full-face helmet, helmets with a retractable chin-bar, and jet helmets, respectively. A possible explanation is that full-face and retractable chin-bar helmets are more often used on larger motorcycles which drive faster, and thus produce more noise. It is noteworthy that taller PTW riders complained more often about noise compared to shorter riders, perhaps since they are less protected against the airflow by a windshield (Figure 2.1).

Table 2.2: Selected subjective parameters as a function of helmet type, expressed as percentage of subjects of both control and accident cases agreeing with the given statements.

Type of helmet	Helmet sensation					
	Helmet not comfortable	Problems with hearing	Narrow field of vision	Helmet too noisy	Headaches after a long trip	Chin-strap not comfortable
Integral (n=264)	8,3%	16,2%	22,1%	39,5%	12,3%	13,0%
Jet (n=215)	7,0%	8,9%	7,6%	21,0%	9,9%	15,9%
Motocross (n=12)	0,0%	0,0%	16,7%	41,7%	8,3%	8,3%
With retractable chin-bar (n=86)	9,3%	12,8%	29,1%	47,7%	20,0%	16,3%
Total (n=577)	7,8%	12,6%	17,7%	33,9%	12,5%	14,5%

Reassuringly, it was confirmed that no subject had a field-of-view smaller than 105° as specified as a minimum horizontal opening angle for helmets (ECE 22). Nonetheless, the age of the rider seems to have an influence on the field-of-view. While riders which were younger than 60 years had an average field-of-view (from left to right) of over 150°, riders of 60 years or more had an average field-of-view of only 143°.

Figure 2.1: Percentage of cases complaining about helmet noise as a function of rider height in cm.



Of all helmets 71% are given light transmittance degrees of more than 83% (Figure 2.2). In most countries transmission values between 90% and 92% were reported, Portugal formed an outlier pulling the overall average to lower values. The low transmission values for Portugal probably reflect a larger number of tinted visors used. Light diffusion (D), such as caused by scratches on the visor, was measured in percent as the quotient of Light flux diffused by the abraded material and flux transmitted by the new material. It revealed relatively small light diffusion values of mostly $D \leq 2\%$ for all countries.

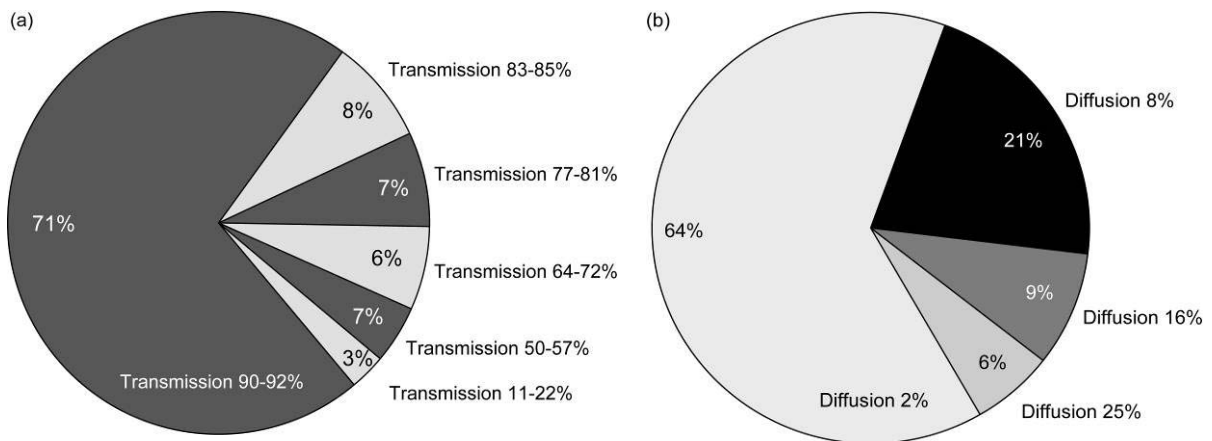


Figure 2.2: Light transmission (a) and diffusion (b) of motorcycle helmet visors.

An initial combination of the data collected in this study allowed the authors to select parameters which may have influence on the wearing sensation of the helmet, which may contribute to an accident occurrence or have influence on the accident outcome. This made it possible to describe the number of unfavourable helmets in use in the different countries. An unfavourable helmet was subjectively defined as a helmet that shows at least one of the following characteristics:

1. Has a damage of some kind, like strong scratches or dysfunctions.
2. Is older than 10 years.
3. Subjectively distorts the view of the rider or narrows his field of vision.
4. That is felt as too noisy and therefore distracts the rider from important acoustic signals.
5. That is not comfortable and gives the rider a head ache after some time.
6. That does not comply with the ECE 22.05 in terms of light transmission of the visor.
7. That has a visor with a reasonable light diffusion. (The diffusion value was chosen to $D > 16\%$ as there are no specified maximum diffusion values in the ECE 22.05).

Here most countries have a share of about 30% or more favourable helmets used on the roads, only Ireland and Portugal with less than 20% have a significantly smaller amount of favourable helmets within the collected cases (Figure 2.3).

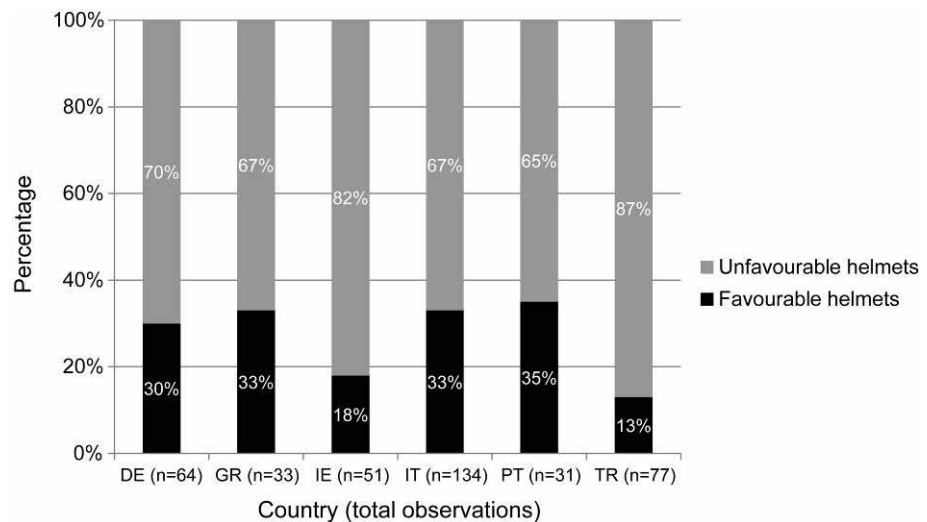


Figure 2.3: Share of favourable and unfavourable helmets per country.

In addition, the dataset allowed for evaluation of parameters which occur more frequent in the accident cases compared to the controls. Since time limited a full data analysis, here an interpretation of the data was given which is mostly not based on statistical analysis. PTW riders aged 15-24 years are under-represented in the accident population, while riders aged 25-44 years are over-represented in the accident population. The data also indicated that PTW riders with a history of an accident are more likely to be involved in a new traffic accident. In addition, riders of PTW with large engine sizes (over 400 ccm) are also over-represented in the accident population. About half of the helmets were damaged at the sides, 23% at the back, 11% at the front and only 10% showed damage on the upper section. In 8% of the cases the PTW rider lost the helmet during the accident. Helmet loss occurred at an above average frequency during lateral impacts to either the right or left side, and also in frontal impact situations. This might suggest that helmet loss occurs due to an impact at other parts than the back of the head.

Comparing the control cases to the accident cases revealed that PTW riders wearing dark coloured helmets are at greater risk of being involved in a traffic accident, compared to riders wearing bright coloured helmets. The data also indicates that helmets with chin and scalp ventilations are under-represented in the accident population, while helmets with no proper ventilation system are over-represented. The visor of the helmet may also influence the risk of being in an accident: riders that feel that the visor of their helmet distorts the view have a greater risk of being involved in an accident as well as riders using dark visors. The light diffusion of the visor however did not show a significance concerning the accident risk (Figure 2.4). The field-of-view did not differ between the control and the accident cases.

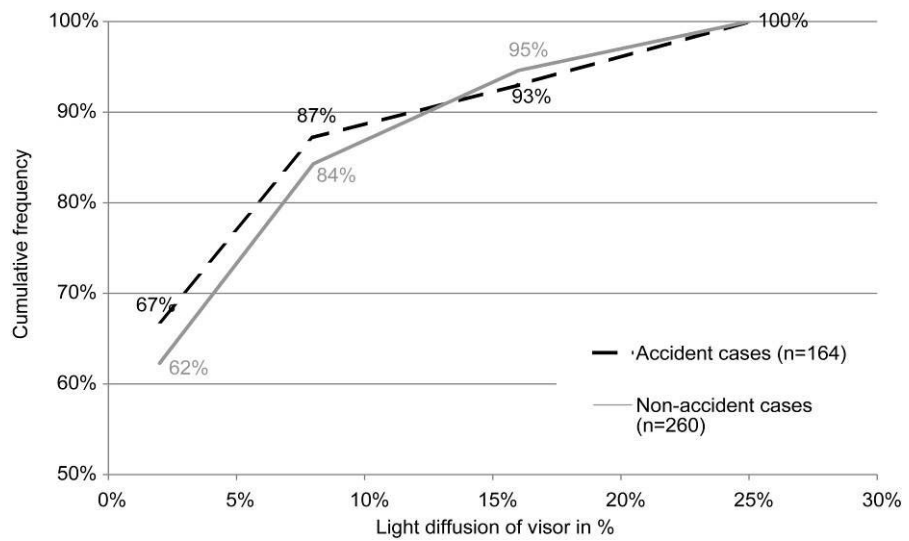


Figure 2.4: Light diffusion of visors, for control cases and accident cases as indicated.

3. Working Group 2 and 3:

Physical boundary conditions and physiological effects

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Full-face motorcycle helmets encapsulate the entire head and thereby affect the perception of the wearer. These helmets are, for instance, thought to be excellent insulators, exposing the head to higher temperatures than ambient. This can lead to discomfort, which is a frequently-mentioned reason for not wearing motorcycle helmets. Besides comfort, there are indications that cognitive performance can also be affected by the altered physical parameters caused by a motorcycle helmet (such as reported under WG4 in this report). Therefore, working groups 2 and 3 covered a range of topics—head thermal physiology, carbon dioxide and oxygen concentration, noise, ventilation, heat transfer and vision—all aimed at improving our understanding of factors which might affect a rider’s capacity to avoid accidents and the acceptability of motorcycle helmets. There is a strong interaction between the studied elements, with helmet design and use affecting each of them.

Figure 3.1 illustrates some of the complexity of the system. The rider’s head and helmet form a single system which is exposed to the outside environment. Noise is generated on the helmet shell by the airflow over the helmet while external, information bearing sound (speech and warning signals, for example), come from outside. Air must be taken into the helmet and expelled from it. The rider looks through the visor and takes in information about the environment. Heat is lost or gained through the helmet, depending on the air speed, temperature, relative humidity, and radiation. These elements interact with each other: if a rider opens a ventilation slot or the visor in an attempt to provide cooling, they may also change the noise level and the gas concentrations inside the helmet.

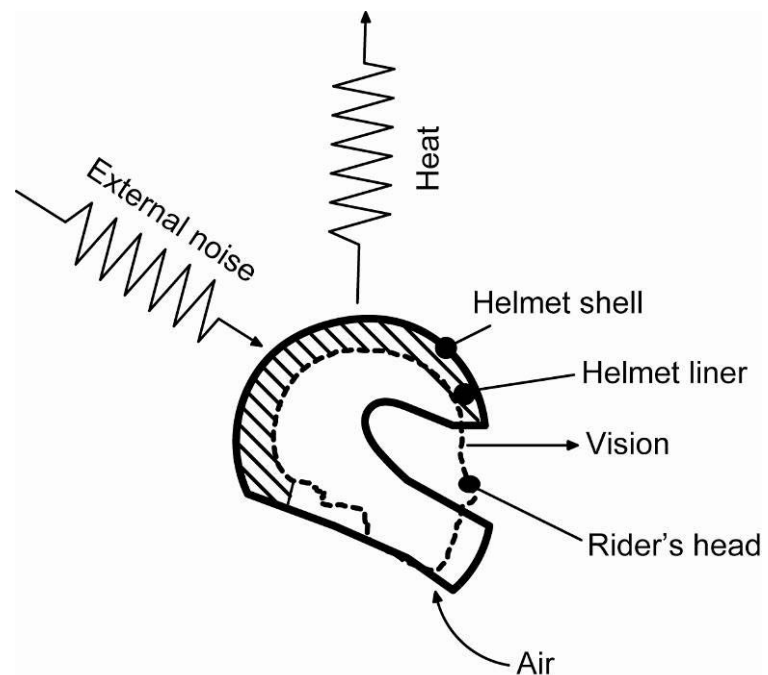


Figure 3.1: The head-helmet system

The rider and motorcycle also interact to change the environment of the helmet. The sketch in Figure 3.1 shows some of the large-scale parameters which must be considered: the rider height affects the position of the head and helmet relative to the motorcycle fairing and windscreen (if fitted), which may themselves be adjustable. Indeed, one of the studies described below found good evidence that hairy riders have different thermal behaviour to bald ones. The grouping of these topics is thus a consequence 1 of the multiple, subtle interactions which affect them.

The work carried out under COST Action 357 and described in this report falls under four main headings: heat transfer, thermal physiology, carbon dioxide and oxygen concentration, vision and noise. The first two of these are described in four papers which form the first systematic work in which the thermal behaviour of a helmet-head system is quantitative under a wide range of conditions. The availability of a large sample of helmets allowed comparisons of different helmets to be made. Taken together, two of the papers (Bogerd & Brühwiler, 2008; Bogerd & Brühwiler, 2009) form a comprehensive study of the thermal effects of helmets taking account of variations in air speed, air vent opening and hair (simulated using a wig). The main conclusions to be drawn from these studies are that there is a large variation in heat loss among helmets. A subject study indicated that for most helmets, changing the ventilation configuration makes no perceivable difference (Bogerd et al., submitted-a). These studies provide helmet manufacturers with suggestions for improvement of these ventilation systems, as well as a method for assessing the ventilation performance.

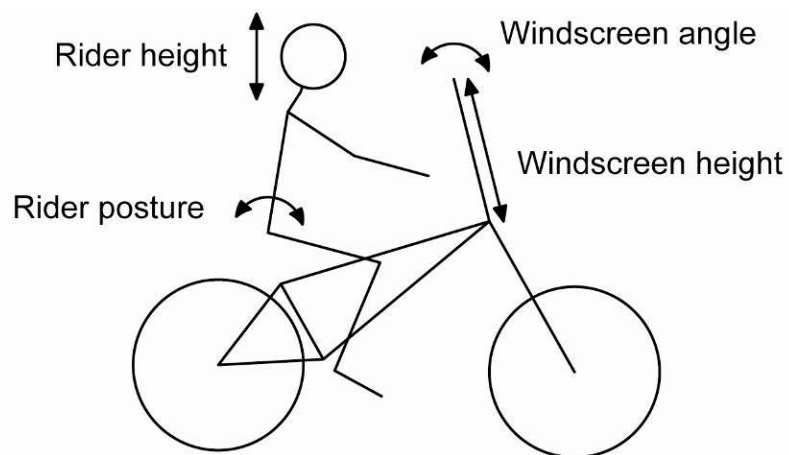


Figure 3.1: Large scale parameters affecting helmet performance

A further study examined, uniquely to our knowledge, the thermal effects of a tinted visor (Buyan et al., 2006). In bright sunshine, the thermal load due to radiation through the visor can be a large part of the total heat transfer of the head. In this study visors of varying tint were compared to a visor covered with aluminium foil. This study indicates a transmission threshold which should be exceeded for a tinted visor to cause perceivable effects.

Another factor which could affect the cognitive performance of riders is increased carbon dioxide concentration inside the helmet and a study below found that, when a rider is stationary, this concentration can be greater than 2%, approaching levels known to affect cognitive performance (Brühwiler et al., 2005). The effect disappears when the rider is in motion, so that the deleterious effects are greatest in slow moving or stationary traffic, such as in the urban environment where the majority of motorcycle accidents happen. Interestingly, the concentrations of carbon dioxide in helmets have not changed in the last 25 years.

Approximately 50% of all PTW accidents are caused by visual failure. Most of these accidents are caused by automobile drivers who fail to give right of way because the driver does not see an approaching motorcycle. This is known as looked-but-failed-to-see, an issue discussed with respect to visual failure in the summary of WG 4. However, part of these visual failures might be explained by field-of-view restrictions caused by a full-face motorcycle helmet, an argument sometimes used

against compulsory helmet wearing. Two studies carried out in the framework of the working groups reported here studied reduced useful-visual-field (UVF) and its effect on simulated traffic (Rogé et al., 2005; Rogé & Gabaude, 2009). The studies were conducted on old and young drivers and an interesting result, relevant to motorcyclists, is that UVF reduces as a function of driving speed, so that if helmets affect UVF this effect is likely to be smaller at higher speeds. An additional study on the topic indicates a relationship between reductions in UVF and increased number of visual failures in a simulated driving test, although the largest reduction may be due to ageing rather than to reduced UVF (Rogé & Pébayle, 2009). These results are a first step towards understanding reduced field-of-view caused by motorcycle helmets.

Finally, we consider noise in helmets. This is a topic that has been considered in the past but with considerable duplication of work. Previous studies have tended to concentrate on measuring noise at, or in, a rider's ear but have rarely examined the mechanisms responsible for this noise. As part of COST Action 357, we present two complementary studies which begin to deepen our understanding of helmet noise and how it can be reduced. The first, as yet unpublished, is a set of measurements taken during on-road riding which include at-ear recordings and, uniquely we believe, pressure measurements from the outside of the helmet shell (Carley et al., unpublished). These data will allow us to study the aerodynamics of the noise-generation mechanism and relate it to the noise exposure of the rider. The second study described below presents the effect of the helmet on the noise input, by measuring the acoustic insertion loss of the helmet, the second element in the chain linking external aerodynamics to internal noise (Młyński et al., 2009). These two studies, taken together, contribute essential elements which will be needed in developing a comprehensive model of the noise generation and transmission problem.

The sum of the work carried out within COST Action 357 is a set of elements which advance beyond the first generation studies of helmets, which were mainly concerned with improving impact protection. As we work towards an integrated model which allows for the assessment and prediction of rider and helmet performance, the studies carried out in this action will be basic contributions of lasting value.

4. Working Group 4: Cognitive effects

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Working Group (WG) 4 was tasked with investigating a wide range of factors that relate to cognition and conspicuity, from both the PTW rider's perspective and the perspective of the typical automobile driver who might come into contact with the motorcyclist. Furthermore, WG 4 also assessed how such research can contribute to the future improvement of simulation, again from both perspectives. The wide remit of this group has led to a substantial number of research projects, all of which have benefitted from the COST Action 357 meetings, where peer review, expert opinion and a collegiate atmosphere dedicated to improving road safety for motorcyclists have led to a honing of existing ideas, and to the birth of new ones. In order to encompass the wide variety of research in WG 4, this section of the final report will contain brief descriptions, or expanded abstracts of many pieces of research. Some of these projects have already been published, while others are still ongoing.

Essentially the research falls into 4 areas. The first area is concerned with the effects of PTW riding or helmet wearing upon the cognition of the rider. There is good reason to suspect that the benefits of full-face helmet protection may be currently offset somewhat by the potentially degrading effect of scalp and face insulation. One study reported on subject reactions to wearing full-face motorcycle helmets in simple cognitive and vigilance tasks, suggesting that factors associated with wearing of a helmet, e.g., head temperature, or increased carbon dioxide levels, may have a real impact on rider's responsiveness (Bogerd et al., submitted-b). At the other end of the spectrum, Crundall et al. (unpublished) are investigating the effect of journey length (wearing a full-face helmet) upon high-level hazard perception skills. This was achieved by taking a PTW hazard perception test into the field and administering it at a police stop-check site for PTW riders. The results are still being analysed but they may provide an insight into how the length of a rider's journey may impact on hazard perception ability, even after other factors such as experience have been controlled for.

The second area of research is concerned with the ability of drivers to spot PTWs. There has been sporadic and contradictory research on conspicuity of PTWs, one study clearly suggests that helmet colour can affect whether you are hit by another vehicle (Comelli et al., 2008). Two other pieces of research (Crundall et al., 2008c; Shahar et al., submitted-b) have also demonstrated the importance of perceptual errors in spotting PTWs compared to automobile drivers' ability to spot approaching automobiles. They suggest that the high spatial frequency of PTW including the rider, may be a key factor in this 'PTW blindness', possibly accounting for the typical looked-but-failed-to-see errors (where an automobile driver reports failing to see a motorcycle prior to a collision despite their best intentions). However, Shahar et al. (submitted-b) also present evidence to suggest that, under certain circumstances, automobile drivers may perceive an approaching PTW but misappraise the risk it poses (e.g. over-estimate the time to arrival), and therefore engage in a dangerous manoeuvre that violates the PTW's right-of-way.

The third area of research is concerned with other factors that may mediate the potential conspicuity effects. Crundall et al. (2008b) reviewed a wide range of conspicuity factors and their interplay with top-down factors. Briefly, top-down factors include influences that relate to the characteristics of the perceiver (i.e., other road users which may come into conflict with the PTW) rather than to the physical attributes of the perceived stimulus. These influences include a variety of factors, such as experience, age, attitudes, fatigue and such as expectations to see PTWs. Crundall et al. (2008b) provided a framework that was employed in a second study to design a questionnaire assessing automobile driver attitudes and knowledge of PTW rider (Crundall et al., 2008a). In summary of their results, it appears that automobile drivers have many attitudes about PTW riders that are divergent from the attitudes held by riders themselves. For instance, certain automobile drivers

demonstrated a lack of empathy for the demands that PTW riders are placed under on the road, which may contribute to driver's lack of urgency or motivation in searching for and responding appropriately to motorcycles. Finally, a study followed up this research by attempting to change automobile driver's attitudes towards PTW riders (i.e., to increase their empathy for the dangers that PTW riders are exposed to) by allowing automobile drivers to witness hazards from the rider's point of view (Shahar et al., submitted-c). Promising results were found, which suggested that the provision of hazard perception video-clips from a PTW rider's perspective were especially useful in changing automobile driver's attitudes.

The final area of research reports on improvements of simulators from both the PTW rider's perspective and the automobile driver's perspective. Stedmon et al. (2009) report on a new motorcycle simulator that incorporates a 25-degree tilt from vertical and counter-steering into a fully functioning virtual environment. Relative validity of the system appears promising. In contrast, Shahar et al. (submitted-d) report on the problems of translating hazards from paper into a motorcycle simulator, with their validation of a commercially available riding simulator. Finally, this research also impacts upon automobile simulators, as issues regarding PTW conspicuity from the automobile driver's perspective require many translational issues to be overcome. Others have reported on the progress in development of the INRETS automobile simulator (Pinto et al., 2008). Yet another group describe ongoing research using high-definition video-clips which provide a near 180 degree view across multiple screens with mirror information inset (Shahar et al., submitted-a). This novel set-up allows automobile driver's visual attention and eye movements to be monitored during two particularly dangerous manoeuvres: pulling out from a t-junction, and changing lanes, both known to be responsible for a substantial part of the PTW accidents.

In sum, the research considers the problem of PTW safety in a large context. While the motorcycle helmet is an important factor in reducing PTW fatalities, there are design issues that need to be considered. The potential negative impacts upon PTW rider's cognitive abilities must be weighed against the cost of future improvements in helmet design. Furthermore, the potentially beneficial effects of conspicuity cannot be considered in isolation. A wide range of other bottom-up factors (i.e., physical properties of the visual world) are equally important, and are likely to interact with helmet colour or pattern (e.g. spatial frequencies). Similarly, there are many top-down influences that also need to be considered. One of the considerable steps forward that has been produced from WG 4 is the creation of a framework to interpret the interplay of all these factors on the automobile driver's ability to look at, perceive and correctly appraise a conflicting PTW. We believe that current research will demonstrate that automobile driver's abilities to avoid colliding with PTWs can be improved through a mixture of top-down training (where to look, appraisal techniques) and bottom-up interventions (increasing conspicuity, and decreasing driver's processing thresholds for PTWs).

5. Conclusions

During the lifetime of the COST Action 357, the members produced over 25 peer-reviewed publications, two books, a multitude of conference contributions, the organization of a new conference focussing on vulnerable road users (VRU), and two Ph.D. theses, all in the framework of this Action. In addition, the Action gave a symposium during the fourth International Conference on Traffic & Transport Psychology, as well as during the first International Conference on Safety and Mobility of VRU¹. Although most results from the finished projects are described in this report, several projects are still underway. Many of these scientific contributions pushed the world-wide state-of-the-art to a higher level. It is difficult to come up with measures for this last statement. However, during the first International Conference on Safety and Mobility of VRU, 37% of all 35 presentations on powered two-wheelers (PTW) are presented by COST Action 357 members; indicating the active role of the Action members in this field, as well as the appreciation of the work by their peers.

The COST Action 357 has also provided a timely opportunity to European experts in the field of traffic safety of PTWs, forming unique interdisciplinary collaborations. This Action has created a platform from which science has been produced as a result of collaborations among psychologists, physiologists, and engineers. The most extensive collaboration was coordinated in Working Group (WG) 1, and involved six institutes based in different countries, who registered multiple factors associated with PTW accidents. Thus, the present Action has motivated several groups to work more intensively on traffic safety of PTWs, likely to result in an increased scientific output on the topic in the years to come. For instance, the present Action played a role in establishing the European seventh framework funded 2-be-safe.

The present Action has stimulated the development of numerous young researchers. Two Ph.D. theses have been completed in the framework of this Action, and part of the work of two additional Ph.D. students has taken place in the Action's network. One of these Ph.D. students was from a lower-middle income country. These students completed several projects at a foreign laboratory within this Action, in Short Term Scientific Missions. However, also several M.Sc. students have been provided with scientific internships. The young researchers of this Action were first author of a total of 13 accepted peer-reviewed publications, with an additional 12 manuscript currently under review, and presented 24 oral presentations at relevant international conferences. Finally, the interim Action leader, who led this Action during the last year, is a young researcher.

The industry has supported this Action by complying to our request for helmets, which results in approximately 25 full-face helmet models in the full size range; showing interest and commitment from the industry towards this Action. In addition, the COST Action 357 held a workshop oriented toward the industry during 66th International Motorcycle Exhibition. This workshop was organized with the support of the industry. One Ph.D. thesis produced within the framework of this Action, containing a detailed analysis of ventilation properties of motorcycle helmets, was distributed among European motorcycle helmet manufacturers. Unfortunately, it is yet too early to evaluate how the Action's results are implemented by the industry.

¹ This symposium is not given at the time of writing. However, it is planned and confirmed.

The authors are of the opinion that the network created in the COST Action 357 would not likely been developed without the funding of COST. The investment is considered efficient, not only expressed by the scientific contributions, but even more so by the interdisciplinary connections which are expected to result in additional project and scientific contributions in the years to come.

6. Outlook

Since the COST Action 357 the scientific attention for motorcycle helmets and powered two-wheelers (PTW) traffic safety has increased, as discussed above. Some topics studies within this Action are the first in the field. As a consequence many open questions remain.

Results obtained in this Action confirm that a thermal manikin headform is a useful tool for investigating and optimizing temperature and airflow perception of headgear. The important role suggested for airflow inside the helmet suggests that a local measure of airflow (Pinnoji et al., 2008; Van Brecht et al., 2008) could help to elucidate temperature and airflow perceptions when wearing such helmets. For the helmet manufacturers, improved general knowledge of the heat transfer of such helmets could be of great use in maximizing comfort of riders, and thereby increasing the acceptance of motorcycle helmets. The study of noise in motorcycle helmets has not developed much since the early studies of the late 1980s (e.g., Purswell & Dorris, 1977), the same is true for carbon dioxide levels in motorcycle helmets. The work published in the open literature has largely consisted of noise measurements, with few attempts to extend and deepen our understanding of the underlying mechanisms. Initial studies have been carried out towards understanding field-of-vision restrictions caused by motorcycle helmets. The interplay between physical field-of-view and usual-visual-field, the later being dependent of riding speed and age, indicated that future studies should take place at relevant (simulated) velocities with subjects representing a population which is most at risk.

A study carried out within WG 4 indicated that tracking performance was the most sensitive parameter for the helmet intervention (Bogerd et al., submitted-b). Tracking performance is related to hand-eye coordination, which could be relevant for traffic safety. Studies under more realistic situations, such as employing a riding simulator could bring further insight, e.g., employing those who are recently developed (Stedmon et al., 2009; Shahar et al., submitted-d). In addition, also understanding the perspective of the automobile driver is crucial since those traffic participants are indicated to be the cause of most PTW accidents; motivating further development of automobile driver simulators for traffic situations involving PTW riders (Pinto et al., 2008). Continuing the development of methods to improve visual skills, and safety attitudes and behaviours of automobile drivers and PTW riders are yet other important steps in the direction of reducing riders fatalities (Shahar et al., accepted, in press; Crundall et al., unpublished), as well as the assessments of those methods (Crundall et al., 2008b).

The multidisciplinary approach focussing on both separate and linked physical and physiological effects and their impact on cognition as initiated by this Action should be continued, and new optimized motorcycle helmet concepts should be developed. In such future work helmet manufacturers should play a more active role. The multidisciplinary approach should ensure that one parameter will not be optimized at the cost of another; and especially that the mechanical impact protection characteristics should not be reduced from their current level. In line with this rationale a new study of the aerodynamic, physiological and cognitive elements concerning motorcycle helmets is underway in the UK.

Many aspects of the work carried out in this action are relevant for other types of protective headgear, especially bicycle helmets. In fact, a network of world-leading multidisciplinary experts such as created for motorcycle helmets and PTW traffic safety by the COST Action 357 does not exist

for bicycle helmets. Such an expert network for bicycle helmets becomes increasingly important. On the one hand since there are strong indications that such helmets are not optimally designed and the current bicycle helmet concepts are not based on empirical results. On the other hand is bicycling becoming increasingly popular, because its health benefit over automobile driving, as well as its beneficial effects on traffic conjunction, and air and noise pollution.

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8. Appendix 1: Summaries of work carried out under Working Group 2 and 3

The following studies are summaries in this appendix:

- Bogerd CP & Brühwiler PA (2009). Heat loss variations of full-face motorcycle helmets. *Applied Ergonomics*, 40; 161-164. Online: <http://dx.doi.org/10.1016/j.apergo.2008.03.001>
- Bogerd CP & Brühwiler PA (2008). The role of head tilt, hair and wind speed on forced convective heat loss through full-face motorcycle helmets: A thermal manikin study. *International Journal of Industrial Ergonomics*, 38; 346-353. Online: <http://dx.doi.org/10.1016/j.ergon.2008.01.003>
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- Buyan M, Brühwiler PA, Azens A, Gustavsson G, Karmhag R & Granqvist CG (2006). Facial warming and tinted helmet visors. *International Journal of Industrial Ergonomics*, 36; 11-16. Online: <http://dx.doi.org/10.1016/j.ergon.2005.06.005>
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Heat transfer of full-face motorcycle helmets: Part I

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Thermal discomfort has been shown to be an issue with motorcycle helmets. Full-face motorcycle helmets should be strong thermal insulators without vents, although current ventilation systems indicate a desire by manufacturers to facilitate heat loss from the head. At present the effectiveness of the available systems is unclear, and motivated this study. We studied heat loss of modern full-face motorcycle helmets to investigate the state-of-the-art of helmet ventilation, including the effectiveness of the vents provided.

Twenty-seven modern full-face motorcycle helmets (9 flip-up and 18 integral models) from 13 manufacturers were examined on a thermal manikin headform (Figure 8.1). The surface temperature of the headform was stabilized at 35 °C, and the power needed to maintain this temperature in a 20 min steady-state period was recorded. This heating power corresponds to the heat loss (\dot{Q}). Values for the scalp (\dot{Q}_S) and face (\dot{Q}_F) sections were obtained separately.



(a)



(b)

Figure 8.1: The headform at the exit of the wind tunnel (a), and with a helmet and scarf installed (b).

Measurements were carried out on all 27 helmets, for their vents open and closed; all measurements were repeated three times. The headform was placed in an upright position at the exit of a wind tunnel. The setup was located in a climate chamber, maintained at 22.90 ± 0.05 °C and $50 \pm$

1% relative humidity, and a wind speed of $50.0 \pm 1.0 \text{ km}\cdot\text{h}^{-1}$ was applied. A scarf (Figure 8.1b) covered the neck section to reduce the heat transfer there for technical reasons; this also simulates a realistic situation, since many motorcyclists wear such protection.

\dot{Q}_S is shown in Figure 8.2; similar qualitative results are found for \dot{Q}_F ranging from 8 – 18 W. Large variations in \dot{Q} among the helmets were observed in both the scalp and face sections. Recently, we have shown in our laboratory that fluctuations of \dot{Q}_S have to exceed at least 1.5 W in order to be perceivable to subjects. Surprisingly, changing the vent configuration only had a small effect on \dot{Q} for most helmets; e.g., in the scalp section only three helmets showed $\Delta\dot{Q}_S > 1.5$.

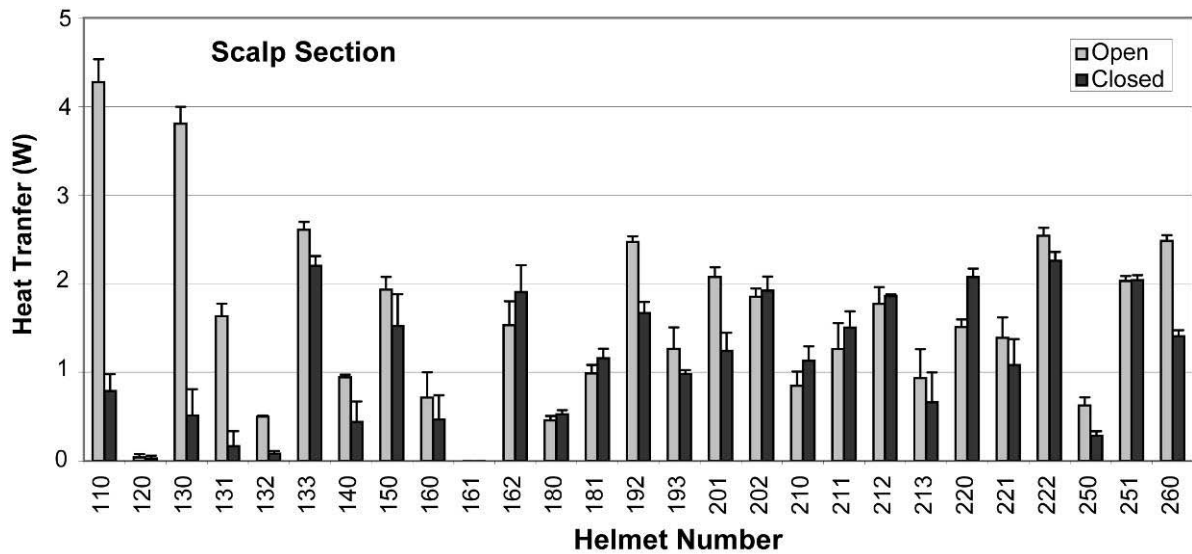


Figure 8.2: Heat loss from the scalp section for both open and closed vent configurations as indicated. The error-bars indicate one standard deviation.

Thus, state-of-the-art full-face motorcycle helmets are seldom capable of enabling control of the heat transfer, or of delivering large values of heat transfer to the scalp at moderate temperatures and riding speeds near 50 km/h. In our second study we examine further details.

Heat transfer of full-face motorcycle helmets: Part II

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In the preceding study it was shown that most motorcycle helmets offer ventilation with generally little control of the heat transfer, as well as low scalp ventilation. Here we report a study of how those observations develop as a function of head angle and wind speed, and the presence of hair. The same conditions were used as in the previous study ($50.0 \pm 1.0 \text{ km}\cdot\text{h}^{-1}$ wind speed, REF) to examine six helmets with a wig installed on the headform (Figure 8.3a). Additional measurements were undertaken without wig at a 30° forward heat tilt (Figure 8.3b). Finally, three helmets were submitted to ten different wind speeds between 0.0 and $78.8 \text{ km}\cdot\text{h}^{-1}$.

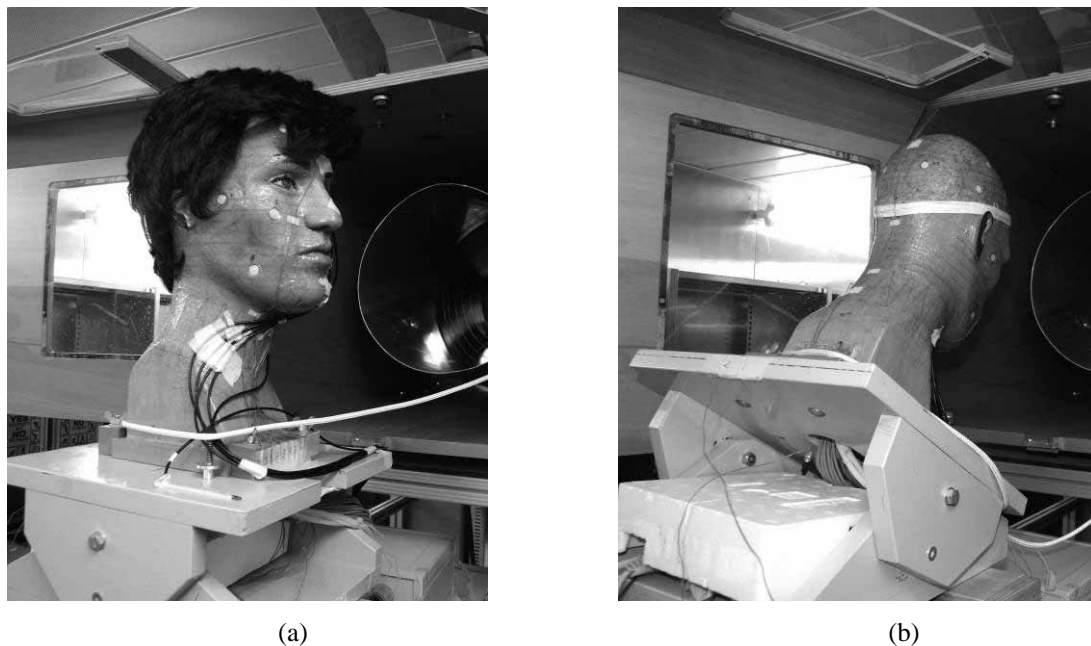


Figure 8.3: The headform with the wig installed (a), and with the 30° forward tilt (b).

The wig decreased heat loss in the face section (\dot{Q}_F) in all cases by a factor of 1.5 ± 0.1 . The heat loss in the scalp section (\dot{Q}_S) was decreased by a factor of 2.3 ± 1.8 . ($\Delta\dot{Q}_S$) was significantly reduced for two helmets, and $\Delta\dot{Q}_F$ for one. The scalp section showed good linear correlations between \dot{Q}_S and wind speed (Figure 8.4), for both vent configurations and ($\Delta\dot{Q}_S$); average $r = 0.92 \pm 0.13$. Also for the face section good linear correlations are found; average $r = 0.96 \pm 0.11$. Interestingly, wind speeds lower than 20 km/h did not affect the heat loss from the scalp with the vent closed.

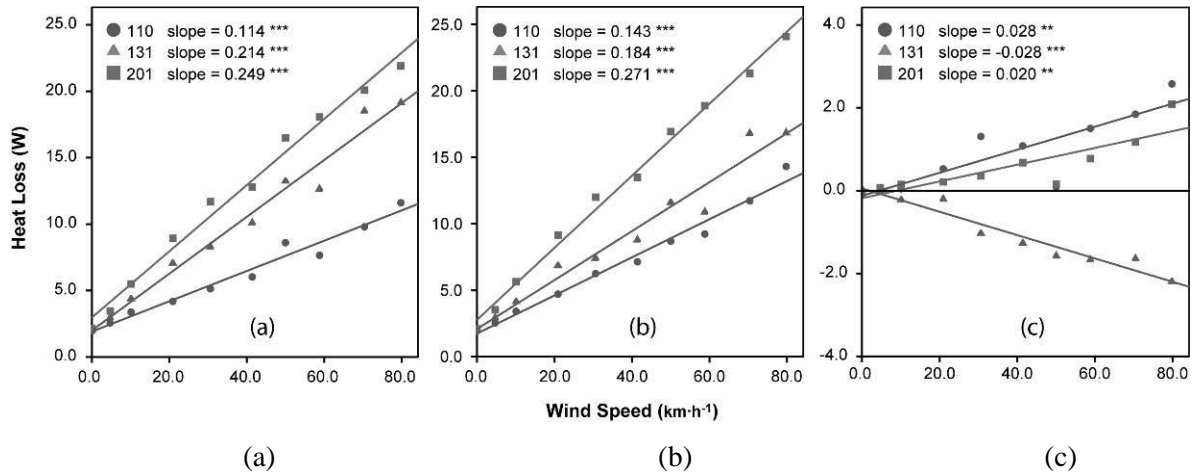


Figure 8.4: Heat loss as a function of wind speed in the scalp section, for (a) vents closed, (b) vents open, and (c) the difference between (a) and (b), for the indicated helmets. The slopes of the linear regression lines are indicated (W/(km/h)).

It can be concluded that the wig reduces the heat loss through a head-motorcycle helmet combination by a factor of ~ 2 , under these conditions. Furthermore, good linear relationships exist between heat loss and wind speed ($0 \text{ km}\cdot\text{h}^{-1} - 80 \text{ km}\cdot\text{h}^{-1}$), making predictions of heat loss behaviour easier based on a limited number of measurements under similar wind conditions.

Thermal perception of ventilation changes in full-face motorcycle helmets: Subject and manikin study

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Thermal perception and comfort are important factors influencing the willingness to wear protective headgear, e.g., full-face motorcycle helmets. However, little is known about the ability of the ventilation systems of such helmets to influence the thermal perception of the wearer. We have previously studied these helmets for heat loss, as reported elsewhere in this document. The aim of the present study was to investigate the relationship between perception and heat loss among other parameters, with the focus on vent-induced effects.

Eight healthy male subjects participated in the study. Each subject visited the laboratory on three different days, once for a familiarization trial and twice for experimental trials. During the experiment the subjects sat at the exit of a wind tunnel, which projected an air stream on the upper torso, neck and head, during the entire experiment. All measurements were conducted in a climate chamber at ambient temperatures of 23.7 ± 0.4 °C and 27.5 ± 0.3 °C, referred to as neutral and warm, respectively. At both ambient temperatures the two wind speeds were applied, denoted moderate (39.2 ± 1.9 km/h) and high (59.3 ± 1.4 km/h). The relative humidity was kept at $50 \pm 2\%$. After equilibration the subjects examined the effect of opening or closing the vents in the scalp section and separately in the face section of four full-face motorcycle helmets (referred to as 110, 130, 201, and 210). The combination of different temperatures, wind speeds, and helmets resulted in a wide range of vent-induced heat loss. After each change the subjects rated their perception of i) temperature, ii) airflow, iii) noise, and iv) comfort. In what follows the results are given for ratings of temperature perception on the scalp. Figure 8.5 exhibits the 93 responses for temperature perception as a function of $\Delta\dot{Q}_s$. The response 'indifferent' was given most often and is associated with $\Delta\dot{Q}_s = 0$; 'warmer' was given at larger negative values, and 'cooler' at larger positive values of $\Delta\dot{Q}_s$. Multinomial logistic regression analysis indicated that, from a pool of parameters, $\Delta\dot{Q}_s$ was the most important determinant for the temperature perception.

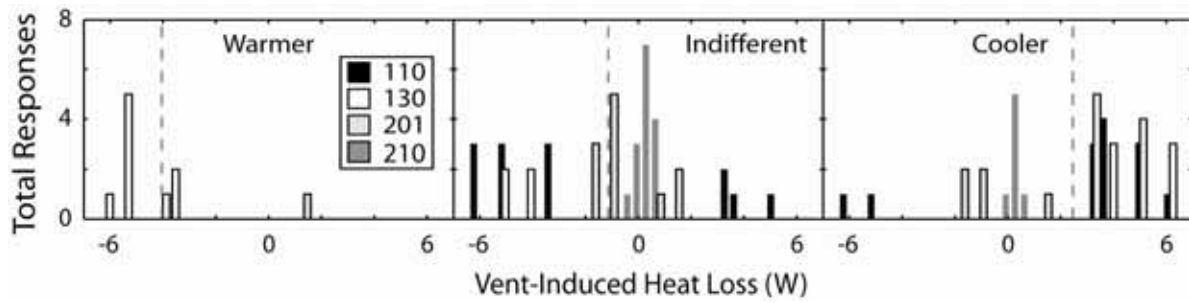


Figure 8.5: Number of responses for temperature perception for the scalp section as a function of vent-induced heat loss, for the indicated helmets.

Thus, subjects are able to systematically perceive effects caused by changing the vent configuration of motorcycle helmets under simulated riding conditions. Furthermore, the main determinant of the response behaviour of the subjects was $\Delta\dot{Q}_S$. However, the relationship between $\Delta\dot{Q}_S$ and response behaviour varied among the helmets. These results show in detail that a thermal manikin headform is a useful tool for investigating and optimizing temperature perception of headgear. Furthermore, lower perception thresholds were found for opening the vents compared to closing. Perceptual differences were found for two helmets at similar values of $\Delta\dot{Q}_S$, and internal temperature distributions suggest that internal airflow patterns may be responsible for this response.

Facial warming and tinted motorcycle helmet visors

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Motorcyclists are overrepresented in traffic accidents. Some have suggested that cognitive performance could be hindered by a motorcycle helmet. Warm temperatures have been associated with an impairment of at least some parameters of cognitive faculty. Elsewhere in this report we investigate the heat transfer from the head through a motorcycle helmet and show that they are good thermal insulators. However, the microclimate created by a motorcycle helmet can also be warmed by an external source, e.g., the sun through radiant transmission through the visor. Finally, such transmission through clear visors might impair vision. The aim of the present study was therefore to evaluate radiant warming through visors, using an electrically controlled tinting visor to change the amount of radiant exposure.

Four visor configurations were evaluated, with a standard clear visor and an aluminium foil-covered visor as the two extreme light transmission configurations (Figure 8.6). In addition, an adjustable electrochromic foil was used at two transmission levels. The visors were first evaluated with a motorcycle helmet installed on a thermal manikin headform. A lamp simulating the solar spectrum was aimed at the visor at a downward 25° onto the manikin. The steady state heat transfer was measured for all four visors. Measurements were then carried out with eight subjects seated to reproduce the manikin positioning; these were asked for their perception of differences among the four visor configurations.

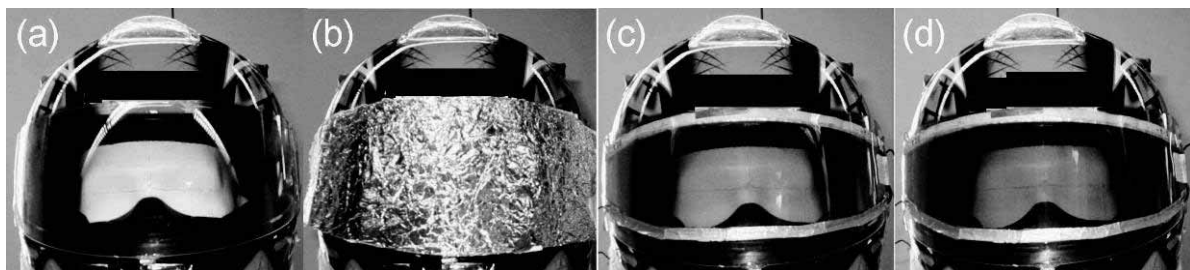


Figure 8.6: The studied visor configurations: a) clear visor, b) electrochromic foil minimum tinted, c) electrochromic foil maximally tinted, and d) aluminium foil.

The results are summarized in Table 8.1. As expected, the clear visor transmits the most radiant heating, and the aluminium-covered visor the least, with the electrochromic foil yielding intermediate values. Subject examinations indicated a perceptible difference between the clear visor and the electrochromic foil, but no perceptible difference between the two electrochromic foil configurations.

Table 8.1: Steady-state heating in the face section of the thermal manikin for the indicated conditions. The confidence intervals indicated for the steady-state power are the maximum standard deviation of the four conditions.

Visor Configuration	Steady-state Power, Face (W)	Difference from Baseline (W)	Relative Load (%)
(d) Al foil (baseline)	6.60 ± 0.05	-	-
(a) Clear visor	4.27 ± 0.05	2.33 ± 0.16	100
(b) Light foil	5.17 ± 0.05	1.43 ± 0.16	61
(c) Dark foil	5.42 ± 0.05	1.18 ± 0.16	51

Thus, tinted helmet visors are not necessarily limited to inducing visual shielding, but can effectively change heat gain as well as subjective perception in a radiant environment. The results indicate that the threshold for reaching a perceptible effect lies between 1.4 W and 2.3 W. In order to convince wearers of their utility, adaptive visors should cause effects exceeding this threshold, but should be able to return to clear visor conditions almost instantaneously, in order not to compromise traffic safety, e.g., when driving into a tunnel.

CO₂ and O₂ concentrations in integral motorcycle helmets

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Several factors can affect the cognitive performance of motorcyclists, of which increased carbon dioxide concentration is one. Two published pilot studies have indicated that inhaling carbon dioxide concentrations of the order of 2.5% impaired cognitive (stereoacuity) performance; the cognitive effect of lower carbon dioxide concentrations has not been evaluated. Full-face motorcycle helmets, which offer the best protection in an accident, encapsulate the entire head, and might therefore facilitate a build-up of carbon dioxide. Two early studies evaluated carbon dioxide concentration for motorcycle helmets and found concentrations of the order of 2% for wind still conditions; such concentrations might be relevant to cognitive faculty of motorcyclists, and therefore to traffic safety.

The aim of the present study is to quantify carbon dioxide concentrations to which motorcyclists are typically exposed while wearing modern full-face motorcycle helmets. In the laboratory, four subjects were seated at the exit of a wind tunnel wearing a typical full-face motorcycle helmet. During this laboratory study three wind speed configurations were applied; i) 0 km/h, ii) 36 km/h, and iii) 62 km/h. In the field, the same helmeted subjects rode motorcycles in traffic. During both studies, the carbon dioxide concentration was measured at the upper lip of each subject, and reported as time-averages, unless noted otherwise.

The results from the subject measurements indicate peak carbon dioxide values of the inhaled air well above 2% at zero wind speed. With the application of wind, carbon dioxide drops to values well below 1%, e.g., at 50 km/h the inhaled carbon dioxide concentration resembles that for a person without a helmet in still air, at about 0.2%. The oxygen deficiency is generally equal to the carbon dioxide concentration. Very good agreement was obtained between laboratory and field measurements, in spite of the motorcycle speeds in the field being 1.3 times as high as the corresponding wind speeds in the laboratory. The effect of opening the visor was investigated at zero wind speed in the laboratory, resulting in negligible differences of the order of 0.03%.

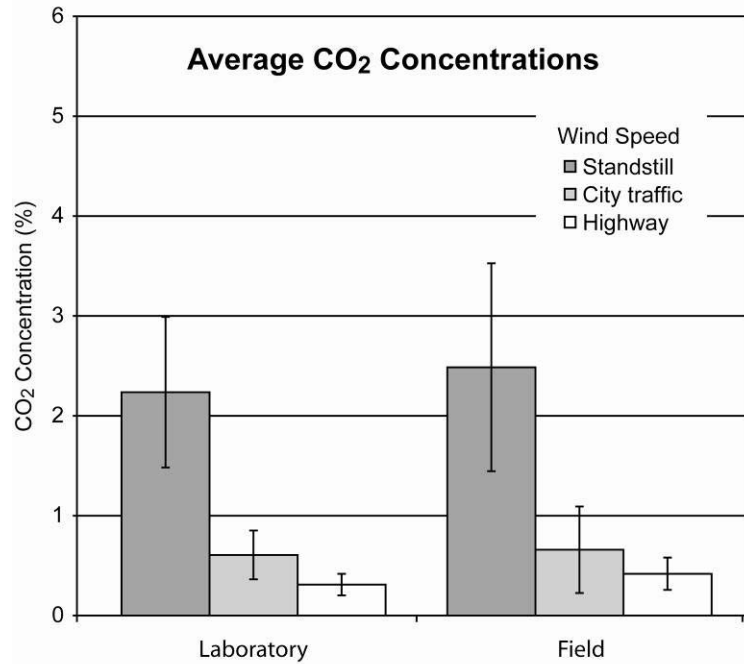


Figure 8.7: Average carbon dioxide concentrations measured for the laboratory and the field measurements. The wind speeds corresponding to the indicated levels are for the laboratory (field) measurements: standstill 0 km/h (0 km/h), city traffic 36 km/h (50 km/h), and highway 62 km/h (80 km/h).

These results indicate that modern helmets reach similar carbon dioxide levels compared to those found 25 years ago. Under still conditions, the carbon dioxide concentration exceeded 2% (Figure 8.7), which is of the order of that associated with impaired cognitive (stereoacuity) performance in one study. These levels may explain part of the slightly-impaired cognitive performance found while wearing a full-face motorcycle helmet reported elsewhere in this report. However, it remains an open question how long the effect of the elevated carbon dioxide concentrations found at zero wind speed affect a motorcyclist, e.g., after riding away from a traffic light. Interestingly, opening the visor seems did not lower the carbon dioxide concentration under still conditions.

Useful visual field reduction as a function of age and risk of accident in simulated car driving

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It has been claimed in the past that helmets increase the likelihood of accidents because they reduce the useful visual field of the rider. In this study, the relationship between useful visual field, age and driving performance was examined in car drivers aged from 23 to 77 years. Although the test was of driving rather than of riding performance, the issue of ‘failure to see’ is important to all vulnerable road users and especially motorcyclists.

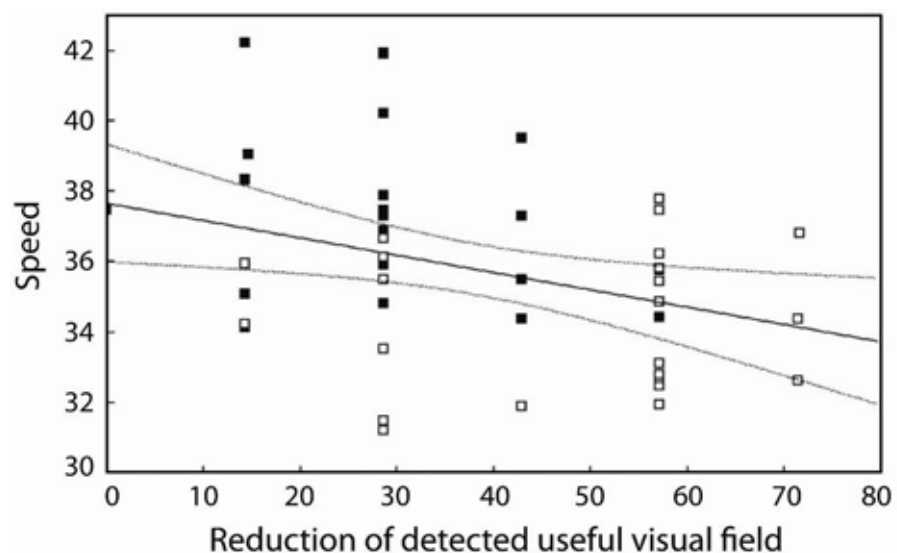


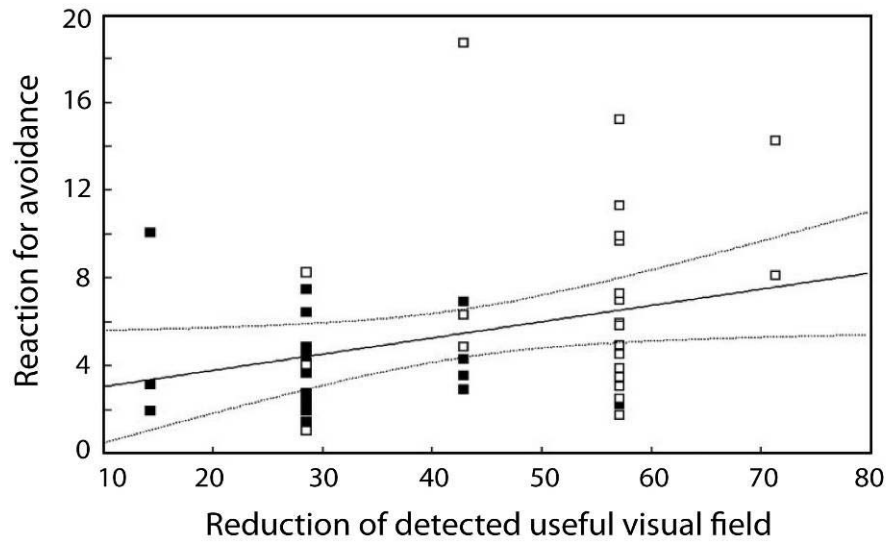
Figure 8.8: Speed as a function of reduction of useful visual field: solid squares: older drivers; open squares younger drivers.

The test used to assess driving performance was the avoidance of a truck entering the road from the driver’s right, similar to the failures of observation which seem to lead to car-motorcycle collisions. The motivation for the trial was to examine the effect of age, via visual field reduction, but the data should give some hints on the effects on motorcyclists’ performance. It was found that the reduction of the useful visual field, estimated using a target-localization task, was related to drivers’ ability to drive and to the reaction for avoiding a collision. The compensating strategy adopted by drivers with reduced visual field was to reduce their speed (Figure 8.8).

Figure 8.9 shows the reaction time as a function of reduction of visual field. Here, the effect of reduced visual field is to increase the reaction time and make collision, in particular a so-called looked-but-failed-to-see, more likely. As the authors conclude: ‘A complete useful visual field seems

indeed to be a major element in the driver's ability to control his or her trajectory in a simulated situation that can lead to a collision,' with some implications for motorcycle safety.

Figure 8.9: Reaction time as a function of reduction of useful visual field: solid squares: older drivers; open squares younger drivers.



Deterioration of the useful visual field with ageing during simulated driving in traffic and its possible consequences for road safety

Joceline Rogé and Thierry Pébayle

National Transport and Safety Research Institute, Bron Cedex, FR

This study extended earlier work and examined the effect of age, of monotonous driving and of traffic density on the useful visual field of drivers. Again, this is a study which examines drivers rather than riders but should offer hints on factors affecting the safety of motorcyclists. Ten young and ten older drivers were tested on a simulator with the task being to follow another car for two hours at 126 km/h. The useful visual field was tested by the driver detecting signals on the rear lights of other vehicles in the simulated traffic. Analysis of the data indicated that age interacted with the location of the peripheral signal and density of traffic interacted with the duration of driving.

Figure 8.10 shows a result from the study: in both heavy and light traffic, the percentage of signals detected falls with duration of driving. This failure to detect a signal is related by the authors to cognitive conspicuity, ‘sometimes evoked to explain collisions between light vehicles and vulnerable road users (such as powered two-wheelers or cyclists) at intersections in accidents of the type “looked but failed to see”’, where a driver looks in the direction of an approaching cyclist or motorcyclist but does not perceive them. Another result of the study was that age interacted with the location of the peripheral signal. The authors discuss these results in terms of models of the deterioration of the useful visual field, a point to which they return in a later paper.

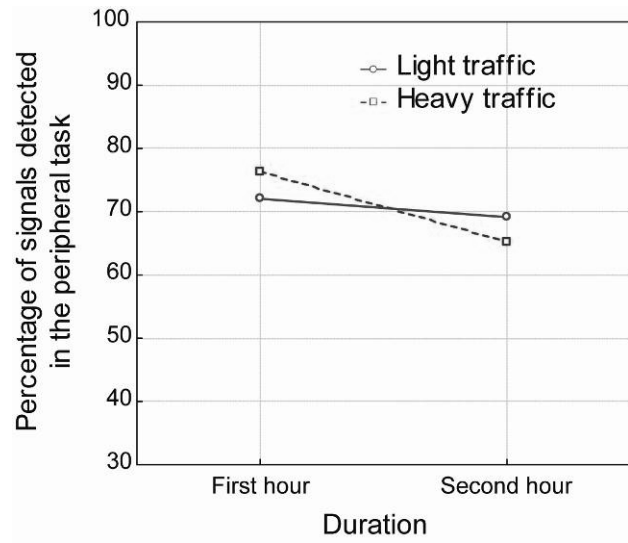


Figure 8.10: Percentage of signals detected in the peripheral task as a function of density of traffic (light versus heavy) and of duration of driving (first hour versus second hour).

Deterioration of the useful visual field with age and sleep deprivation: insight from signal detection theory

Joceline Rogé and Catherine Gabaude

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The goal of this study was to establish whether the deterioration of the useful visual field due to sleep deprivation and age in a screen monitoring activity could be explained by a decrease in perceptual sensitivity and/or a modification of the participant's decision criterion (two indices derived from signal detection theory). In the first experiment, a comparison of three age groups (young, middle-aged, elderly) showed that perceptual sensitivity decreased with age and that the decision criterion became more conservative. In the second experiment, measurement of the useful visual field was carried out on participants who had been deprived of sleep the previous night or had a complete night of sleep. Perceptual sensitivity significantly decreased with sleep debt, and sleep deprivation provoked an increase in the participants' decision criterion. Moreover, the comparison of two age groups (young, middle-aged) indicated that sensitivity decreased with age. The value of using these two indices to explain the deterioration of useful visual field is discussed.

On-road measurement of motorcycle helmet noise mechanisms

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A study was conducted of helmet noise mechanisms using measurements inside and outside a helmet during on-road riding. The in-helmet measurements were made using a microphone at the rider's ear, a well-established technique for noise measurement. The data on the outside of the helmet were taken using a surface-mounted pressure transducer, developed for use in the aerospace industry. To our knowledge, this is the first time such a study has been conducted or, at least, described in the open literature.

Figure 8.11 shows sample spectra for the pressure on the outside of the helmet and at the rider's ear. The external pressure spectrum has the form which might be expected for turbulent flow over a bluff body while the at-ear spectrum (shown dashed) is strongly attenuated above about 500 Hz, a result also obtained by the CIOP group using insertion loss measurements. The difference between the two levels is of the order of 30 dB at higher frequencies demonstrating the inability of a helmet to protect against hearing damage at low frequency and its tendency to attenuate signals, such as speech, at higher frequencies. Current work is focused on examining the aerodynamic mechanisms responsible for the surface pressure fluctuations and the resulting noise.

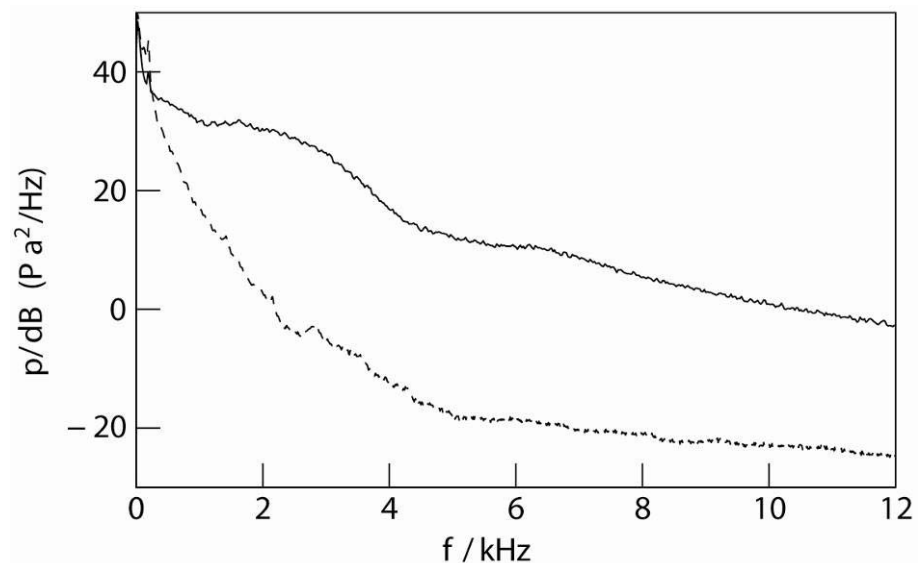


Figure 8.11: Helmet external pressure (solid) and internal noise (dashed).

Attenuation of noise by motorcycle safety helmets

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The noise exposure of a rider is a combination of the generated noise, due to the flow over the helmet, and the attenuation due to sound propagation through the helmet–head structure. In this study, the authors measured the attenuation in two ways: by finding the change in hearing threshold when a user wore a helmet and by measuring the insertion loss due to the helmet by placing a microphone at a user's ear.

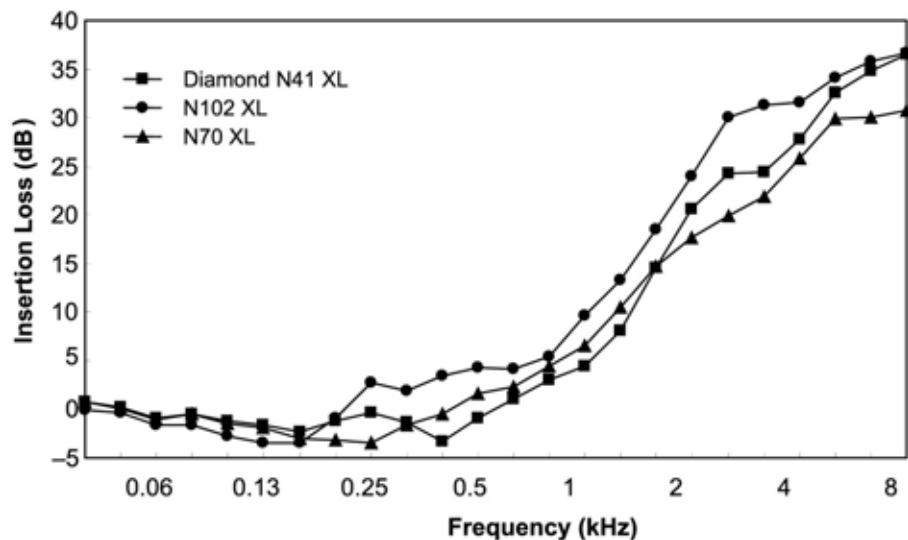


Figure 8.12: Insertion loss of three Nolan helmets

Sample results for insertion loss are shown in Figure 8.12 (it is interesting to compare this to Figure 8.11) and it is clear that there is no attenuation of sound below about 500 Hz. Since the aerodynamically generated noise is worst in the frequency range up to about 1 kHz, this means that helmets offer no noise protection in the range where it is most needed. Above 500 Hz, there is a linear increase in attenuation with the insertion loss at 8 kHz being about 30 dB. The authors note that this combination of no attenuation at low frequency and large attenuation at higher frequency leads to the risk of hearing damage due to the low frequency aerodynamic noise and to difficulty in understanding speech because of the high frequency attenuation.

9. Appendix 2: Summaries of work carried out under Working Group 4

The following studies are summaries in this appendix:

- Bogerd CP, Strässle K, Rossi, RM & Brühwiler PA (submitted for publication). Laboratory subject study of cognitive effects when wearing a full-face motorcycle helmet in warm conditions.
- Crundall D, Andrews B, Van Loon E, & Chapman P (not submitted). Motorcyclists' hazard perception skills as a function of journey time.
- Comelli M, Morandi A, Magazzù D, Bottazzi M & Marinoni A (2008). Motorcycle and helmet bright colours reduce the odds of a class of road accidents: a case-control study. *BioMedical Statistics and Clinical Epidemiology* 2; 71-78.
- Crundall D, Humphrey K & Clarke DD (2008). Perception and appraisal of approaching motorcycles at junctions. *Transportation Research Part F*, 11; 159-167. Online: <http://dx.doi.org/10.1016/j.trf.2007.09.003>
- Shahar A, Clarke DD & Crundall D (submitted for publication). Perception and appraisal of approaching motorcycles at junctions in experienced drivers and riders.
- Crundall D, Clarke DD, Ward P & Bartle C (2008). Car drivers' attitudes towards motorcyclists: A review. Road Safety Research Report No. 85. UK: Department for Transport.
- Crundall D, Bibby P, Clarke DD, Ward P & Bartle C (2008). Car drivers' attitudes towards motorcyclists: A survey. *Accident Analysis & Prevention*, 40; 983-93. Online: <http://dx.doi.org/10.1016/j.aap.2007.11.004>
- Shahar A, Clarke D & Crundall D (submitted for publication). Using motorcycle hazard perception clips and simulators to improve knowledge and attitudes towards motorcyclists.
- Stedmon AW, Hasseldine B, Rice D, Young M, Markham S, Hancox M, Brickell E & Noble J (2009). 'MotorcycleSim': An evaluation of rider interaction with an innovative motorcycle simulator. *The Computer Journal*. Online: <http://dx.doi.org/10.1093/comjnl/bxp071>.
- Shahar A, Poulter D, Clarke DD & Crundall D (submitted for publication). Motorcyclists' and car drivers' responses to hazards.
- Pinto M, Cavallo V & Ohlmann A (2008). The Development of Driving Simulators: Toward a Multisensory Solution. *Le Travail Humain*, 71; 62-95.
- Shahar A, Alberti C, Clarke DD & Crundall D (accepted, in press). Hazard perception as a function of target locations and the field of view. *Accident Analysis & Prevention*.

Laboratory subject study of cognitive effects when wearing a full-face motorcycle helmet in warm conditions

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Wearing a full-face motorcycle helmet offers high protection to the head and face, but may cause discomfort and/or distraction. Microclimate temperatures around the head are higher than the ambient temperatures, due to insufficient ventilation of these highly-insulating helmets. Since it is known that cognitive performance can be impaired by heat stress and also other helmet mediated effects (e.g., increased carbon dioxide levels), we investigated the impact of wearing a full-face motorcycle helmet on cognitive performance.

Following three familiarization trials, nineteen subjects completed two experimental trials, alternatively wearing a full-face motorcycle helmet (HEL) or no headgear at all (CON) in random order. The cognitive performance was assessed with a letter cancellation test (LCT) and a task of simultaneous visual tracking/vigilance test (VTT) and auditory vigilance test (AVT). During each trial, acclimated subjects completed 30 min VTT+AVT preceded and followed by a LCT. In addition, the heart rate (HR) and heart rate variability (SDNN and pNN50) were measured during the VTT+AVT. In addition at the end of each trial, whole-body temperature perception and thermal comfort were assessed. All trials took place in a climate chamber at an ambient temperature of 27.2 ± 0.6 °C, a relative humidity of $41 \pm 1\%$, and with a minimal wind velocity of 1.8 ± 0.2 km·h⁻¹. The basic set-up is shown in Figure 9.1.



Figure 9.1: Photograph of the measurement set-up, with approximate subject positioning in front of the wind tunnel, typical clothing, and the computer screen, keyboard, and joystick used for the simultaneous VTT and AVT tests.

Figure 9.2 displays the displacement as well as the incorrect responses on the visual vigilance task. HEL resulted in a larger displacement on the tracking task, with a median increase of 7.2% (25th percentile -9.9%; 75th percentile 23.7%) ($p = 0.021$). Furthermore, interaction effects were found between the intervention and time, for five out of 46 cases. The heart rate variability parameter pNN50 showed an intervention effect, with 17.5% (-26.9; 62.1) larger values for HEL. Furthermore, HEL resulted in a less favorable temperature perception and thermal comfort ($p < 0.01$). Finally, most cognitive parameters showed a time effect during the 30 min VTT+AVT, indicating poorer performance towards the end.

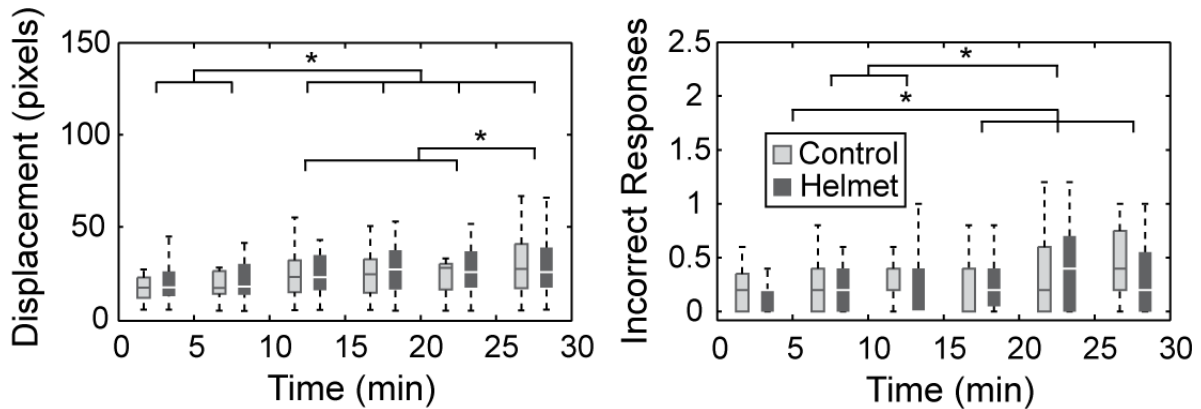


Figure 9.2: Boxplots of the tracking performance and incorrect visual vigilance responses. Significant differences of the time effect are indicated by: * $p < 0.01$.

Thus, the tracking performance was impaired by wearing of a full-face motorcycle helmet, under the applied conditions. In addition, these helmets cause a less favourable whole body temperature perception and thermal comfort. Finally, the decreased heart rate variability during the helmeted condition might indicate a higher level of mental fatigue compared to not wearing a helmet.

Motorcyclists' hazard perception skills as a function of journey time

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Of the few limited attempts that have been undertaken to assess the hazard perception skills of motorcyclists, they have all been conducted in the laboratory with no attempt to control or measure how recently the participants had last been on a motorcycle. Indeed it is reasonable to assume that riding factors such as fatigue, increased head temperature through helmet use, and on-road arousal may negatively affect real world hazard perception compared to a simple laboratory test. In an effort to get closer to the real world factors that may impact on hazard perception, we took our motorcycle hazard perception clips into the field (Figure 9.3). In conjunction with Nottinghamshire Police, we set up a hazard perception test station at a police stop check site. Police riders redirected passing motorcyclists into the site where their motorcycles and insurance details were checked. Following this the motorcyclists had the opportunity to take part in a short hazard perception test from the perspective of the motorcyclist. We recorded hazard responses, eye movements and a number of demographic measures. We also asked riders to estimate how far they had ridden before being redirected into the stop check site. It was predicted that the length of the journey that riders had undertaken prior to the hazard perception test would relate to their hazard perception score after controlling for other factors such as motorcycling experience. Analyses are ongoing.

Figure 9.3: A screen shot from a hazard perception clip. In this clip the motorcyclist overtakes standing traffic only to be confronted with a car that decides to make an impromptu u-turn to avoid road works.



Motorcycle and helmet bright colours reduce the odds of a class of road accidents: a case-control study

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Previous findings suggesting that lack of conspicuity of motorcycle riders can be a major risk factor of accident were often based on studies using inappropriate exposure groups. This case-control study aims to investigate the causal role in accidents of poor motorcyclist clothing visibility. The purpose of this work is twofold: to identify a group of accident configurations where the poor visibility of the motorcyclist clothing plays a causal role and to test whether dark colours of motorcycles and helmets are also over represented in crashes possibly related to the motorcyclist's apparel visibility, with respect to circulating vehicles. If motorcycles/riders involved in cases show a different appearance from those normally circulating, this should mean that their look (colour in particular) plays a role in causing accidents.

Data for the analysis were taken from a multicenter case-control study (MAIDS: Motorcycle Accidents in Depth Study) on the risk of crash and serious injuries for motorcyclists. The cases of the present study were chosen among the Maids accidents for which the primary cause was judged by the reconstruction experts to be the perception error of the four-wheeler driver. However not all driver perception errors are due to poor rider/motorcycle visibility (e.g. a driver might simply forget to look in the direction where the rider comes from). Therefore, it is advisable to further restrict the cases to some categories of accidents, where perception error is more likely to be visibility related.

Inclusion criteria Accidents involving at least two vehicles; accidents caused by a perception failure of the four-wheeler driver; daylight accidents and controls: only crashes occurring and controls circulating between 8:30 a.m. and 5 p.m.; collisions with perpendicular or opposite traffic; motorcycles with engine displacement over 250 cm³. The application of these criteria leads to a sample of 77 cases and 181 controls coming from the Maids database.

The sample containing the included cases and controls has been randomly split into two complementary subsets of similar size: the training and the test samples (Table 9.1). The training sample has been used to select an appropriate logistic model discriminating between cases (included accidents) and controls (normally circulating motorcycles). The test sample is meant for the validation of the final selected model. Among the explicative variables, an indicator named "brightness" has been included, specifying that both helmet and motorcycle colours are bright. Predominantly white, yellow, red, green, orange, gold and silver colours are considered 'bright', whereas black, blue, grey, brown and purple are considered 'dark'. Rider's gender and age have been tried as possible confounders or effect modifiers.

Opposite or perpendicular traffic flows, adverse weather conditions, high displacement motorcycles and four wheels vehicle drivers with low experience in riding, all are elements that seem to increase the likelihood of being involved in garment conspicuity-related crashes. Given these results, a comparison between controls and cases involved in frontal or perpendicular collisions, taking into account only powerful motorcycles (>250 cm³) showed that bright colours of both motorcycle and rider's helmet are more frequent in the control group. This paper adds more evidence towards the fact that shining garments and motorcycles could be perceived more easily by drivers. Countermeasures modifying the appearance of motorcycles and helmets can reduce the risk of a class of motorcycle crashes.

Table 9.1: Odds ratio (OR) of a motorcyclist being involved in a crash, according to "brightness" of helmet and motorcycle.

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

^a Adjusting for age.

^b Reference category.

Perception and appraisal of approaching motorcycles at junctions

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Why do drivers pull out in front of approaching motorcycles at t-junctions? Two possible reasons are that drivers fail to perceive the oncoming motorcycle, or that they incorrectly judge that it is safe to pull out. Two experiments were undertaken to assess these two possibilities using static pictures of t-junctions containing either a motorcycle or a car, or no approaching traffic. The approaching vehicles could be at a near, intermediate or far distance from the junction. In Experiment 1 participants were given 250 ms to spot whether a vehicle was present. At far distances motorcycles were spotted less than cars, and correct response times were slower demonstrating a problem with perceiving motorcycles. In Experiment 2 participants were given as much time as necessary to view each picture before deciding whether it would be safe to pull out in front of the approaching vehicle. While participants were more likely to pull out in front of vehicles in the far location, there was no difference between cars and motorcycles. The results suggest that perceptual errors could occur in the first fixation, though providing all the information available is fully processed there is no differentiation between vehicles, arguing against appraisal errors. Figure 9.4 displays the decrease in participant accuracy to perceive the motorcycle at far distances as a function of the interaction between vehicle and distance.

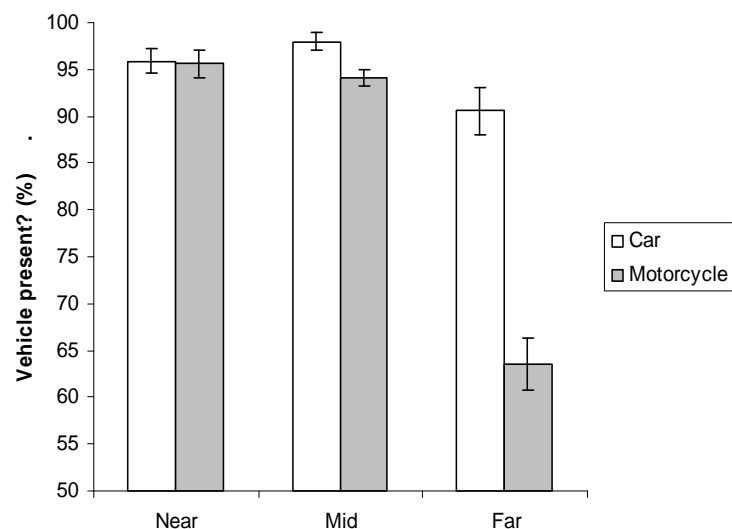


Figure 9.4: The percentage accuracy of car drivers to spot whether vehicles were approaching a t-junction. Motorcycles are poorly represented at far distances.

Perception and appraisal of approaching motorcycles at junctions in experienced drivers and riders

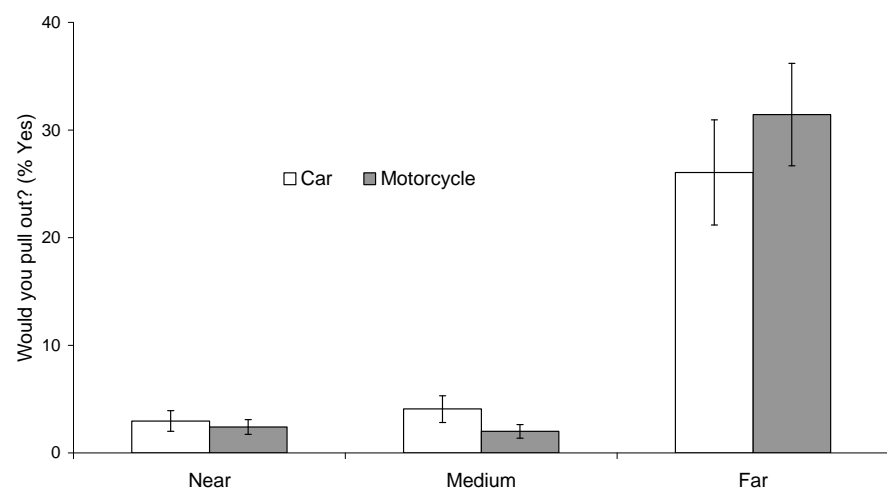
Amit Shahar, David D Clarke & David Crundall

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This study compared the abilities of participants with both car driving and motorcycle riding experience (dual drivers), and of participants with only car driving experience (car drivers) to detect and make judgements about approaching cars and motorcycles in static pictures of t-junctions (cf. Crundall et al., 2008c; see above). In Experiment 1 participants saw pictures for 250 ms with a motorcycle or a car at one of three distances from the junction, or no approaching traffic. They had to report whether an approaching vehicle was present (Figure 9.5). Vehicles that were farthest away from the junction were spotted the least and had slower response times, though this degradation was greater when a motorcycle was present (in support of Crundall et al., 2008c). Dual drivers actually responded more slowly than car drivers, especially with closer vehicles, suggesting a more cautious response.

In Experiment 2, participants were shown the same pictures but were given up to 5 seconds to decide whether it was safe to pull out from the junction (imaging that they were in a car). Participants were more willing to pull out in front of far vehicles, and this tendency was pronounced for motorcycles. Dual drivers were more likely than car drivers to pull out of a junction in front of a far vehicle compared to the car driver group, but they took longer over this decision when the vehicle was a car. The results extend those of Crundall et al. (2008c) by demonstrating that appraisal errors may have a role to play (along with perceptual errors) under certain conditions. The results have also shown a complex interplay of motorcycle experience with the other factors, suggesting that dual drivers over-estimate their ability to pull out of a junction in front of other vehicles (lack of caution) yet take special care over decisions relating to approaching cars (an increase in caution).

Figure 9.5: Percentage responses to pull out in front of a car or motorcycle as a function of the interaction between vehicle and distance. Error bars represent standard errors of means. This graph represents an interaction which demonstrates that motorcycle arrival times may be over-estimated under certain conditions.



Car drivers' attitudes towards motorcyclists: A review

David Crundall, David D Clarke, Patrick Ward, Craig Bartle

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A framework for interpreting the literature and evidence on car drivers' skills and attitudes towards motorcyclists is proposed (Figure 9.6). The framework relates attitudes, knowledge and skills/strategies to three behaviours: Does the driver look at the motorcyclist? Does the driver realise that it is a motorcyclist? Does the driver correctly decide whether the motorcyclist poses a hazard? The additional factor of stimulus-driven influences ('bottom-up' influences) is included in the framework. The review of the literature first identifies a number of bottom-up factors such as A-frame obscuration, movement and conspicuity.

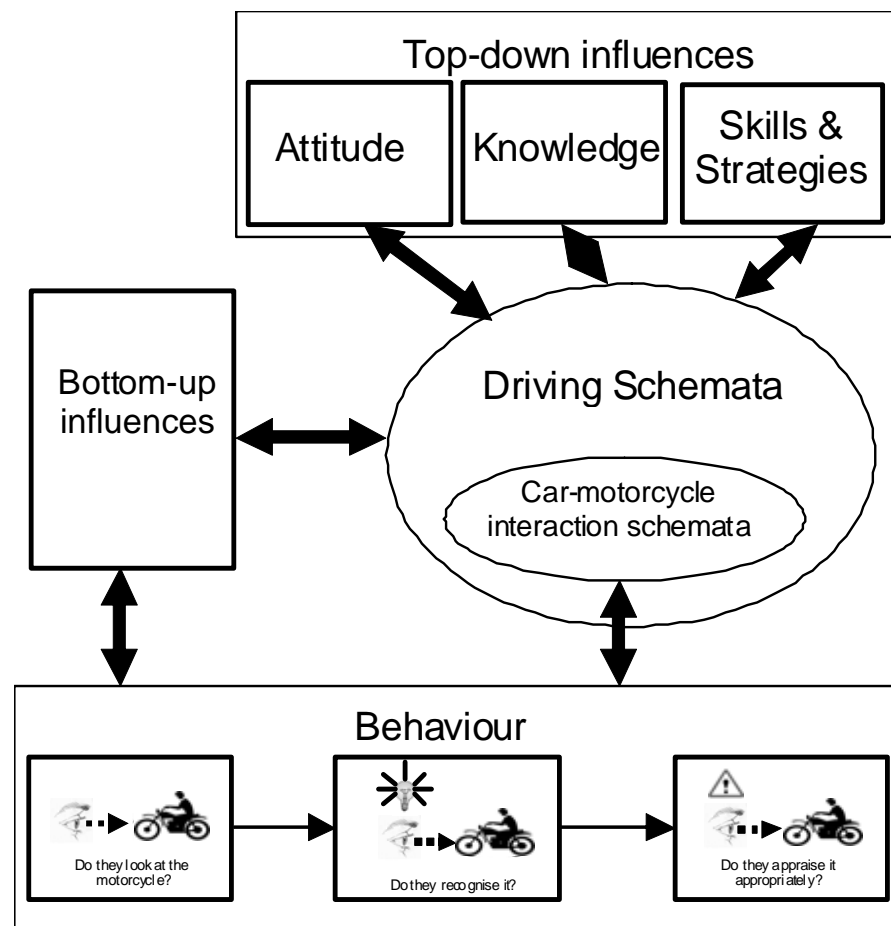


Figure 9.6: A framework to show how car drivers' attitudes can influence the detection of motorcycles.

One particular bottom-up influence seems especially relevant: spatial frequency (the width of the vehicle). Global Precedence theory suggests that we extract low spatial frequency items from a visual scene first (including wide vehicles such as cars). Thus we are more likely to miss narrow motorcycles, which are considered to be high spatial frequency items. Whether a driver looks at a motorcycle can be dependent on many things, including experience and practice with particular road contexts, learned regularities of specific road environments, and the extent of peripheral vision. Attitudes can indirectly influence whether drivers make all appropriate visual checks, and on the basis of the literature review it is suggested that speed may be an important mediating variable. If intentions to speed actually result in higher speeds, then visual search is constrained. Going through a junction at speed reduces the time available for appropriate visual checks.

Whether a driver realises that they are looking at a motorcycle is a more subtle question. In theory a driver could look directly at a motorcycle yet not perceive it. This is the truest form of the Looked But Failed To See error (LBFTS). This again potentially relates to the spatial frequency of the motorcycle, but also to expectations and previous exposure. Empathy with the motorcyclist's plight appears important. Drivers with relatives who ride motorcycles have been reported to have fewer collisions with motorcyclists and have better observation skills in regard to motorcycles.

It is possible that a driver looks at an approaching motorcycle, and even perceives the motorcycle, yet still makes a manoeuvre that leads to a collision. This could occur because they misjudge whether it poses a potential risk, or fail to correctly appraise the approaching motorbike. One of the key theories is the 'size-arrival effect'. According to this theory, approaching speed is related to the size of the vehicle. The consequence of this is that the narrower image of the motorcycle compared to the car may result in the driver over-estimating the time of arrival. The final conclusion summarises the factors of importance and argues for future directions for research in this area to help reduce motorcycle accidents on UK roads.

Car drivers' attitudes towards motorcyclists: A survey

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Motorcyclists are over-represented in UK traffic accident statistics. Many car–motorcycle accidents are however due to the inappropriate actions of car drivers. It is predicted that car drivers at risk of collision with motorcycles have divergent attitudes and beliefs about motorcyclists compared to safer drivers, which may lead to a deficient mental model guiding their interactions with motorcyclists. To assess car drivers' attitudes towards motorcyclists, a survey was undertaken. Over 1300 respondents completed a 51 item questionnaire that included the 3 main factors of the Driver Behaviour Questionnaire (DBQ), 24 motorcycle related items, and 3 general items (driving enjoyment, self-reported frequency of appropriate visual checks, and a measure of frequency of near accidents). Respondents were split into 4 categories of driving experience: less than 2 years, between 2 and 10 years, above 10 years, and finally a group who had more than 10 years experience of both driving a car and riding a motorcycle (termed dual drivers). The three DBQ scales were reliable. Women reported more lapses. Males reported more violations. Drivers with between 2 and 10 years driving experienced reported the most violations. The two least experienced driver groups reported the most errors.

Fifteen of the 24 motorcycle items produced 4 factors, reflecting (a) negative attitudes toward motorcyclists, (b) empathic attitudes toward motorcyclists, (c) awareness of perceptual problems, and (d) spatial understanding. Analyses performed on the negative attitudes toward motorcyclists suggested that all driver groups have higher negative attitudes compared to the dual drivers, and in some cases it is the drivers with between 2 and 10 years experience who have the most negative attitudes towards motorcyclists. Analysis of the empathic attitudes revealed greatest empathy from the dual drivers, followed by those drivers with over 10 years of car driving experience. Analysis of the perceptual problems suggested that females report greater problems with spotting motorcycles at junctions and estimating their speed. All driver groups with no experience of riding a motorcycle reported that motorcycles were difficult spot at junctions. Analysis of spatial understanding scores suggested that females give larger estimates of the width of a motorcycle compared to males. Non-factor items also produced some interesting results.

- Dual drivers gave higher ratings for performing all appropriate visual checks when driving
- The least experienced drivers believed it was easier for motorcyclists to make sudden swerves to avoid accidents compared to car drivers
- Dual drivers agreed more strongly than other drivers that motorcyclists take greater precautions in wet weather compared to car drivers

- Females gave higher ratings on a number of items relating to an inability to spot motorcycles
- Drivers without any motorcycle experience believed that the motorcycle should ride closer to the gutter compared to the responses given by the dual driver group
- Drivers without any motorcycle experience also agreed more strongly than the dual driver group with the statement that motorcyclists often perform inappropriate manoeuvres

Using motorcycle hazard perception clips and simulators to improve knowledge and attitudes towards motorcyclists.

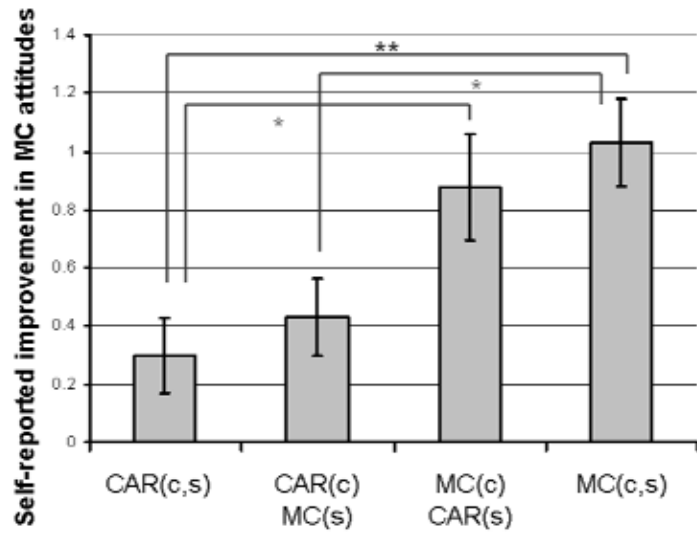
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This study sought to induce positive attitudes and reduce negative attitudes towards motorcyclists amongst car drivers by exposing them to some of the demands that motorcyclists face. For this purpose, hazard perception clips taken from a motorcyclist's perspective, and a motorcycle simulator were used. Car hazard perception clips and a car simulator were used as control conditions. Half of the participants watched clips taken from a motorcyclist's perspective, and half watched clips taken from a driver's perspective. Half of each of these two groups engaged in motorcycle simulated driving and half engaged in car simulated driving. A questionnaire was used to assess knowledge and attitudes towards motorcycles, two weeks before and at the end of the experiment (based on Crundall et al., 2008a; see above).

The results showed that at the end of the experiment the participants had more empathic attitudes and fewer negative attitudes, as well as safer attitudes towards motorcyclists in respect to spatial understanding and perceptual knowledge (Figure 9.7). This improvement was found to be related to the consistency between the clips and the simulator type, but not necessarily to the specific treatment that the participants received. Nevertheless, there was some evidence that the motorcycle hazard perception clips contributed more than the other treatments to participants' perception of their attitude-change. The results also revealed that improvement depended on the initial knowledge and attitudes: those participants with the worst attitudes towards motorcyclists were also the ones who benefitted most.

Figure 9.7: Self-reported improvement in attitudes according to treatment condition. CAR(c) = car hazard perception clips; CAR(s) = car simulator; MC(c) = motorcycle hazard perception clips; MC(s) = motorcycle simulator.



'MotorcycleSim': An evaluation of rider interaction with an innovative motorcycle simulator

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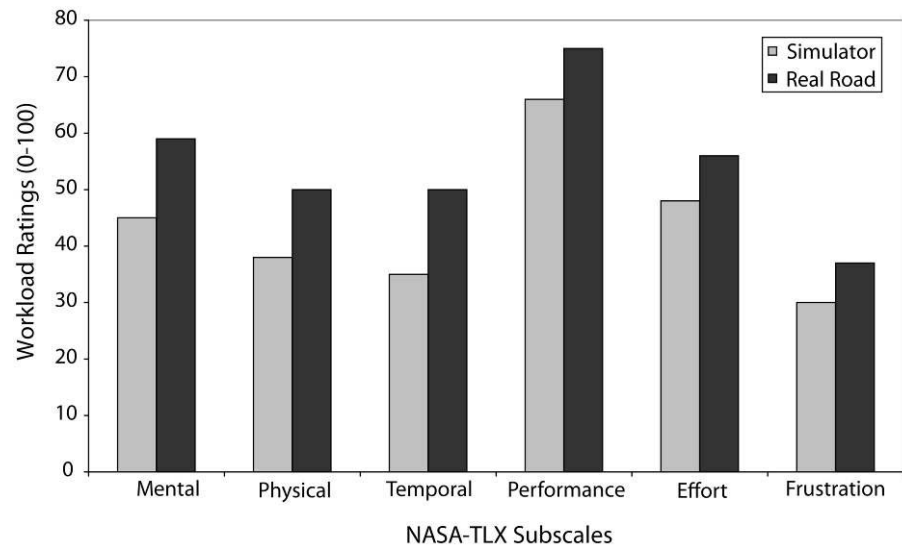
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A user-centred design was employed in the development of an innovative simulator (Figure 9.8) for research into motorcycle ergonomics and rider human factors. Building on initial user requirements and user experience elicitation exercises, an evaluation was conducted to investigate specific issues associated with simulator fidelity. An experimental approach was employed to examine the physical and functional fidelity of the simulator. Using different steering and visual feedback configurations, a battery of objective and subjective dependent variables were analysed including: user perceptions and preferences, rider performance data, rider workload, rider comfort issues and the first evaluation of simulator sickness for a motorcycle simulator. The results indicated that across a number of measures, aspects of functional fidelity were considered more important than the physical fidelity of the simulator. Furthermore the similar pattern noted across the NASA-TLX measures of workload for both real riding and simulated riding indicate that the simulator has relative validity (Figure 9.9). This evaluation takes the development of the simulator a stage further and the paper provides recommendations for future improvements.



Figure 9.8: A rider leans into a bend on MotorcycleSim

Figure 9.9: A comparison on on-road and simulator workload measures. The similar pattern suggests that the virtual riding produces the same relative variation in different subscales of workload



Motorcyclists' and car drivers' responses to hazards

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This study assessed the degree to which hazardous vignettes are perceived as dangerous and realistic by car drivers and motorcycle riders (Exp. 1) and whether riders could be distinguished from drivers on their performance in a commercial motorcycle simulator (Figure 9.10), during safe and hazardous riding situations using the same hazards (Exp. 2). In Experiment 1, car drivers and motorcyclists received a questionnaire which consisted of short descriptions of the scenarios used in the simulator. Half of the car drivers and half of the motorcyclists were told to imagine they were driving a car through the scenario. The other halves were told to imagine they were riding a motorcycle.



Figure 9.10: The motorcycle simulator screen (presented at approximately 3 x 2 metres)

Respondents with the mindset of a motorcyclist rated the scenarios as more realistic than respondents with a car driver's mindset (Table 9.2). Real-life riders however reported the scenarios as more dangerous than real-life drivers, suggesting that their specific motorcycle experience influenced their criterion for danger.

Table 9.2: Mean (SD) realism and danger scores for the four subgroups created by the license x mindset design.

		Motorcyclists drivers	Non-motorcyclists drivers
		M (SD)	M (SD)
Realism	Motorcyclist mindset	5.74 (.65)	5.47 (.99)
	Car driver mindset	5.44 (.81)	5.06 (.76)
Danger	Motorcyclist mindset	5.95 (1.01)	5.35 (.86)
	Car driver mindset	5.56 (.85)	5.12 (.97)

In Experiment 2, naïve participants navigated a simulated route with the same hazards. Performance was coded on objective (e.g., crashes) and subjective (e.g., riding safety and skill) criteria. Experiential differences on some of the measures (and the absence of such differences on other measures, see Table 9.3) suggest that the simulator is useful for distinguishing riders from drivers during safe periods of riding but not necessarily during hazardous periods of riding. The implications of why hazard vignettes discriminate but the same simulated hazards do not are discussed, with emphasis on the crucial elements required to design a successful simulated hazard.

Table 9.3: Means (SD) and *t*-values for the comparisons between non-motorcycling drivers and motorcycling drivers on five dependent variables (* significant at .05 ** significant at .001).

	Motorcyclists drivers	Non-motorcyclists drivers	
	M (SD)	M (SD)	t-value
Time (sec) to complete the route	354 (48.75)	318 (49.65)	1.85
Number of stalls	5.31 (2.4)	.85 (1.4)	5.67**
Safety score (out of 10)	5.77 (1.8)	7.62 (1.8)	-2.62*
Skill score (out of 10)	3.92 (1.94)	7.77 (2.09)	-4.87**
Number of crashes	2.77 (1.17)	2.92 (1.12)	-.34

The development of driving simulators: Toward a multisensory solution

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The use of dynamic driving simulators (Figure 9.11) by researchers and engineers is expanding rapidly due to the many advantages of simulation as compared to traditional methods of investigation, and also as a result of rapid technological progress over the past decades. However, because every simulator is a prototype and there are no set manufacturing standards, their validity and possibilities for development can be questioned. This paper reviews recent developments in the design of simulators for use in research, and describes the reasons and means supporting these innovations.



Figure 9.11: The National Transport and Safety Research Institute (INRETS) simulator.

After defining the need for multisensory stimulation, we describe the main sensory interfaces (visual, motion, tactilo-kinesthetic, and sound stimulation), while paying particular attention to the problem of longitudinal movement cueing and its consequences on braking behaviour. For each of these subsystems, we determine the impact of the most important parameters and their interactions. We point out how the current devices have evolved over time, and describe possible alternatives. We also examine how driving tasks affect the choice of a simulator configuration and its validity. Finally, we tackle the limitations of simulators in relation to simulator sickness, which has been widely studied but not yet overcome.

This review demonstrates the need for in-depth research, not only to assess the validity of simulators and their technological changes, but also to guide their future development. A chart summarizes the features of current driving simulators and describes a wide variety of configurations.

Developing a multiple-screen hazard perception test to investigate car-motorcycle collisions

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Current research in our laboratory is focused on the development of a hazard perception test that will allow research into two major types of collision between cars and motorcycles. The first occurs when cars pull out of junctions into the path of on-coming motorcycles who have the right of way. The second type of accident occurs when the car driver is changing lanes and comes into conflict with an overtaking or filtering motorcycle. We rejected the use of simulators as we wanted realistic textures and distracters as found in video-based hazards perception tests. Unfortunately the typical view provided by a standard hazard perception test does not allow either accident to be investigated, as the field-of-view does not allow drivers to look down the road at t-junctions for approaching vehicles, and no mirror information is provided (see Figure 9.12). To overcome this we filmed our clips with 6 cameras (three forward, three rearward to provide mirror information) mounted on a car. Seventy-five participants (of varying driving experience) viewed the subsequent clips while eye movements and behavioural responses were recorded (Figure 9.13). Analyses are currently being conducted to identify whether drivers fail to look for motorcycles, or whether they look at motorcycles but fail to process them, or whether the problem lies with appraisal (based on the static methodology used by Crundall et al., 2008c).

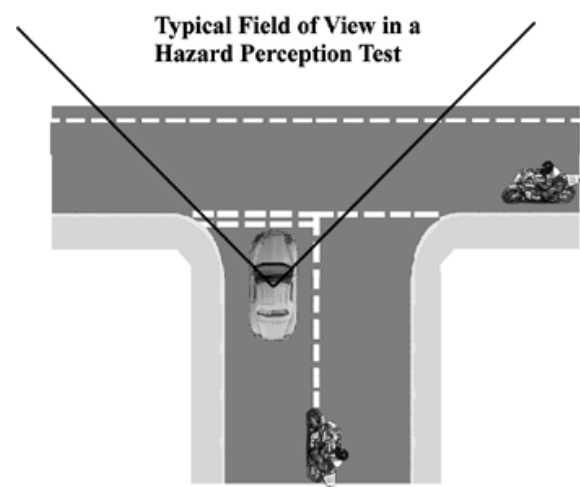


Figure 9.12: Typical hazard perception clips do not allow us to assess the most important car-motorcycle interactions



Figure 9.13: The three-screen hazard perception rig in the laboratory