THE HUMAN FACTORS OF SIMULATION AND ASSESSMENT

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Increasing Motorcycle Conspicuity

Design and Assessment of Interventions to Enhance Rider Safety

Edited by Lars Rößger, Michael G. Lenné, Geoff Underwood

INCREASING MOTORCYCLE CONSPICUITY

Human Factors of Simulation and Assessment

Series Editors

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Ongoing advances in lower-cost technologies are supporting a substantive growth worldwide in the use of simulation and naturalistic performance assessment methods for research, training and operational purposes in domains such as road, rail, aviation, mining and healthcare. However, this has not been accompanied by a similar growth in the expertise required to develop and use such systems for evaluating human performance. Whether for research or practitioner purposes, many of the challenges in assessing operator performance, both using simulation and in natural environments, are common. What performance measures should be used, what technology can support the collection of these measures across the different designs, how can other methods and performance measures be integrated to complement objective data, how should behaviours be coded and the performance standards measured and defined? How can these approaches be used to support product development and training, and how can performance within these complex systems be validated? This series addresses a shortfall in knowledge and expertise by providing a unique and dedicated forum for researchers and experienced users of simulation and field-based assessment methods to share practical experiences and knowledge in sufficient depth to facilitate delivery of practical guidance.

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Foreword

Stéphane Espié

'Sorry mate I didn't see you' is one of the most common explanations given by drivers when they cut-across motorcyclists at intersections. 'I didn't see him' is invoked by pedestrians being hit by motorcyclists, for instance at pedestrian crossings.

The difficulties to properly detect the arrival of powered two-wheeled vehicles' (PTW) and to evaluate their approaching speed are clearly concerns for road safety. The problem is not only perceptual but also cognitive. The relatively low number of PTW in the traffic can partially explain a bad understanding, thus anticipation, of their specific behaviours.

To improve their detectability, and in many countries, PTW have for years to use their daytime-running lights (DRL) in the day time. The recent broadening of the use of car lights during the day, with various marketing-based signatures, may sometimes be a problem for the detection of PTW due to an increase of visual noise.

Several approaches may be proposed to increase the PTW/rider conspicuity, by enlarging the visible shape of the vehicle and/or of the rider. However many proposed solutions where not supported by scientific evidence …

The 2BESafe project aimed at conducting a broad set of scientific research to better understand the motives that underlie PTWs' over-involvement in road accidentology. The 2BESafe program was structured into six research work-packages that included: fundamental research on crash causes and human error (WP1); the world's first Pan-European naturalistic driving study involving instrumented PTWs (WP2); an experimental research on motorcycle rider risk awareness and perception (WP3); the development of research tools to support the 2BESafe human factors and behavioural research program (WP4); a large-scale research program on the factors that underlie drivers' failure to see PTWs and their riders (WP5); and the development of practical countermeasures for enhancing PTW rider safety deriving from all these activities (WP6) (see www.2besafe.eu for more information).

Within WP5, particular attention was given to the PTW conspicuity issue, and several studies have been conducted aimed at paving the way of future improvements in terms of vehicle and/or rider visibility, some of them requiring some changes in the regulation. This work was achieved within the WP5.2 task that involved Dresden Technical University (Germany), Ben Gurion University

(Israel), INRETS/LPC (France), INRETS/MSIS (France), Monash University (Australia) and Nottingham University (United Kingdom).

This book synthesizes this late research field, and I hope it will help researchers, practitioners and stakeholders to propose, in the near future, relevant improvements for road safety regarding PTWs.

PART I
Setting the Stage: Motorcycle Safety and Conspicuity

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Chapter 1

PTW Crashes and the Role of Perception

Zoi Christoforou, George Yannis, John Golias and Peter Saleh

Introduction

Powered two-wheelers (PTWs) are a vulnerable class of road users with *increased accident frequency and severity* (Vlahogianni et al., 2012). In the early 1990s, motorcycle death-rate-per-mile-travelled was estimated to be 22 times the death rate for passenger cars (Preusser et al., 1995). In 2007, US motorcycle riders had a 34-fold higher risk of death in a crash than people driving other types of motor vehicles (NHTSA, 2007). In 2008, European motorcyclists represented 17 per cent of road fatalities while only accounting for 2 per cent of road users (IRTAD, 2009). In Greece this figure is as high as 33 per cent (IRTAD, 2013) while in Singapore it reaches 49 per cent with more than two motorcyclists being killed every week (Haque et al., 2012). Higher crash risk is associated to the fact that driver- and rider-related factors are much more prevalent in PTW accidents compared to vehicle- and environment-related factors. In particular, there exists a clear over-representation of inappropriate perception in PTW crashes (Van Elslande et al., 2013). One often discussed reason for perception failures is that PTW are less conspicuous than other motorized road users (Rößger et al., 2012). Consequently, gap acceptance is often inadequate due to the size-arrival illusion (Horswill et al., 2005); the latter refers to small objects being perceived to arrive later than larger ones. Besides conspicuity, car drivers seem to encounter difficulties in understanding PTWs' manoeuvres and, thus, fail to foresee PTWs' behaviour; foresight is the result of the combination of circumstantial data and permanent knowledge and beliefs (Ragot-Court et al., 2012).

Conspicuity can be examined from two different angles; namely the *sensory and the cognitive perspectives*. Sensory conspicuity is the visual distinction of an object due to its physical characteristics (Wulf et al., 1989). It refers to the extent to which an object can be distinguished from its environment because of its characteristics: angular size, eccentricity, brightness against the background, colour and so on. It reflects an object's ability to attract visual attention and to be precisely located as a result of its physical properties (Rogé et al., 2012). The size and vehicle dynamics of PTWs are such that they have lower sensory conspicuity (Gershon and Shinar, 2013). Cognitive conspicuity depends on the distinction of an object based on the observer's experiences and interests (Wulf et al., 1989). It is linked to the fact that an observer's focus of attention is strongly influenced by his/her expectations, objectives and knowledge (Rogé et al., 2012). Interestingly, inappropriate expectations may be even more important in accident causation than the motorcyclist's physical properties (Hole et al., 1996). PTWs show lower cognitive conspicuity as they account for relatively few vehicle miles travelled compared to automobiles, especially in Western countries (Gershon et al., 2012). Furthermore, not all car drivers have previous PTW riding experience. Helman et al. (2012) distinguishes further among:

- visibility: the extent to which an object stands out from its surroundings when observers are *aware* of its location;
- search conspicuity: the extent to which an object stands out from its surroundings when observers are *searching* for it within a scene;
- attention conspicuity: the extent to which an object stands out from its surroundings when observers are viewing the scene, but *not searching* deliberately for the object.

Vision is the predominant sensory modality used when driving (Crundall, 2011). Consequently, *conspicuity is an important* issue to all road users: be it cyclists (see, for example, Lacherez et al., 2013; Madsen et al., 2013); pedestrians (see for example, Tyrrell et al., 2004); or car drivers (see, for example, Alferdinck, 2004; Berg et al., 2007). However, evidence shows that vulnerable road users tend to underrate the role of visibility factors and conspicuity benefits (Lacherez et al., 2013) while overestimating their own conspicuity (Wood et al., 2013). Comparisons between bicycle and motorcycle crashes suggest that the majority of both crash types occur at intersections and are due to conspicuity issues (Haworth and Debnath, 2013). Nevertheless, PTWs seem to be more concerned due to a combination of factors including high speeds and acceleration rates (if compared to cyclists and pedestrians) and small size (if compared to other motorized road users).

Indeed, PTW conspicuity has been long been recognized as a critical PTW *crash contributory* factor. In 1975, the Greater London Road Safety Unit identifies a certain PTW over-representation in accidents. Detailed analysis of crash data followed. Results indicated that a major contributory factor was the failure of other drivers to observe PTWs in the general street scene (Lalani and Holden, 1978). Riders were then encouraged to wear bright clothing, preferably of fluorescent material and to switch on headlights during the daytime. A lot of research has been undertaken since 1975 on the so-called 'PTW conspicuity hypothesis'. Accident investigations have been carried out in many countries and report that between half and three-quarters of motorcycle accidents involve collision with another vehicle (Huang and Preston, 2004). Markedly, most right-of-way (ROW) accidents involving PTWs are attributed to conspicuity (Pai et al., 2009) while drivers of other vehicles are at fault in the majority of two-unit motorcycle crashes (Haworth and Debnath, 2013).

In view of the above, this chapter's objective is to examine the main determinants of riders' accident risk which are related to conspicuity issues. We perform a literature review in order to explore the role of conspicuity in PTW crash occurrences. English-language publications were selected for relevance through a comprehensive search of major databases (see Table 1.1). The key words used in the search were: ‘conspicuity’ and ‘motorcycles’. To be included, papers were assessed against additional criteria; mainly relevance and publication date. The latter was thought to be critical as earlier literature reviews do exist. In the following section, we briefly discuss the effectiveness of conspicuity interventions. A detailed overview can be found in Chapters 4–10. In the third section, we review PTW accident risks and severity outcomes. Finally, we summarize findings and provide conclusions.

Conspicuity Interventions and Contextual Factors

PTW conspicuity risk can be defined as an increased probability of ‘low’ conspicuity. As many previous studies show (Helman et al., 2012; Lin and Kraus, 2009; Pai, 2011; Wulf et al., 1989) the conspicuity level is changing, relative, and largely dependent upon contextual factors. PTW conspicuity may be related to the motorcycle, to other vehicles, to the riders themselves, to other drivers, to the road environment or to any combination of those factors. Moreover, they may be associated to exogenous or endogenous, modifiable or non-modifiable factors. For example, riders can use daytime running lights to decrease their probability of collision with another vehicle (Saleh et al., 2010), but they do not control ambient traffic conditions. Also, frontal, lateral and rear motorcycle sensory conspicuity may differ significantly. Most importantly, conspicuity is not constant but changes with the time of day, the weather conditions, the urban environment, the presence or absence of other road users. A negative or neutral element, such as a dark jacket in night-time conditions, may have a positive impact in daytime. Inversely, a daytime conspicuity intervention may prove to have a negative impact during night-time. Therefore, it is difficult (if not impossible) to establish a rigorous taxonomy of conspicuity risks and to assess their impact under all possible circumstances. The related literature considers different road environments (rural vs. urban, intersections, light vs. heavy traffic), varying lighting conditions and driver attributes and has mainly focused on the following type of measures:

- Vehicle lights (Cavallo and Pinto, 2012; Farmer and Williams, 2002; Jenness et al., 2011; Hole et al., 1996; Janoff and Cassel, 1973; Lenné and Mitsopoulos-Rubens, 2011; Muller, 1982; Perlot and Prower, 2003; Rumar, 1980; Smither and Torrez, 2010; Thomson, 1980; Umar et al., 1996; Yuan, 2000; Zador, 1985).
- Rider clothing and motorcycle colour (Burg and Beers, 1978; Gershon et al., 2012; Hole et al., 1996; Olson et al., 1981; Smither and Torrez, 2010; Watts, 1980; Williams and Hoffmann, 1979).

- Rider experience (ACEM, 2004; Crundall et al., 2012; Crundall et al., 2008; Mitsopoulos-Rubens and Lenné, 2012).

Riders' Accident Risk

PTWs are believed to have a higher risk of getting involved in accidents compared to other vehicle drivers. If involved in accidents, PTWs are also more likely to experience severe injuries. In New Zealand, for instance, motorcyclists represent 13 per cent of deaths and 9 per cent of road injuries while motorcycles represent only 3.5 per cent of registered vehicles (Helman et al., 2012). This over-representation is even greater if considering the lower mileage of motorcycles: they undertake around 0.5 per cent of travel time or trip legs (Walton et al., 2013). Furthermore, the cause of the majority of PTW accidents is human error and the most frequent human error is a failure to see the PTW within the traffic environment, due to lack of driver attention, temporary view obstructions or PTW low conspicuity (ACEM, 2004). Zador (1985) relates conspicuity to single-vehicle accidents. He claims that one-fifth of PTW single-vehicle accidents result from riders trying to avoid other vehicles. However, low conspicuity is primarily associated with car-versus-motorcycle (CVM) collisions. Inadequate motorcycle visibility is an associated factor in 64.5 per cent of CVM collisions and it is the sole identifiable cause of 21 per cent of collisions (Williams and Hoffmann, 1979).

In CVM collisions, car drivers are mostly at fault: the most common motorcycle crash type is when an automobile manoeuvres into the path of an oncoming motorcycle at an intersection which involves a motorist infringing upon the motorcycle's right-of-way (ROW) (Helman et al., 2012; Pai et al., 2009; Wulf et al., 1989). The motorcycle's ROW is more likely to be violated at unsignalized T-junctions (Pai and Saleh, 2008), non-built-up roads and in poor light conditions (Pai et al., 2009). In an early effort, Fulton et al. (1980) reported that about 67 per cent of near-misses and motorcycle accidents were due to another driver failing to detect the oncoming motorcyclist before emerging from a side turning or before turning across the motorcyclist's path. Preusser et al. (1995) explored a US database of 2,074 crashes fatal to the motorcycle rider and conclude that approximately one-quarter of total crashes are due to some other vehicle failing to grant the ROW and moving into the path of the motorcycle. ROW violations are involved in 40 per cent of all CVM crashes in Great Britain (Clarke et al., 2007) and 64 per cent of CVM crashes (Walton, 2010) in New Zealand. The frequency of this crash pattern is such that PTW ROW violation by another vehicle has become representative of both CVM collisions and conspicuity-related crashes. Umar et al. (1996) define conspicuity-related motorcycle accidents as 'all accidents involving motorcycles travelling straight or turning onto a ROW and colliding with pedestrians and other vehicles'. However, other crash types (single-vehicle accidents for example) and different pre-crash manoeuvres (overtaking for example) may be also related to low PTW conspicuity. Inversely, PTW ROW violations may be due to reasons other than low conspicuity. Sometimes drivers do not look at all when pulling out of a junction; this is not a conspicuity issue (Helman et al., 2012). Nevertheless, this information is available only in laboratory experiments. Most of the accidents (65 per cent) collected in straight sections were motor vehicle collisions between a passenger car and a PTW. Almost half of accidents occurred in darkness, suggesting a problem of sensory conspicuity (Spanish investigation within the project 2BESafe; Saleh et al., 2010).

First and foremost, car drivers violate motorcycle ROW because they 'look but fail to see' (LBFS). LBFS accidents happen when a driver pulls into the path of an oncoming motorcyclist and claims not to have seen him/her approaching (Herslund and Jorgensen, 2003). LBFS accidents mostly occur in daytime. Indeed, daytime PTW conspicuity is lower as, during night-time, headlights provide a strong contrast to the lighting environment (Wulf et al., 1989). Secondarily, car drivers violate motorcycle ROW because they fail to correctly judge the path or speed of the PTW (Gould et al., 2012a). CVM collisions then occur as a result of drivers accepting an inadequate gap among conflicting traffic (Pai et al., 2009). Experimental evidence proves that drivers make more accurate judgements regarding the approaching speed of cars than the speed of motorcycles, especially in night-time conditions (Gould et al., 2012a). Motorcyclists often experience reduced visibility when wearing glasses, visors or wind shields (NPRA, 2004).

Lin and Kraus (2009) classify conspicuity in a Haddon's matrix as a pre-event risk factor related to human, vehicle and environmental crash aspects. Besides the three interventions discussed previously, the following factors seem to be influential:

a. *Human factors*
   Age and gender have an impact on identification and reaction times or even on the effectiveness of conspicuity aids (Smither and Torrez, 2010). Elderly and female motorists appear to be over-represented in gap-acceptance crashes (Pai et al., 2008). Magazzù et al. (2006) suggest that motorcycle conspicuity is lower among older car drivers. Clarke et al. (2007) provide evidence that older and experienced drivers seem to have more problems detecting approaching motorcycles particularly at T-junctions. Injuries to riders are greatest in angle oblique collisions with elderly motorists while teenage motorists seem to predispose riders to a greater injury risk in angle perpendicular crashes while (Pai, 2009). Furthermore, some authors attribute car drivers' failure at junctions to the higher workload during turning manoeuvres at intersections (Hancock et al., 1990) or even to their negative view towards motorcyclists (Crundall et al., 2008). It should be noted that many human factors that are critical to road safety (fatigue, alcohol impairment, drug use and so on) have not been examined under the conspicuity hypothesis.

b. *Vehicle speed and distance*
PTW distance from the viewer is not only a contributing conspicuity factor but also influences the effectiveness of different aids in increasing conspicuity (Gershon and Shinar, 2013). The possible influence of speed on low motorcycle conspicuity has been suggested by a number of authors (see Kim and Boski, 2001; Williams and Hoffmann, 1979). Clabaux et al. (2012) examined the effect of motorcyclists' speed on their involvement in LBFS accidents in France. The authors performed a kinematic reconstruction of 44 accident cases occurring in both urban and rural environments. Results indicate that in urban environments the approach speed of motorcyclists involved in LBFS accidents is significantly higher than in other accidents at intersections. In rural environments, the speed difference was not found to be significant.

c. *Road environment*
Motorcycles' ROW is more likely to be violated on non-built-up roads (Pai et al., 2008). Nevertheless, evidence shows that PTW crashes mostly occur in urban areas while passenger cars are the most frequent collision partners (ACEM, 2004). In the ACEM study (2004), over half of PTW crashes took place at intersections while 90 per cent of all PTW accidents occurred in light to moderate traffic conditions. Poor visibility conditions (horizontal curvature, vertical curvature, darkness) are responsible for increased motorcycle injury severity (Savolainen and Mannering, 2007). Poor sight-line visibility and rider/bike conspicuity are likely to contribute to motorcycle accidents at intersections (NPRA, 2004). Moreover, riding in darkness without street lighting was related to severe motorcyclists' injury (De Lapparent, 2006; Pai and Saleh, 2007, 2008). Motorcyclists are found to be more vulnerable during night time at both intersections and expressways (Haque et al., 2009). Injuries resulting from early morning riding, in general, appear to be the most severe, especially in junctions controlled by stop, and give-way signs and markings (Pai and Saleh, 2007).

Haque et al. (2012) explored motorcycle crash occurrences in Singapore where motorcycles account for 16.3 per cent of motorized vehicle fleets. The authors specified a log-linear model over a database, including a total of 13,568 occurring on expressways, at intersections or away from intersections. Night-time influence was found to increase crash risk particularly during merging and diverging manoeuvres on expressways, and turning manoeuvres at intersections. The authors suggest that this is due to night-time conspicuity. Of course, conspicuity explains to an extent the latter but other factors may come into play as well: lower traffic volumes and higher speeds, more sensation-seeking and risk-taking behaviours and so on. Intersections (poor sight-line visibility and rider/bike conspicuity are likely to contribute to motorcycle accidents at intersections). Analyses of Spanish PTW crash data show that the most frequent type of intersection where accidents occurred is a roundabout (7 out of 8) in interurban areas. Most of the accidents collected in these junctions occurred without daylight conditions so it could be suggested that kerbs should be painted with the aim of raising their conspicuity (Saleh et al., 2010).

Overall, accident studies and *post-hoc* crash investigations establish only indirect links between crash outcomes and conspicuity factors and interventions. The difficulty in directly associating conspicuity interventions to safety outcomes starts from the very definition of conspicuity-related motorcycle accidents that remains rather unclear. A second major barrier to establishing this link is that conspicuity-related factors cannot be collected from conventional (national) crash databases (Shaheed et al., 2012). In the absence of relevant data, researchers mainly perform before-after evaluations or longitudinal studies comparing crash data with and without the treatment. In all these cases, the presence of bias – due to site particularities or other reasons – cannot be excluded. A third methodological problem consists in comparing among subsets of crash dataset: single- vs. multi-vehicle motorcycle accidents, daytime vs. night-time motorcycle accidents and so on. Such comparisons juxtapose crashes with clearly different causes. Comparisons between groups of crashes with common causes (for example, car drivers' failure to detect a car) would be more appropriate. Besides, empirical evidence shows that CVMs are not that different from CVCs. Cercarelli et al. (1992) investigated 500 CVM crashes and compared them to over 3,000 CVC crashes. The analysis did not identify any consistent pattern between crash-type and lighting conditions. Walton et al. (2013) performed a case-control study between CVC and CVM crashes in New Zealand. This analysis again showed that CVM crashes are not easily distinguished from CVC crashes as they follow similar patterns.

We identified only two recent studies establishing empirical causal links between conspicuity and motorcycle accident risk. In 2004, the ACEM funded a comprehensive Motorcycle Accident In-Depth Study (MAIDS) project that covered five European countries: France, Germany, Italy, Spain and the Netherlands. The authors compared 921 motorcycle accident cases with 923 controls and offered very interesting insights on conspicuity contributory factors. White PTWs were found to be over-represented in crash occurrences. Dark PTW rider clothing decreased conspicuity in 13 per cent of all accidents. Wells et al. (2004) designed an innovative population-based case-control study in New Zealand. The authors interviewed 463 motorcycle riders (cases) involved in car-motorcycle crashes resulting to the motorcyclist's injury or death. In the latter case, a proxy respondent was interviewed instead. In addition, 1,233 motorcycle riders were randomly recruited and interviewed (controls). Statistical analysis of responses revealed that injury crashes mainly occurred in urban zones with 50km/h speed limit, during the day and in fine weather. Riders wearing reflective and fluorescent clothing had a 37 per cent lower risk. The use of a white helmet was associated with a 24 per cent lower risk compared to a black helmet. DRL was found to be associated with a 19 per cent lower risk of involvement in injury crashes. No association was found between risk and the frontal colour of rider's clothing or motorcycle.