Increasing road user conspicuity: Design and assessment of interventions to enhance rider safety

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Abstract

The use of Powered Two Wheelers (PTW; motorcycles, scooters, mopeds) continues to steadily increase in both developing and developed countries. Increasing the visibility of PTWs to other road users will become a progressively important avenue for improving rider safety. The package of research presented in this paper was part of the European Commission's 2-be-Safe project, involving 27 research organisations across Europe and Australia, a world first human factors approach to better understanding and improving PTW safety. A package of this research, involving 8 research groups across Europe and Australia, this paper presents the first collection of research that examines the influence of a wide range of factors on PTW rider detection by car drivers. The experimental studies presented here used driving simulation and still images to assess the efficacy of various treatments (clothing colour, lighting configuration, etc) on drivers' interactions with PTWs. This paper focuses on the outcomes from the Australian research. This research provides detailed theoretical and practical guidance on the development and evaluation of measures designed to increase PTW visibility in traffic.

Introduction

Safety problems arising from accident studies

Motorcycles represent less than 4% of the number of registered vehicles in Victoria, and account for around 1% of vehicle kilometres travelled. In Victoria in 2012, 22% of fatally injured riders were involved in head on or overtaking crashes and 24% were involved in crashes with another vehicle at an intersection (Transport Accident Commission, 2013).

Internationally, results of the MAIDS-study (ACEM, 2004) showed that 64 % of all considered PTW accidents in urban areas were PTW to passenger car collisions. Numerous studies have found that car drivers are significantly more often responsible for accident causation by right-of-way errors and/or turning errors than PTW riders (see Rößger et al., 2012). Further findings suggest that failures in perception, in particular, contribute to the risk of collisions between PTW riders and other vehicle drivers. The MAIDS-study showed that, of the proportion of all PTW accidents, a considerable number (36.6%) arose primarily from the inability of other road users to perceive the PTW rider. According to analyses of 212 motorcycle-to-other-vehicle accidents in the United Kingdom (UK; McCarthy, Walter, Hutchins, Tong, & Keigan, 2007), traffic scan errors by the drivers of other vehicles contributed to accident causation in 67% of the cases.

Given these findings it is reasonable to consider phenomena related to PTW conspicuity as a critical factor in the interaction between PTWs and cars. In order to conduct experiments focusing on problems of PTW conspicuity, it is appropriate to focus on those situations which are particularly risky for PTW riders. Thus, identifying typical situations of critical multi--vehicle interactions is one starting point: what are typical situations where the interactions between drivers and riders are more likely to cause drivers to misperceive or neglect PTW riders?

Analysis of 1790 accident files in the UK (Clarke, Ward, Bartle, & Truman, 2004) revealed that the most prevalent type of accidents involving PTW riders were right-of-way-violations at T-junctions or crossroads. Further, the other vehicle was most often at fault in accidents of this type. These crash patterns are mirrored in several other studies (e.g., Sexton, Fletcher, & Hamilton, 2004; Haworth, Mulvihill, Wallace, Symmons, & Regan, 2005).

The conspicuity of powered two wheelers

Previous research has indicated that, relative to cars, PTWs are not detected as readily. Rumar (2003) stressed that primary reasons for the poorer detection of PTWs included poor conspicuity and errors in drivers' ability to estimate PTW speed accurately. Studies considering PTWs' conspicuity have suggested that the *visual conspicuity* of PTWs is reduced due to their small size, their often dark colours, and their irregular contours (Hancock, Wulf, Thom, & Fassnacht, 1990; Olson, Halstead-Nussloch, & Sivak, 1981). With regards to motorcyclists' clothing, Wells et al. (2004) identified a relationship between helmet colour and accident risk. Wearing a white helmet (rather than a black one) was found to reduce rider accident risk. In the MAIDS study, it was found that the motorcycle riders' use of dark clothing decreased their conspicuity by 13% (ACEM, 2004). However, it was also found that the use of bright clothing enhanced PTW conspicuity in only 5% of cases. It is worth noting, however, that in the MAIDS study the contribution of clothing to overall conspicuity was determined by ratings of the investigators and thus was subjective.

More important than the fluorescent nature or colour of the motorcycle (or the clothing/helmet) in and of itself is the contrast between the motorcycle (and the motorcyclist's clothing) and the background against which the motorcycle appears (Hole, Tyrrell, & Langham, 1996). The effect of the background was also considered in the MAIDS study, where background conditions positively affected PTW conspicuity in 7.5% of cases, and negatively affected conspicuity in 14.4% of cases. In a recent experiment carried out with a car-driving simulator, the sensory conspicuity of motorcycles doing filtering manoeuvres was improved through a modification in the level of colour contrast between the motorcycle and the traffic (Rogé, Ferretti, & Devreux, 2010). It was found that a high colour contrast improves the conspicuity of motorcycles in certain speed and traffic conditions for some motorists.

According to Brenac et al. (2006), the *cognitive conspicuity* of PTWs is poor because of unusual behaviours (such as high speeds) and low exposure frequencies. The role of inadequate expectations due to the low exposure rate of motorcycles has also been discussed by Wulf et al. (1989) as a critical factor in the late detection of PTWs. Thus, road users develop expectations based on their everyday driving activities and build up mental models which may efficiently support recognition and decision-making processes within the majority of situations but which may be inadequate in certain other situations. For example, when a driver, with the intention of turning, is looking for other vehicles to give way to at an intersection, the driver is more likely to expect to see an approaching car rather a motorcycle, particularly in regions where the prevalence of PTW in traffic is low. Furthermore, PTW riders often appear at locations which are unusual for other vehicles (e.g. between lanes and on the shoulders) and thus can be unexpected by drivers (Shinar, 2007). The crucial role of such conceptual-driven processes is also supported by analyses conducted by Magazzù, Comelli and Marinoni (2006). These authors reported that car drivers who also hold a motorcycle licence are less likely to be involved in car-motorcycle collisions than car drivers who do not hold a motorcycle licence.

Daytime running lights (DRLs) have been discussed quite frequently as a means by which to increase PTW conspicuity. The use of DRLs by motorcyclists became mandatory in many countries in the 1970s, on the basis of the assumption that DRLs enhance the attraction of road users' attention towards a PTW by increasing the PTWs' contrast with the background. It has been suggested that this attention-attracting feature can compensate to some extent for low expectancies and attentional failures (Shinar, 2007). The positive effect of DRL usage on preventing PTW accidents has been supported by numerous studies (Hendtlass, 1992; Olson, et al., 1981; Williams

& Hoffmann, 1979; Zador, 1985). Using slides of traffic situations as stimuli, Hole and Tyrell (1995) found that observers detected motorcycles with DRLs more rapidly than unlit motorcycles.

Besides the enhancement of the object-background-contrast, Rumar (2003, p. 7) identified as a further potential advantage of DRLs that DRLs could "*work as a means to identify a vehicle category*". Experiments conducted by Hole and Tyrell (1995) showed that motorcycles without running lights were detected more slowly when subjects had previously been repeatedly exposed to motorcycles with running headlights. The authors argued that due to the repeated exposure of motorcycles with running headlights, drivers develop a "*perceptual set*" for detecting motorcycles. That is, a distinctive and unique feature (headlight ON) will be associated with the presences of a motorcycle, and in consequence, will be used as a cue to accelerating recognition processes and decisions about whether a motorcycle is present or not. Thomson (1980) also emphasised the safety potential of a unique and standardised identifier on motorcycles, which could facilitate recognition of motorcycles by other motorists and enhance motorcycle conspicuity. In addressing the question of whether a cue is reliable, and thus appropriate for facilitating recognition and decisions, Thomson discussed two aspects as critical. A class of objects should be homogeneous with respect to the appearance of cues within the class (standardised) and the appearance of the cues should be heterogeneous between different classes of objects (unique) (Theeuwes & Godthelp, 1995). If both requirements are fulfilled, cues might potentially serve as valuable guides even within recognition processes that occur automatically. In that way, DRLs might provide a consistent feature, a sort of visual signature, which would make it easier for other users to identify PTWs.

In Europe until recently, PTWs were the only vehicle type to operate with their lights on during daytime hours. However, in 2008, the European Commission, introduced the requirement (ECE-R87) that, from 2011, all new cars in Europe be fitted with dedicated white DRLs. The possible loss of PTWs unique features in Europe raises concerns that the introduction of DRLs on cars could result in a decrease in PTW conspicuity and safety.

Objectives and research questions

The European Commission recently co-funded an extensive world-first three-year program of human factors research into Two-Wheeler Behaviour and Safety ("2-Be-Safe"). Involving coordinated efforts from 27 research partners across Europe, Israel and Australia, the 2-Be-Safe project was the first major project to address human factors issues concerning PTW safety.

One of the work packages, led by the Technical University of Dresden, was devoted to studying the role of PTW conspicuity in improving safety for riders. Key areas of focus included the examination of the influence of differently lighting configurations and backgrounds on driver detection of PTW in simulated environments. The data presented in this paper are from the Australian component of the study. The data collected in the UK, France, Israel and Germany as part of this project are presented in Rößger et al. (2012).

Method

Participants

A total of 43 drivers (36 males and 7 females) completed the study. The mean age of participants was 37.06 years (SD = 9.33). All participants were experienced car drivers.

Driving simulator

The study was carried out in the portable driving simulator (ECA-FAROS EF-X) facility located at the Monash University Accident Research Centre (MUARC) in Melbourne, Australia. The simulator consists of a small, stationary cab with an adjustable seat, pedals, steering wheel, gear box and seat belt. The visual images for the driving scenarios are presented on three 19 inch LCD monitors, providing a field of view of 120 degrees. Stereophonic sound is delivered through speakers and is used to provide the driver with engine noise and the sound of other traffic.

Scenario Design and Procedure

Each of the simulator trials contained a gap acceptance task where drivers completed a right-turn across the path of oncoming vehicles. The scenarios were developed using a two-lane urban road (speed limit of 60 km/h) with a single unsignalised "T" intersection. Weather conditions were clear and all trials simulated daytime lighting.

All simulator trials had the same basic design. As the participant in the simulator cab ("own-cab") travelled towards the intersection, a series of four vehicles (all travelling at 60 km/h) approached from the opposite direction in the adjacent lane. Participants' task was to turn at the first opportunity where they felt that they had sufficient room in the stream of oncoming traffic to turn through safely. This is illustrated in Figure 1.

At the intersection, the positioning of the oncoming vehicles relative to own-cab was such that participants had two options: either to attempt to turn through the gap between the second vehicle and the third vehicle ("target vehicle") or to wait until all four vehicles had passed the intersection before turning. This gap acceptance paradigm had been used successfully to differentiate the turning performance of novice and experienced drivers (Mitsopoulos-Rubens, 2010; Mitsopoulos-Rubens, Triggs and Regan, 2009) and therefore was adapted for the current study (see Figure 1).

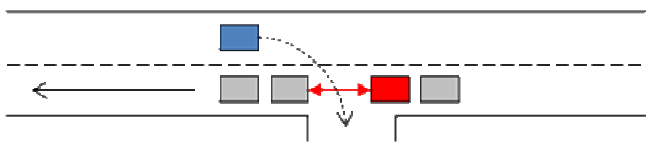

Figure 1. Schematic of the gap acceptance scenario. The rectangles represent the vehicles in the scenario. The red rectangle indicates the target vehicle while the blue represents the participant's vehicle.

The nine experimental trials were developed using the combinations of the three time gap levels (short, medium, long) and the three target vehicle types (passenger car, motorcycle headlights on, motorcycle headlights off). These nine trials were presented twice, along with four trials in which there was no target or fourth oncoming vehicle. These four trials served as distracter trials, and were not included in any of the analyses. A total of 22 trials were developed.

Across trials all vehicles (including motorcycle riders' clothing and helmet) were of a similar colour (dark green-blue). This colour palette was similar to that of the scenario background, and was deliberately chosen to maximise the likelihood of the motorcycle headlight manipulation distinguishing effectively between those scenarios where the motorcycle had low sensory conspicuity (headlights off) and those scenarios where the motorcycle has relatively higher sensory conspicuity (headlights on). This distinction was verified by colleagues at the University of Nottingham through an analysis of the motorcycles' saliency using the Itti and Koch (2000) saliency algorithm, which offers an approach through which to differentiate the most conspicuous objects in an image from those that are less conspicuous.

Analysis showed that the motorcycle was the most salient object in the image when the motorcycle headlights were on, In contrast, when the motorcycle headlights were off, the motorcycle did not feature in the top six objects identified through the analysis as the most salient objects in the image. With the exception of the motorcycle with headlights on, all vehicles in the scenarios operated with their headlights off. After consenting to participate in the study the participants completed several familiarisation and practice trials. All 22 trials were presented to participants in one of four pseudo-random orders. At the conclusion of the session, each participant was compensated a nominal fee for their involvement.

Experimental design

The overall design of the study was a 3 x 3 within-subjects design. The two within-subjects variables were: target vehicle (passenger car, motorcycle with headlights on, motorcycle with headlights off), and time gap (short, medium and long). Time gap was the distance in seconds between the front of the second oncoming vehicle and the front of the target vehicle. Gap acceptance data were analysed using the generalised estimating equation (GEE) approach.

Results

To explore gap acceptance, data were drawn from all trials where a target vehicle was present – that is, where the target vehicle was a car, a motorcycle with lights on, or a motorcycle with lights off. Of principal interest was the effect of motorcycle headlight status (on or off) on individuals' gap acceptance decisions. The expectation was that heightened sensory conspicuity (i.e. headlights on) would be associated with fewer gap acceptances than relatively lower sensory conspicuity (i.e. headlights off), with this difference being most pronounced at the short and medium time gaps. The condition where the target vehicle was a passenger car served as a further baseline condition. The general expectation here was that participants would accept fewer gaps overall ahead of the passenger car than ahead of a motorcycle with headlights off.

The initial GEE estimated several effects, including main effects of target vehicle and time gap, and the interaction between target vehicle and time gap. Of interest here, the final GEE model showed a significant time gap main effect ($\chi^2(2)=105.62$, $p<0.01$), and a significant time gap x target vehicle interaction ($\chi^2(4)=10.07$, $p=0.04$). The interaction is depicted in Table 1.

Table 1. Proportion of trials where the gap was accepted for each target vehicle at each time gap (MC = motorcycle)

Time Gap	Target Vehicle Type		
	Car	MC lights on - High Saliency	MC lights off - Low Saliency
Short	8.9	1.1	9.2
Medium	41.6	49.9	42.9
Long	84.9	80.7	82.6

Before exploring the interaction it is first important to highlight that, in general, participants responded to increases in time gap as intended, with a higher rate of gap acceptance associated with the longest time gap and the lowest rate associated with the shortest time gap. This pattern is confirmed through the time gap main effect. The interaction appears to have been driven by different rates of gap acceptance across the three target vehicle types at each of the three time gaps. At both the short and long time gaps, there were fewer trials where the gap was accepted when the target vehicle was the motorcycle with lights on than either when it was the car or the motorcycle with lights off. This difference appears to be more pronounced at the short time gap.

A separate GEE was carried out for each time gap to further explore the interaction. A significant target vehicle main effect was observed at the short time gap only ($\chi^2(2)=6.21$, $p<0.05$). Examination of the parameter estimates confirms that, at the short gap, the odds of accepting a gap ahead of a motorcycle with headlights off were significantly greater than the odds of accepting a gap ahead of a motorcycle with headlights on (Relative OR=0.127; 95% CI=0.024-0.679). No other significant differences between target vehicle conditions were observed. More detailed results are published elsewhere (Mitsopoulos-Rubens & Lenné, 2012).

Discussion

The aim of the Australian component of the research was to explore, in a driving simulator, the effects of manipulating sensory conspicuity (motorcycle low-beam headlights) on drivers' decisions to turn across the path of an oncoming motorcycle in daylight conditions. The general expectation was that improvements in sensory conspicuity would lead to fewer gap acceptances overall and, in particular, at the short and medium time gaps.

The findings were partly in accordance with expectations. Target vehicle was found to interact with time gap to influence drivers' gap acceptance. Specifically, the results suggest that improvements in motorcycle sensory conspicuity - through low-beam headlights at least - may confer some benefit in gap acceptance, albeit at short distances only, by encouraging drivers to accept fewer gaps ahead of a motorcycle with headlights on than ahead of a motorcycle with headlights off. The overall implication of these findings is that low-beam headlights are associated with more conservative rates of gap acceptance at the shortest, most safety critical time gaps only – an effect that could be the result of earlier detection and more accurate perception of the approaching object as a motorcycle which carries with it a certain level of risk that ought to be avoided.

Also noteworthy is that the odds of accepting a gap ahead of a passenger car did not differ from those of accepting a gap ahead of a motorcycle with headlights off. This is contrary to previous findings (e.g., Hancock, Caird, Shekhar and Vercruyssen, 1991), which suggest that, because of their smaller size, more gaps are accepted ahead of a motorcycle than a passenger car because of drivers' tendency to overestimate motorcycles' time-to-arrival. It is unclear why this effect occurred. One possibility is that, even though the passenger car was larger than the motorcycle, the passenger car was still not overly conspicuous given that its colour palette resembled that of the scenario background. A further possibility relates to the presence of the fourth oncoming vehicle, a passenger vehicle, which may have obscured any effects due to potential misjudgements in time-to-arrival. The time-to-arrival effect is often presented as an alternative to the sensory conspicuity hypothesis of why motorcycles feature prominently in right-turn/left-turn against crashes (e.g., Olson, 1989). The present results suggest that the issue is more complex and is likely to involve a combination of contributing factors, including both conspicuity failures and errors in time-to-arrival estimates.

There is another dimension of conspicuity that is interesting to consider here: the role of expectancies shaped by individual experiences. There is evidence that car drivers who are also licensed motorcycle riders are involved in fewer car-motorcycle collisions than car drivers who do not hold a motorcycle licence (Magazzù, Comelli and Marinoni, 2006). It has been suggested that the mechanism underlying this effect is that drivers who are also motorcycle riders have a heightened awareness of, and are more attentive towards, motorcycles on the road (Wulf, Hancock and Rahimi, 1989). That is, relative to drivers with no riding experience, drivers who are also riders may be more attuned to riders on the road leading to more efficient detection and perception of a motorcycle and/or more conservative appraisal of the risk posed by the approaching motorcycle. This would translate, in either case, to more efficient and cautious decision making, for example, with drivers who are also riders electing to turn ahead of a motorcycle on fewer occasions than a driver with no riding experience. This issue relates to the concept of "cognitive conspicuity", which has been defined as the salience or prominence of an object as determined by its significance to the observer (e.g., Hancock et al., 1990). To date, little systematic research has been undertaken to explore in a more direct sense the role of cognitive conspicuity on individuals' decisions to turn across the path of a motorcycle. It is conceivable that riding experience may moderate the effects of motorcycle low-beam headlights on drivers' decision making. That is, while sensory conspicuity treatments might act directly on detection and perception processes to influence driver decision making indirectly, cognitive conspicuity treatments, which rely on top-down processing, might influence the extent to which the effects of sensory conspicuity treatments are realised. Further research can aim to explore and disentangle the mechanisms underlying the effects observed here.

In summary, the research presented here constitutes further evidence in support of low-beam headlights on motorcycles as a mechanism through which to improve motorcycle sensory conspicuity during daytime conditions. While the effects were not as widespread as expected, the results still suggest that there is the potential for more cautious decision making at short time gaps. Further research in a more realistic setting, with less contrived traffic and environmental conditions, would be advantageous in helping to corroborate the present findings.

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