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Cyclist visibility at night: Perceptions of visibility do not necessarily match reality

by JM Wood*, RA Tyrrell**, R Marszalek*, P Lacherez*, T Carberry*, BS Chu*, and MJ King***

*School of Optometry and Institute of Health and Biomedical Innovation, Queensland University of Technology, Brisbane, Australia

**Department of Psychology, Clemson University, South Carolina, USA

***Centre for Accident Research and Road Safety - Queensland (CARRS-Q), Queensland University of Technology, Brisbane, Australia

Abstract

Visibility limitations make cycling at night particularly dangerous. We previously reported cyclists' perceptions of their own visibility at night and identified clothing configurations that made them feel visible. In this study we sought to determine whether these self-perceptions reflect actual visibility when wearing these clothing configurations. In a closed-road driving environment, cyclists wore black clothing, a fluorescent vest, a reflective vest, or a reflective vest plus ankle and knee reflectors. Drivers recognised more cyclists wearing the reflective vest plus reflectors (90%) than the reflective vest alone (50%), fluorescent vest (15%) or black clothing (2%). Older drivers recognised the cyclists less often than younger drivers (51% vs 27%). The findings suggest that reflective ankle and knee markings are particularly valuable at night, while fluorescent clothing is not. Cyclists wearing fluorescent clothing may be at particular risk if they incorrectly believe themselves to be conspicuous to drivers at night.

Keywords

Night visibility, Cyclists, Reflective clothing, Age

Introduction

Cyclists are considered to be among the most vulnerable of all road users. They have among the largest proportion of self-reported near-miss crashes, significantly higher than that of motorists and comparable to that of pedestrians [1]. The injury consequences of a crash are also more severe for cyclists, where the probability of a cyclist being seriously injured following involvement in a crash was found to be almost 27% in Australian data collected over a four-year period [2]. The vulnerability of cyclists was further highlighted by Sonkin et al. [3], who reported that while child pedestrian fatality rates per 10 million miles fell from 1.08 to 0.27 (75%) during the period 1985 to 2003, child cyclist fatality rates only decreased from 0.84 to 0.55 (35%) per 10 million miles travelled.

Night-time cycling has been shown to be more dangerous than cycling in daylight, with 40% of cyclist fatalities occurring at night despite much lower exposure rates than in the daytime [4]. Rodgers [5] notes that while only 12% of cyclists reported that they rode after dark, 35% of cyclist deaths occur outside of daylight hours. The role of visibility in contributing to fatal accidents was examined further by Owens and Sivak [6], who

found that 78.8% of all fatal collisions involving vulnerable road users (cyclists or pedestrians) occurred during low-light conditions. When visibility was degraded further by poor atmospheric conditions, such as rain or fog, 92.3% of all fatal accidents involving a vulnerable road user occurred in low-light conditions [6]. A high proportion of cyclist fatalities have been reported to be related to problems with frontal rather than rear conspicuity [7], and motorists involved in night-time collisions with cyclists commonly report that they did not see the cyclist until it was too late to avoid a collision [8, 9].

The use of static or flashing front and rear bicycle lights is one widely adopted approach for improving cyclist visibility and is now a legal requirement when cycling on roads at night in many countries, including Australia. Another relatively inexpensive and practical approach to improving the conspicuity of cyclists is the use of high-visibility clothing.

In a previously published survey of 1460 participants (622 drivers and 838 cyclists), Wood et al. [10] explored the beliefs and attitudes of cyclists and drivers regarding cyclist visibility and safety, and cyclists' use of different clothing configurations, with a particular focus on improving visibility under reduced illumination conditions, including dawn, dusk and night-time. In that study we found that cyclists believe they are more visible (and that they are visible at longer distances) than did drivers under the same circumstances.

This was early evidence that, like pedestrians [11], cyclists may overestimate their own visibility in low light conditions. The survey also revealed that although cyclists endorsed the use of high-visibility clothing and aids, particularly in low-light conditions, relatively few cyclists reported wearing selected high-visibility clothing on a regular basis. Cyclists as a group may thus underestimate the importance of attracting other road users' attention when visibility is limited, such as under night-time conditions.

In the study described above [10], cyclists also rated wearing a reflective vest as being the most effective means of improving visibility, over and above the use of reflective strips worn on the moveable joints. This is relevant because empirical research on the night-time conspicuity of pedestrians has repeatedly revealed the opposite: that reflective strips on the major moveable joints are highly effective in improving pedestrian conspicuity, presumably due to humans' high perceptual sensitivity to distinctively human patterns of joint movement ('biological motion' or 'biomotion') [12].

Numerous studies have demonstrated that drivers are able to recognise the presence of pedestrians more often and at much longer distances when they are wearing reflective strips in a biomotion configuration, than when they wear a reflective vest [13-15]. It is thought that reflective vests are less useful because they limit the placement of the reflective material to the torso, which presents much less motion information to approaching drivers. Although the patterns of movement involved in cycling are inherently different from those associated with being a pedestrian, highlighting a cyclist's movements (by placing reflective markings on the cyclist's ankles and knees) might be an effective low-cost approach to enhancing cyclist conspicuity.

In our survey [10] we also found that cyclists may overestimate the usefulness of some visibility aids – for example, fluorescent clothing – at night. Fluorescent clothing acts by converting the wavelength of ultra-violet (UV) light (present in sunlight) to longer visible wavelengths, which leads to an overall increase in reflected visible light under daytime conditions. However, streetlights and vehicle headlights do not provide substantial amounts of UV; thus, fluorescent materials are not a particularly valuable conspicuity aid during typical night-time conditions. Interestingly, the majority of the cyclists and drivers in our survey considered fluorescent bicycle clothing to be more visible at night than white clothing. Therefore, road users may also be inadequately informed regarding the limitations of certain visibility aids. The failure of road users to understand such issues could be critical.

In the current study we evaluated the benefits of a range of visibility aids for cyclists under real world night driving conditions. These data are important, as without objective evidence demonstrating the effect of improving visibility on drivers' perceptions and reactions to cyclists on the road, it is not possible to inform cyclists or other road users with regard to their benefits, or indeed possible limitations.

We included both young and older drivers in this study in order to explore the extent to which driver age impacts on night-time cyclist visibility, given that previous studies have shown that pedestrian visibility at night is significantly impaired with increasing age [13, 14]. We compared the on-road data collected here with the perceptions of cyclists' own visibility that we had gathered in our previous survey-based study, which determined how well cyclists' perceptions of visibility aids aligns with the *actual* benefits of visibility aids [10].

Methods

In this study volunteer participants drove around a closed road driving circuit at night and indicated when they recognised the presence of a cyclist wearing a range of different clothing configurations.

Participants

Participants included 12 young ($M = 25.3$ years, range 18-35) and 12 older ($M = 72.5$ years, range 66-80) visually normal individuals who had a current driver's licence and were regular drivers, with a visual acuity of 6/9 (20/30) or better. The study was conducted in accordance with the requirements of the Queensland University of Technology Human Research Ethics Committee.

Closed-road test circuit and experimental vehicle

All driving was conducted under night-time conditions and was assessed on a 1.8km closed-road circuit [13, 14]. The circuit, which is representative of a rural road, consisted of a two- to three-lane bitumen road and included hills, bends, curves, lengthy straight sections, and standard road signs and lane markings. There was no additional ambient lighting on the circuit, and experimental sessions were only conducted on nights when there was no rain and the road surface was dry.

Two cyclists were positioned at different locations around the circuit, and pedalled in place on a resistance trainer so as to ensure naturalistic cyclist motion, while maintaining a consistent location that is critical for purposes of experimental control (Figure 1). Each cyclist was equipped with a two-way radio, as was the experimenter in the test vehicle. This allowed all communications regarding participant clothing to be conducted between laps and outside of the vehicle, so that the participants could not hear the conversations.

The data presented in this paper relate to the test cyclist positioned at point 'A' at the top left of Figure 1. In order to isolate the effects of clothing on cyclist visibility, the bicycle did not have front or rear lights. We have previously observed that a significant proportion of cyclists do not always use their lights under low-light conditions, and so this reflects a reality of night driving [10].

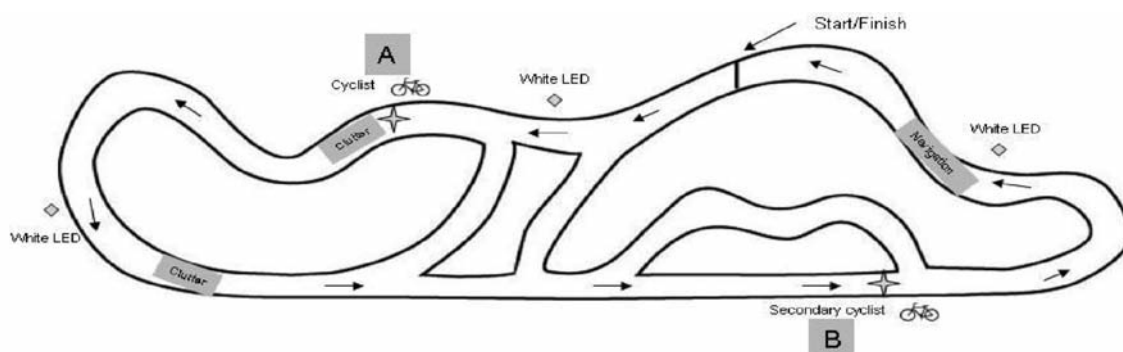


Figure 1. Schematic map of the closed-road circuit showing the location of the two cyclists and the three clutter zones. The test vehicle's direction of travel is indicated by arrows. The position of the glare lights are indicated by stars.

To simulate the effects of other vehicles being present, two pairs of battery-powered headlights were placed along the circuit, in close proximity to the test cyclist. The glare lights were positioned 5.4m in front of and 5.1m to the left of the test cyclist (when viewed from the perspective of an approaching driver). To the driver, these headlights approximated an oncoming vehicle's headlights and the glare from them added a degree of visual challenge. The test cyclist was positioned in the outermost oncoming lane (as seen from the participant's point of view) and was a minimum of two lanes removed from the test vehicle. The test cyclist was also surrounded by clutter provided by an array of reflective cones and posts.

To provide an additional degree of visual complexity and also to act as distracters, three additional clutter zones were set up along the circuit. Two of the clutter zones consisted of small- and medium-sized retro-reflective traffic cones, large retro-reflective posts and flashing amber lights. The third zone consisted solely of three pairs of large retro-reflective traffic cones and was used as a 'navigation zone' – where the driver was required to guide the test vehicle through the zone without hitting any cones. This was done to increase driver workload.

White flashing LEDs were positioned at three locations around the circuit, which served to simulate an oncoming bicycle and also to reduce the expectancy of the drivers. The LEDs were positioned on the right-hand shoulder of the road on black posts at a height approximating the front light of a bicycle.

The direction that the test cyclist faced was also varied between laps to simulate the two most common crash configurations reported by cyclists in our previous paper [10], where 38% reported a crash in which the motorist collided with a cyclist turning across their path when they were both heading in the same direction, and 19% reported being sideswiped. For half of the laps the cyclist faced in the same direction as the driver, and for half the laps the cyclist was positioned side-on to the driver (see Figure 2), as if they were about to enter the traffic from a street at 90 degrees to the driver's direction of travel.



Figure 2. Photograph of the section of the road circuit where Cyclist A was positioned

Clothing conditions

For each lap, the test cyclist wore one of four clothing outfits: (1) a black tracksuit, (2) a black tracksuit with a fluorescent yellow cycling vest with no retro-reflective materials present, (3) a black tracksuit plus a fluorescent yellow cycling vest that included silver retro-reflective markings (Netti Litehook®) on the shoulders, front and rear of the torso, or (4) the same black tracksuit and retro-reflective vest with the addition of 50mm-wide silver retro-reflective strips (3M Scotchlite® 8910 silver fabric) positioned on the cyclist's ankles and knees.

A second cyclist was present on all laps at location B (see Figure 1). This reduced the participants' ability to associate a cyclist with a particular location on the circuit. The second cyclist wore the same range of clothing configurations as the test cyclist in an independently determined random order (minus the fluorescent vest).

Procedures

Participants drove around the circuit in a right-hand drive sedan fitted with two digital video cameras mounted on the roof of the vehicle [16]. The system recorded two overlapping images of the road scene and was linked to a LED marking system, which recorded the moment the participant pressed a large luminous dash-mounted touch pad to indicate recognition.

Participants were given a practice lap in order to familiarise themselves with the car, the road circuit and the tasks required of them. The practice lap was followed by 10 data collection laps. These comprised the eight combinations of cyclist clothing and bicycle direction presented in a random order for each participant, plus two laps where the test cyclist was absent, which was held constant between participants.

Participants were instructed to follow the specified route, to drive at a comfortable speed and to press the touchpad whenever they recognised that a cyclist was present in the road scene ahead. Participants were instructed to read aloud all road signs encountered so as to increase driver workload (these data were not recorded). To quantify the participants' responses to the cyclist we recorded whether the participant pressed the response button at any point along their approach to the cyclist. Thus, we could track the percentage of trials in which the participants correctly identified the presence of the test cyclist.

Results

An independent samples t-test was conducted on the proportion of cyclists recognised by each participant, according to the age group of the participants. There were four false sightings of pedestrians over the total of 240 laps, but this number was too small to be usable in the analysis.

Overall, younger drivers identified nearly twice the number of cyclists as did older drivers; on average, younger drivers identified just over half of the cyclists (51%), whereas older drivers identified just over a quarter (27%). This age effect was

significant, $t(22) = 4.12$, $p < .001$. As can be seen in Figure 3, older drivers did not detect any of the cyclists wearing black or fluorescent clothing, and less than half of the cyclists wearing reflective vests. Younger drivers performed much better; however, they detected less than half of the cyclists wearing black or fluorescent clothing.

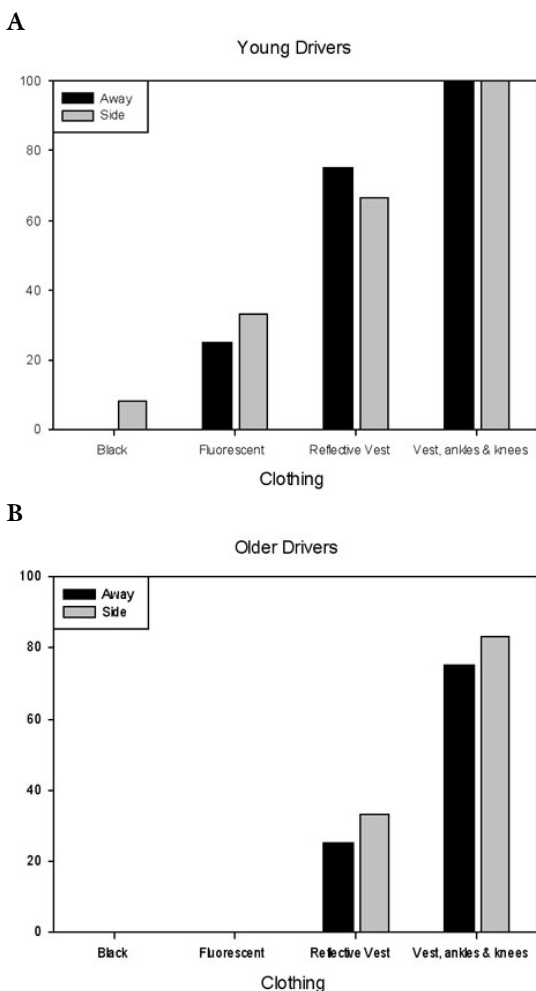


Figure 3. Percentage of cyclists recognised as a function of clothing and cyclist direction for the young (A) and older (B) drivers

A repeated measures t-test was conducted on the proportion of cyclists recognised by each participant according to whether the cyclists were entering the roadway as if from a side road or were pedalling in the same direction as the driver, and found no significant differences $t(22) = .81$, $p = .427$. Data were thus combined across the direction conditions, to enable a two-way analysis of variance between clothing and age in terms of the number of cyclists correctly identified.

The analysis revealed a large overall effect of clothing, $F(3,66) = 45.7$, $p < .001$. Overall, drivers identified the largest number of cyclists wearing the vest plus the ankle and knee reflectors (90% correctly recognised), followed by the reflective vest alone (50%), the fluorescent clothing (15%), and lastly black clothing (2%). All pair-wise differences were significant, with the

exception of black and fluorescent clothing, which were not significantly different from one another.

There was no significant interaction between age and clothing, indicating that the effects of clothing were similar for the two age groups, $F(3,66) = 1.83$, $p = .151$. While older drivers were less likely than young drivers to identify the cyclists, the degree to which they were less successful than young drivers did not vary according to clothing configuration.

Discussion

In this field study we sought to determine how the ability of drivers of different ages to recognise the presence of cyclists at night-time is influenced by the cyclist's clothing. The data demonstrate that cyclist clothing and driver age both significantly affect the ability of drivers to recognise cyclists under real world night-time driving conditions. Collectively these results are important, particularly when considered in the context of our previously collected data regarding cyclists' perceptions of their own visibility and how often they wear such visibility aids.

There was a strong effect of clothing on the percentage of cyclists who were recognised by drivers. Adding ankle and knee markings to a typical reflective cycling vest provides a powerful enhancement of the cyclist's conspicuity. This manipulation increased the percentage of drivers who recognised that a cyclist was present from 50% to 90% overall, with 100% of cyclists being recognised by the younger cohort of drivers.

Even though this configuration did not use a 'full' biological motion configuration, the effect was just as robust as those demonstrated in prior studies for pedestrian visibility [13-15]. That the cyclist only wore the reflectors on the ankles and knees and yet was still easily recognised suggests that 'full' biological motion (i.e., placing reflectors on all major moveable joints) may not be necessary for the successful recognition of cyclists, and that a convenient subset – marking just the ankles and knees – may be sufficient. This hypothesis will be further explored in our future studies.

Recognition of the cyclist wearing the reflective vest without the ankle and knee markings (50%) was better than for the cyclist wearing either the fluorescent (15%) or black clothing (2%), but for older drivers, recognition levels for the vest were as low as 30%. This may be a surprise to the many cyclists who rely on reflective vests as a visibility aid at night. It may not, however, be unexpected to researchers, who have previously demonstrated that pedestrians also have a strong tendency to overestimate their own visibility at night and to underestimate the conspicuity benefits provided by biological motion [11].

The relatively low conspicuity levels of the cyclists when wearing the reflective vest alone is likely to be attributable to the lack of perceptible torso motion signifying the presence of a cyclist. Importantly, in our survey [10], cyclists ranked reflective vests as being most visible under reduced illumination

conditions. Thus, typical cyclists do not seem to appreciate that reflective vests may not maximise their conspicuity and that biological motion markers can increase their conspicuity. Added to this is the low level of use of visibility aids in general by cyclists at night, with only 35% of cyclists reporting that they wear reflective clothing either 'often' or 'always'.

Our findings that the visibility benefits of fluorescent vests are small, that they do not offer a significant improvement on black clothing, and that older drivers fail to recognise cyclists wearing fluorescent clothing on any trials are important when considered in light of the results of our earlier survey [10]. In that study both cyclists and drivers rated the visibility benefits of fluorescent vests to be high even under night-time conditions; indeed, there was little difference in their ranking of the visibility benefits of the fluorescent clothing for either day or night-time conditions.

However, fluorescent materials have little visibility benefit at night, as they are activated only by UV radiation, which is lacking in headlights and streetlights. Cyclists appear to assume incorrectly that the visibility advantage of fluorescent materials is equivalent irrespective of lighting. Thus, cyclists who habitually wear fluorescent – as opposed to reflective – materials may considerably overestimate their visibility at night. This may result in cyclists unintentionally placing themselves at elevated risk. Future research should explore the interaction between bicycle lights and clothing to ascertain whether there are differential effects on cyclist visibility at night.

Overall, the older drivers recognised cyclists significantly less often than did younger drivers. While the younger drivers saw the cyclists 51% of the time, older drivers identified them only 27% of the time and never identified them wearing black or fluorescent clothing. The reduction in the ability of older drivers to recognise the cyclists is likely to be due partly to changes in visual function, especially age-related changes in visual acuity and contrast sensitivity (ability to see faint images), which may be exacerbated under low luminance conditions [17].

Importantly, when the cyclists were wearing the vest with reflectors on the ankles and knees, the older drivers recognised them (80%) almost as often as did the younger drivers (100%). The finding that cyclists are rarely seen by older drivers when they are not wearing reflective clothing at night is important, given the growing numbers of older drivers on our road systems and the fact that many drive at night-time.

Collectively, the findings of this study provide important preliminary data to suggest that cyclist visibility in low light is strongly influenced by the clothing worn by the cyclist, and highlight the importance of education among the general population with regard to the utility of high-visibility clothing. The data also underscore the fact that even alerted drivers commonly fail to recognise the presence of cyclists, dependent on the clothing configurations worn. These data also provide evidence to support our previous findings with regard to

misunderstandings that cyclists have with regard to their own visibility at night and suggest that cyclists may need to be better informed with regard to the limits, as well as the benefits, of specific visibility aids.

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