Pedestrian Visibility at Night: Effects of Pedestrian Clothing, Driver Age, and Headlamp Beam Setting

Joanne M. Wood¹, Richard A. Tyrrell², and Trent P. Carberry¹

¹Centre for Eye Research, Queensland University of Technology, Australia
²Department of Psychology, Clemson University, USA

Corresponding author:
Joanne M. Wood
Centre for Eye Research, School of Optometry
Queensland University of Technology
Victoria Park Rd, Kelvin Grove Q 4059
Australia
Phone: 07 3864 5701
Fax: 07 3864 5665
email: j.wood@qut.edu.au

Richard A. Tyrrell
418 Brackett Hall, Dept. of Psychology
Clemson University
Clemson, SC 29634-1355
USA
Phone: 864-656-4977
Fax: 864-656-0358
email: tyrrell@clemson.edu

Trent P. Carberry
Centre for Eye Research, School of Optometry
Queensland University of Technology
Victoria Park Rd, Kelvin Grove Q 4059
Australia
Phone: 07 3864 5673
Fax: 07 3864 5665
email: t.carberry@qut.edu.au

Submitted August 1, 2002 for presentation at the 2003 Annual Meeting of the Transportation Research Board, Washington, D.C.

Word count: 4553 words
ABSTRACT

Reduced visibility is believed to be a major contributor to night-time pedestrian fatalities. In this study, the ability of drivers to recognize the presence of roadside pedestrians was determined and recognition distances measured using a parallax-based device. Ten young and ten older participants drove at night around a closed road circuit and pressed a button whenever they recognized a pedestrian. Four pedestrian clothing conditions were tested (black, white, retroreflective vest and retroreflective material in the ‘biomotion’ configuration) in both low and high beam conditions. Two pedestrians walked in place on the shoulder of the road, one in darkness (primary) and one in a high glare position (secondary). Response distances were recorded for the primary pedestrian. Overall, drivers identified only 61% of pedestrians in the presence of glare and 76% in the absence of glare, with only 5% of darkly clad pedestrians being identified in the glare condition. Averaged across conditions, the primary pedestrian was identified at 76.5m (251ft), with distances being shortest for darkly clad pedestrians (13m (43ft)), and greatest for the ‘biomotion’ pedestrian condition, which improved response distances by up to 50X. The vest condition failed to produce similar benefits, despite having an equivalent amount of retroreflective material. Overall, older driver response distances were 58% of those of the younger drivers. These results demonstrate that while all drivers have significant difficulty recognizing pedestrians at night, elderly drivers experience even greater difficulty. The results also demonstrate the value of clothing configurations that enhance the perception of biological motion.
INTRODUCTION
Pedestrian fatalities are a major road safety issue. In the United States, 78,000 pedestrians were injured and 4,739 pedestrians were killed in the year 2000; pedestrian fatalities accounting for 85% of all non-occupant fatalities in that year (1). One of the basic driver errors responsible for such collisions is believed to be the late detection of other road users (2). Fatal pedestrian collisions are over-represented at night, where nearly two-thirds (64%) of all fatal pedestrian collisions occur under night-time conditions (1) and more than half of all pedestrian deaths and injuries occur when pedestrians cross or enter the road system (3). Reduced visibility is believed to be one of the major contributors to pedestrian collisions that occur at night (4). This is supported by recent studies which have also demonstrated that crashes involving pedestrians are most common in the dark time periods of daylight saving transitions, in some cases showing up to seven times more risk at night compared to daytime (5). In contrast, this study found that single-vehicle run-off-road crashes showed little difference between light and dark time periods, suggesting factors other than light level play the dominant role in these crashes.

The conspicuity of pedestrians at night can be enhanced by visibility aids such as street lighting, reflectors, reflective clothing and lights. Retroreflective garments, such as vests and jackets are also widely used by construction workers, police and emergency personnel who have greater exposure at night-time, in order to enhance their visibility and safety. Retroreflective material positioned on the moveable joints to create the sense of “biological motion” has also been advocated as a means of enhancing the visibility and recognition of pedestrians (6).

There have been a number of studies that have sought to determine how the use of such visibility aids might enhance pedestrian visibility. Many of these studies have been undertaken in the laboratory, using either slide or video-based representations of pedestrians wearing different clothing combinations. Although these provide good baseline data on which to design field studies, they do not necessarily represent the lighting or environmental conditions, vehicle or pedestrian motion present in real road conditions, nor do they necessarily provide a good sense of face validity. A series of studies have been undertaken under either closed or open road situations where the participants acted as passengers (7,8). Other studies have used participants as drivers on closed road circuits, however, many have used distance measurement techniques which have potential limitations (9), or have used driving populations made up entirely of undergraduate or members of institutions who are not necessarily representative of the general driving population (10).

In the study reported here, we determined the percentage of drivers who recognized pedestrians walking in place on the shoulder of a real road, in the absence (primary pedestrian) and presence of glare (secondary pedestrian). The recognition distances for the primary pedestrian were systematically recorded using a novel parallax-based measurement device. Participants included people recruited from the wider community of a range of different ages. The effect of different pedestrian clothing conditions and headlight beam were also investigated systematically.

METHODS
Participants
There were a total of 20 participants divided into two groups of ten drivers (mean ages: 27.8 ± 4.7 yrs (range 21-34 yrs), and 67.9± 5.30yrs (range 60-75 yrs)). All participants were licensed drivers with at least three years of driving experience, and all reported that they drove regularly. All participants passed the minimum drivers’ licensing criteria for binocular visual acuity of 6/12 (20/40).

Experimental Vehicle & Closed Road Circuit
The experiment was conducted under night-time conditions on a closed road circuit which has been used in previous studies of driving and vision (11). The circuit consists of a bitumen road, with hills, curves, bends and straight sections and standard road signs and road markings. The circuit does not include any street lighting; a 1.8 km (1.1 mile) section of the circuit was used for this study. A series of glare lights, consisting of a set of stationary battery-powered headlights were positioned at three locations along the circuit to simulate the effect of oncoming headlights. These headlights were activated when the test vehicle drove through a remote sensor. A series of 50 cones with retroreflective markers distributed along the circuit acted as distracters and provided a degree of visual clutter.

The experimental vehicle was a 1997 Nissan Maxima, which had been serviced (including headlamp alignment) immediately prior to the experiment. Two synchronized digital video cameras were mounted a fixed distance apart on the roof of the vehicle. This system produced two overlapping digital images of the road scene, and was linked to a fibroptic marking system and response button which recorded the exact moment that the participant recognised a pedestrian, thus identifying the relevant stereoscopic pairs of images. These images were analysed off-line to determine the positions of a corresponding point in the marked images. The change in position of these points is the parallax, which was
measured and the recognition distance thus calculated. The technique has a high level of accuracy and validity, the measured accuracy of the system being better than 5-10% of the true distance (12,13). To minimize measurement error further, traffic cones with retroreflective markers had been positioned strategically in advance. Thus when a participant driver pressed the button to indicate that a pedestrian was recognized, the measurement system was only required to measure the distance from the test vehicle to the nearest traffic cone. The distance from that cone to the pedestrian was known in advance and was added to the measurement.

Four experimenters were involved in any one experimental run. Two experimenters were seated in the experimental vehicle, while two experimenters acted as pedestrians located at different positions on the circuit. Both pedestrians were positioned on one shoulder of the roadway; the test vehicle was driven towards the pedestrians in the far lane, such that there was at least one lane of travel separating the pedestrian and the test vehicle. One pedestrian was situated at the end of a 400 m (1312 ft) straight section of the track and was referred to as the primary pedestrian. The secondary pedestrian stood on an opposite portion of the circuit, 10.2 m (33.5 ft) behind one of the three glare lights. Each pedestrian had a two-way radio, as did the backseat experimenter. All communication was conducted between trials with the experimenter outside of the vehicle, so the subject could not hear the conversations.

Clothing and headlight beam conditions
For each experimental run the pedestrians wore one of four clothing conditions, black, white, vest or biomotion:
- Black: a black cotton sweatshirt (2% reflectance), a pair of black cotton sweatpants, black gloves and black shoe covers.
- White: a large white cotton lab coat (68% reflectance) with white gloves and white cotton leggings.
- Vest: the clothing from the Black condition described above with the addition of a retroreflective panel measuring 30cm x 17.5cm (525 cm²) worn on the chest.
- Biomotion: the clothing from the Black condition with the addition of retroreflective straps (2.5 cm (1 inch)) around the wrists, elbows, shoulders, waist, knees and ankles. The total area of visible retroreflective material was matched to the Vest condition (525 cm²).

Each pedestrian wore each of the four clothing conditions twice, once for a low beam lap and once for a high beam lap. Pedestrians walked in place as the test vehicle approached. This allowed the inclusion of natural pedestrian motion while keeping the pedestrians in a known location.

Procedures
Each participant completed ten laps of the test circuit. The first lap was a practice lap; all data were collected on laps 2-10. To increase driver workload, participants were instructed to read aloud all road signs that they encountered. Their only other instructions were to follow the prescribed route, to drive at a comfortable speed, and to press a large (6 cm x 12 cm) luminous dash-mounted response button as quickly as possible each time they recognized that a pedestrian was present. They were instructed not to press the button until they were confident that what they saw was in fact a pedestrian. They were also informed that there wouldn’t always be pedestrians on the circuit.

Two primary dependent variables are reported here. First, the percentage of trials in which pedestrian recognition occurred is reported. Pedestrian recognition was recorded as having occurred if the driver pressed the response button at any point along the approach to a pedestrian or immediately after having passed a pedestrian. This procedure is conservative in that recognition here does not imply that the driver would have been able to initiate a successful avoidance maneuver. Recognition was measured for both the primary pedestrian (no glare) and for the secondary pedestrian (glare). The second dependent variable is the driver’s response distance, which is defined here as the distance from the vehicle to the primary pedestrian (no glare) at the moment the response button was pressed. Response distances were coded as zero for all trials in which the driver did not recognize the pedestrian or had passed the pedestrian before pressing the button. Detection distances (the driver’s response distance plus the distance traveled during the driver’s reaction time) were also recorded but are not presented here. Response distances to the secondary pedestrian were not measured.

RESULTS
Tables 1 and 2 present the percentage of drivers who correctly identified the presence of the pedestrian, as a function of pedestrian clothing, the beam condition and the age of the driver. The data are given for the identification of pedestrians in the absence of glare (primary pedestrian, see Table 1) and in
the presence of glare (secondary pedestrian, see Table 2) and demonstrate that overall, drivers correctly identified only 61% of pedestrians when glare was present, while 76% were identified in the absence of glare. Importantly, when the data were considered in terms of driver age, less than half of the pedestrians were identified in the presence of glare by the older drivers (48%) compared to 75% for the younger drivers. The data also clearly demonstrate that the darkly clad pedestrians were identified least often, regardless of condition or driver, with only one driver (5%) recognizing the pedestrian wearing black in the presence of glare when the headlamps were on low beam. Interestingly, recognition in these conditions increased to 35% when high beams were used. Also interesting is the fact that recognition of the pedestrians wearing white clothing was equal to or better than recognition of the pedestrian wearing the retroreflective vest. When the same amount of retroreflective material was worn in the biomotion configuration, however, the pedestrians were identified by 100% of the young drivers, and by 75% of the older drivers, even when the glare challenge was present.

The percentage of pedestrians seen was modeled as a function of pedestrian clothing, headlamp beam, presence or absence of glare and driver age using a logistic regression model. This indicated that pedestrian clothing ($\chi^2 = 64.5$, $p<0.000$), headlamp beam ($\chi^2 = 7.9$, $p=0.005$), glare ($\chi^2 = 13.3$, $p<0.000$), and the age of the driver ($\chi^2 = 41.6$, $p<0.000$) were all significantly associated with correctly identifying the presence of the pedestrian.

The response distances for the recognition of the primary pedestrian are represented in Figure 1 as a function of driver age and pedestrian clothing for each beam condition. Averaged across all no-glare conditions, pedestrians were identified at a mean distance of 76.5 m (251 ft) (SE = 7.0m). A mixed ANOVA with two within subject factors (clothing and headlamp beam) and one between subject factor (driver age) demonstrated that the main effects of pedestrian clothing ($F(3,54) = 49.29$; $p<0.000$) and headlamp setting ($F(1,18) = 11.07$; $p=0.004$) were both significant. The main effect of driver age was also significant, indicating that, overall, older drivers had shorter response distances than younger drivers ($F(1,18) = 10.54$; $p=0.004$). None of the interactions were significant. Model-based contrast analysis indicated that the differences in response distances for the different clothing conditions were significant ($p<0.05$), with the exception of the comparison between response distances for the pedestrians wearing white clothing and vest.

**DISCUSSION**

The present experiment sought to quantify the ability of drivers to recognize the presence of roadside pedestrians at night. Young and old drivers drove a test car around a closed-road test circuit and pressed a large dash-mounted response button whenever they recognized that a pedestrian was present. A novel parallax-based measurement system was used to measure response distances. The data strongly demonstrate that pedestrian clothing, headlight beam setting, and the age of the driver all significantly affect both the probability that a driver will recognize the presence of a roadside pedestrian and the distance at which pedestrians are recognized under night-time conditions.

Pedestrian clothing had a strong effect on pedestrian visibility. When the pedestrians wore black clothing, they were recognized on only 52.5% of the younger drivers’ trials, and on only 15% of the older drivers trials. Thus most of the darkly clad pedestrians were never recognized by the drivers. Further, examination of mean pedestrian recognition distances suggests that recognition often occurs at a point that may not allow drivers to stop in time to avoid a collision. These results are in general agreement with those of previous researchers who have found recognition distances of the order of 50 m or less for black or gray dummy pedestrians (7) and for real pedestrians wearing black when the participants acted as passengers (8) and drivers (10). Thus even when drivers are alerted to the possibility of encountering pedestrians it seems clear that they are unable to achieve a safe level of performance in detecting low contrast pedestrians.

The drivers’ ability to identify pedestrians was dramatically improved when pedestrian contrast was increased. When pedestrians wore white clothing, they were recognized on 97.5% of the younger drivers’ trials and on 70% of the older drivers’ trials and recognition distances increased by factors as high as 25X (for the older drivers for the high beam condition). Given the profound effect that clothing reflectance has on pedestrian detection, it is interesting to note that previous studies have demonstrated that pedestrians dramatically underestimate the visibility benefits of reflective clothing (14,15).

The addition of retroreflective materials provided some unexpected results. Merely adding a retroreflective vest on top of the black clothing did not enhance visibility as much as might be anticipated. Indeed, it was only when the same amount of retroreflective material was distributed in the form of

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1 The camera system failed to record the visibility distance for older drivers, when the pedestrian wore white clothing for the high beam condition. The driver saw the pedestrian for that run. The missing data point was replaced by the mean response distance for that age group for that condition (76.1m), this step made no difference to the results of the ANOVAs.
“biomotion”, where the material was attached to the moveable joints, that the effects of retroreflective material exceeded that of wearing white cotton clothing. Such results are in general agreement with those of Owens et al. (16), who showed that wearing retroreflective material in the biomotion configuration, rather than as a diagonal slash of retroreflective material on the chest, had significant advantages in terms of improving older drivers’ ability to recognize pedestrians, although these improvements were not quantified in terms of recognition distances. In the present study, when the pedestrian wore the biomotion configuration in the absence of glare, they were seen on 100% of the trials for both the young and the older drivers. The biomotion advantage was also relatively robust to glare: the secondary pedestrian was recognized by 100% of the young drivers and by 75% of the older drivers. Recognition distances for the biomotion condition were improved by factors as high as 52X when compared with the black pedestrian condition, and these effects were greater for the older drivers. These results support those of earlier demonstrations of the utility of biomotion by Owens et al (6), Luoma et al (8) and Blomberg et al (10).

Still, however, the present data suggest that the benefit of a biomotion configuration is even larger than was thought. Interestingly, Luoma et al (8) showed that the benefits of retroreflective markers on the major joints had even greater effects if the pedestrians were crossing the road rather than approaching the driver as was the case in our study, so the benefits of wearing such materials may be even greater.

Headlamp beam also had a significant effect on recognition. Overall, changing from low to high beam improved recognition distances from a mean of 59 m (194 ft) to 94 m (308 ft), with recognition distances improving by a factor of 3.5 for the black clad pedestrian. The finding that recognition distances are longer under high beam compared to low beam conditions is in general accord with the findings of Mortimer and Olson (17) and also of Shinar (18) whose participants acted as passengers driven along a rural road. However, the latter author also found that the effects of beam were only significant for the darkly clad pedestrians and not when the pedestrians were wearing a retroreflective tag (18).

The ability of older drivers to recognize the presence of pedestrians was consistently worse that that of younger drivers. While young drivers recognized 84% of the pedestrians overall (94% with no glare and 75% with glare), older drivers recognized only 53% of the pedestrians (59% with no glare and 48% with glare). The older drivers also identified the pedestrians at significantly shorter distances compared to the younger drivers. Overall, the recognition distances for the older drivers were 58% of those of the younger drivers. Depending on the clothing and beam conditions, older drivers’ mean response distances, ranged from 0-76% of the mean response distance of the younger drivers. The age effect was particularly strong when the pedestrians wore black clothing. These differences are in general agreement with those of Chrysler et al (9) who reported that sign legibility distances for older drivers were only 65% of those of the younger drivers, and in an object detection task, older drivers had a 20% to 45% reduction in visibility distances compared to the younger drivers. Interestingly, Luoma et al (8) found smaller age-related decreases in pedestrian recognition distances. That may relate to the fact that their participants were passengers, not drivers. The participants in our study drove under realistic conditions while performing a sign detection task.

Perhaps the most important finding of this study was the difficulty that drivers of all ages have in recognizing the presence of roadside pedestrians. Overall, only 76% of the pedestrians were identified when glare was absent and only 61% of the pedestrians were identified when glare was present. Further, the overall mean distance at which pedestrians were recognized (76.5 m (251 ft) for all non-glare trials), was quite short relative to typical total stopping distances. Even more dramatically, when pedestrians were dark clothing and were illuminated by low beam headlamps (conditions which are perhaps most typical), pedestrians were seen on only 40% of the trials without glare and 5% of the trials with glare. Thus even alerted drivers frequently fail to see pedestrians walking along the roadside, and when they do see the pedestrian it may be too late to initiate a successful avoidance maneuver. These results are sufficiently striking to raise serious concerns for the safety of pedestrians at night and to explore methods of making pedestrians more conspicuous to drivers (19,20). Further, the limited ability of drivers’ to see pedestrians at night should be conveyed to pedestrians in an effort to convince pedestrians to avoid placing themselves at risk in the nighttime traffic mix (14, 15).
ACKNOWLEDGEMENTS

The authors would like to express appreciation to Queensland Transport for allowing the use of the facilities at the Mt Cotton Driver Training Centre and to the staff of the Mt Cotton Centre for their generous cooperation and support. Tabitha Faulks and Rachel Pickering are also thanked for their dedicated and able assistance in data collection. This study was supported by grants from the Australian Research Council, Queensland University of Technology and Clemson University.
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**TABLE 2.** Percentage of drivers who recognized the presence of the pedestrian in the presence of glare (secondary pedestrian).
FIGURE 1 Pedestrian recognition distances (m) for the primary pedestrian (no glare) as a function of driver age (young drivers dark bars: old drivers light bars), and pedestrian clothing for the low beam (A) and high beam (B) conditions.
TABLE 1 Percentage of drivers who recognized the presence of the pedestrian in the absence of glare (primary pedestrian)

<table>
<thead>
<tr>
<th>NO GLARE (% recognition)</th>
<th>Young Drivers</th>
<th></th>
<th></th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Black</td>
<td>White</td>
<td>Vest</td>
<td>BioMotion</td>
</tr>
<tr>
<td>Low Beam</td>
<td>70</td>
<td>100</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td>High Beam</td>
<td>90</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Old Drivers</td>
<td></td>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Low Beam</td>
<td>10</td>
<td>70</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>High Beam</td>
<td>20</td>
<td>90</td>
<td>50</td>
<td>100</td>
</tr>
</tbody>
</table>

"Recognition" here is defined operationally as the driver indicating recognition at any time during the approach to the pedestrian or immediately after having passed the pedestrian. Thus recognition does not imply that the driver would have been able to stop before reaching the pedestrian.
TABLE 2 Percentage of drivers who recognized the presence of the pedestrian in the presence of glare (secondary pedestrian)

<table>
<thead>
<tr>
<th>GLARE (% recognition)</th>
<th>Young Drivers</th>
<th>Old Drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Black</td>
<td>White</td>
</tr>
<tr>
<td>Low Beam 0</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>High Beam 50</td>
<td>50</td>
<td>100</td>
</tr>
</tbody>
</table>

“Recognition” here is defined operationally as the driver indicating recognition at any time during the approach to the pedestrian or immediately after having passed the pedestrian. Thus recognition does not imply that the driver would have been able to stop before reaching the pedestrian.