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Configuring retroreflective markings to enhance the night-time conspicuity of road workers

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ABSTRACT

This study investigated whether the night-time conspicuity of road workers can be enhanced by positioning retroreflective strips on the moveable joints in patterns that convey varying degrees of biological motion. Participants were 24 visually normal adults (12 young M = 26.8 years; 12 older M = 72.9 years). Visual acuity, contrast sensitivity and glare sensitivity were recorded for each participant. Experimenters acting as road workers walked in place on a closed road circuit within simulated road work sites, facing either the oncoming driver or the roadway (presenting sideways to the driver) and wearing one of four clothing conditions: (i) standard road worker vest; (ii) standard vest plus thigh-mounted retroreflective strips; (iii) standard vest plus retroreflective strips on ankles and knees; (iv) standard vest plus retroreflective strips positioned on the extremities in a configuration that conveyed biological motion ("biomotion"). As they drove along the closed road participants were instructed to press a button to indicate when they first recognized that a road worker was present. The results demonstrated that regardless of the direction of walking, road workers wearing biomotion clothing were recognized at significantly ($p < 0.05$) longer distances (3×), relative to the standard vest alone. Response distances were significantly shorter for the older drivers. Contrast sensitivity was a better predictor of the ability to recognize road workers than was visual acuity or glare sensitivity. We conclude that adding retroreflective strips in the biomotion configuration can significantly improve road worker conspicuity regardless of the road worker's orientation and the age of the driver.

1. Introduction

Collisions involving vehicles and pedestrians comprise a significant road safety issue and are over-represented at night (Sullivan and Flannagan, 2002; Griswold et al., 2011), with pedestrians being up to seven times more likely to be involved in a fatal collision at night than in the day (Sullivan and Flannagan, 2002). This is particularly relevant for road workers, given that traffic crashes at road-work sites occur relatively frequently, particularly at night (Sayer and Mefford, 2004; Arditi et al., 2007). Reduced conspicuity has been suggested to be a key causative factor, based on analyses of crash databases that have shown that the increased numbers of crashes involving pedestrians at night is primarily a consequence of reduced illumination, rather than fatigue or alcohol levels (Owens and Sivak, 1996; Sullivan and Flannagan, 2002).

A number of studies have demonstrated that night-time pedestrian conspicuity can be enhanced by wearing clothing designs that incorporate retroreflective materials. Research has further demonstrated that pedestrians are most conspicuous to drivers at night when retroreflective material is attached to the pedestrian's major moveable joints, which takes advantage of drivers' perceptual capacity to recognize the unique patterns of motion (known as biological motion or biomotion) that characterize normal human gait (Johansson, 1973). These studies have demonstrated that retroreflective strips positioned in the full biomotion pattern provide substantial advantages for improving pedestrian conspicuity, which result more from highlighting pedestrians' motion rather than their form (Balk et al., 2008). Biomotion configurations have been shown to maximize conspicuity even when the drivers experience challenges such as advanced age (Wood et al., 2005; Owens et al., 2007), modest visual impairment (Wood et al., 2012a), headlamp glare (Wood et al., 2012a) and visual clutter surrounding the pedestrian (Tyrrell et al., 2009).

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We have also explored the advantages of biomotion configurations in the context of enhancing the conspicuity of road workers at night. In one study, which was conducted at work sites on two open roadways (one suburban and one freeway), participants sat in stationary vehicles and provided subjective ratings of the conspicuity of road workers who walked in place while wearing different configurations of reflective material (Wood et al., 2011). Participants' ratings were consistently maximized in the full biomotion configuration (markings positioned on 8 moveable joints), and a configuration that added ankle and knee markings to a standard vest also provided significant conspicuity benefits relative to the vest alone. These data were valuable in that they provided the first evidence that biomotion effectively enhances the conspicuity of road workers at open-road work sites. However, the in-traffic setting precluded measurement of the distance at which drivers first responded to the presence of the road workers. A key question for the safety of road workers (and other vulnerable road users) is whether they can be recognized in time for the driver to avoid a conflict and potential fatality. Thus the aim of the current study was to quantify the distance at which drivers recognized the presence of road workers embedded within the clutter of a simulated work zone on a closed road. We also considered the possibility that the benefits of biomotion clothing might vary as the orientation of the road worker varies (since it is only in the frontal orientation that all markers are visible). Luoma et al. (1996) observed that pedestrians crossing a road wearing biomotion-configured reflective clothing were more visible than those approaching along the side-walk, despite the fact that the pedestrians crossing the road were facing to the side, and therefore potentially less reflective surface was visible to the oncoming driver. However a key difference in their study was that those pedestrians crossing the road were also differentially illuminated relative to those on the sidewalk. By matching the degree of illumination and presenting pedestrians side- or front-facing without crossing the path of the vehicle, we aimed to investigate whether the orientation itself changes the effectiveness of the biomotion clothing. This is relevant under real work conditions when road workers or pedestrians walk or run in a variety of directions relative to traffic. Additionally, we included both young and older drivers, given that it has been shown that older drivers have more difficulties recognizing pedestrians at night (Luoma et al., 1996; Luoma and Penttinen, 1998; Wood et al., 2005; Tyrrell et al., 2009).

2. Methods

2.1. Participants

Participants included 12 younger drivers (mean age = 26.83 years ± 6.51 years, range 18–35 years; 5 men and 7 women) and 12 older drivers (mean age 72.92 years ± 5.07 years, range 66–80 years; 7 men and 5 women). Participants were recruited via a number of different methods, including presentations by the research team, recruitment notices placed on university noticeboards, participation in previous studies, and from among undergraduate and graduate students at Queensland University of Technology. All participants were licensed drivers and reported that they drove regularly. Participants passed the minimum Australian drivers' licensing criteria of binocular visual acuity of 6/12 (20/40) or better. All participants wore the optical correction normally worn while driving, if any. Participants were given a full explanation of the experimental protocols, and informed, written consent was obtained, with the option to withdraw from the study at any time.

A confidential pre-experimental questionnaire was administered to obtain a general sense of the driving habits of the participants. This included information regarding driving experience and night-time driving experiences over the previous year.

Visual acuity and letter contrast sensitivity were also measured binocularly for each participant under normal room illumination conditions. Distance high contrast visual acuity was assessed using the high contrast (90% contrast) letter chart of the Berkeley Glare Test, at a viewing distance of one meter using an appropriate working distance correction, and scored on a letter by letter basis (-0.02 log units per letter correct). Letter contrast sensitivity was determined using the Pelli-Robson chart, scored on a letter by letter basis (0.05 log units per each letter correct). Disability glare was also measured binocularly using the Berkeley Glare Test, by assessing the ability to recognize low-contrast letters (10% contrast) in the presence and absence of a glare source at the medium setting of 750 cd/m^2 (Bailey and Bullimore, 1991). The glare score is the difference in visual acuity for the glare and no-glare conditions.

2.2. Closed road test circuit and experimental vehicle

Testing was conducted at night on a closed-road circuit that has been used in previous studies and is represented schematically in Fig. 1 (Wood and Troutbeck, 1994). The circuit is representative of a rural road, and includes a series of hills, bends, curves, intersections, lengthy straight sections and standard road signs and lane markings but does not include ambient lighting (Wood and Troutbeck, 1994; Tyrrell et al., 2004, 2009; Wood et al., 2005, 2012a).

Experimenters walked in place on the right shoulder of the roadway at two different locations along the circuit where simulated 'road work' zones had been set up. The experimenters acted as road workers for the purpose of this study (and are referred to as road workers throughout the paper). The primary road worker was located at the end of a 400 m straight section of roadway which started and finished at approximately the same elevation but featured a dip halfway along its length. To reduce the drivers' expectation that the road worker would always be in a single location,

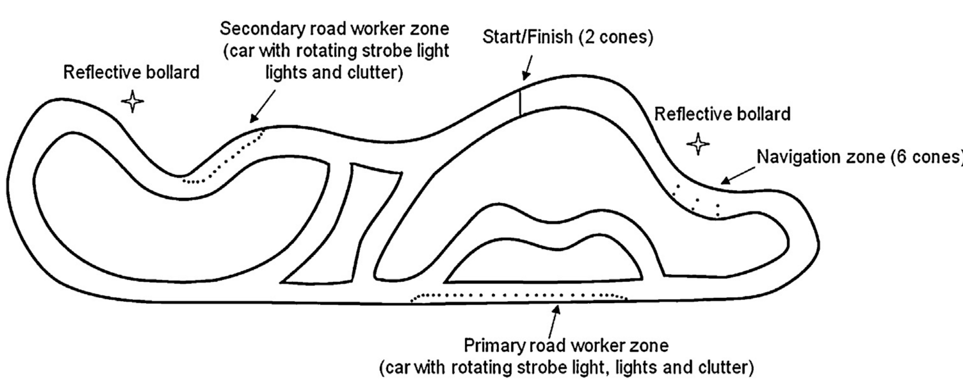

Fig. 1. Schematic representation of the closed road circuit and the position of the pedestrians and road work zones adopted for this study.