Wood, Joanne M., Lacherez, Philippe, & Tyrrell, Richard A.
(2014)
Seeing pedestrians at night : effect of driver age and visual abilities.
Ophthalmic and Physiological Optics, *34*(4), pp. 452-458.

http://doi.org/10.1111/opo.12139

Running Head: Night-time Pedestrian Recognition

Seeing pedestrians at night: effect of driver age and visual abilities

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The authors report no conflicts of interest and have no proprietary interest in any of the materials mentioned in this article.

This research was funded by an Australian Research Council Linkage Grant. The authors would like to express appreciation to the Department of Transport and Main Roads for allowing the use of the facilities at the Mt Cotton Driver Training Centre and to the staff of the Mt Cotton Driver Training Centre for their generous cooperation and support.

ABSTRACT

Purpose: To quantify the effects of driver age on night-time pedestrian conspicuity, and to determine whether individual differences in visual performance can predict drivers' ability to recognise pedestrians at night.

Methods: Participants were 32 visually normal drivers (20 younger: M=24.4 years ± 6.4 years; 12 older: M=72.0 years ± 5.0 years). Visual performance was measured in a laboratory-based testing session including visual acuity, contrast sensitivity, motion sensitivity and the useful field of view. Night-time pedestrian recognition distances were recorded while participants drove an instrumented vehicle along a closed road course at night; to increase the workload of drivers auditory and visual distracter tasks were presented for some of the laps. Pedestrians walked in place, sideways to the oncoming vehicles, and wore either a standard high visibility reflective vest or reflective tape positioned on the movable joints (biological motion).

Results: Driver age and pedestrian clothing significantly ($p<0.05$) affected the distance at which the drivers first responded to the pedestrians. Older drivers recognised pedestrians at approximately half the distance of the younger drivers and pedestrians were recognised more often and at longer distances when they wore a biological motion reflective clothing configuration than when they wore a reflective vest. Motion sensitivity was an independent predictor of pedestrian recognition distance, even when controlling for driver age.

Conclusions: The night-time pedestrian recognition capacity of older drivers was significantly worse than that of younger drivers. The distance at which drivers first recognised pedestrians at night was best predicted by a test of motion sensitivity.

KEY WORDS: age, motion sensitivity, pedestrian recognition, night-time driving

INTRODUCTION

Older drivers commonly report difficulties with visibility at night, and some report that they are reluctant to drive at night,[1-4] presumably because they have more difficulty seeing under low illumination. Crash data suggest that driving at night can be more dangerous than driving during daytime hours; adjusted for distance driven, the fatality rate at night is two to four times higher than that for the daytime.[5] An important class of low contrast hazard that might easily be missed under night-time conditions is pedestrians, who unlike most vehicles may not be illuminated. For crashes involving pedestrians, the night-time pedestrian fatality rates are up to seven times higher than those in the daytime.[6] Analyses of crash databases indicate that reduced lighting and poor visibility are associated with these relatively high crash rates, rather than other factors that vary between day and night-time, such as driver fatigue and alcohol consumption.[6, 7]

The contribution of vision to the higher night-time crash risk is supported by studies of self-reported night-time driving difficulty and driving cessation. In large cohort studies of older adults, self-restriction of night-time driving was significantly associated with reductions in contrast sensitivity (CS) and low contrast visual acuity (VA) in glare.[8] Similarly, those with a reduction in CS and visual fields were shown to have a higher likelihood of night-time driving cessation.[9] A real-world driving study indicated that reduced luminance impaired the driving recognition ability of both younger and older drivers and that these impairments in performance were better predicted by CS and low luminance VA than by photopic measures of high contrast VA.[10] Importantly, the measures of visual function in that study did not assess divided attention (which may be important in determining the capacity of drivers to detect peripheral and less visible road objects), or motion sensitivity (which may determine the capacity to detect the presence of movement from pedestrians or cyclists). The capacity of motion sensitivity in predicting various aspects of driving performance has been demonstrated in a small number of studies including on-road driving performance under closed [11] and open road [12] conditions, as well as laboratory-based indices of aspects of driving performance.[13-15] Many important cues in driving involve visual motion, including detection of hazards that move relative to the visual background, such as bicycles, other vehicles and pedestrians; the coherence (or lack of coherence) among these objects relative to the background is potentially a critical cue for discriminating the hazards from their backgrounds.[16-18]

The aim of this study was thus to determine the extent to which driver age impacts on drivers' recognition of pedestrians at night and whether tests of visual function including motion sensitivity and visual attention are better than standard measures of visual performance (e.g. VA and CS) in predicting the distance at which night-time pedestrians are first recognised.

METHODS

Participants

Participants included 20 younger (mean age 24.35 ± 6.42 years, range 18-38) and 12 older drivers (mean age 72.00 ± 4.95 years, range 63-80) who were recruited via a number of different methods, including presentations by the research team, recruitment notices placed on university noticeboards (both electronic and physical), participation in previous studies and graduate students. All participants were licensed drivers and satisfied the minimum Australian drivers' licensing criteria for binocular visual acuity of 6/12 (logMAR +0.30) or better when wearing their habitual optical correction (if any). All participants were naïve to the hypotheses under investigation.

The study followed the tenets of the Declaration of Helsinki and was approved by the Queensland University of Technology Human Research Ethics Committee. All participants were given a full explanation of the nature and possible consequences of the study, and written informed 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. Only those findings of relevance to general driving characteristics are reported here. The young participants reported a mean of 7.08 ±5.77 years of driving experience compared to 52.92 ± 4.46 years for the older participants. When questioned about night-time driving experiences over the previous year, younger participants reported that 45.5% (±18.4%) of their driving was undertaken under night-time conditions compared to 12.8% (±8.8%) for the older participants.

Vision Assessment

Participants completed a battery of visual tests each of which were conducted binocularly and while wearing their habitual distance correction.

Visual Acuity: Distance high contrast visual acuity was assessed under photopic illumination conditions using a logMAR Bailey Lovie chart at a viewing distance of 3 m and scored on a letter by letter basis.

Contrast Sensitivity: Letter contrast sensitivity was measured using the Pelli-Robson chart under the recommended testing conditions using a letter by letter scoring system and an additional working distance lens.[19]

Motion Sensitivity: Central motion sensitivity was measured using a computer-based random dot kinematogram.[12] Participants viewed (at a distance of 3.2 m) a field of dots (subtending 3.9° x 3.9°), within which a smaller (2.9° x 2.9°) central panel of dots moved coherently in one of four directions (up, down, left or right) over four discrete steps. Participants were instructed to indicate the predominant direction of motion of the central dots. Across trials the extent of the movement (in terms of the displacement of each pixel between frames) was varied in a 2-down 1-up staircase, with 8 reversals. The threshold (D_{min}) was defined as the average of the displacement for the last six reversals in the series.

Useful Field of View: Participants completed all three subtests of the commercially available UFOV, which measures visual processing speed for attentional tasks of increasing difficulty.[20, 21] Subtest 1 (visual processing speed) is a central discrimination task, while Subtest 2 (divided attention) consists of the same central discrimination task while the participant is also required to localise a peripheral target presented randomly along one of eight radial spokes. Subtest 3 (selective attention) involves the same tasks as in Subtests 1 and 2 with the addition of visual distracter targets. The outcome measure was given as the target duration (in milliseconds) at which each of the subtests was performed accurately 75% of the time.

Driving Assessment

Testing was conducted on a closed road circuit that has been used in previous studies,[22-24] on nights during which there was no active precipitation and all road surfaces were dry. The experimental vehicle was an instrumented right-hand drive 1997 Nissan Maxima with automatic transmission and halogen headlights on the low beam setting. A dual-camera parallax-based video measurement system was utilized to determine the distance at which the driver first recognised the presence of a pedestrian, which was recorded by the participant tapping a touch pad.[22-24] Eye movements were also recorded while driving around the circuit using the ASL Mobile Eye (Applied Science Technologies, Bedford, MA)[25]; these data will be reported separately in a future publication.

Two pedestrians walked in place on the right shoulder of the roadway. One was located at the end of a 400 m straight section of roadway and was termed the ‘primary pedestrian’. To reduce the drivers’ expectation that the pedestrian would always be in a single location, another pedestrian, known as the ‘secondary pedestrian’, was located at a corner at the opposite side of the circuit; data for this pedestrian are not reported due to the limited sight distance available.

As the test vehicle approached, the pedestrians walked in place, facing either directly towards or directly away from the roadway. This allowed for the inclusion of natural patterns of motion while ensuring the safety of the pedestrian (by preventing them from entering the roadway). Each pedestrian was equipped with a two-way radio, as was the experimenter in the test vehicle; all communications regarding pedestrian clothing and direction of pedestrian travel was conducted between laps while the experimenter was outside of the vehicle so the participant could not hear the conversations.

For each lap the pedestrians wore one of two kinds of clothing included retroreflective materials in configurations that have been shown to enhance pedestrian recognition relative to non-reflectorised clothing.[22] In both conditions the primary pedestrian wore a black tracksuit top and bottom and black shoes. For the *vest* condition, the pedestrian also wore a standard lightweight fluorescent yellow vest with 50 mm wide silver retro-reflective (Scotchlite® 8910 Silver Fabric, 3M) material on the shoulders, front and back in a U-shaped pattern. The *biological motion (biomotion)* condition featured the same vest with the addition of 50 mm wide silver retro-reflective strips (Scotchlite® 8910 Silver Fabric, 3M) surrounding the elbows, wrists, ankles, and knees.

To reduce expectancy effects and to make the driving task more relevant to everyday driving, distracter tasks were added to two thirds of the laps. These included auditory and visual distracter tasks which have been used in previous studies.[26, 27] These tasks required participants to verbally report the sum of pairs of numbers (e.g., “2 + 5”) that were presented either visually via a dashboard-mounted monitor or auditorily via a computer speaker. The monitor was positioned on the dashboard just left of the steering wheel. The visual distracters consisted of the simultaneous presentation of pairs of numbers (each digit subtending between 3.5 and 4.8 degrees of visual angle). The auditory stimuli were presented at a comfortable listening level set by each participant using an adaptive technique. Pairs of numbers were presented approximately every 3.5 seconds.

Each participant completed a series of data collection laps that included 2 clothing x (either of 2 pedestrian orientations) x 3 levels of distraction (non, visual, or auditory)). In addition, an initial (practice) lap familiarised the driver with both the vehicle and the driving circuit. The order of the different combinations of clothing, orientation (either to the left or the right) and distracters was randomised. Examination of the frequencies of randomisation indicated that task order was effectively random across both clothing $\chi^2(5) = 7.12$, $p = 0.212$, and distracter conditions χ^2 $(10) = 14.185$, $p = 0.165$. Three additional laps during which one or both pedestrians were absent were included to further reduce expectancy.

Participants were instructed to follow the specified route, to drive at a comfortable speed and to press the dash-mounted touch pad (and announce “pedestrian!”) as soon as they were confident that they recognised that a pedestrian was present ahead. The outcome measure was the distance at which the participants first recognised the primary pedestrian.

Data Analysis

The mean distance at which the pedestrian was first recognised was analysed using a three-way linear mixed effects model with the factors of Age (with two levels: Young and Old), distracters (with three levels: None, Visual and Auditory) and Clothing (with two levels: Vest and Biomotion), with subjects as a random factor, and condition order as a continuous covariate. To examine which of the visual function measures best predicted the overall mean recognition distance for each participant, Pearson bivariate correlations and Pearson partial correlations (controlling for driver age) were conducted. All data met the assumptions of normality and homogeneity of variance, and multivariate tests of significance were employed to rule out problems associated with sphericity.

RESULTS

Table 1 presents the mean visual function data for the younger and older participants. Although the mean visual acuity for the older group was slightly better than 6/6, it was significantly worse than the mean acuity of the younger group. The mean letter contrast sensitivity and motion sensitivity were also significantly worse for the older group, but differences in performance on the UFOV were significantly slower only for the selective attention subtest, but not for visual processing speed or divided attention subtests.

Table 1: Mean (and standard deviation) scores on tests of visual performance for the younger and older participants

	Younger	Old	p-value young vs older drivers
Visual Acuity (logMAR)	-0.20 (0.06)	-0.02 (0.09)	0.000*
Contrast Sensitivity (log units)	2.07 (0.10)	1.91 (0.06)	0.000*
Motion Sensitivity (log min arc)	-0.98 (0.10)	-0.75 (0.17)	0.000*
UFOV Test 1: Processing Speed (ms)	16.7 (0.0)	19.7 (7.5)	0.078
UFOV Test 2: Divided Attention (ms)	29.2 (29.1)	63.1 (87.8)	0.120
UFOV Test 3: Selective Attention (ms)	63.9 (41.8)	231.4 (122.3)	0.000*

*p<0.05

Figure 1 shows the mean pedestrian recognition distances as a function of age group and pedestrian clothing. The mean distance at which the drivers first recognised that a pedestrian was present was 190.3m collapsed across all drivers, pedestrian clothing and distracter conditions. Overall, the older participants recognized the pedestrians at significantly shorter distances than did the younger participants $F(1,30)=33.38$, $p<.001$; with the older participants recognising pedestrians at approximately half the distance of the younger participants (129.1m vs 251.5m).

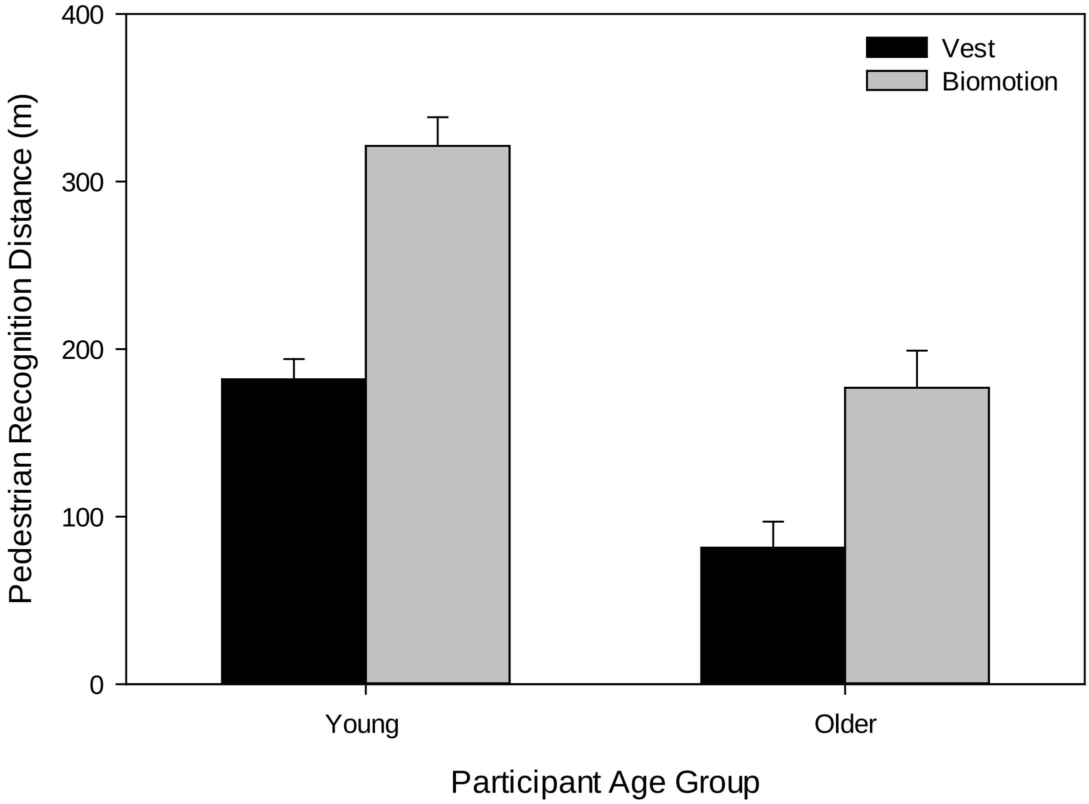

Figure 1: Pedestrian recognition distance as a function of driver age group and clothing

The clothing manipulation had a significant effect on pedestrian recognition distance ($F(1,30.95)=105.77$, $p<0.001$). When averaged across driver age and distracter conditions, drivers responded to the pedestrian wearing biomotion clothing at a mean distance (249.0 m) that was almost twice as long as that of the standard vest alone (131.7 m). Response distances were also affected by the presence or absence of distracters ($F(2,29.56)=5.254$, $p=0.011$ such that the visual distracter condition resulted in significantly shorter recognition distances than the audio distracter condition (189.7 vs 219.39 m) but the audio and baseline conditions (207.71 m) did not differ significantly. There was no significant age × distracter ($F(2,29.62)=0.16$; $p=0.86$) interaction. The interaction between clothing and distracters ($F(2,29.68)=0.46$; $p=0.64$), and the three-way interaction between clothes, distracters and age (*F*(2,29.64)=0.03; *p*=0.97) were also non-significant. There was however a significant two-way interaction between clothing and age F(1, 30.04)=6.30, p=0.02 (see Figure 1). Although for both groups, the biomotion clothing configuration was visible at a longer distance than the vest, this effect was stronger for the younger participants.

An analysis of the visual predictors of the mean distance at which pedestrians were first recognised (after collapsing across the clothing and distracter variables), revealed that visual acuity, contrast sensitivity and motion sensitivity were all significant bivariate predictors, as was the UFOV test 3 (selective attention; see Table 2). In each case, drivers with better visual sensitivity (or faster UFOV response times) tended to recognise the pedestrians at longer distances. The relationship between motion sensitivity and overall pedestrian recognition distance for both age groups is shown in Figure 2.

Table 2: Correlation between pedestrian recognition distances and visual function measures (the partial correlations represent the magnitude of the relationships independent of driver age).

Visual Function Measure	Correlation	Partial Correlation
Visual acuity (logMAR)	-0.57**	-0.02
Contrast sensitivity (log units)	0.53**	0.06
Motion sensitivity (log min arc)	-0.72**	-0.44*
UFOV Test 1: Processing Speed (ms)	-0.12	0.21
UFOV Test 2: Divided Attention (ms)	-0.19	0.10
UFOV Test 3: Selective Attention (ms)	-0.66**	-0.23

* p < .05, ** p < .01

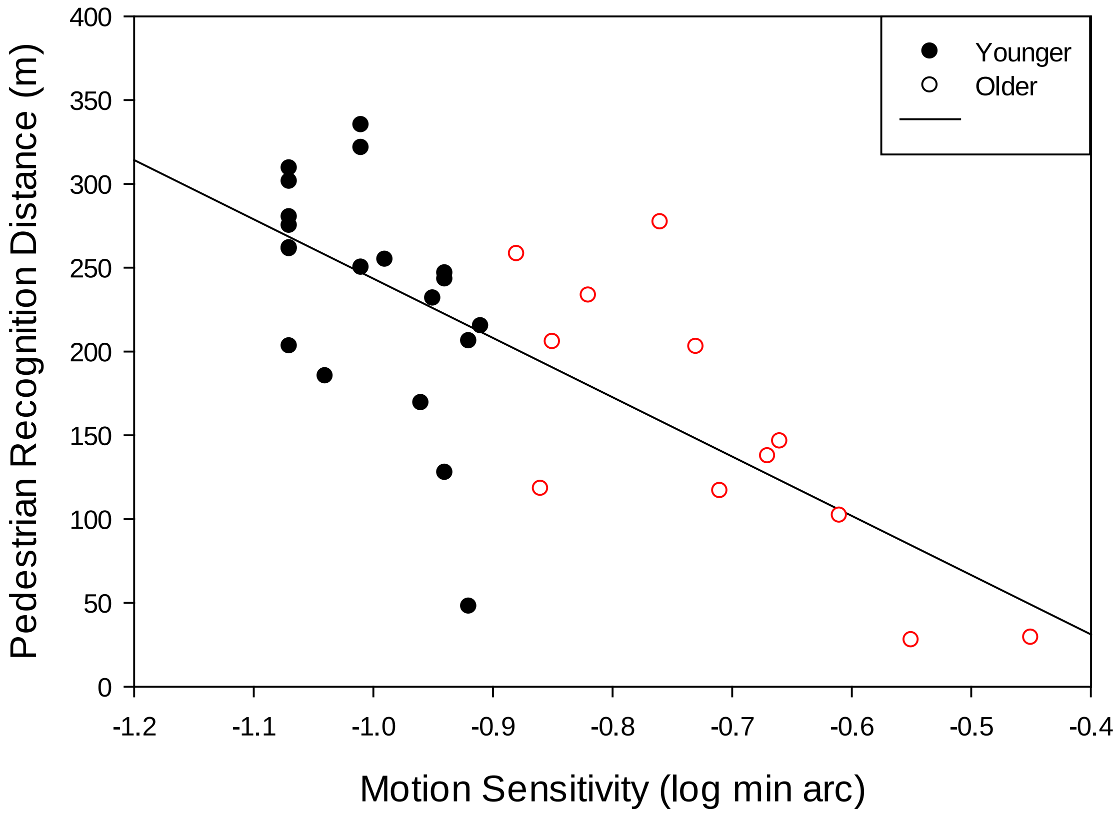

Figure 2: Relationship between motion sensitivity and overall pedestrian recognition distances for both younger and older drivers.

To determine whether the relationship between the visual measures and pedestrian recognition distance were driven purely by ageing, partial correlations were also conducted with age as a covariate (Table 2). The partial correlations revealed that after the age effect was statistically removed, motion sensitivity was the only significant predictor of pedestrian response distances. This suggests that for both older and younger drivers visual sensitivity to motion may be an important independent determinant of their ability to recognise walking pedestrians at night.

DISCUSSION

Overall the results of this study show that recognition of pedestrians at night under real-world driving conditions was significantly impaired in this cohort of older drivers relative to their younger counterparts, and that visual function measures, particularly motion sensitivity, were significantly related to these night-time recognition distances. As has been shown in a number of previous studies, [22-24, 28] pedestrians wearing reflective tape in the biomotion configuration were significantly more conspicuous than those wearing a reflective vest, however, this effect was less for the older drivers. In addition, while distracters impacted on overall recognition distances, the age-related degradation in the ability to see and respond to the presence of walking pedestrians at night did not interact with the presence of distracters.

The reduced capacity of older drivers to recognise and respond to the presence of persons walking on or near roadways at night is in accord with previous studies for both pedestrians,[22, 29] and cyclists.[30] Interestingly, the magnitude of the age-related decreases in night-time pedestrian recognition distances reported by Luoma et al.[29] were slightly smaller than those reported here (74% decrease compared to 51% in the study reported here). This may relate to the fact that their participants acted as passengers (seated in either the passenger seat or the back of the vehicle), and did not have the additional demands of either driving a vehicle or performing an additional distracter task as did the participants in the current study.

From our data we calculate that at an approach speed of 60km/hr (37 mph) the mean difference in response distance observed here between the older drivers (with a mean response distance of 129.1 metres) compared to the younger drivers (251.5 metres) would equate to the average younger driver having an additional 7.3 seconds available to respond to the pedestrian. This could represent the difference in terms of response time between being able to avoid a collision and being unable to avoid one, with the very serious consequences associated with vehicle-pedestrian collisions. The general motor slowing associated with increased age[31] may have contributed to the differences in response distances reported here, as older drivers are likely to have taken longer to press the touch pad than did the younger drivers. This age-related motor slowing would also translate to increased time to press the brake pedal in response to a hazard under real world driving conditions. The reduced ability of the older drivers to respond to the presence of road workers (and other vulnerable road users) is also likely to be related to changes in visual function, which are exacerbated under low luminance conditions.[32]

In terms of the association between performance on standard vision tests and the capacity to recognise night-time pedestrians, our findings suggest that while both visual acuity and contrast sensitivity are associated with night-time pedestrian recognition distances, only motion sensitivity predicted recognition distance after controlling for age. This is likely to be because the capacity to detect small amounts of movement underpins the ability to recognise the movement of the retroreflective elements worn by the pedestrians. The widely documented reduction in motion sensitivity with increasing age[33-35] is thus linked with a critical component of night-time driving safety, namely pedestrian recognition, across the lifespan. This is in accord with the suggestion by previous authors that visual motion provides an important cue for discriminating the movement of hazards, such as pedestrians, against their backgrounds.[16-18] Our findings add further support regarding the importance of the detection of various forms of visual motion and performance measures directly or indirectly related to driving performance.[11-15, 36] It is important to note, however, that the extent to which motion sensitivity can predict the recognition of pedestrians not wearing retroreflective elements remains unknown, since both of the clothing conditions in the present study included retroreflective elements.

Interestingly, of all of the UFOV measures, only subtest 3, which assesses selective attention, was significantly correlated with recognition distances, although this relationship was partially explained by the effects of age. The finding that the selective attention component of the UFOV is most predictive of the capacity to recognise pedestrians when controlling a vehicle and under more complex driving conditions is not unexpected, given the need to focus attention on important and salient objects when there are numerous other features within the road environment. This finding concurs to some extent with a previous study which demonstrated that older drivers with declines in selective attention made more unsafe traffic-entry judgments than older drivers with normal levels of attention, including shorter time-to-contact estimates, longer times to cross the roadway and selected shorter safety cushions (the difference between time-to-contact and time-to-cross the roadway).[37] The UFOV selective attention subtest was also the best predictor of crashes and the ability to detect and react to hazards in a driving simulator.[38] and in a closed road environment in the presence of distracters.[21]

An important but necessary limitation to this study is that the test pedestrians walked in place. This was important in order to ensure that the position of the pedestrians was known at all times to maintain safety, to provide control across the clothing conditions and other manipulations, and to facilitate accurate measurements of response distance. To reduce the drivers' expectation that the pedestrian would always be in a single location another pedestrian, known as the 'secondary pedestrian', was located at a corner at the opposite side of the circuit and there were also laps when the pedestrians were absent. The order of the clothing and distracter conditions was also fully randomised to ensure that any practice effects did not systematically affect performance over time.

In summary, our study demonstrates that older drivers have significant problems recognising pedestrians at night-time and that motion sensitivity is strongly associated with the ability to recognise the presence of (reflectorised) pedestrians walking near the roadway at night. Importantly, participants were required to control a vehicle as they drove around a driving circuit and undertook a range of distracter tasks that reflect the complexity of the driving task, thus the task of recognising pedestrians in this study was more similar to that normally involved during driving. The older participants were also regular drivers who volunteered to be involved in a night-time study and thus are likely to be higher functioning than that of the wider population of older drivers. Thus our finding of the problems that drivers have in general recognising pedestrians at night, and in particular, the problems of older drivers, is likely to be greater in the wider older driving population.

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