Differences between Older and Younger Drivers in Steering Around Moving Obstacles in a Driving Simulator

FINAL REPORT

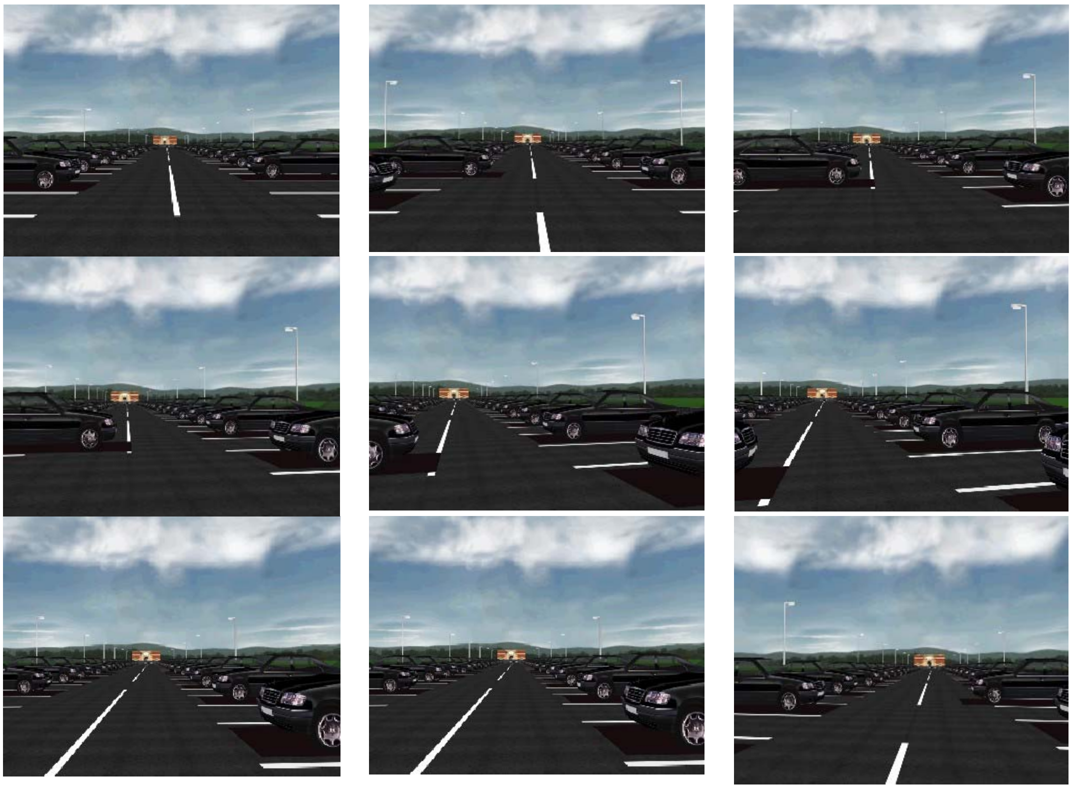

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Table of Contents

Front Cover: *Screen captures from the driving simulator task of steering through gaps formed by cars moving from a parked position into the roadway. For an animation of a full trial run at 2× speed, please see the accompanying file: moving obstacles.wmv*

Executive Summary

We examined differences in car steering behaviour around moving obstacles in young and older groups comprising equal numbers of men and women. A full-sized, immersive driving simulator was used to precisely control both the driving environment and measures of steering behaviour: response time, swerving severity and the accuracy of placing the virtual car in a gap to avoid the moving obstacle. Every effort was made reduce the effects of anxiety and motion sickness in the simulation tasks.

We found the following new results:

- In the simulator, drivers were automatically taking into account the spatial extent of their 'car', and using this to make appropriate safe swerving manoeuvres. As in real life, the edges of the 'car' were invisible.

- Obstacles on the right were responded to consistently more quickly than those on the left.

- Differences in steering behaviour around obstacles between the young and older group were not due to the older group having slower steering response times.

- Rather, the differences in steering arose because the older group did not make a sufficiently wide (and hence more risky) berth around the obstacles compared to the younger group. This riskier behaviour ('cutting corners') is also seen in more often in women than men, especially in older women.

- Even though the older group had reduced visual capacity (acuity, depth perception and contrast sensitivity), they actually performed more safely when light levels were reduced. Measures of three-dimensional spatial visualisation indicates that the older group have significantly less capacity in this area than the young group, and it is suggested that differences in the ability to visualise spatially may be producing the differences in steering performance.

Future research should be conducted to follow-up on how spatial cognition contributes to accuracy in steering cars. It is recommended that such deficits in older drivers be overcome by training drivers to take wider berths around obstacles, and/or providing indicators of the spatial extent of the vehicle: sonar range finding or cameras viewing both front and rear quarters of the car.

Acknowledgements

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For their assistance in recruiting older participants, the research team would like to thank the 50+ Registry at the Australasian Centre for Aging at the University of Queensland and Ms Val French at Older People Speak Out. We would also like to thank Anna Pleuger, Danielle Reeves and Haley Armstrong for their assistance with data collection

The work has been prepared exclusively by the authors and is not endorsed or guaranteed by the Trust.

Abbreviations

ANOVA = Analysis of Variance

DCQ = Driving Cognitions Questionnaire

M = Mean score

MMSE = Standardised Mini Mental Status Examination

MMSQ = Motion Sickness Susceptibility Questionnaire (Revised)

MRT =Mental Rotation Test

NA = Nearest Approach between obstacle car and car been driven

ND = Neutral Density – the grey tint level in a filter

RMS = The quadratic mean of the position of the virtual car on the road – it corresponds to the magnitude of the swerve manoeuvres

RT = response time taken to initiate steering manoeuvre

SEM = Standard Error of the Mean

SD = Standard Deviation

SUDS = Subjective Units of Distress

Preface

The research described in this project was approved by the Griffith University Human Research Ethics Committee Protocol PSY/A8/06/HREC

Main related research output as of November, 2011:

Bennett, L (2008) The Effect of Age and Gender on Driving Ability under Low Light and Mesopic Luminance Conditions Unpublished honour's thesis, Griffith University, Mt Gravatt

Hine, T., Wallis, G., Conlon, E. & Wood, J. (2010, July) Obstacle avoidance and steering behaviour in younger and older drivers in changing light levels. In T. Machin (Chair) *The impact of ageing on capacity for and decisions about driving* Invited symposium conducted at the 27th International Congress of Applied Psychology, Melbourne, Australia.

Hine, T., Wallis, G, Conlon, E. & Wood, J. (2012) Differences between older and younger male and female drivers in steering around moving obstacles in a simulated environment. In preparation for submission to *Accident Analysis and Prevention.*

Introduction

In combination with continued low birth rates and increasing life expectancy, the proportion of Australians aged 65 and over is rapidly expanding. In less than 50 years, the number of people aged 65 and over is predicted to increase by approximately 13% to 15% to up to 28% of the Australian population, while the proportion of people aged 85 and over is projected to climb from 1.5% (in 2004) to approximately 10% (Australian Bureau of Statistics, 2011). The 'greying' of Australia's population, along with an increase of licensed older drivers in each subsequent generation, will result in a rapid, dramatic increase in the number of elderly drivers on the road

This increase in older drivers on our road systems poses a significant problem for road safety, considering older drivers are at much higher risk of being involved in a car crash, when annual mileage is accounted for (Laughran & Seabury, 2007; Sims, McGwin, Allman, Ball & Owsley, 2000; Stamatiadis & Deacon, 1995). In their extensive study of 509,183 vehicle crashes in the United States from 1978 to 1988, Stamatiadis and Deacon (1995) calculated a relative accident involvement ratio (RAIR) based on the number of at fault drivers of a particular characteristic (age and gender) involved in crashes under different conditions (daylight, night time, location, season and year). Older women drivers had an overall higher relative crash involvement rate (RAIR = 1.510) than did older men (RAIR = 1.266), while young women drivers (RAIR = 1.009) were less likely to have an accident than young men (RAIR = 1.167).
Older drivers (59+ years old) were also far more likely to be involved in accidents at intersections (RAIR = 1.381) than both younger (16-35 years old; RAIR = 1.099) and middle-aged drivers (36-58 years old; RAIR = .729). These findings demonstrate that the age effect on the RAIR is exacerbated at intersections, where other cars are moving in from either left or right, rather than at non-intersections (Stamatiadis & Deacon, 1995). This scenario is the basis of the current study.

Not only are older drivers at risk of causing at accident, they are at greater risk of being seriously injured or killed if involved in an accident (Dickerson et al, 2007; Sims et al, 2000). While this increase in crash risk seems to be due, in part, to a decrease in visual function with increasing age (Owsley et al., 1991, 1998, 2011), a clear link has not been established (Wood & Owen, 2005) and other factors have been shown to be involved, for example, cognitive and physical impairments (for a review, see Anstey, Wood, Lord & Walker, 2004; Langford & Koppel, 2006).

In both phases of this experimental study, we compared an older group's performance with a young group and have focused on visuo-spatial factors. In the first experimental phase, we explored the effects of motion sensitivity and different ambient light levels, and given the results from this phase, explored age-differences in visual spatial abilities in phase II. Older adults often report difficulty judging the speed of their own car and that of other vehicles and have problems when encountering the sudden appearance of unexpected vehicles (Kline et al, 1992). On the other hand, research into motion detection declines in older people using motion-coherence tests has found that while older people demonstrate slightly higher motion detection thresholds, indicating a relative reduction in motion detection sensitivity compared to younger age groups, there is a strong interaction with gender. That is, older men generally have detection thresholds similar to young men and women, while older women demonstrate a much larger relative reduction in motion detection sensitivity (Atchley & Anderson, 1998; Gilmore, Wenk, Naylor & Stuve, 1992). In a collection of recent studies, it has become apparent that motion perception, as measured by several tests of motion discrimination and detection, strongly correlates with the ability of older adults to drive safely (Henderson & Donderi, 2005; Henderson *et al*, 2010; Raghuram & Lakshminarayanan, 2006; Wood, 2002; Wood *et al*., 2008). In particular, it has been noted that ageing is associated with decrements in time-to-contact judgments, as well as the perception of speed and heading (Conlon & Yerkes, 2008; DeLucia & Mather, 2006), which are critical skills in enabling smooth and fast responses to hazards on the road. Motion perception has also been strongly linked to self-reported failures of attention using established questionnaire measures (Henderson & Donderi, 2005; Henderson *et al*, 2010; Raghuram & Lakshminarayanan, 2006). Conlon and Herkes (2008) found that reductions in motion sensitivity across the whole visual field were highly correlated with problems in older drivers' perception of other vehicles and gaps in traffic when negotiating lane changes and intersections.

These motion sensitivity declines seem to be exacerbated in mesopic, or 'twilight' conditions. Hine et al. (2006) have shown declines in motion detection between older and young participants when ambient light levels decreased from photopic to mesopic levels. This decline has been shown to translate into differences in steering behaviours. Owens and Tyrell (1999) found that the average number of steering errors made by an older group significantly increased as the luminance levels decreased. Indeed, the older driver's steering performance had significantly declined when light levels reached the mesopic range ($0.03cdm^2$), which is comparable to twilight driving conditions. Older adults also drive significantly slower overall than younger adults and even slower as luminance levels decrease, however this reduction in speed has been shown to be insufficient to maintain daylight levels of recognition of traffic signs, pedestrians and road obstacles (Owens, Wood & Owens, 2007).

Before any evaluation of these visual factors on driving and aging can be undertaken, some account must be taken of anxiety and confidence levels in the drivers. Older drivers seem to lack this self-awareness and demonstrate over-confidence, such that they are unable to appropriately self-regulate their driving behaviour and in turn are placing themselves and other road users at greater risk (Donorfio et al, 2009; Horswill et al., 2011). On the other hand, older drivers reporting more driving lapses were also more nervous and these drivers were more likely to be female (Parker et al, 2001).

Finally, the research reported here is experimental, gathered in a fixed base simulator. We measured moment-to-moment changes in steering behaviour in avoiding moving obstacles. The driving performance of older adults in driving simulators has been demonstrated to be highly correlated with their on-road performance (*r* =.716*;* Lee, 2002). Using a driving simulator is preferable to on-road testing, as it affords the researcher a greater and more precise level of control over important variables together with the elimination of potentially confounding variables not possible on the road. Driving simulation ensures the safety of all participants. However, one limitation of using a driving simulator, is anecdotal evidence that a large proportion of older adults tend to be susceptible to motion sickness in simulators. This was carefully monitored in pilot work prior to the main experimental study in Phase I.

Study Aims – Phase I

The current study aims to combine applied driving research with experimental vision research by comparing the performance of an older and a young group in a driving simulator on a steering task under both low light and mesopic (twilight) viewing conditions. Unlike any previous research, the current study will require young and older drivers to complete a series of avoidance manoeuvres in response to moving cars in a life-like situation, and continuously measure steering response times and the riskiness of the manoeuvres.

The study will:

1. Seek to confirm that the two age groups do not differ in terms of driving anxiety and confidence, and thus control for the possible influence of these factors on steering performance.

2. Examine differences in Response Time (RT), which is operationalised as the time taken to make a steering response to a moving car that blocks participants' driving paths. From previous work, it is expected that the older drivers will demonstrate significantly slower RTs than younger drivers, especially under the 'twilight' conditions.

3. Examine the risk of collision with moving cars by measuring the nearest approach (NA) of the driven car to the moving cars.

4. Measure any motion sickness in the two groups and ensure that the driving simulator task is designed such that these risks are minimised.

METHOD – PHASE I

Participants

Cybersickness pilot study

The initial pilot work was designed to test for motion sickness within our immersive driving simulator. This has been termed ‘cybersickness’ (McCauley & Sharkey, 1992), and there have been anecdotal reports as well as evidence in the published literature that the elders are more susceptible than younger individuals to this condition (Lee, Lee, Cameron & Tsang, 2003). A total of 35 (M = 38.85 years, SD = 24.70) participants from two age groups, 17-24 years old and 65-77 years old, were recruited for this initial pilot experiment.

Overall, 136 older people were contacted by mail and 46 older people who met the inclusion criteria expressed an interest in the study (33.8% response rate). The first 13 older individuals to respond were invited to participate in the pilot study. The 13 participants in this older group had a mean age of 70.38 years (SD = 3.25) and 61.5% were female. Each participant was screened via a brief telephone interview for the ocular diseases glaucoma, cataract, and any serious physiological and psychological conditions (such as previous heart attack or stroke or diagnosed depression and anxiety). Only participants self-reporting that they were free from ocular disease and physiological and psychological conditions were invited to participate. They were also required to hold a current driver’s licence and drive regularly. Older participants were also screened for cognitive impairment using the Mini-Mental State Examination (MMSE, Folstein, Folstein & McHugh, 1975, see below). All of the participants scored within the normal range for their age and education level (M = 28.69, SD = 1.65).

The twenty-two participants in the young group had a mean age of 20.23 years (SD = 1.72) and 54.5% were female. They were recruited from the School of Psychology, Griffith University. All young participants were required to hold a current driver’s licence and drive regularly.

Main Study

All participants experiencing either none or mild cybersickness symptoms in the pilot study were invited back to participate in the main study, and six of the identified seven older participants without cybersickness agreed. 85 additional older people were contacted and 34 expressed an interest in participation. The final sample for this study constituted 62 participants, 30 of whom comprised the young sample and were aged between 17 to 22 years old (M = 20.13 years, SD = 1.57, 56.6% female). The 32 older participants were aged between 65 to 75years old (M = 68.59 years, SD = 2.65, 57.4% female). All older participants were within the normal range on the MMSE (M = 28.84, SD = 0.99). All participants wore their standard optical correction for testing, if required.

Materials

Driving Cognitions Questionnaire - The Driving Cognitions Questionnaire (DCQ; Ehlers,et al 2007) was used to assess driving related anxiety. By asking participants to indicate, on a scale of 0 (never) to 4 (always), how often they experience a series of driving-related cognitions, the DCQ yields an overall score out of 80 and an individual score on three different anxiety constructs: panic-related thoughts, accident-related thoughts and social concerns. The DCQ has demonstrated a high level of internal reliability (Cronbach's α = 0.88 to 0.96) across three different studies for the overall score and a minimum of 0.78 for the separate factors (Ehlers, et al 2007). The DCQ has also demonstrated its validity, with strong correlations with other measures of driving avoidance and anxiety.

Motion Sickness Susceptibility Questionnaire revised – The MMSQ revised (Golding, 1998) is one of the few motion sickness questionnaires available that is both simple and quick to administer and score. The MMSQ revised is also highly reliable with a Cronbach's α of 0.86 and a split half reliability of 0.77. The MMSQ is moderately correlated with other measures of motion sickness susceptibility (r = 0.45) and is only slightly correlated with other sources of nausea and vomiting (r = 0.3). It was used only in the main study.

Mini-Mental State Examination – The MMSE (Folstein et al, 1975) has been commonly used to screen for cognitive deterioration in older adults for many years and is quick and easy to administer. In this study, the MMSE was used as a screening tool for mild cognitive impairment that may affect the steering performance of the older participants. The MMSE has a high test-retest reliability over a few days (correlations of r=.0 887 and r = 0.98). Furthermore, scores obtained on the MMSE have been shown to differ significantly between older adults experiencing mild dementing illnesses, cognitive impairments and normal healthy controls. Folstein et al. (1975) also reported high correlations between MMSE score and Verbal IQ and Performance IQ, as measured by the Wechsler Adult Intelligence Scale (r = 0.776 and r = 0.660 respectively).

SUDS – The Subjective Units of Distress Scale (SUDS; Wolpe, 1990) is a self-report anxiety rating scale that is simple and easy to administer and has been used many times in virtual reality research (see Krinjin et al, 2004). The scale ranges from 0, which corresponds to feeling calm and relaxed to 10, which is equivalent to feeling extremely panicked. Despite a lack of clear information about its reliability and validity, SUDS does correlate highly with other measures of anxiety, such as heart rate (Alpers, et al, 2005). In this research, participants were asked to rate their anxiety on a total of eight occasions: prior to the experiment, immediately before and after the demonstration trials and each condition which included the end of the experimental trials. Each SUDS rating was presented individually in a booklet and participants were prompted by the experimenter at the appropriate time, to complete the corresponding rating by pencil.

Equipment and Procedure

Information about the study was provided via an informed consent package to each participant. Basic demographic information, including age, gender and level of education was collected at this stage. Each participant completed a 60 minute testing session comprising pencil-and-papers tests followed by the driving simulator tasks. Participants were tested individually on the St Lucia campus of the University of Queensland within the virtual reality facility at the Perceptual and Motor Systems laboratory. An experimenter was present during testing to provide training and assistance when necessary. At the completion of testing, volunteers received a $30 Coles or Woolworths voucher and Psychology students received participation credit. All participants were reimbursed for any parking costs incurred during the course of the study.

Virtual Reality Equipment and Driving Stimulus

Graphics computations for the VR system was provided by a Silicon Graphics Onyx300 workstation, which runs Infinite Reality 2® graphics. The driving simulation program was written specifically for this research project. An example of the projected virtual reality environment can be seen in Fig. 1 and is described in further detail below in the Procedure section. The virtual environment was projected in full colour on to a white wall: 2.33m high and 3.12m wide by an overhead BARCO 808S projector. Participants were seated at a viewing distance of 2.7m in front of a Momo® force-feedback steering wheel, which provided return force-feedback, similar to that experienced in real life from a normal steering wheel. The corresponding field of view was 60° horizontal × 47° vertical.

As this experiment was primarily concerned with a measurement of participant's steering response, no pedals or gear changer were used. Therefore, the acceleration, deceleration and the speed of the 'car' were controlled by the driving simulation program, which also ensured the consistency from trial-to-trial and from participant-to-participant. If braking and acceleration were not regulated by the program, then there would have been resultant speed-accuracy confounds in the steering response. In essence, the younger group may have driven at a faster speed, and would have braked and accelerated more quickly. Hence, it would have been very difficult to compare their steering behaviour with the old group.

In the *pilot work*, at the beginning of each trial, the 'car' that was being driven by the participant quickly accelerated (in two seconds) to an equivalent speed of 15kmh and at the end of trial decelerated at the same rate. However, to reduce instances of cybersickness, in the *main* experiment it was decided to remove the visual effects of roll rotation of the virtual car driven by the participants from the visual simulation, as this may have been contributing to the experience of motion sickness symptoms, while not adding greatly to the fidelity of the VR environment. The acceleration and deceleration of the 'car' was also extended to a period of five seconds, in order to reduce the experience of any motion after effects.

The driving simulation program consisted of a basic car park, with thirty black Mercedes Benz cars parked in perpendicular parking spaces along either side of a straight road of about 180 metres, fifteen cars either side. At the end of the car park there was a low wall and building. As in real life, the centre of the road was marked with a dashed white line. A random selection of six of these cars rolled out in sequence, triggered by the proximity of the participant within the virtual world. Once triggered, the vehicle rolled to a point close to the centreline at a speed of 10 km/hr. A gap was left either to the left or right of this obstacle car for the participant to drive around the obstructing vehicle. Participants were instructed to initially line up both their 'car' and their driving position with the centre white line, that is, not to one side or the other, and to avoid hitting the cars when they rolled forward by swerving around them. They were then asked to return to the white line immediately following each avoidance manoeuvre. In each trial, six avoidance manoeuvres were required and all participants were to complete a total of six trials under each light condition: low light and mesopic. Stills from a full trial run are shown on the front cover of this report and a 2× speed animation of a trial is shown in accompanying file: *moving obstacles.wmv*.

Manipulation of the Overall Luminance Levels

In order to regulate the light levels in the driving simulator, the participants wore gas-welding goggles, fitted with Wratten Neutral Density (1.0 ND) filters, which reduced the amount of light uniformly across the visual field by 90% in the 'twilight' or mesopic condition without affecting the contrast of the stimulus. In the 'low light' conditions, 0.0 ND filters (that is, clear) were used. The goggles slightly reduced peripheral vision, however the entire simulator screen was still visible and the goggles were large enough to fit over participant's glasses.

Using a Minolta CS-100a ChromaMeter with 1° diameter sampling field, the on-screen light levels of the driving simulation were measured at various parts of the screen to ensure that the amount of light available in the low light condition would be above the mesopic range. In this case, the luminance was found to range from 11.8cdm^{-2} (measured on brightest white cloud) to 7.18cdm^{-2} (as measured on the black tarmac). While this was clearly not photopic – that is, full daylight conditions of at least 75-100cdm^{-2}, it was similar to the luminance levels in previous simulator research (16.7cdm^{-2}, Brooks et al, 2005). This level was the highest possible luminance that still maintained the on-screen contrast at low, but visible levels. Through the 1.0 ND filter producing the 'twilight' conditions, the on-screen luminance ranged from 0. 96cdm^{-2} (measured on brightest white cloud) to 0.61 cdm^{-2} (as measured on the black

Figure 1. A still image from the beginning of the driving simulation program.

tarmac). This was considered to be well within the mesopic limits (Owens & Tyrrell, 1999) and as such was an adequate reduction in the luminance between the conditions. Maximum Michelson contrast levels were calculated to be 0.22 which is in the low range.

Procedure

Participants were invited into the VR lab antechamber where informed consent was obtained. All participants were warned about possible risk of feeling motion sick at this time. The demographic questionnaire, the DCQ and the MMSE (for the older group) and the first SUDS rating were also administered at this time. Participants were then randomly assigned to the luminance condition that they would complete first and given the corresponding goggles fitted with the appropriate ND filter. All participants who completed the twilight condition first were given 8 to 10 minutes of dark adaption.

Prior to formal testing, an induction into use of the driving simulator and steering wheel was provided. This was followed by the second SUDS rating. Participants then completed the demonstration trial to allow them to become accustomed with the steering wheel, after which SUDS three and four were completed: the first related to how the participant felt in the previous trial and the next to measure anticipatory anxiety. Each participant then completed a block of six experimental trials, with a minimum of 15 seconds break in between each trial. The short break was provided to allow for any motion-after-effects to diminish before the next trial. After the first block of six trials, the participant completed SUDS five and six and changed filters for the next luminance condition. Participants completing the twilight condition second were then given 8 to 10 minutes dark adaption. The next block of six trials were completed, followed by SUDS seven and eight.

Based upon results and feedback from participants in the pilot research, in the *main* experiment, the procedures were further modified to provide more instruction and practice on steering before any measurements were obtained. Thus the initial instruction in steering in the simulator was extended to include a trial in which no cars pulled out into the participant's path. This allowed participants more time to become accustomed to the steering wheel response. Prior to this, the experimenter also demonstrated this trial and an experimental trial in which it was necessary to avoid colliding with the obstructing cars prior to the participants practice trials. Participants were also informed that the steering wheel was quite sensitive and were instructed to avoid making large, rapid steering wheel movements. These changes were implemented to minimise any unnecessary steering wheel movement, thereby reducing the discrepancy between the actual and the expected vestibular, visual and kinaesthetic sensory information received (Golding, 2006), reducing the risk and severity of motion sickness symptoms.

Finally in the *main* experiment, the MMSQ was completed at the end of the experimental session. This was done following the simulation to avoid suggesting motion sickness symptoms in the participants due to exposure to the MMSQ items. There is a small body of research that indicates completing motion sickness questionnaires prior to exposure to sickness inducing stimuli can increase the incidence of motion sickness (Young, Adelstein & Ellis, 2007).

RESULTS – PHASE I

Demographics and Driving Behaviour

The demographic information for participants included in the pilot study was similar to the main study and thus will not be presented here. Information for participants in the main study is summarised below in Table 1. As was expected, older participants had been licensed for significantly longer and had experienced a greater number of crashes over their driving history: χ^2 (1) = 9.54, $p<.005$, than younger participants. However both groups drove a similar number of days per week, while significantly more of the older drivers avoided driving at night-time (28.1%): χ^2 (1) = 4.885, $p<.05$, than did younger participants (6.7%).

Table 1

Demographical and other information for the Study Two. Mean and (SD)

Group	*N*	% Female	DCQ	MMSQ	Yrs Edu.	Yrs Licence	No. Days Driven	% Involved in an accident
Young	30	56.7	11.83 (7.01)***	37.21 (37.96)*	13.67 (1.14)*	2.54 (1.29)***	5.53 (1.95)	43.3**
Old	32	56.3	5.44 (5.21)***	18.03 (33.67)*	15.43 (3.6)*	48.05 (7.74)***	5.80 (1.68)	81.3**

Independent groups *t*-tests: *p < .05, **p < .005, *** p <.001; DCQ – Driving Cognitions Questionnaire; MMSQ – Motion Sickness Susceptibility Questionnaire.

Cybersickness and Anxiety

The *pilot* study did reveal large differences in cybersickness between groups. Of the thirteen older participants, three reported mild nausea or disorientation, three reported moderate nausea and had their number of trials halved. A further four older participants experienced severe nausea. In the latter cases the experiment was stopped. In all, nine of thirteen older participants reported experiencing some symptoms of cybersickness, while not one of the younger participants reported sickness. These reports led to the modifications described above.

In the main experiment, data from the DCQ, MMSQ and SUDS ratings were all positively skewed, so log transforms were performed on the data before statistical analysis. There were 90% of the younger group and 66% of the older group experienced no symptoms of cybersickness, 10% of the younger group and 12% of the older group experienced minor symptoms and finally 22% of the older group experienced moderate symptoms which lead to a number curtailed repetitions (< 6) in each block of trials (see below).

Independent-groups *t*-tests revealed that the young participants were both significantly more anxious drivers, t (60) = 4.093, p <.005, as measured by the DCQ, and significantly more susceptible to motion sickness, t (59) = 2.102, p <.05, as measured by the MMSQ, than the older group. On the other hand, following results of the pilot work, significantly more older participants actually experienced cybersickness symptoms, χ^2 (2) = 7.836, p<.05.

Moment-to-moment levels of anxiety during the experiment were measured with the SUDS (see Fig. 2). A 2 × 2 × 8 mixed ANOVA was conducted on the tranformed SUDS scores (measured at times one through eight), age group (young and older) and gender (male and female).

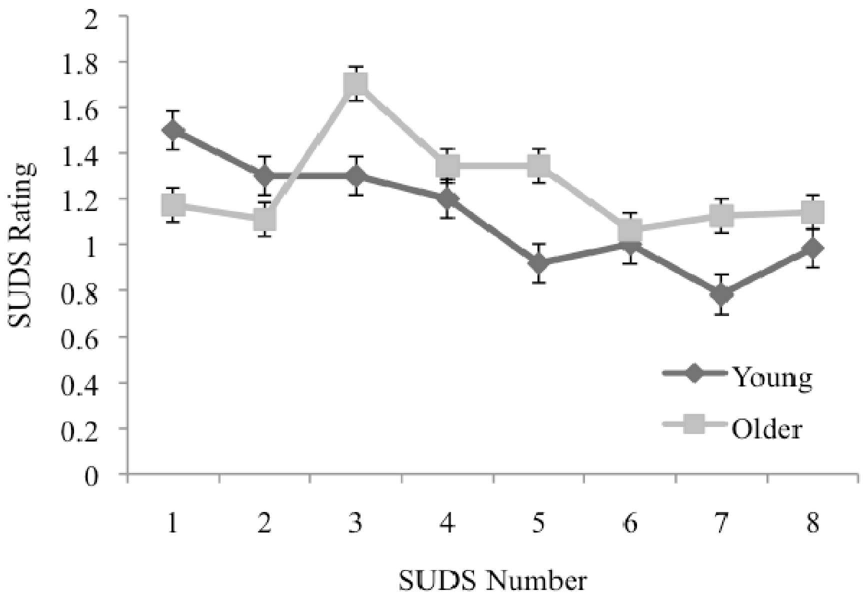


Figure 2. The M and SEM of the SUDS score at each of the eight times measured. At SUDS 2, participants were asked how anxious they were having to drive in a simulator and at SUDS 3, there were asked how anxious they were having completed for themselves a practice run. There was significant SUDS × age group interaction at these times [$F(1,59)=6.880$, $p<.05$ (partial η^2 = .104)]: the older group's anxiety went up, while the young group's anxiety did not change.

A significant main effect of SUDS time, $F(4.381, 413)$[1] = 4.381, $p<.005$, was found along with a significant SUDS × age group interaction, $F(4.381, 413)=2.454$, $p<.05$. The interaction has been further analysed in the caption to Fig. 2.

Steering Behaviour

For each trial, the participant's position on the road was recorded as a series of (*x*,*y*) coordinates every 27 ms (sample rate 36 Hz). Their steering wheel angle and angle of heading were also recorded. A number of algorithms were used to process the recorded raw data and calculate the measures of driving performance for each swerve manoeuvre: response time (RT), nearest approach (NA) and the amount of variation in steering (RMS). RT was calculated as the time taken, in seconds, from when the obstacle car began moving, to when the participant turned the steering wheel 4 degrees of angle from the current angle of heading in initiating the avoidance manoeuvre. This was an arbitrary measure, but chosen to avoid registering any random movement of the steering wheel unrelated to the swerve manoeuvre. NA was calculated as the distance, in metres, between the edges of the virtual car to the edge of the obstacle car, at the point where the two cars were closest. The amount of variation or swerving in participant's on-road steering during a trial in avoiding six obstacle cars was calculated from the quadratic mean of their (*x*,*y*) coordinates, across each trial in each condition. This is the RMS – root mean square – parameter. Finally, the participant's average road position was calculated, from participants' *x* coordinates, with the centre line

[1] Degrees of freedom reflect GG corrections due to violations of sphericity.

equalling zero and positive and negative values indicating an average position that was to the right and left, respectively of the centre line. Data from the last 18 metres of the road were not included in the analyses as this was beyond the location of the last car, but before any participant had commenced their final turn to avoid the wall (see animation: *moving obstacles.wmv*)

Each participant was required to complete six avoidance manoeuvres per trial, three each for cars rolling in from the left and right sides. All young participants and 24 of the older participants completed six repeat trials in each condition, while four older participants completed only four trials and four older participants completed three trials of each condition. The number of repeat trials were curtailed due to incipient motion discomfort which seem to build up over trials in the case of some of the older participants. The RT and NA were then averaged separately for each side (left and right) across all trials for each participant.

RT A 2 × 2 × 2 × 2 mixed ANOVA was conducted across luminance levels (low light *vs* mesopic 'twilight'), the side that the obstacle car rolled in from (left *vs* right) and two between subjects variables of age group (younger *vs* older) and gender (male *vs* female). The dependent variable was average steering RT (described above) collapsed across the repeated trials. The only significant main effect was that of side, left or right $F(1, 57) = 38.78$, $p < .0005$ (partial $\eta^2 = .4005$). Post-hoc pair-wise comparisons using the Sidak adjustment[2] found that responses made to obstacles on the right-hand side (M = 2.172 seconds, SEM = 0.026) were significantly faster (100 msec) than those made on the left-hand side (M = 2.273 seconds, SEM = 0.023; $p < .0005$).

The trends in RT were interesting in that the older group overall responded a little faster than the younger group. Under the simulated 'twilight' conditions though, older group's RT slowed down somewhat whereas the younger group speeded up.

NA Along the same lines as the RT analysis above, a 2 × 2 × 2 × 2 mixed ANOVA with luminance and side as the within-subjects variables, and gender and age group as the between-subjects variables was performed on the average NA data. For the sake of clarity, the main effects will be reported first, but these have to be interpreted with respect to the significant interactions reported later. Participants gave a wider berth on the left hand side (M=1.116 metres, SE= .033) than on the right hand side (M=.965, SE= .033, $F(1, 57) = 30.86$, $p < .0005$, partial $\eta^2 = .351$). Younger participants gave a wider berth overall (M = 1.166, SE = .044) than did older participants (M=.916, SE= .042, $F(1, 57) = 17.119$, $p < .0005$ partial $\eta^2 = .231$), while men (M = 1.106, SE = .045) allowed for a slightly greater berth between their virtual car and the obstacle car than did women (M = .975, SE = .040, $F(1, 57) = 4.678$, $p < .05$, partial $\eta^2 = .076$).

[2] To reduce type I error rate

There was a significant luminance × age group interaction, F (1, 57) = 4.648, $p< .05$ (partial η^2 = .075) as shown in Fig. 3. There was a significant side × age group × gender interaction $F(1, 57) = 6.596$, $p<.05$ (partial η^2 = .104) shown in Fig. 4. Again, post-hoc pair-wise comparisons were utilised to make sense of this three-way interaction. Young male participants gave obstacle cars the widest berth overall, but particularly on the left-hand side (M= 1.35, SE = .074) and differed significantly from the older male participants (M= .989, SE = .069) only on the left-hand side (p =.001). In contrast, the young female participants differed significantly from the older female participants only on the right-hand side (M= 1.033, SE = .063 and M= .747, SE = .061 respectively, p <.005). The smallest average NA was the result of older females swerving to avoid the obstacle cars from the right.

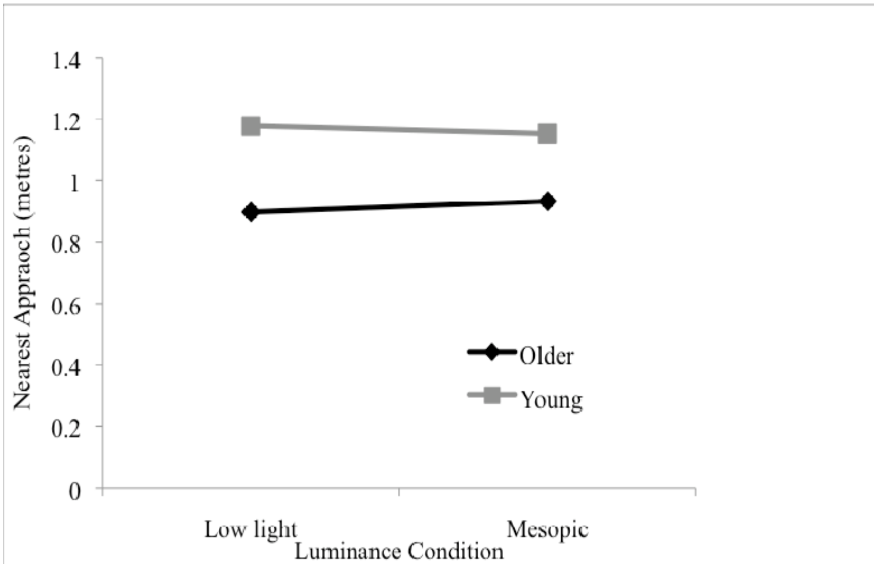


Figure 3. The mean of the NA collapsed across side and gender. The main effect for age is clearly shown. The interaction shown is due to the fact that the older group increased their NA buffer in the twilight conditions, whereas the young group did the opposite

Average Road Position Even though participants were instructed to line up both their body and the steering wheel with the white marking in the centre of the road, most offset themselves a little to the right. This positional offset seems to be an automatic response and was unsurprising since virtually all participants (except for one) learnt to drive in right-hand drive cars What was surprising was that the size of the offset was highly correlated with the difference in NA between obstacle cars coming from the left versus the right. It was as though the width of the virtual car was being taken into account (see Fig 5). Offset was not correlated with the difference in RT between left and right sides.

RMS – amount of swerving. A 2 × 2 × 2 mixed ANOVA was conducted with luminance, age group and gender each with two levels as stated above. The dependent variable was RMS variation in road position. A significant main effect of age group was found $F(1, 57)=8.002$, $p<.01$, where older participants had significantly less amplitude in their swerving (M=.551, SE=.023) than did the young participants (M=.647, SE=.025).

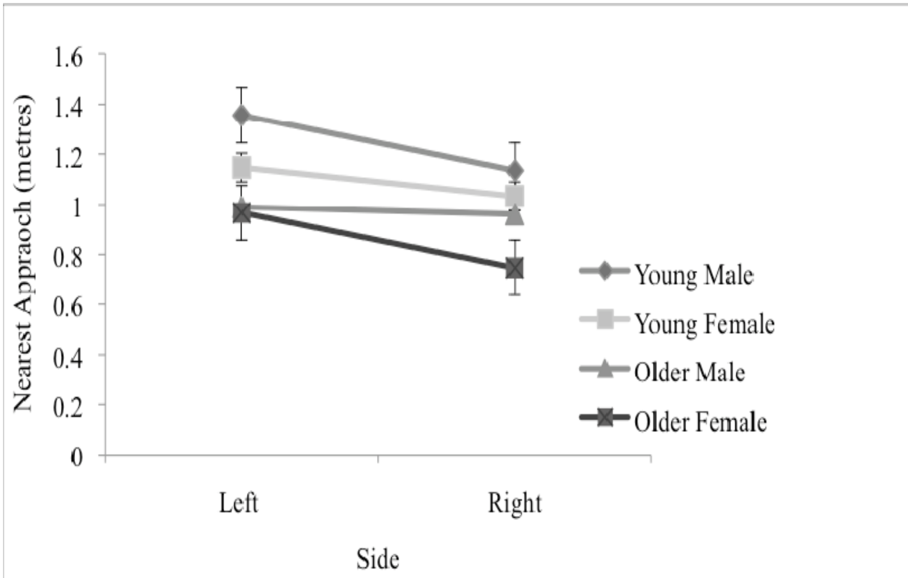


Figure 4. The M and SEM of average NA plotted to show the side main effect (NA for obstacle cars coming from the left > than those coming from the right) as well as the three way interaction analysed in the text. The smallest, and hence riskiest NAs, were seen on older females

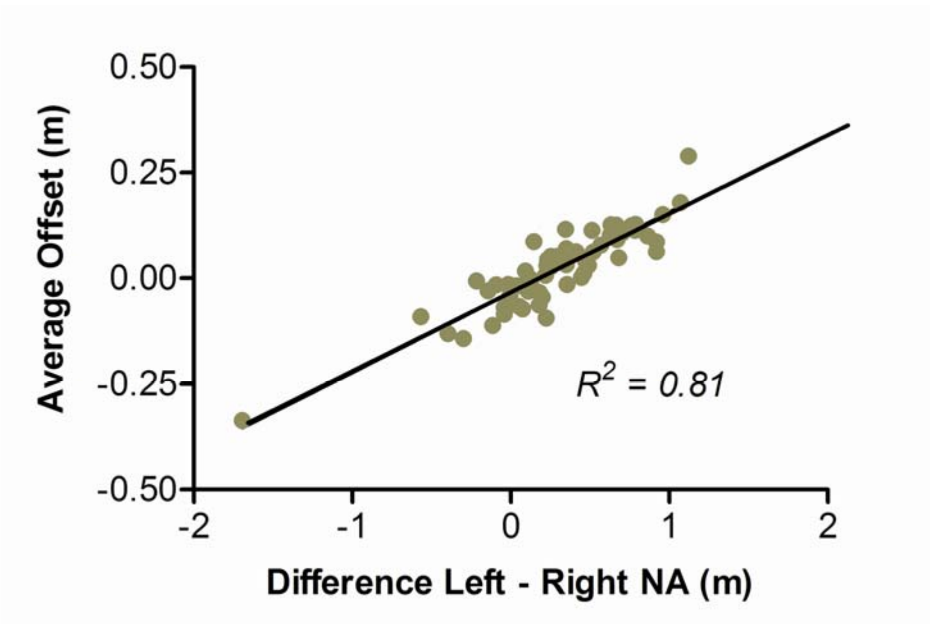


Figure 5. Average offset on the road (positive values offset to the right of the centreline) versus the average difference in NA (left *vs* right) plotted for all 62 participants. The outlier on the lower left learnt to drive in a large, left-hand-drive vehicle in the USA.

This is illustrated in an example of the virtual car's trajectory on the road for a young and an older driver (Fig 6). There was, however, a significant luminance × age group interaction $F(1, 57)=4.081$, $p<.05$, partial $\eta^2=0.067$). The older group showed greater swerving under the mesopic condition ($M=.565$, $SE=.025$) than under the low light condition ($M=.537$, $SE=.023$). The young participants displayed the opposite pattern in their swerving, such that they made greater deviations under the low light condition (M=.649, SE=.024) than under the mesopic condition (M=.645, SE=.027).

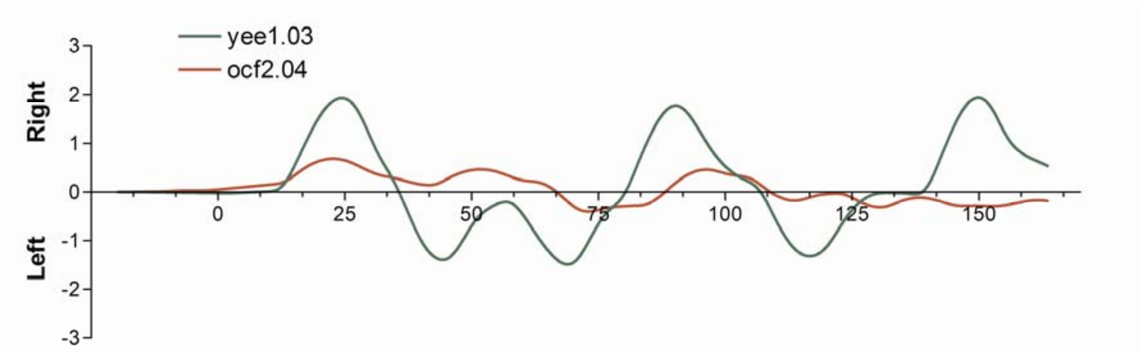


Figure 6.. An example of the difference in swerving behaviour in a trial from a young male (yee) and a trial from an older female (ocf). The *y*-axis is the deviation from the centreline and the *x*-axis is the distance along the road (both in metres but not to scale). For each of these two trials, the six obstacle cars rolled out at different random locations – the peaks and troughs in the deviation given an indication as to where this occurred.

DISCUSSION PHASE I

Anxiety Overall, older drivers were considerably less anxious then their younger counterparts - they did have on average 45 years more driving experience. During the experimental study, older participants experienced less anticipatory anxiety than the younger group, but became significantly more anxious once they became aware of the task they had to perform, compared to the young participants. However, importantly, both groups rated themselves low on the SUDS rating scale throughout the experiment, and hence it can be considered that anxiety was not a confounding factor in this study.

Cybersickness There was a difference in cybersickness between the younger and old group, in spite of our best efforts to reduce this in the main experiment. This occurred even though the older group reported less occurrence of motion sickness in the previous experiment than the younger group. When confronted with the full immersive screen, there tended to be a slow build-up in queasiness in a significant proportion of the older group. On the other hand, in the younger group any motion sickness disappeared after a few seconds exposure to the simulation. One explanation for the increase in motion sickness symptoms among the elderly participants may be an age-related decline in postural control (Baloh, Spain, Soscotch, Jacobson & Bell, 1995). In addition, older adults exhibit balance impairments when receiving incongruous visual and vestibular sensory information (Matheson et al, 1999). Taken together, prior research findings suggest that in our study older adults were already predisposed to motion sickness due to declines in their vestibular system resulting in a reduction in postural control. Our experimental simulation exacerbated this being through a visual display with an absence of, and thus conflicting, vestibular input.

RT The response time findings were not expected. In explanation, the response times were not simply reaction times to a single, one dimensional response like braking, where a difference between the older and young group would have occurred. Rather, participants were required to detect a moving obstacle, judge its speed and direction, judge the necessary distance to leave between themselves and the obstacle and then produce an accurate, coordinated visual-motor steering response. This is quite different from a simple reaction time task. In this case, there was no difference between the groups. One unanticipated result was the significantly shorter response times made by all participants to cars moving in on the right-hand side. Participants are likely to have an ingrained habit of giving way to vehicles on the right, which requires a faster response time, than responding to vehicles approaching on the left. As such, these findings could reflect an inherent survival instinct and reflect over-practiced driving responses.

NA and RMS As with response time, the most striking finding for nearest approach was the effect of side, such that all participants made a larger avoidance manoeuvre on the left-hand side than on the right. As stated above, this may reflect an ingrained habit of driving a right-hand drive car. In a 'real life' situation, while driving a right-hand drive car, a greater portion of the car (the passenger side) is to the left-hand side of the driver. It could then be that all participants made an assumption about the dimensions of their virtual car and allowed more room on their left-hand side to avoid the obstacle, as they would while engaging in normal everyday driving. As the participants were interacting with the virtual environment as they would in 'real life', it can be concluded that they were fully immersed within the driving simulation.

In the higher ambient light condition, the older drivers allowed less of a buffer between their car and the obstacle than did the young drivers, and hence exhibited an increased risk of actual collision. There was a similar overall effect for men and women, with the significant interaction meant that the older, female drivers approached closest to the obstacle cars. These findings were reflected in the amount of swerve produced by the older and younger, male and female groups. When the light level was reduced to simulate twilight levels, the older group drove more safely by systematically increasing their gap between the virtual car and the obstacle vehicles.

Considering the driving simulation and the steering task required of our participants, the spatial extent of the car was never evident because it was a virtual car whose spatial configuration was represented in the mind of the driver. However, in real life, the precise spatial edges of a vehicle are also not visible to the driver. Again, they have to be present in the mind of the driver, so in steering around obstacles sufficient gap is left between the car and the obstacle. Such ability to visualise has been shown to be important in parking a car – that is, placing it between stationary obstacles; men are faster and more accurate than women (Wolf et al., 2010). Moreover, it is possible that a mental rotation task which could be administered with as a computer based test, or in a slightly different format as a pencil-and-paper test, could tap into this spatial cognition ability (Jansen & Heil, 2010). As an explanation of our NA results, such tests were administered in Phase II to the same participants.

METHOD – PHASE II

Participants

All 62 participants who completed Phase one of the study were invited back to participate in Phase 2. Six of the original participant group had left the state and two could not participate due to illness. Forty-eight of the original 62 (77.4%) participated in Phase II: 25 (out of 30) of the younger group and 23 (out of 32) of the older group. All participants wore their standard optical correction for testing, if required.

Materials and Equipment

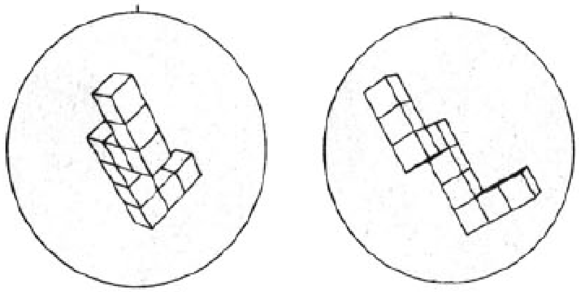
The standard tests for vision acuity, contrast sensitivity and depth perception were administered. To gain an insight into differences among the drivers' ability to mentally manipulate objects and gaps in three-dimensional space, two standard tests were used: one computer based and the other one pencil-and-paper.

Mental Rotation tests

Shepard and Metzler (1971) Mental Rotation of 3-D Objects. Stimuli were presented on a 24 inch Dell colour monitor screen resolution was 1920 × 1080 pixels. The program used was modified from CogLab™ 2.0 standard mental rotation task (Francis, Neath & vanHorn, 2008). On each trial (which were self-paced), two 3-D block shapes appeared on the screen: one to the left and one to the right (see example, Fig 7A). The two shapes were either identical, or different. One shape was also rotated around the vertical axis. The rotation was 0, 20, 40, 60, 80, 100, or 120 degrees relative to the orientation of the other shape. The task was to determine whether the two shapes were the same or different by pressing one of two keys on the keyboard: 'z' or '/'. There was a minimum of 70 trials: five trials for each pair of "same" and "different" stimuli at each rotation angle. Trials in which the participant's response was incorrect were signalled by a tone and were repeated so that reaction times (measured from when the stimulus was displayed to when a key was pressed) were only recorded for correct trials following the standard methodology. Practice of this task was provided to the participant before the experimental run. Depending on the number of errors the participant made, the task lasted between ten and 30 minutes

Mental Rotation Test (MRT; Vandenburg & Kuse, 1978*)* This was a pencil-and-paper test conducted in two identical parts: each part lasted three minutes and the participant was requested to work as quickly as they could without sacrificing accuracy. The task is illustrated in Fig 7B. The participant had to find two objects within the four circles on the right that matched the primary object on the left. The only difference between the original object and the chosen object(s) was that they were presented at different angles. There were 10 such problems in each part (for a total of 20) with a rest period between parts. Three practice trials with feedback were given at the beginning of the test.

A.



B.

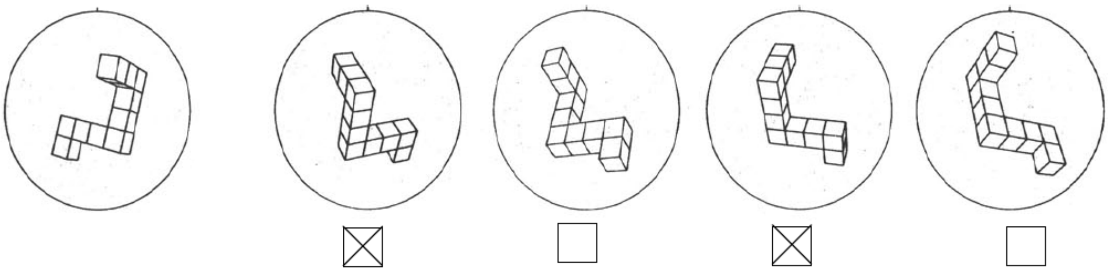


Figure 7. Stimuli used in the two mental rotation tasks. A. The CogLab task was displayed on a monitor where two block arrangements of either the same or different three dimensional spatial configuration. The participant had to respond to whether one arrangement was the same the other except rotated about a vertical axis. B. Vanderberg and Kuse (1978) pencil-and-paper mental rotation task. For each problem there was a primary object on the far left and the participant had to determine which of the four drawings on the right (here marked with crosses) is the same object as the one on the left.

Vision Testing

Visual acuity, contrast sensitivity and stereopsis were assessed under the recommended illumination. Visual acuity was assessed at 3 m, contrast sensitivity to the the Cambridge Low Contrast gratings (CLCG, Wilkins *et al.*, 1988) was assessed at 6 m, stereopsis was assessed at 40 cm.

Visual acuity was assessed for each eye as well as binocularly. The National Vision Research Institute of Australia's Hi-Lo contrast LogMAR chart was used. One set of letters on this chart is at high contrast, the other set is at 10% contrast.

Contrast sensitivity The CLCG measures contrast thresholds for gratings with a spatial frequency of 4 cpd, close to the maximum of the normal human visual system. They include 10 plates that display a horizontally oriented square wave grating with Michelson contrasts that range from 13% to 0.14%. The plates are presented to participants in pairs, each presentation consisting of a grating and a blank plate that has the same mean reflectance as its grating pair. Participants must make a two-alternative forced choice when they indicate which of the two plates contains the grating. The test was completed in order of decreasing contrast. Each time an error was made, the sequence was restarted at three plates preceding the error. The plates where errors were made were recorded on three runs through the sequence.

Stereopsis The Titmus circles stereotest displays nine polarized stereograms each consisting of four sets of annuli. One set is constructed from two orthogonally polarized images consistent with a particular retinal disparity when the test is viewed through congruent polarized lenses so that each eye sees a different image. The test was oriented to present crossed retinal disparities, so that the inner circle of one of the four sets of concentric circles appeared to float above the rest. The nine stereograms are consistent with retinal disparity angles ranging from 800 to 40 arc secs.

Procedure

Information about the study was provided via an informed consent package to each participant. The computer based mental rotation test was conducted at low-lighting levels from a viewing distance of 70 cm. It was displayed in high contrast black-on-white. All other tests were completed with all room lights on, with additional lighting used in the case of the vision tests. The order of the vision tests was randomised, however, one of each of the mental rotation tests were completed at either the beginning or end of the testing session. Sessions lasted 50 to 90 minutes.

RESULTS AND DISCUSSION – PHASE II

Visual Tests

ANOVAs were performed on these data, however, while there were no significant main effects for either gender or any significant interactions, there was always a main effect for age group. In summary, the young group had better visual acuity (at each of high and low contrast), contrast sensitivity and stereoacuity than the older group. The results of the visual tests are summarised in Table 2 where independent groups *t*-tests illustrate these differences.

Table 2
Results of Vision Tests for Phase 2: Mean and (SEM)

Group	*N*	% Female	VA Hi	VA Low	LogCLCG (Av)	Titmus
Young	25	68.0	5.57 (0.20)**	8.04 (0.35)***	1.06 (0.045)**	8.91 (0.35)*
Old	23	56.5	7.64 (0.59)**	12.63 (1.18)***	0.693 (0.09)**	7.59 (0.34)*

Independent groups *t*-tests: *p < .05, **p < .005, *** p <.001; VA – raw NVRI acuity at either high or low contrast, binocular viewing ; CLCG – Cambridge Low Contrast Gratings threshold in log Michelson contrast, averaged across both eyes; Titmus – stereoacuity test.

Mental Rotation Tests

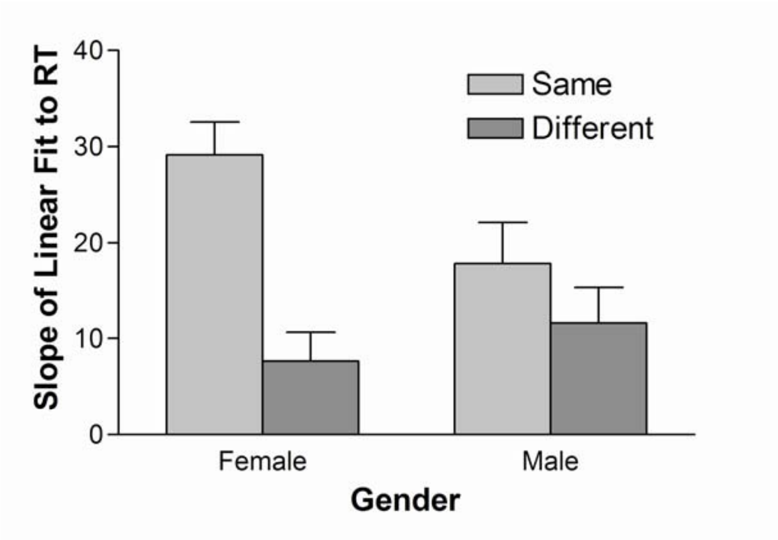


Figure 8. Average slope of a linear fit to reaction time as a function of rotation angle. The higher the slope, the more the data conforms to Shepard & Metzler's (1971) chronometric mental rotation model. If the two block shapes were different rather than the same, females had greater difficulty than males.

Each of the mental rotation tests proved difficult for all participants, but especially for the older participants. One older female did not complete the computer-based task, and a number believed that they were just 'guessing'. In the MRT, the number of correctly solved problems was added up for each participant and a group (young *vs* older) ×gender between-group ANOVA was performed. Even though men performed slightly better than women following previous research, it was not significant. The young group (M = 13.5, SEM = 0.95) did perform much better than the old group (M = 7.9, SEM = 0.93; $F(1,44) = 18.5$, $p < 0.001$). All responses in the computer based task were correct responses: the parameter to be measured here was if the block arrangement was being rotated in the mind's eye, that is, the effectiveness of their spatial visualisation. Reaction times to the various angles were examined and following Shephard and Metzler (1971) a line was fitted for the angles 0, 20, 40 and 60° for each of the 'same' and 'different' responses. Reaction times reached a ceiling beyond 60°. The level of the participant's mental rotation capacity was operationalised as the slope of this line: if there were no mental rotation, then there would be no relationship between angle and response time, and the slope of the line would be near zero. There was no significant main effect for gender. There was a main effect for 'same' versus 'different': 'same' responses yielded much higher slopes than 'different': $F(1, 43) = 18.6$, $p < .001$, partial $\eta^2 = .302$. However, this main effect was moderated by a gender interaction with 'same' versus 'different': $F(1, 43) = 5.62$, $p = .02$, partial $\eta^2 = .116$. For the different task, the females were having much more difficulty rotating the blocks than they did in the same task whereas males found the task of similar difficulty (see Fig 8).

The results of Phase II show that the older people were performing in the driving simulator with lower visual capacity than the younger group. However, this in itself would not necessarily explain their riskier behaviour in smaller spatial buffers between their car and the obstacle. In fact, when light conditions were reduced leading to further deterioration in their visual capacity, their margin of safety increased. The spatial visualisation tests clearly show that the older group are less able than the younger group in this area, and this, one the older group are not being as cautious, may be producing the NA results.

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