CITATION:

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Investigation of the interaction between visual impairment and multi-tasking on driving performance

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Purpose:
This study investigated the effects of visual and auditory secondary tasks on the driving performance of young and old participants with simulated visual impairment and those experiencing age-related declines in visual attention.

Methods:
Twenty eight participants comprising two age groups (younger, M=27.3 years; older M=69.2 years) drove around a closed road circuit under both single and dual task conditions. Measures of driving performance included detection and identification of road signs, detection and avoidance of large low contrast road hazards, gap judgment, lane keeping and time to complete the course. Performance was assessed for two levels of visual impairment compared to a baseline condition. Visual impairment was simulated using goggles designed to replicate the effects of cataracts and blur; all participants had binocular visual acuity greater than 6/12 when wearing the goggles and satisfied the visual requirements for driving. The secondary task required participants to verbally report the sums of pairs of numbers presented either through a computer speaker (auditorally) using computer-generated files or via a dashboard mounted monitor (visually) while driving.

Results: Visual impairment significantly reduced driving performance ($p<0.05$) and these differences were greatest for the cataract condition. Multi-tasking further exacerbated the effects of visual impairment, where the visual dual task had a greater detrimental effect on driving performance than the auditory dual task ($p<0.05$), particularly for the older drivers.

Conclusions: Multi-tasking (for example, talking on a mobile phone or using in-vehicle navigational devices) had a significant detrimental impact upon driving performance and these effects were exacerbated for older drivers and for those with simulated visual impairment. The implications of these findings are far reaching in modern society where the driving and in-vehicle environments are becoming increasingly complex and the elderly comprise the fastest growing segment of the driving population.

Introduction

Older drivers have high fatal crash rates that are comparable to, or greater than, young drivers and they are also considered to be at fault in 80% of all crashes. Crashes involving older road users are estimated to cost the Australian economy $500 million per year. The underlying reasons for this disproportionate involvement of older individuals in crashes have not been well established. It is recognised, however, that the effects of age alone are not sufficient to account for many of these crashes. This has led to an increased interest in examining the performance of sub-populations of drivers with sensory impairments that become more prevalent with age. Impairment of visual function is of particular interest, and has been cited as a likely contributing factor to the increased crash rates of the elderly (Shinar & Schieber 1991). Although there is less evidence in relation to the effects of impairment in auditory function on driving, hearing impairment has also been implicated as a risk factor for vehicle crashes (Ivers et al 1999). Importantly, the driving situation and the in-vehicle environment are becoming increasingly complex; hence the problems of the older driver are likely to increase in the future. Some vehicles are equipped with sophisticated navigation and entertainment systems, which like mobile phones, add to the driver's attentional burden distracting them from their primary task. Some of these navigation systems are specifically marketed as safety enhancing features for older drivers, yet their potential to improve safety has not been demonstrated.

Intrinsic factors likely to impact on older drivers' performance include vision, hearing and cognition. The contribution of impaired vision to the driving difficulties of the elderly is evidenced by a range of studies. Crash risk is increased in older drivers with cataracts (Owsley et al 1999) and glaucoma (Owsley et al 1998) and in those drivers with impairments in selected visual functions including visual fields, dynamic visual acuity, contrast sensitivity and visual attention (Wood 2002a). Studies using a closed road circuit have shown that simulated vision impairment, specifically cataracts and visual field restriction (Wood & Troutbeck 1992; 1994; 1995) and true vision impairment, including cataracts, glaucoma and age-related maculopathy (Wood 1999; 2002b) significantly impair driving performance. Impaired vision makes it difficult to detect and react to formal and informal road cues, and exacerbates existing deteriorations in physical ability and judgment. In addition, the problems of vision impairment are likely to increase as driving and in-vehicle environments become more complex and drivers are required to divide their attention across multiple tasks. More specifically, for the vision impaired, the ability to perform concurrent tasks may be compromised because the processing and/or interpretation of visual input may represent a significant attention demanding task in itself. Recent evidence suggests that this may be the case. Turano et al (1998) reported that individuals with vision impairment have greater difficulty walking in unfamiliar places; they expend more mental effort and walk more slowly than those with normal vision. Importantly, the deficits in walking exhibited by the visually impaired individuals were further exacerbated compared to controls, when participants were given a secondary auditory task. The implications of these findings for driving performance are yet to be investigated.

Hearing impairment is also highly prevalent in older people, with recent Australian studies reporting that approximately 60% of community-based people over 60 years of age have an impairment (Hickson et al 1999). To date, the impact of such impairments on driving performance has not been fully examined. Gallo et al (1999) reported an association between hearing impairment and reports of adverse driving events and Ivers et al (1999) found that higher crash rates were associated with poorer visual acuity and self-reported hearing loss, especially in the right ear. Similarly, driving cessation has been linked with hearing and vision impairment (Gilhotra et al 2001). To date much of the research has relied on self-reported driving performance which has poor face validity. In addition, some older drivers will experience dual sensory loss (ie, both hearing and vision impairment) and the impact of these together on driving performance is unknown.

Older drivers are also more likely to experience declines in cognitive functioning which may increase crash risk especially under dual task conditions. For instance, although older adults experience small declines in some cognitive abilities including short term memory span and recognition memory, age-related changes are larger for tasks requiring prospective memory (ie, reminding themselves to perform a task in the future), executive function and working memory (Grady & Craik 2000). These latter tasks usually require participants to maintain and/or manipulate information in working memory while performing another concurrent task. Recent studies have documented a link between tests of cognitive function and driving performance measures (Szlyk et al 2002). Studies have also begun to identify how loads on cognitive processes including working memory affect the efficiency of visual search that may be important for detecting potential road hazards (Han & Kim 2004).

The multiple resource model of Wickens (1980) predicts greater interference between tasks that compete for the same perceptual modality (visual or auditory), associated working memory subsystems (visuo-spatial sketchpad or phonological loop) or mode of response (manual or vocal). Thus a secondary auditory task is predicted to interfere less with the manual control task of driving because it relies on a distinct set of resources associated with verbal perception, verbal working memory and generation of a vocal response. However, the addition of a secondary visual task necessitates sharing of resources with visual perception and spatial working memory. The processing of a degraded visual image may place significant demands on this finite pool, thereby reducing any excess capacity that would be allocated to another visual task. In addition to these central effects on performance (i.e., cognitive), a secondary visual task may also produce interference at a more peripheral level. The visual presentation of information creates a competing visual channel that must be monitored by shifting gaze from outside to inside the vehicle. A shift in gaze could potentially result in poorer hazard and sign detection and loss of vehicle control. Driving simulator studies have shown that when drivers are engaged in a secondary task they miss more traffic signs and respond more slowly (Strayer & Johnson 2001) and are less likely to detect changes in driving scenes (McCarley et al 2001). These results could reflect top-down influences on the strategic allocation of attention. For instance, drivers might respond to increased load by attending more to the driving scene directly in front rather than monitoring lower priority peripheral visual stimuli (eg, pedestrians). Alternatively, a dual-task may divert attention from the driving scene to the mobile phone conversation.

The overall aim of this study is to develop a clear understanding of the interaction between visual impairment, age and multi-tasking on real world measures of driving performance.

The order of runs around the driving circuit was randomized and the driving runs were conducted over two visits to the test track separated by at least a week to minimize learning effects. Driving performance was assessed on a 5.1 km closed road circuit (Wood & Troutbeck 1994) free of other vehicles and representative of rural roads. The participants drove a right-hand drive sedan with automatic transmission and power steering. Participants were given a practice run in order to familiarize themselves with the car, the road circuit and the driving tasks. The practice run was performed in the opposite direction to the recorded run in order to minimize any familiarity effects. For the main test circuit, participants were instructed that they would be required to perform a number of concurrent tasks whilst driving at what they felt was a safe speed, to drive in their own lane except when avoiding hazards and to obey all regulatory signs. Performance measures consisted of the time to complete the road course, number of road signs recognized, the number of road hazard s recognized and the number hit, correct gap judgments, as well as correct responses on the secondary task.

Methods

The effects of multi-tasking on measures of driving performance including the detection and recognition of road signs and large low contrast hazards, judgment of gaps between cones and time to complete the course were obtained for young and older participants as they drove around a closed road driving course under two different levels of simulated visual impairment.

Participants

Fourteen young (Mean age = 27.3) and fourteen elderly (Mean age = 69.2) participants with normal corrected vision and who were in good general health completed the experiment. All participants were licensed drivers with at least three years of driving experience, and all reported that they drove regularly.

The study was conducted in accordance with the requirements of the Queensland University of Technology Human Research Ethics Committee. All participants were given a full explanation of the experimental procedures and written informed consent was obtained, with the option to withdraw from the study at any time.

Driving course

Performance was assessed when the participants were driving under two types of visual impairment compared to a baseline condition. Visual impairment was simulated using two sets of goggles, one of which was designed to replicate the effects of cataracts and the other represented blurred vision. The cataract goggles described previously by Wood and Troutbeck (1995) were used to simulate the effects of cataracts and reduced distance visual acuity to an average level of 6/12; and are hereafter known as the cataract condition. Binocular plus lens blur was used to reduce visual acuity of each participant to that of the cataract simulator goggles and are hereafter referred to as the blur condition. All participants had binocular visual acuity greater than 6/12 when wearing the goggles and satisfied the visual requirements for driving.

The secondary task required the participants to verbally report the sums of pairs of numbers presented either through a computer speaker (auditorally) or via a dashboard mounted monitor (visually) while driving. The visual task consisted of large numbers subtending between 3.5 and 4.8 degrees of visual angle, which were well above the visual threshold of all participants. The auditory stimuli were presented at a comfortable listening level set by the participant. Pairs of numbers were presented roughly every 3.5 seconds.

A composite driving score was derived to capture the overall driving performance of the individual participants compared to the whole group and included road sign recognition, cone gap perception, course time and the number of hazards hit. Z scores for each of these four driving measures were determined and the mean Z score for each participant was calculated to provide a composite score. Equal weighting was assigned for all tasks.

Results

The group mean data for the composite driving Z score are given in Figure 1 and demonstrate the change in performance of drivers as a function of whether they were driving with normal vision, blurred vision or with simulated cataracts, whether they were required to complete a secondary visual or auditory task while driving and their age group.

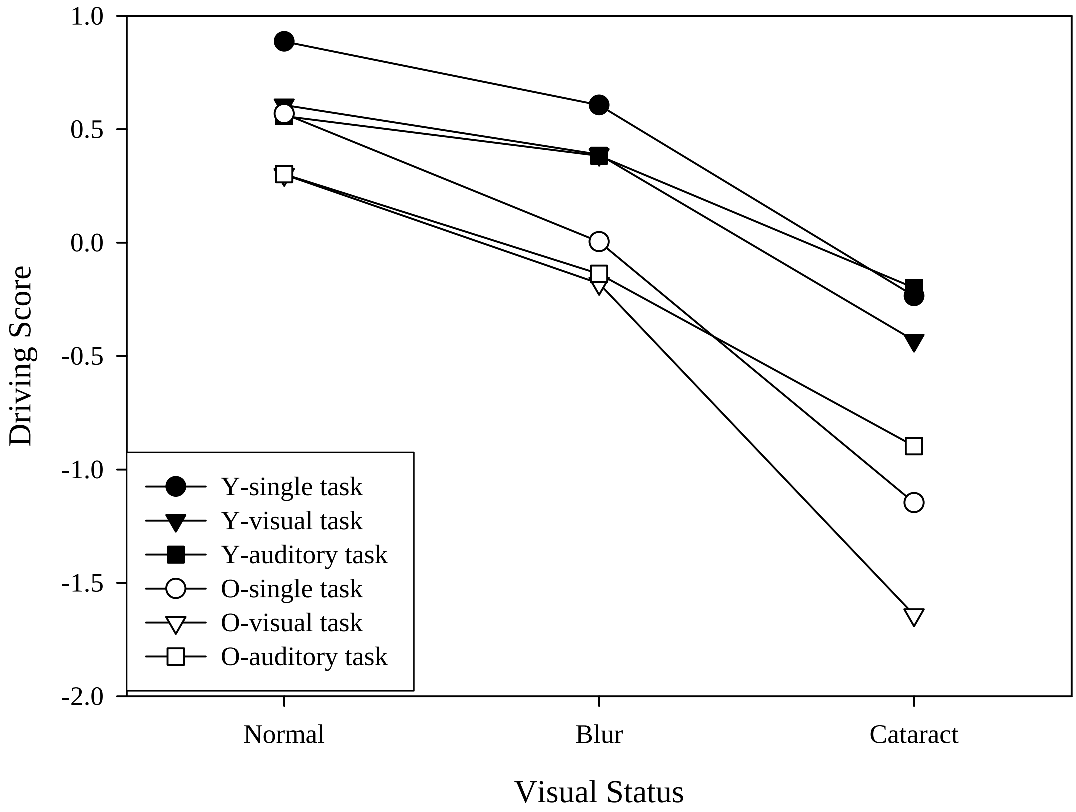

Figure 1: Group mean data for the composite driving score as a function of visual status, task and driver age; where the filled symbols represent the younger participants and the open symbols represent the older participants.

An ANOVA with two within subject factors (driving task and visual status) and one between subjects factor (driver age) demonstrated that the main effects of driving task, [$F(2,52) = 6.726$, $p=0.003$], and visual status, [$F(2,52) = 62.07$, $p=0.000$] were both significant. The main effect of driver age was also significant, indicating that, overall, older drivers had poorer driving performance than younger drivers, [$F(2,26) = 11.76$, $p=0.000$]. There were significant interaction between vision and group [$F(4,52) = 4.45$, $p=0.004$] and task and vision [$F(4,104) = 3.85$, $p=0.006$]. Model-based contrast analysis indicated that driving performance was significantly better ($p<0.05$) for the single task condition compared to either the dual visual and auditory secondary task conditions (but these were not significantly different from one another). Driving performance scores were all significantly different from one another under the three visual conditions ($p<0.05$), where performance was most compromised when driving under the simulated cataract condition. The interaction effects indicated that the detriment to driving performance was greater for the older drivers under simulated cataract conditions and for all drivers under the cataract condition when they were undertaking the visual dual task.

Group mean data for performance on the secondary summing task are given in Figure 2 as a function of whether the summing task was presented visually or auditorally, the visual status of the drivers (either normal, blur or cataracts) and the age of the drivers.

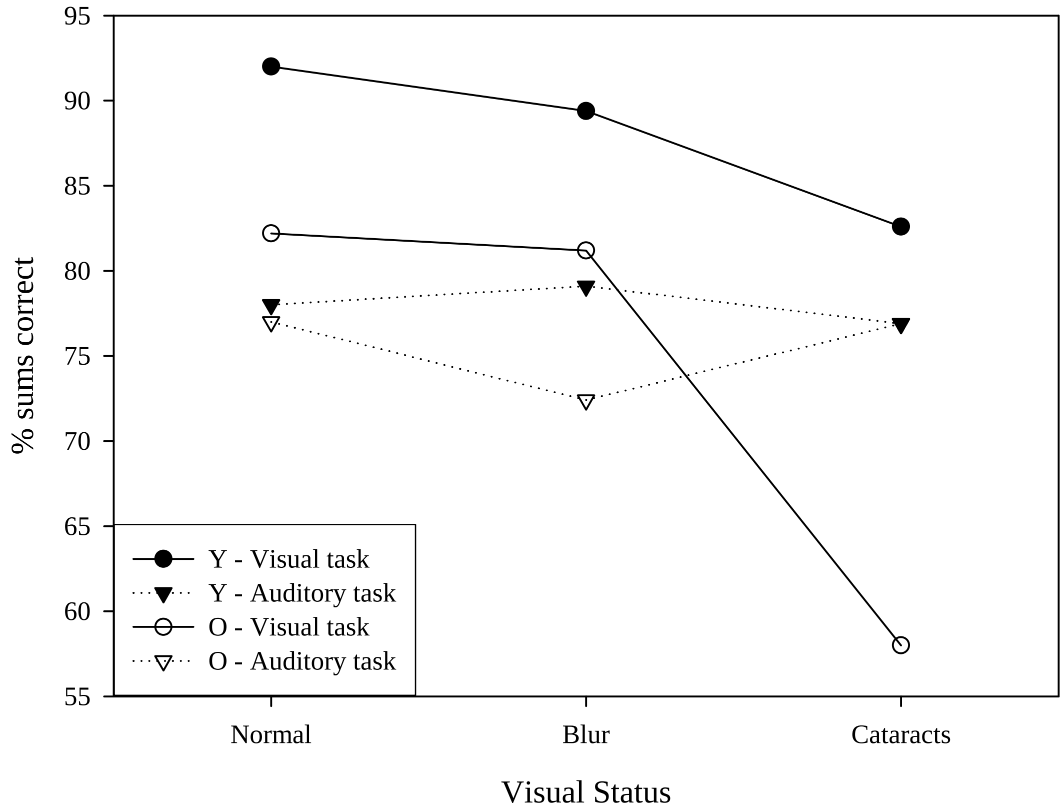

Figure 2: Group mean % correct performance on the secondary task as a function of visual status, task and driver age; where the filled symbols represent the younger participants and the open symbols represent the older participants.

An ANOVA with two within subject factors (driving task and visual status) and one between subjects factor (driver age) demonstrated a significant main effect on the percent correct on the summing task for visual status, [F(2,50) = 17.09, p=0.000] and significant interactions between task and vision [F(2,50) = 11.69, p=0.000] and task, vision and group [F(2,50) = 4.72, p=0.013], where participants made significantly more errors on the visual dual task when driving under cataract conditions and these effects were exacerbated for the older drivers.

Discussion

The results demonstrate that driving performance was worse when participants drove under conditions of simulated visual impairment, under the dual-task compared to the single task condition and that there was an interaction between the two. Age-related differences were also seen in the composite driving score, where the older drivers had poorer performance than that of the younger drivers.

The visual status of drivers had a substantial effect on driving performance, where the simulated cataract condition resulted in the greatest decrement to driving performance, despite the fact that visual acuity through the simulated cataracts was equal to that of the blur condition. The results for simulated cataracts are in accord with previous findings which suggest that cataracts have a detrimental effect on indices of driving performance (Wood &

Troutbeck 1994; 1995; Owsley et al 1999) and these effects were greater for the older participants (Wood & Troutbeck 1995). Importantly, the results which compare the impact on driving performance of the blur condition and cataract condition indicate that driving performance is not well predicted by standard measures of visual acuity, as these were equal between the two conditions.

The overall driving performance of all participants was worse when they were driving under dual task conditions compared to the single task conditions and this is in agreement with previous driving simulator studies. Richards et al (2002) using a laboratory-based image-flicker task reported that response times to search for change in images of driving scenes were significantly slower in the presence of a concurrent auditory task. In addition, simulator based studies have shown that driving performance is impacted when participants have to respond to a secondary task (Strayer & Johnson 2001). The secondary task appears to cause interference affecting detection of hazards and changes in the driving scene (Recarte & Nunes 2003). Dual tasking has also been shown to be a problem in the driving situation as evidenced by findings showing that cell phone use increases crash risk by more than four-fold (Redelmeier & Tibshiranin 1997). Interestingly, we found no interaction between driver age and task, except when the participants were driving under the simulated cataract condition, when the older drivers were most affected. Recent studies on driving simulators have also shown that as in our study of real world driving the effects of the secondary tasks are not significantly affected by driver age (Strayer & Drew 2004).

The results also demonstrate that the effects of the visual task were similar or greater than the auditory dual-task on driving performance, and these effects interacted with visual status; where the effects of the visual dual task were greatest when the participants were driving under the simulated cataract condition. These results are in general accord with the predictions derived from theories of divided attention (Wickens 1984), which suggest that a visual task would interfere with driving more than an auditory task, because the visual task is competing for the same attentional reserves as that of driving. These findings are also consistent with data that suggest that cell phone conversations may interfere with the attention-capturing properties of stimuli in the driving environment (Strayer et al 2003). Participants also reported feeling uncomfortable when taking their eyes off the road to look at the visual display. Interestingly, secondary task performance was also worse for the visual dual task when driving under cataract conditions and these effects were exacerbated for the older drivers.

In summary the results suggest that both the young and older drivers were affected by the presence of a secondary task, such that dual task performance (either with visual or auditory distracters) was worse than single task performance for both age groups. Simulated cataracts caused the greatest decrement in performance under visual dual conditions, particularly for older drivers. Importantly, though visual acuity for the blur and cataract conditions was matched, the impact of impairment from cataracts far exceeded that of blur, indicating that visual acuity is a poor predictor of the detrimental effects of cataracts on driving performance. The driving performance of the older drivers was also significantly worse than that of the younger participants and this is in accord with previous studies which have reported that the crash rates of older drivers are higher per distance travelled than that of their younger counterparts (eg. Stamatiadis & Deacon 1995). The results also suggest that there is no particular benefit in presenting information in either an auditory or visual domain, although there was a trend for the visual dual task to have a greater impact upon overall driving performance under the simulated cataract condition, particularly for the older drivers.

Acknowledgements

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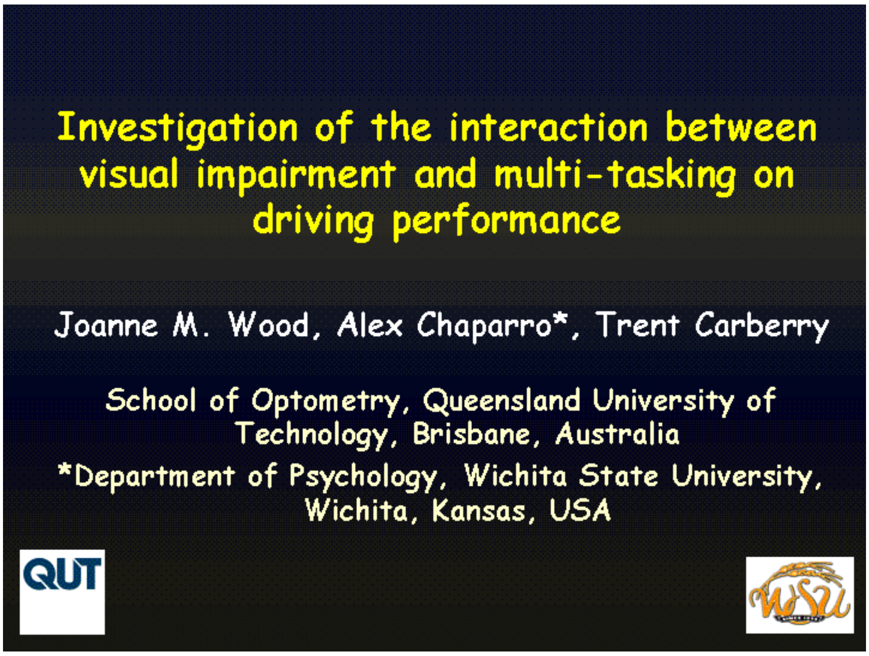
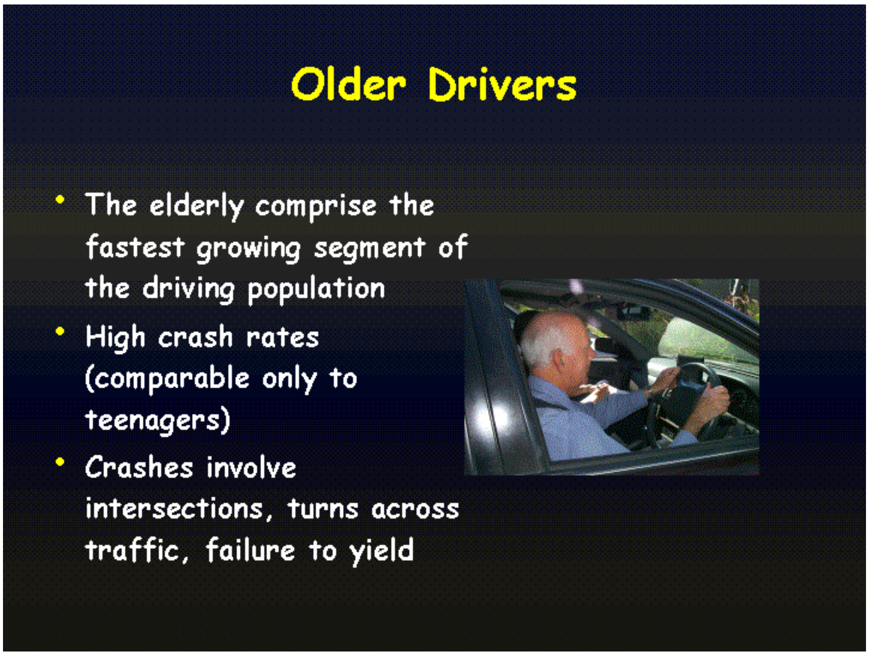
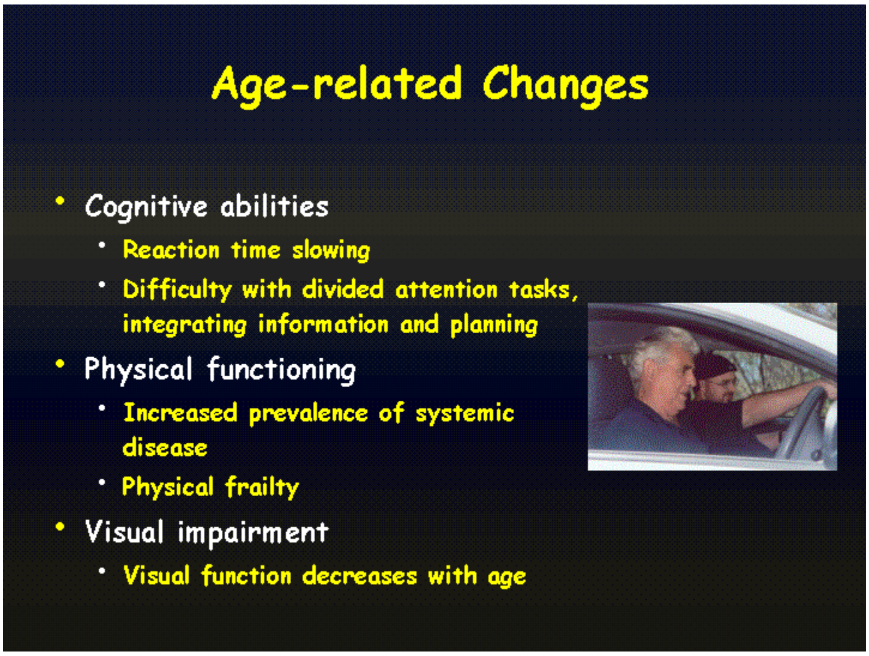
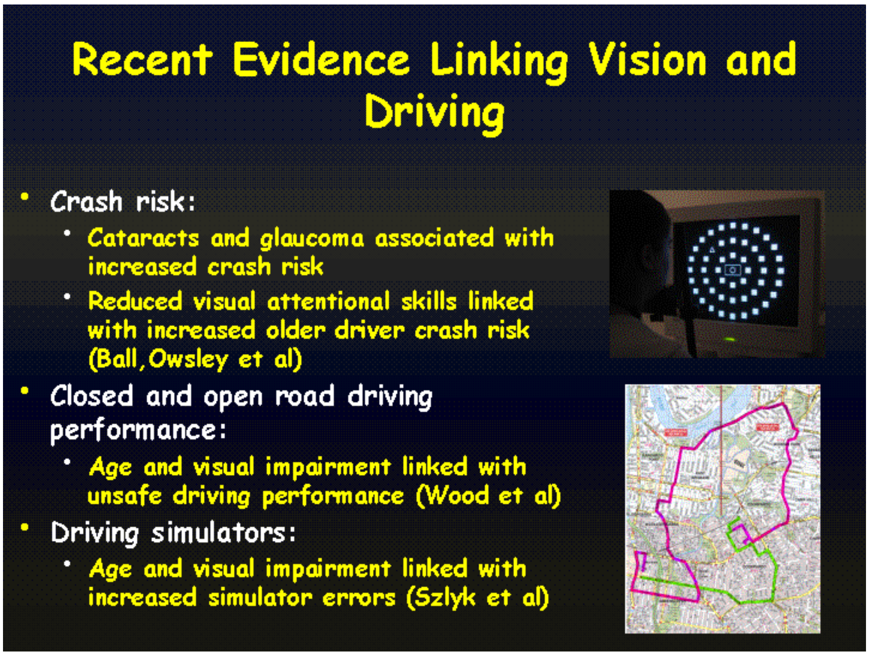
PRESENTATION SLIDES

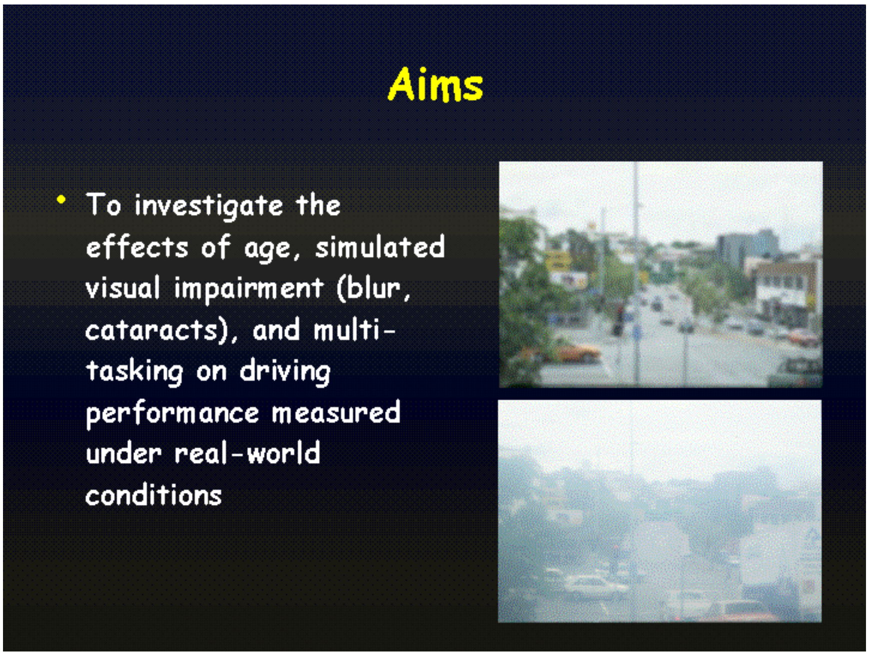


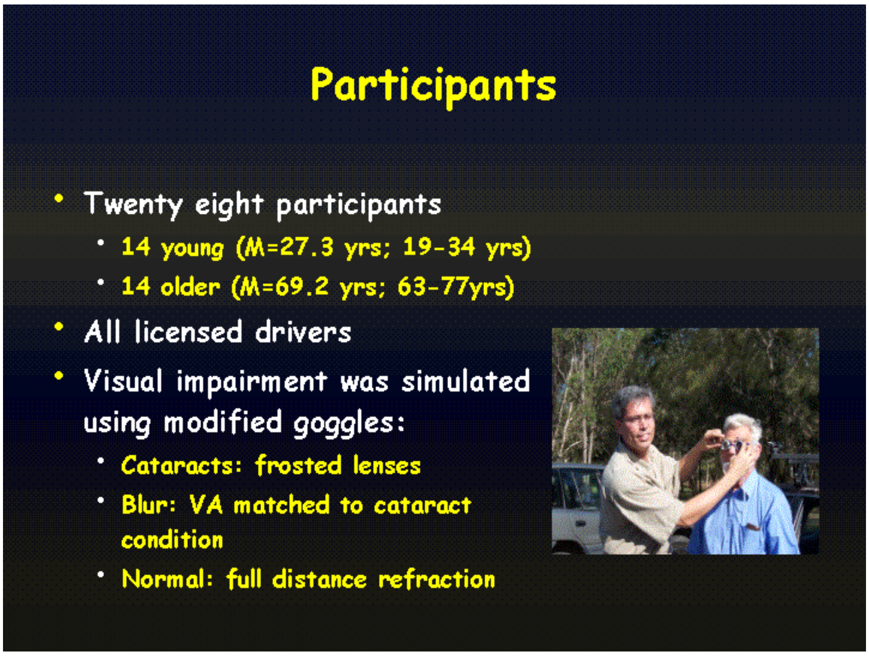


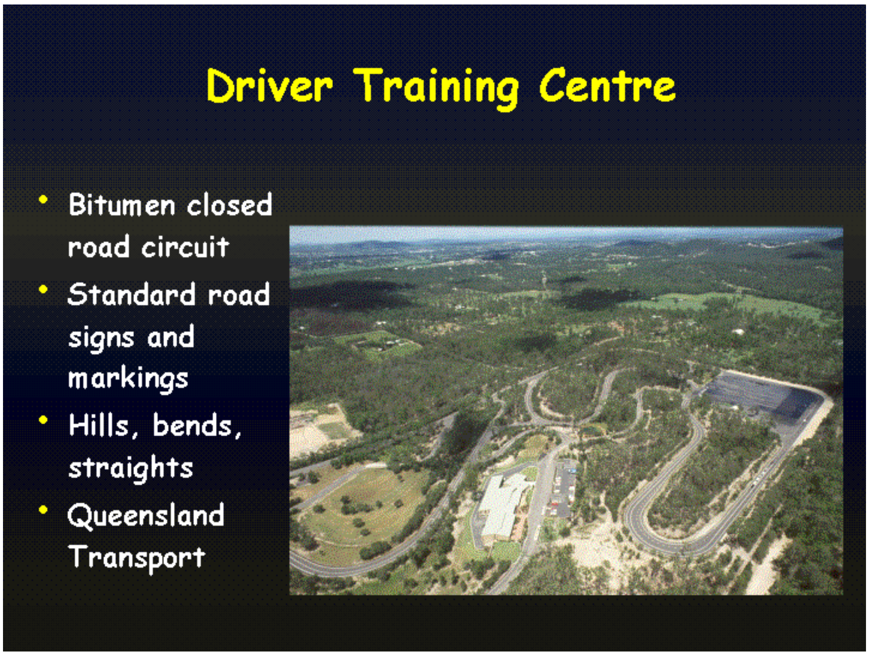

Age-related Changes
Cognitive abilities
Reaction time slowing
Difficulty with divided attention tasks, integrating information and planning
Physical functioning
Increased prevalence of systemic disease
Physical frailty
Visual impairment
Visual function decreases with age

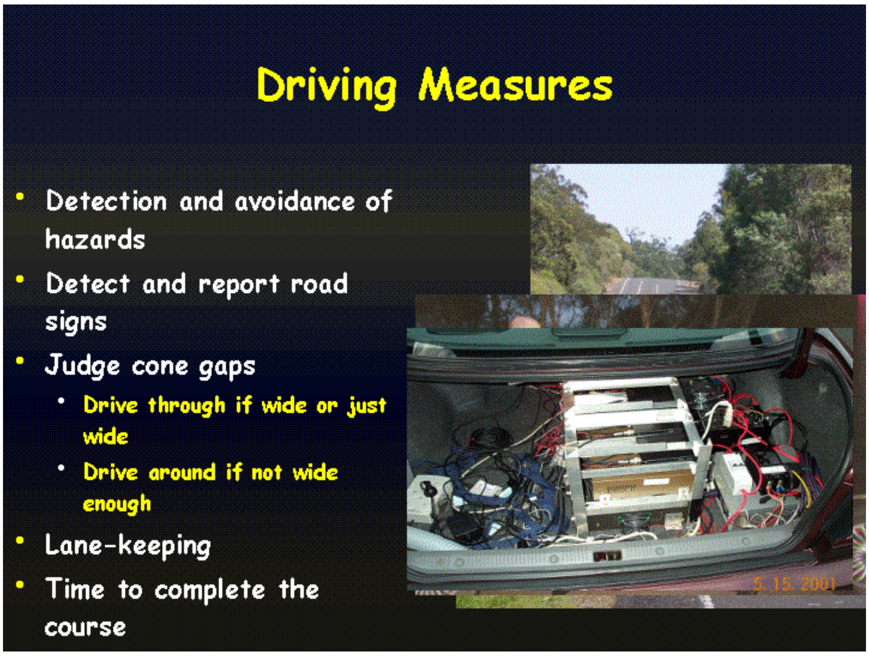

Recent Evidence Linking Vision and Driving
Crash risk:
Cataracts and glaucoma associated with increased crash risk
Reduced visual attentional skills linked with increased older driver crash risk (Ball, Owsley et al)
Closed and open road driving performance:
Age and visual impairment linked with unsafe driving performance (Wood et al)
Driving simulators:
Age and visual impairment linked with increased simulator errors (Szlyk et al)

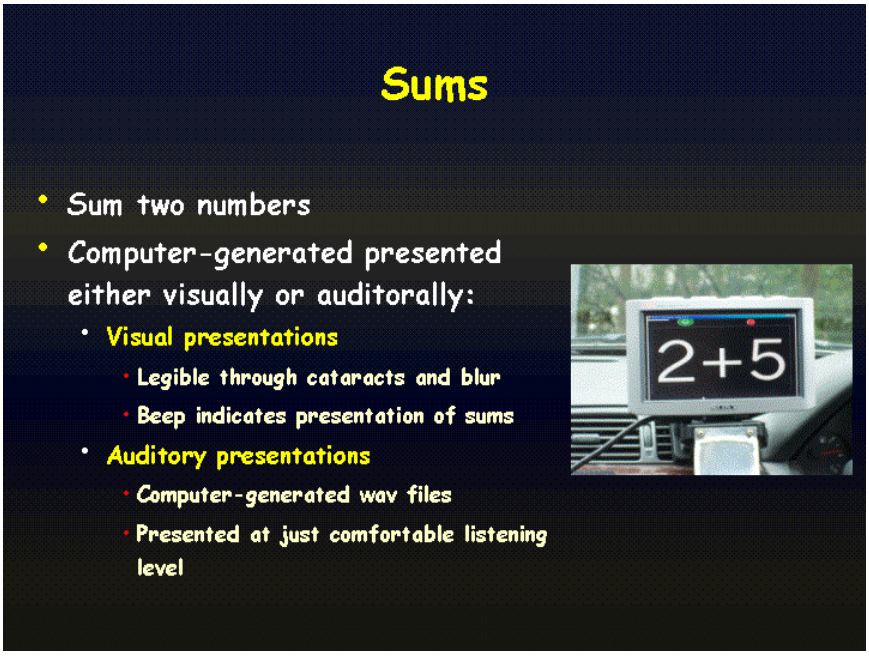

Age-related Changes
• Effects of vision and aging likely to be exacerbated by increasing complexity in the:
• Driving environment
• In-vehicle environment

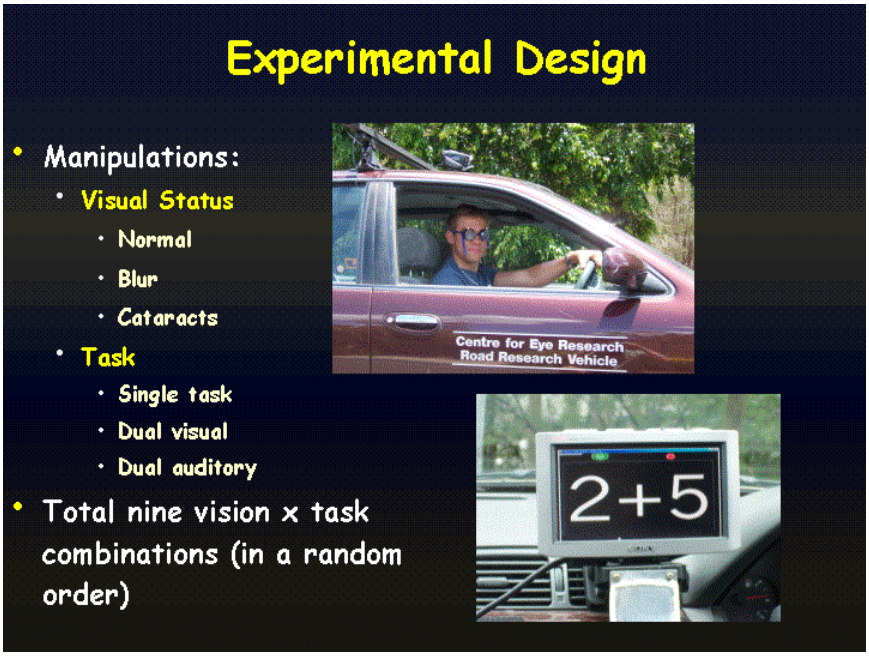

Aims
• To investigate the effects of age, simulated visual impairment (blur, cataracts), and multi-tasking on driving performance measured under real-world conditions

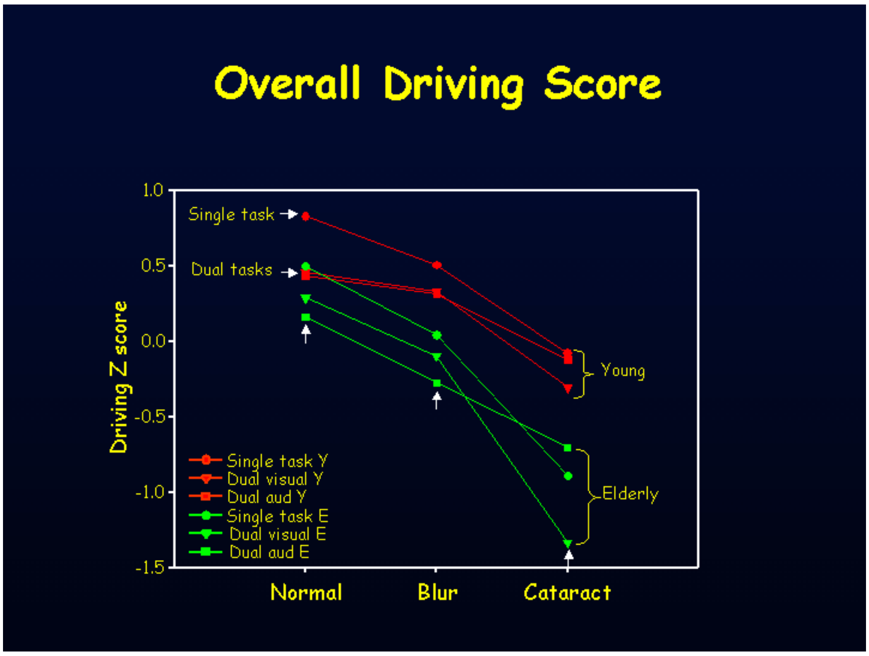

Participants
Twenty eight participants
14 young (M=27.3 yrs; 19-34 yrs)
14 older (M=69.2 yrs; 63-77yrs)
All licensed drivers
Visual impairment was simulated using modified goggles:
Cataracts: frosted lenses
Blur: VA matched to cataract condition
Normal: full distance refraction

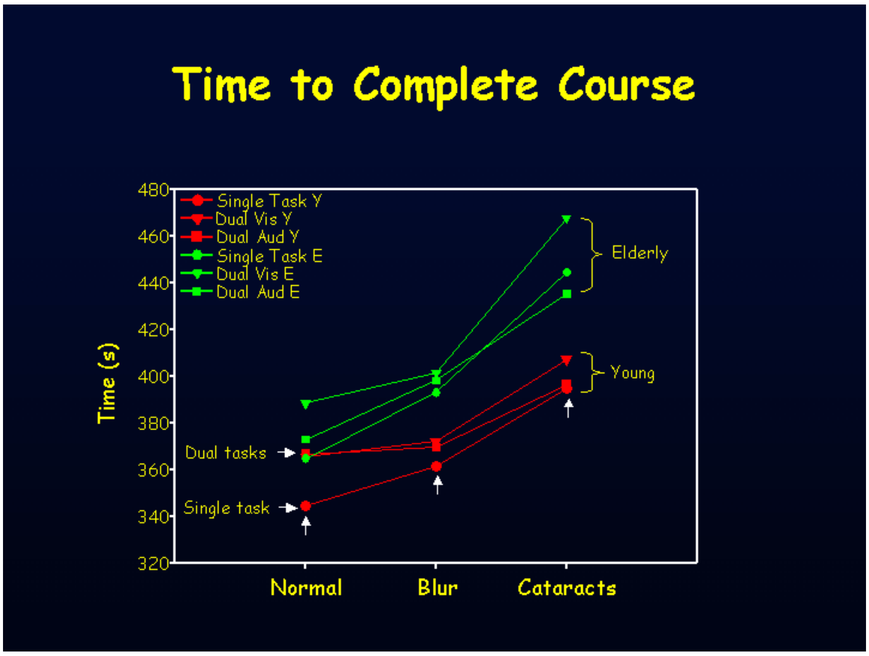

Driver Training Centre
Bitumen closed road circuit
Standard road signs and markings
Hills, bends, straights
Queensland Transport

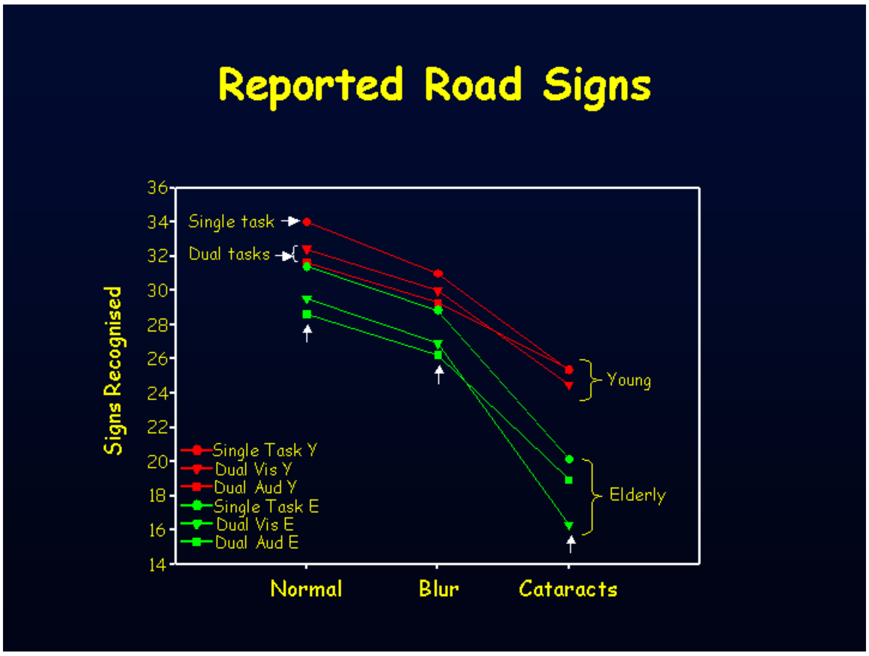

Driving Measures
• Detection and avoidance of hazards
• Detect and report road signs
• Judge cone gaps
• Drive through if wide or just wide
• Drive around if not wide enough
• Lane-keeping
• Time to complete the course

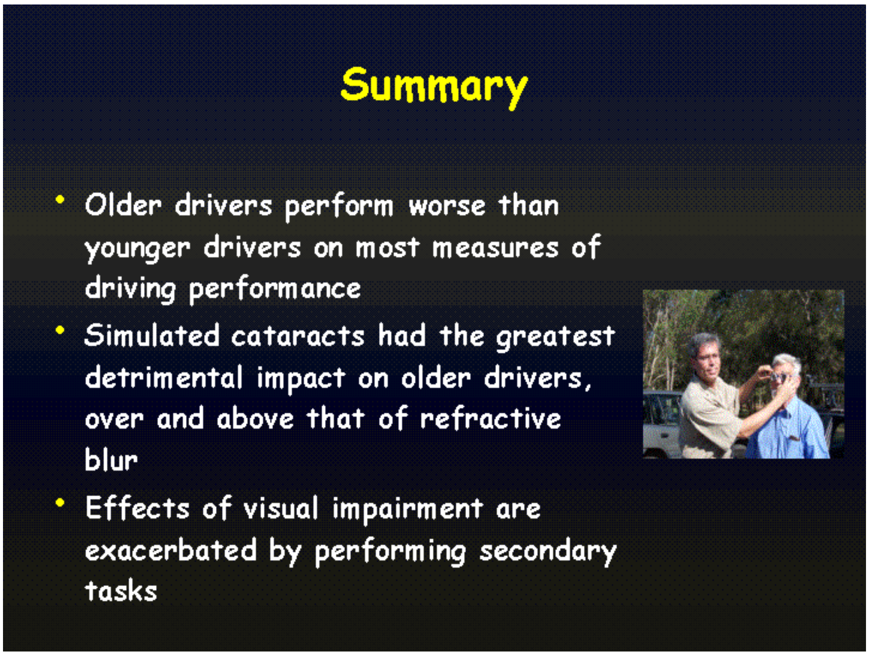

Sums
• Sum two numbers
• Computer-generated presented either visually or auditorally:
• Visual presentations
• Legible through cataracts and blur
• Beep indicates presentation of sums
• Auditory presentations
• Computer-generated wav files
• Presented at just comfortable listening level
2+5

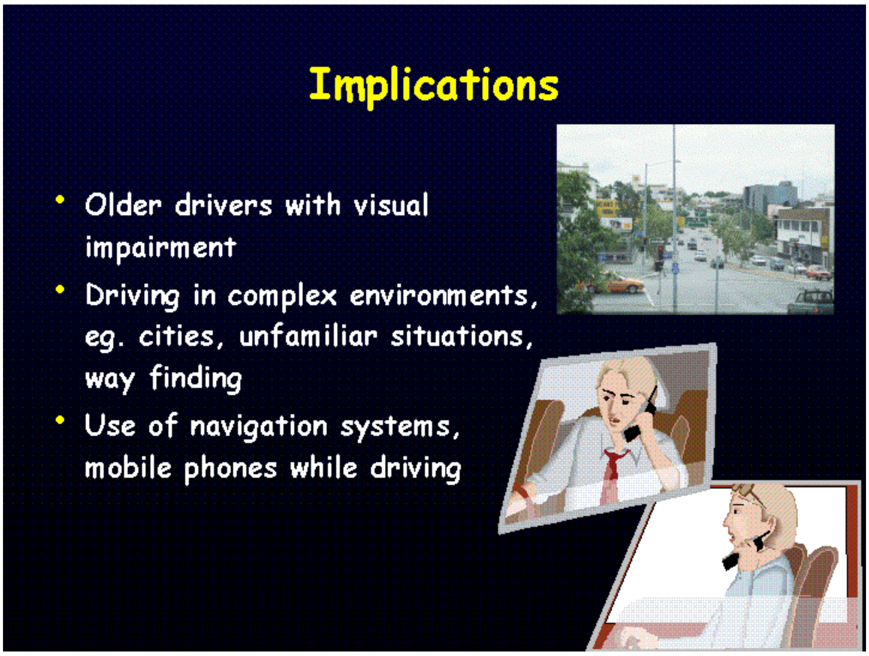

Experimental Design
Manipulations:
Visual Status
Normal
Blur
Cataracts
Task
Single task
Dual visual
Dual auditory
Total nine vision x task combinations (in a random order)
Centre for Eye Research
Road Research Vehicle
2+5

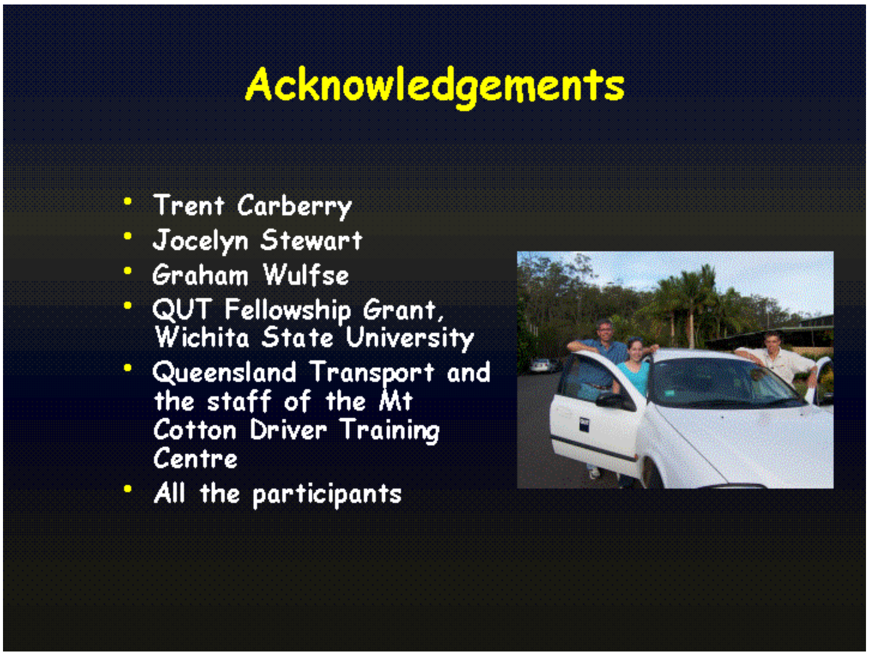

Overall Driving Score
Driving Z score
1.0
0.5
0.0
-0.5
-1.0
-1.5
Single task
Dual tasks
Young
Elderly
Single task Y
Dual visual Y
Dual aud Y
Single task E
Dual visual E
Dual aud E
Normal
Blur
Cataract


Time to Complete Course
Time (s)
480
460
440
420
400
380
360
340
320
Single Task Y
Dual Vis Y
Dual Aud Y
Single Task E
Dual Vis E
Dual Aud E
Elderly
Young
Dual tasks
Single task
Normal
Blur
Cataracts


Reported Road Signs
Signs Recognised
36
34
32
30
28
26
24
22
20
18
16
14
Single task
Dual tasks
Young
Elderly
Single Task Y
Dual Vis Y
Dual Aud Y
Single Task E
Dual Vis E
Dual Aud E
Normal
Blur
Cataracts


Summary
Older drivers perform worse than younger drivers on most measures of driving performance
Simulated cataracts had the greatest detrimental impact on older drivers, over and above that of refractive blur
Effects of visual impairment are exacerbated by performing secondary tasks


Implications
Older drivers with visual impairment
Driving in complex environments, eg. cities, unfamiliar situations, way finding
Use of navigation systems, mobile phones while driving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