Ergonomics, 1999, vol. 42, no. 3, 428–443

Effects of car window tinting on visual performance: a comparison of elderly and young drivers

Nicholas R. Burns*, Ted Nettelbeck, Michael White and Jacqueline Willson

Department of Psychology, University of Adelaide, South Australia 5005, Australia

Keywords: Visual perception; Automobile driving; Perceptual masking; Aged; Accidents; Traffic.

A major concern in allowing the tinting of car front side windows to 35% visible light transmittance (VLT) is that tasks performed through these windows often require the rapid detection of low-contrast, unilluminated targets. If the tinting interferes with detection of targets then road safety may be compromized. Speed of cognitive and visual processing declines with age; performance on backward pattern masking tasks can indicate this slowing in processing speed. Two experiments compared performance of the young and elderly adult on two backward pattern masking tasks with levels of VLT from 100 to 20%. The first experiment found a decrement in performance for the elderly at 63% VLT and for all participants at 20% VLT. The second experiment found a decrement in performance for the elderly at 35% VLT. It was concluded that road safety may be compromized if the front side windows of cars are tinted to 35% VLT.

1. Introduction

The focus of research and debate about acceptable levels for the tinting of car windows, in terms of possible decrements in visual performance of drivers, has shifted from concern mainly with the front windshield and the primary vision area (PVA) to concern with the front side windows of vehicles. This shift has occurred because the parties to the debate, particularly road safety authorities and window body-tinters and producers of window film, are agreed, first, that the PVA should have a minimum visible light transmittance (VLT) of about 75%. (Australian Design Rule ADR 8/00 specifies 75% for the PVA, whereas the Federal Motor Vehicle Safety Standard No. 205 [FMVSS 205] of the National Highway Traffic Safety Administration [NHTSA] of the USA specifies 70%.) Second, it is agreed that for the windows to the rear of the driver a minimum VLT of between 35 and 65% is acceptable because of the very different demands of visual tasks likely to be performed through these windows (Dain 1994).

For the front side windows of motor vehicles, the positions of the parties to the debate are still opposed. Proponents for tinting windows argue that the minimum VLT should be 35% for all windows except the windshield. They point, first, to the benefits of tinting windows to this VLT level (claimed to include glare reduction, heat reduction, protection from harmful ultraviolet radiation, protection from laceration, standardization in manufacture of car window glass, increased aesthetic appeal of vehicles and enhanced privacy for vehicle occupants); and, second, to the

*Author for correspondence. Now at: Centre for Visual Sciences, Research School of Biological Sciences, Australian National University, Canberra, ACT 0200, Australia.

fact that no detrimental effects of tinting front side windows to 35% VLT have been adequately demonstrated from road crash data. Road safety authorities, on the other hand, argue, first, that the claimed benefits of the tinting of windows may be illusory and point to disbenefits of such tinting (including the reduced ability of other road users to see into the car through tinted windows and also to the concerns of police in terms of officer safety and suspect identification). Second, road safety authorities maintain that extant evidence from laboratory studies points to decrements in visual performance associated with viewing out through tinted windows, which are likely to compromise road safety and which are relevant to driving tasks performed through the front side windows.

The main current argument against adopting the 35% VLT standard for front side windows is that it would be detrimental to road safety through its effect of reducing visibility for the driver. Although there is an extensive literature on the effects of tinting on driver visual performance (reviewed by White 1992, Jenkins 1994, Sayer and Traube 1994), many of the papers relate to the earlier debate concerning the effects of allowing the windshield to carry a light body-tint and are not relevant to the current debate about darker film tints on front side windows. The earlier empirical studies were predominantly of night-time seeing distances using low-contrast targets illuminated by car headlights. A number of other earlier papers (discussed by Zwahlen and Schnell 1994) report the results of the mathematical modelling of night-time seeing distances without presenting new empirical evidence. These empirical and modelling studies are obviously of little relevance to vision through the front side windows, where the headlights have little or no effect. Those of the previous studies that have relevance to the current debate are now considered.

There are only six empirical studies, all of which have been reported in the past 10 years, that present evidence of potential relevance to the front side window debate (Rompe and Engel 1987, Wakeley 1988, 1992, Stackhouse and Hancock 1992, Derkum 1993, Freedman *et al.* 1993). In contrast with the earlier empirical studies, these six studies were all laboratory-based. Participants performed a visual task under conditions of low illumination that stimulated dusk or night driving. Headlight illumination (real or simulated) was not used because objects detected through the front side windows would not normally be illuminated by a car's headlights.

These six studies included five that used some combination of measures of target detection and response latency as the dependent variables and one (Derkum 1993) that used measures of visual acuity. All of the studies included conditions with VLT levels near 35% and illuminance levels that simulated twilight or night-time conditions, or both. Three of the studies (Rompe and Engel 1987, Derkum 1993, Freedman *et al.* 1993) reported decrements in performance associated with decreasing levels of VLT. Of the other three studies that did not, two (Wakeley 1988, 1992) have been criticized for using targets with contrast levels that were too high to be affected by reduced VLT levels (White 1992), and the third (Stackhouse and Hancock 1992) was satisfied with decrements in performance with 30% VLT that were equivalent to a target detection failure rate of 23%.

The ecological validity of these studies is mainly determined by the extent to which the experimental procedures capture the essence of 'conspicuity', and particularly that aspect of conspicuity referred to by Cole and Jenkins (1980) as sensory conspicuity (because the rapid detection and avoidance of an object in a potential accident situation seems more dependent on actually seeing the target, rather than attending to it because of its appraised meaning or relevance). There are good reasons for believing that a measure of conspicuity in terms of the speed of the response of the visual system might prove to be as valid and sensitive as any previous measure. As part of normal driving, the driver is often required to make numerous, fast fixations to scan the visual field adequately. There are some complex situations where the driver's ability to scan the road environment adequately is tested to the limit. Given that each fixation takes longer under conditions of poor illumination, or target contrast or both, drivers will sometimes be driving beyond the limits of their scanning rate.

Backward pattern masking can be used to provide an estimate of the speed of the visual system. If a target pattern is presented for a brief period, followed by a meaningless visual 'mask', the target will only be recognized if a sufficient period (in the vicinity of 50 – 100 ms) is allowed to elapse between the onset of the target and the onset of the mask. The minimum period between the presentation of the target and mask that still allows the participant to recognize the target is known as 'critical stimulus onset asynchrony' (CSOA). The measurement of CSOA provides an index of the speed of the visual system.

Backward masking CSOAs have been used in a number of applied contexts to provide measures of the speed of processing of the visual system. It has been found, for example, that CSOAs are significantly longer for retarded participants (Nettelbeck 1985) and are significantly lengthened by small quantities of alcohol (reviewed by Moskowitz and Robinson 1988). Of more relevance to the driving task are the findings that CSOAs are longer for the elderly (summarized by White 1996). This increase in backward masking CSOAs for the elderly reflects the more general decline in speed of processing found in the elderly and is thought to be causally prior to the decline found in performance by the elderly on measures of higher-order cognition (Nettelbeck and Rabbitt 1992, Kail and Salthouse 1994). Finally, backward masking CSOAs are probably longer under conditions of low illumination, and for low-contrast stimuli (Hellige *et al.* 1979), although there is little relevant research on target and mask energies. In the context of the current paper, it is worth noting that sex differences are not thought important for backward masking CSOAs (Nettelbeck 1987).

The experiments reported here compared backward masking CSOAs for the elderly and young adult. The expectation was that the elderly would process visual information more slowly (i.e. longer backward masking CSOAs). The backward masking CSOAs were measured under conditions of high and low illumination, and with high- and low-contrast targets. It was expected that CSOAs would be longer for low illumination and low-contrast target conditions. Finally, the CSOAs were measured when the targets were viewed with several levels of VLT. In terms of relevance to the debate about road safety, it was predicted that there would be an interactive effect of age, illumination, target contrast and VLT. That is, the elderly would be at a disadvantage in terms of their abilities to scan the visual field adequately; this disadvantage would be exacerbated by low illumination, low-contrast targets and low VLT. This outcome would imply that tinting of front side windows to 35% VLT may lead to an increase in road crashes involving elderly drivers, or that elderly drivers may be restricted to daytime driving.

2. Experiment 1

The masking task used in this experiment arose from a model of comparative judgement (Vickers 1970, Vickers *et al.* 1972) and is termed 'inspection time' (IT).

There is a reliable negative correlation of about -0.5 between CSOA on this task (i.e. IT) and IQ and for this reason the task has been extensively studied (reviewed by Nettelbeck 1987, Kranzler and Jensen 1989). Further, it has been demonstrated that IT estimates are significantly longer for the elderly (Nettelbeck and Rabbitt 1992). In its most common form the task involves the presentation of a target stimulus consisting of two vertical lines of markedly different length, joined at the top by a line. The target stimulus is followed by a patterned mask and the participant indicates on which side of the figure, left or right, the shorter line appeared.

The experiment reported here measured IT under conditions that simulated day or night driving illuminance (i.e. optimal versus marginal viewing conditions) and at several levels of VLT. As noted above, the general decline in speed of processing (and cognitive ability) found in the elderly means that IT estimates will be longer for them. This, together with the interaction of this decline in speed of processing with the effects of reduced visual information (low illumination, decreased VLT), leads to the following hypotheses: (1) that elderly persons have longer IT estimates than the young adult; (2) that under marginal ('night-time') viewing conditions IT estimates will be longer; (3) that for these marginal viewing conditions IT estimates will increase as VLT level decreases; and (4) this increase in IT estimate will be greater for the elderly. Support for these hypotheses would imply that the speed of visual processing in elderly drivers is compromised under marginal viewing conditions and that this effect is heightened when viewing with reduced VLT.

2.1. *Method*

2.1.1. *Participants*: Thirty participants were recruited into two groups; one comprised eight males and 10 females with a mean age of 70.6 (SD = 5.5) years, and the other comprised three males and nine females with a mean age of 22.8 (SD = 2.4) years. The former group was recruited from the general community; 10 had education at the tertiary level and eight at the secondary level. Of the latter group 10 were university students and two had education at the secondary level. It was therefore considered unlikely that differences in IQ between groups would influence the outcome. Potential participants underwent optometric testing (see below) to preclude anyone with abnormal vision; all held a current driver's licence but their driving habits were not ascertained. It is worth noting that, in South Australia, drivers > 70 years are required to furnish a medical report annually and to undertake practical driving tests at 75 years, 80 years and annually from that time on. The elderly sample here, then, had a mean age close to that at which the legislative restrictions on elderly drivers begin to apply.

2.1.2. *Optometric testing*: All potential participants attended an optometric clinic for a standard optometric examination. Only those with vision, contrast sensitivity, and ocular physiology deemed normal continued their participation in the experiment.

2.1.3. *Stimuli and tasks*: Stimuli in the IT task were presented using a Gerbrands G-1130 three-field tachistoscope, converted in-house to four fields. Internal illumination of the tachistoscope was set at maximum intensity for all fields during the optimal viewing condition ('day-time') and was set at 85% for the marginal ('twilight') viewing condition. These settings produced luminance levels of 4.5 and 1.1 cd/m^2 respectively, measured at the tachistoscope eyepiece and with the spotmeter pointed at the target approximately 0.75 m away. These values are recognized as somewhat unreliable but do demonstrate the large luminance difference between the two conditions.

Neutral density filters were used in the tachistoscope eyepieces to produce three levels of VLT with 63, 32 and 20%. These levels span a range of VLTs that begin at a level somewhat lower than that deemed acceptable for the PVA of a motor vehicle, include a condition close to that being argued for by the proponents of the 35% VLT level for all windows except the windshield, and decrease to a level likely to be attained by a window that has a 35% VLT level when new but that has deteriorated in use (White 1994).

The stimulus cards for the tachistoscope were grey (with a colour density of 10 according to the Kodak Gray Scale) and the target and mask figures were constructed on the cards with black precision slit tape. This means that the contrast between the target and background was relatively low. The target figures were made from 1 mm-wide tape and the mask figure was made from 4 mm-wide tape. The alternative target figures consisted of two vertical lines joined at the top by a horizontal line; the longer line subtended a visual angle of 2.6° and the shorter line subtended a visual angle of 1.8°. The horizontal distance between the vertical lines subtended a visual angle of 0.8°. The mask was similar in form to the target but was symmetrical with both vertical lines subtending a visual angle of 3.4° (figure 1). Each trial began with the binocular presentation of one of the alternative targets (each of the targets appeared equiprobably) in the centre of the visual field. After the SOA determined by the IT estimation algorithm (see below) the target was replaced by the mask. The participant responded by pressing the corresponding key, left or right, on a custom panel to indicate on which side the shorter line had appeared. If unable to discriminate which figure had appeared the participant was required to guess. Two seconds after the response, the next trial began.

2.1.4. *Design*: Participants completed six sets of trials, corresponding to the six possible combinations of luminance (two levels) and VLT (three levels). To incorporate a number of practice trials at the beginning of each condition the initial SOA was 450 ms. Additionally, the experimental design was partially balanced by randomly allocating participants to one of four possible orders for completing the six conditions, thereby controlling for any additional practice effects. These four orders of conditions were such that, for any participant, the VLT levels either increased or

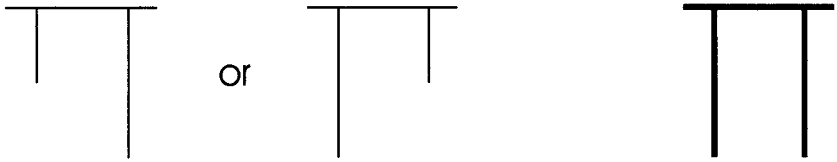

Figure 1. Target and mask figures used in experiment 1. The figures were black and the background was grey (with a colour density of 10 according to the Kodak Gray Scale).

decreased for both luminance conditions. The order of luminance conditions was approximately balanced across participants, as were the alternative orders of VLT levels.

2.1.5. *Procedure*: Participants attended one experimental session. Each was seated before the apparatus in a small, artificially lit room, with the key panel in front. The nature of the task, including the IT estimation procedure, was explained and emphasis was placed on the requirement for accuracy in responding as opposed to speed in responding. Participants were informed that they should take as much time as they required to respond and that a new trial would not commence until after a response was made. Before commencing the experimental trials, a series of practice trials was provided to ensure participants understood what was required of them. Those with prescriptions for visual correction were given practice both with and without glasses; provided that they could correctly discriminate all practice trials with ease, they were permitted to perform on the experimental task without prescriptions if this was more comfortable.

The entire sequence of stimulus presentations was automated by a computer program, with brief rests between the VLT levels in each luminance condition and for approximately 5 min between luminance conditions. The SOA on any trial was determined according to an adaptive staircase algorithm (Wetherill and Levitt 1965), which was set to return an IT estimate at the 90% accuracy level; this required approximately 100 trials for each condition.

2.2. *Results*

Repeated measures ANOVA showed a significant three-way interaction between age group, luminance level, and VLT level (Pillai's trace = 0.35, $F(2,27) = 7.30$, $p < 0.01$). Figure 2 shows the means and SD for IT, plotted for each condition. It can be seen that decreasing VLT level was associated with increased IT for both age groups in the low-luminance viewing condition but that the elderly exhibited a more marked increase. Polynomial contrasts demonstrated a linear trend for VLT level that was significantly different for the low- and high-luminance viewing conditions. No difference was apparent for the two groups in the high-luminance condition, but the young and elderly exhibited different patterns of linearity in the low-luminance condition ($t\,(56) = 3.2$, $p < 0.01$). Examination of figure 2 shows that mean IT was longer for the low-luminance viewing condition irrespective of the VLT level and that this effect was greater for the elderly ($F(1,28) = 22.66$, $p < 0.001$). Finally, the mean IT was longer for the elderly group in each condition ($F(1,28) = 25.37$, $p < 0.001$). The results of the repeated measures ANOVA were therefore consistent with the experimental hypotheses.

2.3. *Discussion*

The elderly exhibited longer mean ITs; this is consistent with the finding that speed of processing decreases with increasing age. Under optimal viewing conditions VLT level did not significantly affect mean ITs of either age group. This finding supports the claim that tinting of car windows will not affect driver performance when viewing conditions are optimal and is therefore consistent with previous research that has used target detection and response times as dependent variables. However, under marginal viewing conditions VLT level did significantly increase mean ITs and this increase was significantly greater for the elderly group. It can be concluded from this that, under these marginal viewing conditions, elderly drivers were affected by VLT levels as high as 63% (compared with performance under optimal viewing conditions) and that performance deteriorated as VLT decreased. These results are similar to those reported by Freedman *et al.* (1993). The young adults also showed a deterioration in performance as VLT decreased from 63 to 20%.

This experiment did not include conditions equivalent to viewing through no windows or through windows carrying only a very light body-tint. It is the comparison of performance in these conditions to performance with 35% VLT that is critical in terms of relevance to road safety. There is also a question as to the nature of the IT task, in that it has been shown to be vulnerable to the use of various cues embedded in the task (White 1996) that may allow some participants to perform at a level that is not determined strictly by the speed of the visual system. These embedded cues may be a particular problem when the stimuli are presented tachistoscopically. Experiment 2 was therefore designed to replicate and extend the findings of this first experiment by including conditions that directly compared both a no window condition and a lightly tinted car window condition with a car window tinted to 35% VLT. Second, an additional backward masking task that was ostensibly free of embedded cues was included, thereby testing the generality of the effect of VLT on backward pattern masking CSOAs. Finally, all stimuli were presented on a high performance computer monitor.

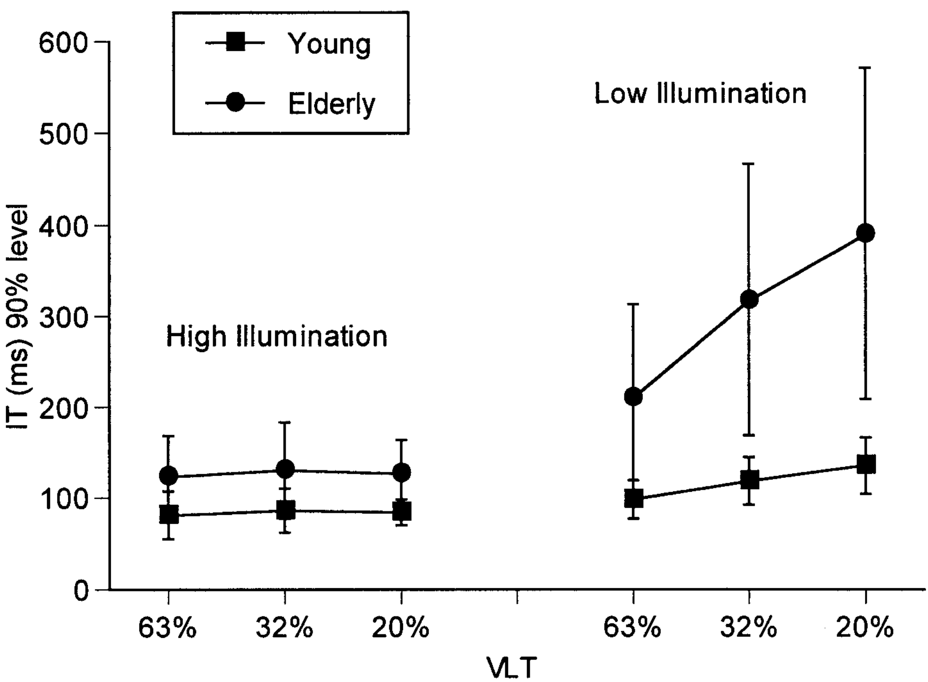

Figure 2. Mean IT estimates plotted for both young and elderly groups for two levels of illumination ('day-time' and 'twilight') and three levels of visible light transmittance (VLT).

3. Experiment 2

Because experiment 1 had demonstrated no decrement in performance with decreasing VLT under optimal viewing conditions, this experiment included only one level of illumination, which simulated twilight driving conditions. Two levels of target contrast were employed, high and low. These levels simulated driving conditions where headlight illumination is usually available (that is, the front and rear windows) and where no headlight illumination is likely (that is, front side windows) respectively. Three levels of VLT were used: in one condition there was no window; in the other two conditions actual front side windows were used. One window carried a light body-tint, the other had a film applied to produce a VLT of 35%. Finally, in addition to the IT task used above, a second backward masking task was designed. Theory (White 1996) and pilot studies suggested that this task (known hereafter as the alphanumeric task because it involved recognition of alphanumeric characters) was equivalent to the IT task but avoided the embedding of movement cues within the task.

White (1996) has argued that the relevant criterion for designing pattern masking tasks is that the targets are clearly distinguishable from the mask; the numbers of targets or the relationships between targets are irrelevant. On these grounds the first hypothesis was therefore that the two tasks would be equivalent except that the alphanumeric task may provide a 'purer' measure of speed of visual processing. Nevertheless, the two tasks should produce the same pattern of results to different levels of VLT or target contrast.

Specific hypotheses were: (1) compared with young adults, elderly adults have longer ITs (in the case of the alphanumeric task the more general term CSOA will be employed); (2) IT (or CSOA) will not be significantly different for the no-window and light body-tint window conditions, irrespective of the target contrast; (3) for the 35% VLT condition, IT (or CSOA) will be significantly longer than for the 100 and 81.3% VLT conditions; and (4) this increase will be greater for the elderly group and will be greater for the low-contrast target condition than for the high-contrast target condition. Support for these hypotheses would imply that 35% VLT level would deleteriously affect all drivers when viewing through the front side windows of vehicles under night-time conditions; this effect would be exacerbated for elderly drivers because of the slower processing speed found in the elderly.

3.1. *Method*

3.1.1. *Participants*: Twenty-six participants were recruited into two groups; one comprised nine males and four females with a mean age of 73.9 (SD = 2.4) years, and the other comprised four males and nine females with a mean age of 24.0 (SD = 2.2) years. The former group was recruited from the general community; five had education at the tertiary level and eight at the upper secondary level. All of the latter group were university students. It was again considered unlikely that differences in IQ between groups would influence the outcome. Potential participants underwent optometric testing (see below) to preclude any with abnormal vision; all held a current driver's licence and drove a vehicle at least weekly. Elderly participants were paid A$30 on completion of their participation in the experiment.

3.1.2. *Optometric testing*: All potential participants attended the same optometric clinic as in experiment 1. Again, a standard optometric examination was performed.

Only those participants with vision, contrast sensitivity and ocular physiology deemed normal continued their participation in the experiment.

3.1.3. *Car windows*: Two identical, new front side windows were purchased from a local spare parts supplier. For one, an automotive window tinting retailer applied a tint film. VLT levels were measured in accordance with the Code of Practice for Surface Films for Motor Vehicle Windows (South Australian Department of Transport, April 1992). The windows as purchased had a VLT of 81.3%; after the application of the film the tinted window had a VLT of 35.1%.

3.1.4. *Stimuli and tasks*: All stimuli were presented on a high-performance monitor (with a vertical refresh rate of 120 Hz) under the control of a PC running at 90 MHz and fitted with a video accelerator card. The timing of stimuli was controlled by use of the vertical retrace flag of the video card and the stimuli were redrawn during the vertical retrace; this meant that the stimuli were presented for durations that were multiples of 8.3 ms. To manipulate target contrast the stimuli were drawn in two combinations. The first combination used white targets and masks presented on a black background; this was the high-contrast condition. For the low-contrast condition light-grey targets and masks appeared on a dark-grey background.

The IT task was very similar to that used in experiment 1. The alternative target stimuli consisted of two vertical lines joined at the top by a horizontal line; the longer line subtended a visual angle of 0.6° and the shorter line subtended a visual angle of 1.2°. The horizontal distance between the vertical lines subtended a visual angle of 0.6°. The mask consisted of the same horizontal line as in the target figure and two vertical lines which subtended a visual angle of 1.8°. These lines were the same thickness as the target lines and overwrote the target lines. The alphanumeric task consisted of the presentation, on each trial, of one of eight segmented alphanumeric characters: '2', '3', '5', '7', 'F', 'H', 'U' and 'Y'. Each element of the alphanumeric characters subtended a visual angle of 0.5°. The mask consisted of a segmented matrix consisting of 31 elements each subtending a visual angle of 0.5° (figure 3). The central elements of this mask, in various combinations, constituted the target figures.

Each trial began with the presentation of two small circles, one above and one below the position where the target would appear; after 523 ms the target was drawn and remained on the screen for the SOA determined by the estimation algorithm, the initial SOA being 315 ms. Each of the targets appeared equiprobably. After the SOA the mask was drawn and remained on the screen for 374 ms. The participant responded verbally as to which side the shorter line had appeared (for the IT task), or nominated which of the characters had appeared (for the alphanumeric task). If unable to discriminate which target had appeared the participant was required to guess; the experimenter pressed the corresponding button on a custom response board. Two seconds after the response, the next trial was presented.

3.1.5. *Design*: There were two experimental sessions. At one session conditions involving the IT task were completed and at the other conditions involving the alphanumeric task were completed; the order of sessions was balanced across participants. Within a session there were six experimental conditions corresponding to two levels of target contrast (high versus low) and three levels of tinting (100, 81.3 and 35.1% VLT). The tasks involving one of the contrast levels were completed in the order 100, 81.3 and 35.1% VLT. The tasks with the other level of contrast were

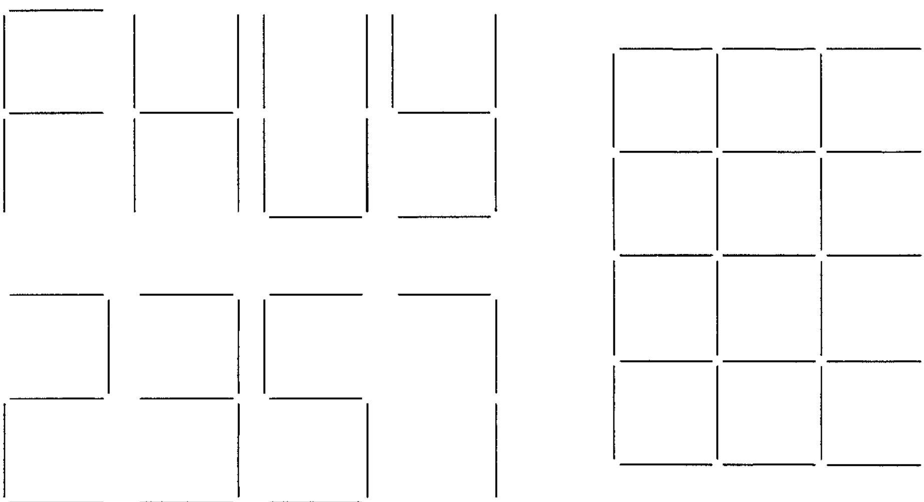

Figure 3. Target and mask figures for the alphanumeric task used in experiment 2.

then completed in the same order; the order of contrast was balanced across participants. Additionally, the 100% VLT condition, with the high-contrast target, was repeated at the end of the experimental session. This order of VLT conditions meant that the practice effect for each task operated against the hypothesis of decrement in performance (i.e. increase in IT or CSOA) with decrease in VLT level.

3.1.6. *Procedure*: The participant was seated in a dimly lit room (vertical illumination at eye-level was 2.2 lx) at 0.75 m from the computer monitor. Spectacles, specially prescribed to correct vision for this viewing distance were worn by 10 of the elderly participants. For the conditions requiring viewing through one of the windows, the window was placed between the participant and the computer monitor at 0.25 m from the monitor.

The task to be performed at the experimental session was explained using diagrams and presentations of unmasked stimuli on the monitor. Unmasked trials were then presented with a duration of 830 ms; all participants practiced until performance was error-free for 20 consecutive trials. To familiarize the participant with the low-contrast target, viewed through the 35.1% VLT window, 10 unmasked trials with a duration of 830 ms were presented. Next, the participant was required to perform to a criterion level for the low-contrast target viewed through the 35.1% VLT window; 15 of 16 unmasked trials with a duration of 33 ms were required to be correctly discriminated. All participants met this criterion. These explanations, practice and criterion procedures required approximately 30 min, which was considered sufficient time for dark adaptation (Davson 1990: 219 – 220).

Next, the estimation procedure was explained with emphasis placed on the requirement for accuracy of responding as opposed to speed of responding. Before the first experimental condition commenced three sets of practice trials for this condition were presented. These consisted of 10 trials each at SOAs of 830, 415 and 315 ms; perfect performance was required at the first two SOAs and nine out of 10 correct trials were required at the last SOA before the experimental conditions began. In this experiment the adaptive staircase algorithm was set to return an IT estimate (or CSOA) at the 80% accuracy level.

3.2. *Results*

The results for the two pattern masking tasks were analysed separately. Figure 4 shows the mean IT measures plotted for each condition.

Repeated measures ANOVA determined that the three-way interaction between age group, target contrast and VLT level was not significant (Pillai's trace = 0.12, $F(2,23) = 1.66$, $p = 0.21$). The pattern of the results was, however, similar to that of experiment 1 and the non-significance of the three-way interaction appears to be due to the great variability in performance on the IT task of the elderly sample. It can be seen in figure 4 that, for the elderly group, the SDs were approximately half the magnitude of the mean IT estimates but for the young group they were only one-third of the magnitude of the mean IT estimates.

Examination of figure 4 confirms that the elderly had longer IT estimates than the young ($F(1,24) = 12.55$, $p < 0.05$). The interaction between target contrast and age group was significant ($F(1,24) = 10.03$, $p < 0.05$); IT estimates were longer in the low-contrast target condition for the elderly. It can be seen that, as expected, there was little difference between the IT estimates for the 100 and 81.3% VLT conditions

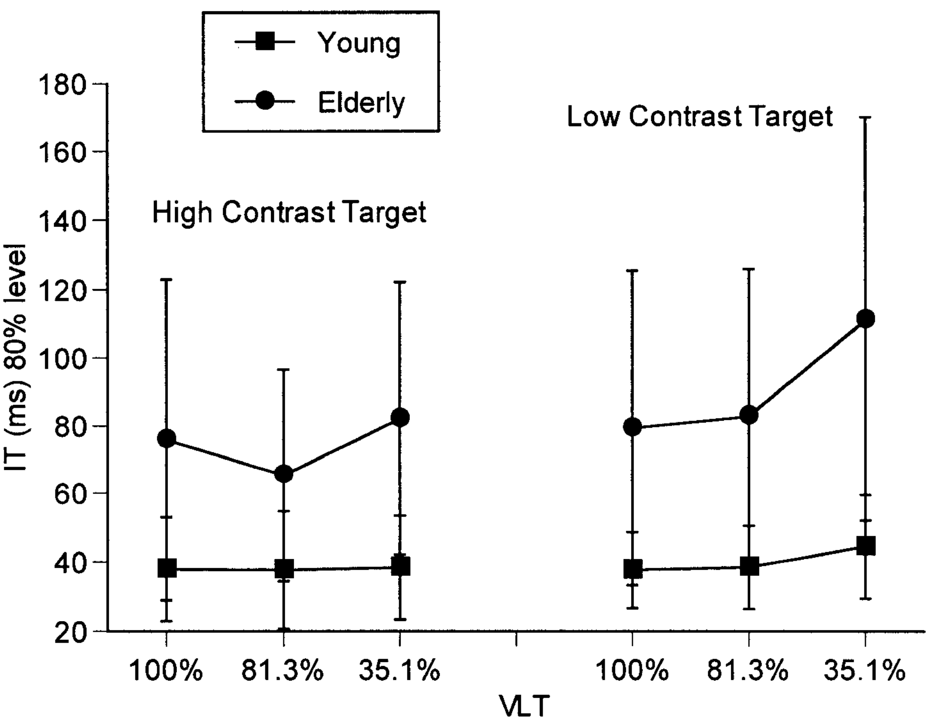

Figure 4. Mean IT estimates plotted for both young and elderly groups for two levels of target contrast and three levels of visible light transmittance (VLT).

in either contrast condition for either age group ($t(24) = 0.84$, $p = 0.41$). Consequently, tests of the effect of 35.1% VLT on IT were made against the mean of the 100 and 81.3% VLT conditions. The interaction between age group and the effect of 35.1% VLT was significant ($t(24) = 3.89$, $p < 0.001$), and the interaction between contrast and the effect of 35.1% VLT was significant ($t(24) = 2.58$, $p < 0.05$). It can be concluded that the elderly had increased IT estimates with 35.1% VLT and that this increase was greater for the low-contrast target condition. As was the case for the overall three-way interaction (see above), the interaction between target contrast effect, the effect of 35.1% VLT and age group was not significant ($t(24) = 1.34$, $p = 0.19$). The results for this task, then, support the experimental hypotheses and are consistent with the outcome of experiment 1.

Contrary to our hypothesis, the outcome for the alphanumeric task was different from that of the IT task. Figure 5 shows the mean CSOA measures plotted for each condition.

Examination of figure 5 confirms that the elderly had longer CSOA estimates than the young ($F(1,24) = 13.23$, $p < 0.05$). Unlike the IT task, however, there was a significant difference between the 100 and 81.3% VLT conditions ($t(24) = 2.65$, $p < 0.05$); this may reflect a practice effect. The extent of any practice effect can be gauged by comparing performance on the high-contrast target with 100% VLT condition with the estimate for the same condition repeated at the end of the experiment. For approximately half of the participants this was the first experimental condition completed and for the others it was the fourth experimental condition. Therefore, any improvement in performance found in the repeated performance of

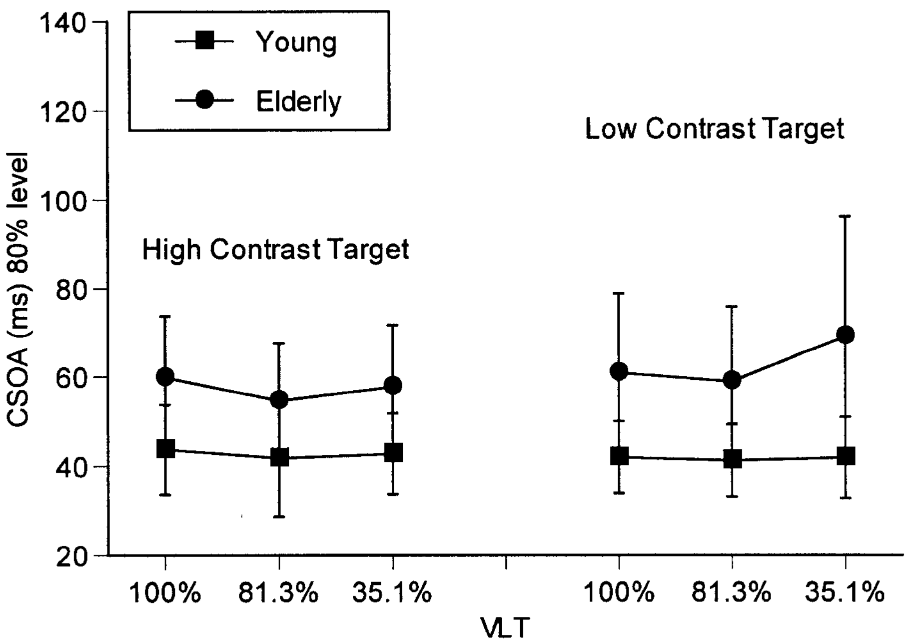

Figure 5. Mean CSOA estimates for the alphanumeric task plotted for both young and elderly groups for two levels of target contrast and three levels of visible light transmittance (VLT).

this condition will underestimate the extent of any practice effect. The mean CSOA for the experimental condition for the young sample was 44 ms (SD = 10) and for the repeat of the condition 37 ms (SD = 9). This was a significant improvement ($t(12) = 4.48$, $p < 0.05$). For the elderly, the mean CSOAs were 60 ms (SD = 14) and 51 ms (SD = 12) respectively ($t(12) = 3.07$, $p < 0.05$). The interaction between target contrast and age group was not significant ($F(1,24) = 3.94$, $p = 0.06$). Therefore, to test the hypotheses with respect to 35.1% VLT the ANOVA was restricted to two levels of VLT, 83.1 and 35.1%. The interaction between age group and the effect of 35.1% VLT was significant ($F(1,24) = 5.63$, $p < 0.05$); examination of figure 5 reveals that this was due to an increase in CSOA for the elderly. There were no other significant effects. Nevertheless, this task again demonstrated an effect, on the elderly, of decreasing VLT to 35%. This finding then is consistent with that found for the IT task in this experiment and in experiment 1. The difference between the overall outcome on this task compared with the IT task, however, suggests that the assumption that this and the IT task are qualitatively the same was mistaken; the implications of this are discussed below.

3.3. *Discussion*

The finding from experiment 1 that backward pattern masking CSOAs (including IT) were longer for the elderly was replicated. In experiment 2, however, it was found that for the IT task this decrement in performance for the elderly was not consistent across participants. Those participants found to have longer IT estimates under optimal viewing conditions showed the greatest decrement in performance for the worst-case viewing conditions. This finding may have practical implications in that not all elderly drivers will be affected to the same extent by decreased VLT levels. That some will be quite seriously affected means that legislation concerning permissible VLT levels for car windows needs to be framed to take account of this group.

It was found that there was no difference between viewing with 100% VLT or 81.3% VLT, except for an improvement in performance on the alphanumeric task for the 81.3% VLT condition attributable to practice. The implication of this is that the use of windows carrying a light body-tint poses no increased risk of road accidents even in marginal viewing conditions. On the other hand, for both the IT task and the alphanumeric task the results showed that the elderly are detrimentally affected by reduction in VLT level to 35%; the IT or CSOA estimates were longer for the elderly with 35% VLT and this effect was greater for low-contrast targets. The implication of this is that, for the conditions most likely to apply when viewing through the front side windows of a vehicle at night-time, the elderly are compromised in their ability to scan the road environment adequately.

The differences found between the IT task and the alphanumeric task are in some respects puzzling. White (1996) explained that according to the integration theory of backward pattern masking the 'relevant criterion for a simple sequential figural discrimination is that the targets, however many they might be, are clearly distinguishable from the mask' (p. 356). It was on this basis that the alphanumeric task used here was designed; pilot studies had shown that performance with this task and the IT task were equivalent. The results here, then, were contrary to our expectation. The explanation for this appears to be two-fold. In the pilot study referred to the participants were highly practiced at the IT task and it is possible that rather than making a judgement as to which of two lines was shorter they were recognizing the figure as a whole. This is precisely what the alphanumeric task involves. Rather than making a discrimination or judgement about the target figure, what is actually required is the recognition of the target. Given that our participants were all highly familiar with the letters and numbers used as the targets, but naive with respect to the IT task, then this may account for the difference in the pattern of the results for the two tasks. That is, rather than using highly overlearned characters as targets it would have been better to design a task with more targets to be discriminated but that were unfamiliar to the participants.

There are practical implications arising from this unexpected finding. Given that the major concern with respect to the level of tinting for front side windows is with whether lowered VLTs will increase the likelihood of road crashes due to a failure to detect the presence of low-contrast targets under night-time viewing conditions, then, our results suggest that concern is warranted. The IT task requires the detection of a small difference in the length of two lines, not the recognition of an overlearned character. Similarly, the detection of the presence of a cyclist or pedestrian through the front side window on a rainy night at an ill-lit intersection requires the detection of a small difference in figure-background contrast or of a flicker of movement. The IT task may have better captured the essence of sensory conspicuity and therefore the results for the task may be more ecologically valid.

4. General discussion and conclusions

As noted above, this study was the first to use backward pattern masking tasks to index the effect of reduced VLT on visual performance. Experiment 1 clearly demonstrated that there was a decrement in performance associated with decreased VLT level over the range 62 – 20%. This finding was consistent with those of earlier studies (Rompe and Engel 1987, Derkum 1993, Freedman *et al*. 1993). Experiment 2 attempted to determine whether this decrement in performance applied for conditions that simulated the driving tasks associated with driving in marginal conditions and specifically those tasks performed through the front side window. The outcome was that 35% VLT, the level being proposed as the standard for all windows except the windshield, deleteriously affected the elderly. It was noted that this effect was more pronounced for those of the elderly whose speed of visual processing showed most senescent decline. However, all participants in this study had been found to have normal vision and ocular physiology and all were licenced drivers.

As noted in the discussion of experiment 2, the IT task may have provided some ecological validity in assessing the effects of reduced VLT on elderly drivers. Three earlier laboratory based studies (Rompe and Engel 1987, Derkum 1993, Freedman *et al*. 1993) also found performance decrements as VLT was decreased. However, an empirical study in the field may be required to provide definitive evidence on the effects found in the experiments reported here.

One issue that was raised by some of the elderly participants in these experiments is worth commenting on; often elderly drivers are aware of their limitations and limit their driving accordingly. For example, the elderly are believed to reduce their rate of everyday, night and peak-hour driving (Ernszt and O'Connor 1988). Cognisance of this should be tempered by the expectation that, in Western societies, the numbers of elderly drivers is increasing rapidly (in line with the ageing of these populations).

On the basis of the experiments reported here, the conclusion is drawn that the level of tinting for front side windows should not be reduced to 35% VLT. A conservative level would be the same as that for the PVA of the windshield. The results found here suggest that such a level poses no increased risk of road crashes due to decrement in visual performance.

Acknowledgements

We are grateful to Caroline Miller and Sally Goodwin for recruitment of the participants and collection of the data for the second experiment. Our thanks to Andrew Griffiths for the optometric examinations and his input to the research. The first experiment formed part of the requirements for an Honours degree in Psychology made by J.W., supervised by M.W. The second experiment was supported by a grant from the Australian Federal Office of Road Safety to Ted Nettelbeck.

References

Cole, B. L. and Jenkins, S. E. 1984, The nature and measurement of conspicuity, *Australian Road Research Board Proceedings*, **10,** 99–107.

Dain, S. J. 1994, Visual aspects of automotive window films. In M. J. Griffiths and C. J. Jones (eds), *Window Tinting and Road Safety: Proceedings of a Symposium held in Sydney, Australia, 10 May 1994* (New South Wales: Roads and Traffic Authority), 21–26.

Davson, H. 1990, *Physiology of the Eye* 5th edn (London: Macmillan).

Derkum, H. 1993, Effects of various transmission levels in windshields on perception. In A. G. Gale, I. D. Brown, C. M. Haslegrave, I. Moorehead and S. Taylor (eds), *Vision in Vehicles*, (vol. IV) (Amsterdam: North-Holland), 63–68.

Ernst, R. P. and O'Connor, P. J. 1988, *Report on Accident Countermeasures Focussing on Elderly Drivers* (South Australia: Road Safety Division).

Freedman, M., Zador, P. and Staplin, L. 1993, Effects of reduced transmittance film on automobile rear window visibility, *Human Factors*, **35,** 535–550.

Hellige, J. B., Walsh, D. A., Lawrence, V. W. and Prasse, M. 1979, Figural relationship effects and mechanisms of visual masking, *Journal of Experimental Psychology: Human Perception and Performance*, **5,** 88–100.

Jenkins, S. E. 1994, A rational basis for safe limits for window tinting in automotive glass. In M. J. Griffiths and C. J. Jones (eds), *Window Tinting and Road Safety: Proceedings of a Symposium held in Sydney, Australia 10 May 1994* (New South Wales: Roads and Traffic Authority), 11–19 (summary); Appendix, 1–40 (full text).

Kail, R. and Salthouse, T. A. 1994, Processing speed as a mental capacity, *Acta Psychologia*, **86,** 199–225.

Kranzler, J. H. and Jensen, A. R. 1989, Inspection time and intelligence: a meta-analysis, *Intelligence*, **13,** 329–347.

Moskowitz, H. and Robinson, C. D. 1988, *Effects of Low Doses of Alcohol on Driving-related Skills: A Review of the Evidence* (Washington: National Highway Traffic Safety Administration).

Nettelbeck, T. 1985, Inspection time and mild mental retardation. In N. R. Ellis and N. W Bray (eds), *International Review of Research in Mental Retardation*, vol. 13 (New York: Academic), 109–141.

Nettelbeck, T. 1987, Inspection time and intelligence. In P. A. Vernon (ed.), *Speed of Information Processing and Intelligence* (Norwood: Ablex), 295–346.

Nettelbeck, T. and Rabbitt, P. M. A. 1992, Aging, cognitive performance, and mental speed, *Intelligence*, **16,** 189–205.

Rompe, K. and Engel, G. 1987, *The Influence of Windshields with Lower Light Transmission in Driver's Vision During Night Driving*. (S. A. E. Technical Paper Series No. 870062 (Warrendale: Society of Automotive Engineers).

Sayer, J. R. and Traube, E. C. 1994, *Factors Influencing Visibility Through Motor Vehicle Windows: Review of the Literature*. Report No. UMTRI-94-20 (Michigan: University of Michigan Transportation Research Institute).

Stackhouse, S. P. and Hancock, P. A. 1992, *The Evaluation of Vehicle Window Tint Density on Target Detection Capability* (Minneapolis: University of Minnesota).

Vickers, D. 1970, Evidence for an accumulator model of psychophysical discrimination, *Ergonomics*, **13,** 37 – 58.

Vickers, D., Nettelbeck, T. and Willson, R. J. 1972, Perceptual indices of performance: The measurement of 'inspection time' and 'noise' in the visual system, *Perception*, **1,** 263 – 295.

Wakeley, H. 1988, *Safety Benefits and Costs of Tinted Glazing.* Report IITRI-P08513-12 (Chicago: Illinois Institute of Technology Research Institute).

Wakeley, H. 1992, *Automobile Glazing Transmittance and Pedestrian Recognition by Young and Older Drivers* (Chicago: Illinois Institute of Technology Research Institute).

Wetherill, G. B. and Levitt, H. 1965, Sequential estimation of points on a psychometric function, *British Journal of Mathematical and Statistical Psychology*, **18,** 1 – 10.

White, M. 1992, *An Evaluation of Some Recent (1988 – 1992) Reports on the Effects of Car Side and Rear Window Film Tinting on the Visual Performance of Drivers* (South Australia: Office of Road Safety).

White, M. 1994, *The Desirability of 35% Visible Light Transmission of Car Front Side Window: The Debate Continues* (South Australia: Office of Road Safety).

White, M. 1996, Interpreting inspection time as a measure of the speed of sensory processing, *Personality and Individual Differences*, **20,** 351 – 363.

Zwahlen, H. T. and Schnell, T. 1994, Visibility Through Tinted Automobile Windshields at Night. Paper prepared for presentation at the 12th triennial Congress of the International Ergonomics Association, Toronto, Canada, 15 – 19 August, 1994.