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ORIGINAL ARTICLE

A Yellow Filter Improves Response Times to Low-Contrast Targets and Traffic Hazards

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ABSTRACT

Purpose. Anecdotal evidence suggests that some sunglass users prefer yellow tints for outdoor activities, such as driving, and research has suggested that such tints improve the apparent contrast and brightness of real-world objects. The aim of this study was to establish whether yellow filters resulted in objective improvements in performance for visual tasks relevant to driving.

Methods. Response times of nine young (age [mean ± SD], 31.4 ± 6.7 years) and nine older (age, [mean ± SD], 74.6 ± 4.8) adults were measured using video presentations of traffic hazards (driving hazard perception task) and a simple low-contrast grating appeared at random peripheral locations on a computer screen. Response times were compared when participants wore a yellow filter (with and without a linear polarizer) versus a neutral density filter (with and without a linear polarizer). All lens combinations were matched to have similar luminance transmittances (~27%).

Results. In the driving hazard perception task, the young but not the older participants responded significantly more rapidly to hazards when wearing a yellow filter than with a luminance-matched neutral density filter (mean difference, 450 milliseconds). In the low-contrast grating task, younger participants also responded more quickly for the yellow filter condition but only when combined with a polarizer. Although response times increased with increasing stimulus eccentricity for the low-contrast grating task, for the younger participants, this slowing of response times with increased eccentricity was reduced in the presence of a yellow filter, indicating that perception of more peripheral objects may be improved by this filter combination.

Conclusions. Yellow filters improve response times for younger adults for visual tasks relevant to driving.
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Key Words: yellow filter, driving, hazard perception, polarizing filter, contrast

Yellow- or amber-tinted lenses are popular choices among sunglass users for outdoor activities, such as driving, shooting, and skiing.[1,2] Individuals report a subjective increase in both the brightness and contrast of visual stimuli with yellow filters.[2,3] Objective verification of such claims, however, is difficult. Although objective measurements show that yellow filters enhance contrast for stimuli of specific colors on certain backgrounds, contrast may be reduced for other color combinations.[4] For achromatic stimuli, there is some basis for the suggestion that yellow filters improve contrast. For instance, light scatter (which is greater for short than for longer wavelengths) is reduced by yellow filters, suggesting that yellow filters should mitigate the visual effects of scatter, such as reduced contrast sensitivity.[5] Others have noted that yellow filters reduce chromatic aberrations.[6–8] It has also been reported that pupil dilation in the presence of a yellow filter is greater than that with a matched neutral density filter, which might partly explain the perceived improvement in brightness that some individuals report.[9]

Several authors have reported that contrast sensitivity (and, in some cases, visual acuity) for achromatic stimuli is improved by using yellow filters for those with visual impairment arising from cataract or other eye diseases, as well as for visually normal people.[1,4,5,10–18] In addition, some authors have observed a reduction in glare sensitivity and disability glare with yellow filters.[13,19,20] Other researchers, however, have failed to find improvements in visual function with yellow filters,[21–25] and published reviews have concluded that there is inconsistent evidence for their effectiveness.[14,26]

To objectively demonstrate a potential perceptual advantage for the use of yellow filters in real-world settings, a necessary first step is to demonstrate that they improve aspects of visual perception that are relevant to real-world tasks, such as driving. One early study

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showed that response times to low-contrast and low–spatial frequency gratings were reduced with yellow filters;[27] however, this result is yet to be replicated. Demonstration of reduction in response times is relevant to driving because even slight delays in responding to hazards on the road might have fatal consequences. In a recent study, yellow-tinted intraocular lenses (IOLs) were associated with reduced glare sensitivity and reduced collision rates in a driving simulator compared with those found with standard IOLs.[20] Thus, there is some basis for the potential role of yellow filters in improving vision for driving.

We aimed to further investigate previous observations that response times to achromatic gratings might be reduced with yellow filters. Because not all stimuli of relevance to driving will be directly fixated by the driver, we investigated whether performance gains are dependent on target eccentricity. We also investigated whether similar improvements occur for a task that is predictive of real-world driving, the Hazard Perception Test (HPT).[28] This test is an indicator of driving safety and therefore provides a first step in assessing the effectiveness of yellow filters in real-life perceptual tasks. Hazard perception tests are currently used for licensing purposes in the United Kingdom and in some states of Australia.[29] They consist of a series of videos of real-world driving in which participants are asked to identify road hazards and respond by indicating their location on a touch-screen as quickly as possible. Performance on such tests has been associated with self-reported crash involvement in both retrospective[30–33] and prospective studies.[34]

We compared the performance of both young and older participants on each of these tasks (the HPT and the low-contrast grating detection task) to establish whether any performance gains with yellow filters varied with age. If yellow filters reduce response times to stimuli associated with driving, such a benefit should be useful for older individuals, particularly those with visual impairments that specifically affect contrast sensitivity. However, some previous researchers have noted that the effectiveness of yellow filters declines with age[1] possibly because the crystalline lens itself becomes more yellow over time. It is therefore important to establish whether any performance gains that might be obtained using yellow filters are similar for older and younger adults. In addition, because commercially available tinted driving glasses often have a polarizing component, we evaluated the yellow filter with or without a polarizing lens. Based on previous findings, we predicted that yellow filters would reduce response times to both tasks and that the improvement would be greater for the younger age group.

METHODS

Participants

Eighteen adults were recruited to form two age groups (nine young: mean age, 31.4 years, range, 20 to 39 years; 9 older: mean age, 74.6 years, range, 67 to 82 years). The study was conducted in accordance with the Declaration of Helsinki and was approved by the Queensland University of Technology Human Research Ethics Committee. All participants were given a full explanation of experimental procedures, and written informed consent was obtained with the option to withdraw from the study at any time.

Design and Materials

The experiment was a 2 (yellow filter: present or absent) by 2 (polarizing filter: present or absent) within-subject design. Participants conducted a series of visual function tests under each of four lens conditions: yellow (with and without polarizing filters) and neutral density (with and without polarizing filters). The neutral density filter was the baseline comparison. The order of filter conditions was counterbalanced across participants.

Filters

Four filters were matched for luminance transmittance (AS/NZS 1067:2003). Participants wore either standard trial frames or Halberg clips enabling a sufficient field of view for all tasks. The baseline filter was a neutral density filter with 28% luminous transmittance. The yellow filter was a Kodak Wratten No. 12 with an additional neutral density filter (27% transmittance). The other two filters were the yellow Kodak Wratten No. 12 combined with an achromatic linear polarizer (25% transmittance) and the achromatic linear polarizer combined with a neutral density filter (26% transmittance). Fig. 1 shows the spectral transmittances of the filters.

Static Visual Acuity

Binocular visual acuity was tested using a high-contrast logMAR chart at 6 m with the habitual correction used for driving for each of the four filter conditions. Each correctly recognized letter was scored as −0.02 log units, and subjects were instructed to guess even when they were not sure. Three versions of the chart were presented in a random order to each participant, with one chart at random being repeated to make up the four repeated testing conditions, once for each of the filter conditions.

Pelli-Robson Letter Contrast Sensitivity

Binocular letter contrast sensitivity was measured with the Pelli-Robson Letter chart[35] at 1 m with an appropriate working distance correction for each of the four filter conditions. Each correctly recognized letter was scored as 0.05 log units, and subjects were instructed to guess even when they were not sure. The same chart was used in all test conditions.

Hazard Perception Test

A modified version of the HPT was used as an index of the potential for driving safety.[28,29,31,36–38] The HPT has been validated on a large sample of Australian drivers, and a version is used for licensing purposes by the QLD Department of Transport.[37] The HPT consists of videos of real driving scenes recorded from the driver's point of view in which another road user creates a potential traffic conflict (something that would require the driver to take evasive action such as steering away or braking to avoid the hazard, eg, a pedestrian crossing the road in the near distance or a car entering from a side road). The participant is asked to indicate the location of the offending road user by tapping the location of the road user on the computer screen as quickly as possible. The response time in seconds is recorded for each correct response. A

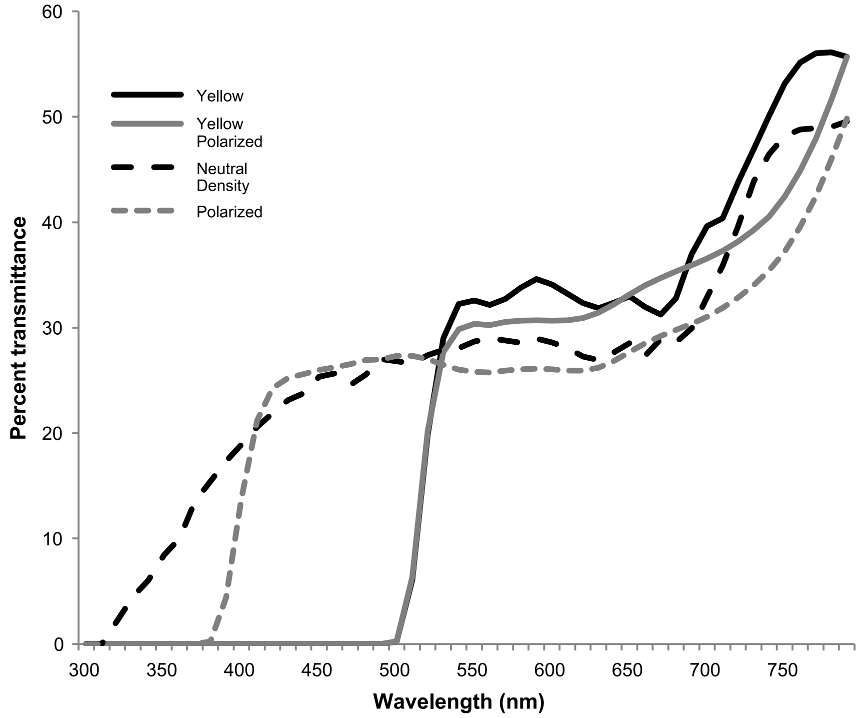

FIGURE 1.

Spectral transmittance profiles of the four filters used in the experiment.

response is coded as correct only if the participant taps the hazard during the time the hazard is present.

For this study, 100 videos of daytime driving scenes in Queensland and Australian Capital Territory roads were selected and edited to a maximum of 30 seconds each. Because of the diversity of scenes and lighting conditions presented, luminance ranged from 5 to 40 cd/m^2. Participants were tested at a working distance of 50 cm with an appropriate working distance correction; maximum target (hazard) eccentricity was approximately 22 degrees, and participants freely viewed the screen as would be the case for normal driving. Videos were presented via a standard cathode-ray computer display with no polarizing component. For each video, the hazard could appear at any time. Because there was no objective metric to define when the hazard might become visible to an ideal observer, we normalized the response times by calculating the participant's deviation from the mean response time of the whole group (both age groups combined) for each hazard. A block of 25 unique videos (with a total duration of ~25 minutes) was presented for each filter condition.

Response Time to Low-Contrast Target

Participants were presented with a series of low-contrast (11%) Gabor patches subtending approximately 8.93 degrees.[2] Each stimulus appeared at a random location on the screen (with the constraint that the maximum eccentricity could not exceed 12.63 degrees). Stimuli were presented on a mid-gray (18 cd/m^2) background on a standard cathode-ray computer screen with no polarizing component at a distance of 50 cm. As proposed in a previous study,[27] this is a sensitive measure of response time differences given the consistency of the stimuli between experimental conditions. Grating frequency was 0.5 cycles per degree, and the interstimulus interval was 2 to 5 seconds. Participants were asked to press any one of the arrow keys on the keyboard immediately on seeing the Gabor patch. There were 50 trials for each filter condition, with a total duration of approximately 6 minutes. Participants were not required to fixate centrally but could move their eyes freely around the screen.

Analyses

Three-way mixed model analyses of variance (ANOVAs) were conducted on each of the HPT and Gabor simple reaction time tests, with the factors of lens color (yellow vs. neutral density), polarization (polarized vs. nonpolarized), and age group (young vs. older). To examine the effects of the eccentricity of the stimuli for the simple reaction time test, a linear mixed effects analysis was conducted with participant identity as a random factor, and lens color, polarization, and the eccentricity for each trial as repeated-measures variables. As recommended,[39,40] models were compared using several covariance structures, including first-order autoregressive, compound symmetry, and scaled identity. The autogressive model was selected because it provided the best fit to the residuals (as determined by the Akaike Information Criterion).[41]

RESULTS

Table 1 shows the mean visual acuity and contrast sensitivity of the two groups for each of the lens conditions. There were no significant effects of lens color or of polarization for either vision test. Older participants had significantly decreased visual acuity ($F_{1,16}$ = 65.22, $p < 0.001$) and letter contrast sensitivity ($F_{1,16}$ = 49.67, $p < 0.001$) relative to the young participants.

TABLE 1.

Mean (SD) logMAR visual acuity and log contrast sensitivity measures across the different experimental conditions

		Lens type			
		Nonpolarized		Polarized	
Age group	Measure	Neutral density	Yellow	Neutral density	Yellow
Young	Visual acuity (logMAR)	−0.14 (.08)	−0.13 (.06)	−0.15 (.05)	−0.13 (.09)
	Letter contrast sensitivity (log units)	1.92 (.05)	1.94 (.04)	1.95 (.04)	1.94 (.04)
Older	Visual acuity (logMAR)	0.11 (.04)	0.11 (.06)	0.13 (.09)	0.09 (.12)
	Letter contrast sensitivity (log units)	1.68 (.11)	1.72 (.08)	1.58 (.37)	1.71 (.11)

Response Times for Detection of a Low-Contrast Gabor Stimulus

A three-way ANOVA found no significant main effects or two-way interactions between the factors, but there was a significant three-way interaction between lens color, polarization, and age ($F_{1,16}$ = 6.28, p = 0.023).

Follow-up two-way ANOVAs of the effects of lens color and polarization for each of the age groups did not reveal any significant main effects for either group but revealed a significant two-way interaction between the factors for the young participants ($F_{1,16}$ = 5.39, p = 0.034). The interaction is shown in Fig. 2. There was a significant effect of lens color for young participants when the lenses contained a polarizer, such that response times were reduced significantly with the yellow filter.

For the young participants, a secondary analysis was conducted, examining the effect of the filters as a function of stimulus eccentricity. Again, there was a significant interaction between lens color and polarization (t_{1784} = 2.82, p = 0.005), such that there was a significant effect of lens color for the polarized but not for the nonpolarized condition. There was also a significant two-way interaction between lens color and eccentricity (t_{1784} = 2.57, p = 0.01). To visualize the interaction, data were split into tertiles according to the stimulus eccentricity, and data were plotted for the top and bottom third of the stimuli according to eccentricity (Fig. 3). Overall, response times increased with increasing eccentricity, but this increase was significantly less in the presence of a yellow filter; thus, the yellow filter resulted in a differential improvement in performance in the periphery.

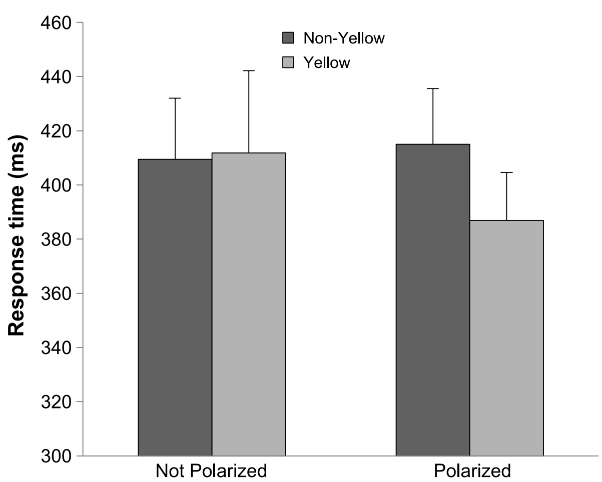

FIGURE 2.

Effects of lens color and polarization on response time for detecting a low-contrast Gabor stimulus for the younger participants. Error bars are +1 SE.

Hazard Perception Test

A three-way ANOVA revealed a significant main effect of age group ($F_{1,16}$ = 10.67, p = 0.005) such that younger participants were quicker to recognize the hazards than were older participants, but there was no significant main effect of lens color ($F_{1,16}$ = 3.14, p = 0.095). There was a significant two-way interaction between lens color and age ($F_{1,16}$ = 6.93, p = 0.018). Fig. 4 shows the two-way interaction. For young, but not for older, participants, yellow

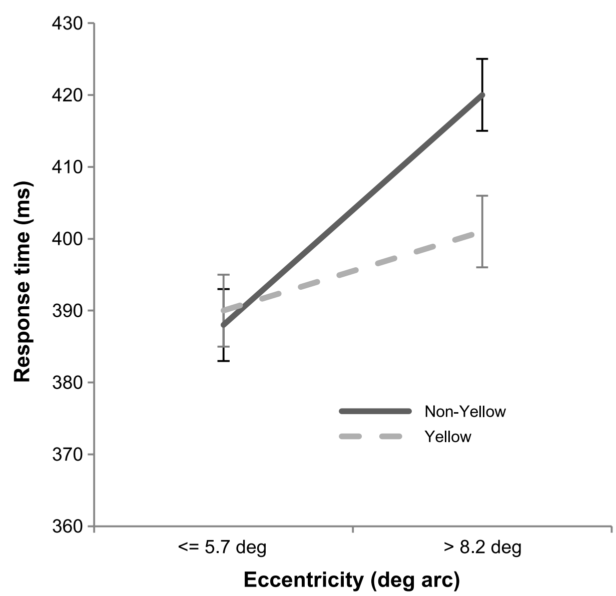

FIGURE 3.

Interactive effect of lens color and eccentricity on response time for detecting a low-contrast Gabor stimulus for the younger participants. Data are presented for the top third (>8.2 degrees) versus bottom third (<5.7 degrees) of stimulus eccentricities separately for the yellow and non-yellow lens conditions. Error bars are ±1 SE.

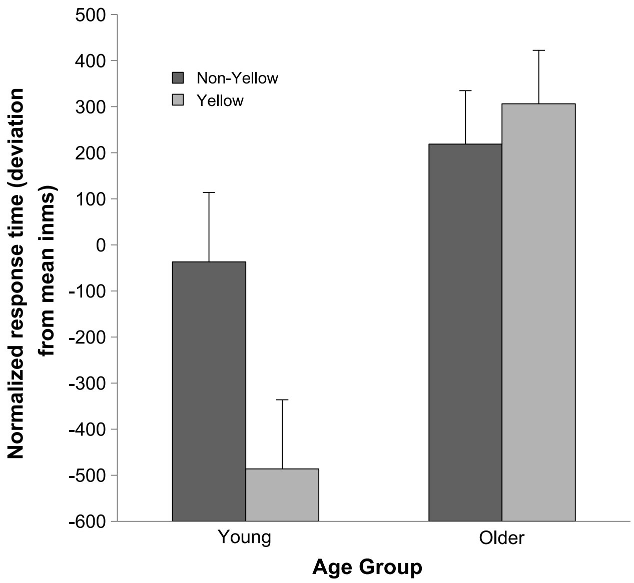

FIGURE 4.
Interactive effect of lens color and age group for the HPT. The dependent measure is deviation from the norm (in seconds) for each video presented.

filters reduced response times to hazards significantly, with a 450-millisecond mean difference between the yellow and neutral density filter conditions.

DISCUSSION

This study tested the hypothesis that yellow filters, which have previously been suggested to improve contrast sensitivity and reduce light scatter, improve response times for tasks relevant to driving. A secondary hypothesis was that improvements are greater in young than in older people. Specifically, we tested whether participants' response times to video presentations of road hazards, as well as computer-generated low-contrast targets, would be reduced with yellow filters. In contrast to some previous studies, we did not observe any significant improvement in either contrast sensitivity or visual acuity with yellow filters.[1,4,5,10–18] It is likely that the chart-based assessments did not permit a sufficiently fine gradation to observe significant effects. For the perception of the low-contrast target, the young participants exhibited a reduction in response time only when the yellow filters were combined with a polarizer, whereas for older participants, neither yellow nor polarizing filters reduced response times significantly. For the HPT, young participants responded almost half a second faster with the yellow filter than without it.

This reduction in response times for the younger participants on the HPT might translate into considerable safety benefits if carried over into a real-world driving environment. A reduction of 450 ms corresponds to reductions in travel distances of 7.5 and 13.9 m at speeds of 60 and 100 km per hour, respectively. Such a difference in travel distances could represent the difference between a serious collision and safe avoidance of a hazard.

The finding that the effects of the yellow filters was absent for older participants is consistent with the previous findings of Luria.[1] As suggested previously, it is possible that addition of yellow filters for the older eye may have less overall effect because the older lens may already be somewhat yellowed because of natural aging. It should be noted that the older participants had reduced letter contrast sensitivity and visual acuity, which may have influenced the results. Three of our older participants had IOLs (two participants binocularly, the other in only one eye); the remaining six participants had natural lenses. Hence, for older adults, yellow lenses may not be advantageous for those with natural crystalline lenses. Instead, for older adults, it may be more beneficial to explore the benefits of yellow-tinted versus clear IOL implants as in the recent study by Gray et al.[20]

In addition, we observed that among our younger participants, the yellow polarizing lens maintained response times at an overall faster level even for stimuli presented eccentrically. In this experiment, participants were not specifically instructed to fixate centrally, but the assumption was that, in general, the direction of gaze would be toward the center of the display and the finding of a significant increase in response time with eccentricity is consistent with this interpretation. In all conditions, response times increased with eccentricity, but this effect was significantly less with a yellow polarizing lens. It has previously been observed that response times to visual targets depends both on eccentricity and the visual salience of the stimulus (i.e., the degree to which the stimulus can be discriminated from its background) with a trade-off such that, with greater salience, there is a reduced cost associated with eccentricity.[42,43] It is likely that the present observations are indicative of the same phenomenon: because contrast is an important determinant of visual salience[44] and it has been shown that yellow lenses increase contrast of images,[5,18] the increased contrast of the stimuli to some extent counteracted the increased response times associated with eccentricity.

The finding that the beneficial effects of the yellow lenses was enhanced when combined with a polarizer was unexpected because the effects of a linear polarizer are best observed in outdoor environments where there are reflections of horizontal stray light that act as glare sources. It is possible that the benefit observed here related to the reduction in minor reflections from the edges of the computer screen or surrounds that would have enhanced the apparent contrast and therefore also salience of the targets. No such reflections were tangibly obvious on inspection, but nonetheless, this is a possible explanation. Given that the low-contrast target consisted of a horizontally oriented Gabor, it is also possible that reduction of horizontally oriented noise in the form of light scatter may have increased the signal strength of the Gabor, making the grating more visible, although again this was not obvious on inspection. Although unexplained, this finding suggests that investigating the combined influence of sunglass tint and polarization in future studies may be useful.

It is still important to consider the interaction between lens tint and the color of relevant targets for a given activity, as well as the typical colors of the backgrounds against which these stimuli are seen. The results from the HPT suggest that, for the video scenes used for this study (which included 100 separate scenes from typical everyday driving), the perception of stimuli was improved among the young participants with the use of the yellow filter. Nonetheless, an in-depth study is necessary to establish whether any important road safety–related stimuli may be missed or evoke slower response times because of reduced chromatic contrast in the presence of the yellow filter. Such information might serve as an important caution against the use of these filters.

In conclusion, this finding provides important evidence that the perception of stimuli directly relevant to a real-world task is improved in the presence of yellow filters—at least for young participants. Future studies should examine the effects of sunglass tints in on-road measures of driving performance and in other activities.

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