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Differences in Apparent Contrast in Yellow and White Light (Reprint)

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RESEARCH NOTE

Differences in apparent contrast in yellow and white light

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Summary

The purpose of this study was to investigate suprathreshold contrast perception in white and yellow light. The contrast of black-on-white letters was adjusted to match the perceived contrast of yellow-on-yellow letters presented simultaneously on a video display. At lower contrasts (7–15%), the apparent contrast of yellow letters was slightly enhanced compared to black-on-white letters (mean enhancement = 23%), but this effect diminished with increasing contrast. The slight enhancement in yellow light was independent of letter size, and could not be explained by luminance differences between yellow and white displays. This effect may relate to the subjective improvement often reported when wearing yellow (blue-blocking) lenses.

Introduction

Yellow (blue-blocking) filters have been used for many years to enhance vision for various tasks including marksmanship, skiing, and aviation. Notwithstanding their commercial success and numerous anecdotal reports of subjective improvement with yellow filters, evidence for enhancement of visual performance is lacking. There is no measurable improvement of visual acuity with yellow filters[1–4], and range for detection of an approaching aircraft is not significantly different from that achieved with neutral filters[5]. While there is some evidence for enhancement of contrast sensitivity[1,6], other laboratories found no effect[7–9]. Yellow filters have been shown to reduce reaction time[10], and to enhance detection of depth in snow-covered terrain[11]. In these studies, it was noted that enhancement of vision with yellow filters is limited to stimuli of low to moderate spatial frequencies. Perceived brightness through yellow filters also was found to be greater than luminance matched neutral filters[12].

The optical, neural and/or psychological basis for visual enhancement with yellow filters is unclear. Since chromatic aberration of the eye causes short-wavelength (blue) light to be focused proximal to the retina, elimination of blue light with yellow filters conceivably could enhance vision. However, this optical effect would be greatest for higher spatial frequencies, and there is no improvement of acuity with yellow lenses. Atmospheric scatter of light, which increases at shorter wavelengths, is reduced with yellow filters, and this could increase visual performance. However, this effect also would not be limited to moderate spatial frequencies, and field measurements revealed no measurable improvement of range detection with yellow filters. It also has been suggested that the improvement is neural in origin, representing a reduction of opponent input from chromatic pathways[10,11]. This explanation seems consistent with visual enhancement limited to moderate spatial frequencies since chromatic pathways do not process fine spatial detail. Kelly[12] provided evidence that the enhancement of brightness perception through yellow filters is mediated by rod signals to chromatic pathways. More recently, it was suggested that differences in pupil size may underlie perceptual differences with yellow and neutral filters[15].

While most previous studies with yellow filters used threshold measurements under successive test conditions (yellow versus neutral filter), fewer attempts have been made to explore this phenomenon with suprathreshold stimuli and simultaneous viewing conditions. Suprathreshold stimulation is more representative of real-world conditions.

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In the present study, a suprathreshold, contrast matching approach was used to explore perception of letters displayed side-by-side in yellow and white light. The chromaticity of the yellow field was similar to the white field as viewed through a broad-band, yellow filter.

Method

The stimulus for contrast matching was two 4-letter columns of Snellen Es presented side-by-side on a video display (Zenith model ZCM-490 VGA monitor, P22 phosphor; *Figure 1*). Display luminance, chromaticity and contrast of individual letters were under software control, and verified by photometric measurement of each software step in gun intensity (Minolta CS-100 and LS-100 photometers). The left half of the display was yellow (red and green guns activated), while the right half was white (red, green and blue guns), and each letter was presented as an intensity decrement (lower luminance) relative to its background which had the same chromaticity as the letter. The Michelson contrast of letters on the white hemifield was controlled by reducing the red, green and blue guns symmetrically relative to a constant white background ($x = 0.288$, $y = 0.330$; 113.2 $cd\,m^{-2}$), while letter contrast on the yellow field was controlled by reducing the intensity of the red and green guns relative to the constant yellow background ($x = 0.391$, $y = 0.525$; 109.3 $cd\,m^{-2}$). Although a yellow display generated by combining the red and green guns of a colour monitor may not be equivalent to viewing the world through a spectrally restictive longpass filter, the chromaticity of the yellow hemifield ($x = 0.391$, $y = 0.525$) was quite similar to the chromaticity of the white hemifield viewed through a broad-band yellow filter ($x = 0.398$, $y = 0.540$). The transmittance of this filter is shown in *Figure 2*.

On any single trial, the contrast of the yellow hemifield was fixed, while the contrast of the black-on-white letters could be adjusted by the subject to match the apparent contrast of the yellow letters (*Figure 1*). The size of the letters in each column decreased from top to bottom, and corresponded to Snellen letter sizes of 20/600, 20/300, 20/150 and 20/75 at the 75 cm viewing distance. These letter sizes were used since they include a range of moderate spatial frequencies (1 to 8 c/deg) for which visual enhancement with yellow filters has been reported[10,11]. The horizontal and vertical spacing of the letters was symmetrical in proportion to their size (*Figure 1*).

Subjects were tested under normal binocular viewing conditions with habitual refractive corrections in place. To emphasize natural viewing conditions, no correction for accommodation was used, and none of the subjects were presbyopic. Each subject was seated comfortably in a darkened room 75 cm from the display. The subject was instructed to adjust the contrast of each black-on-white letter on the right such that it appeared equally clear and equally different from its background as the corresponding yellow letter on the left. The subject could increase or decrease the contrast of the black-on-white letters by

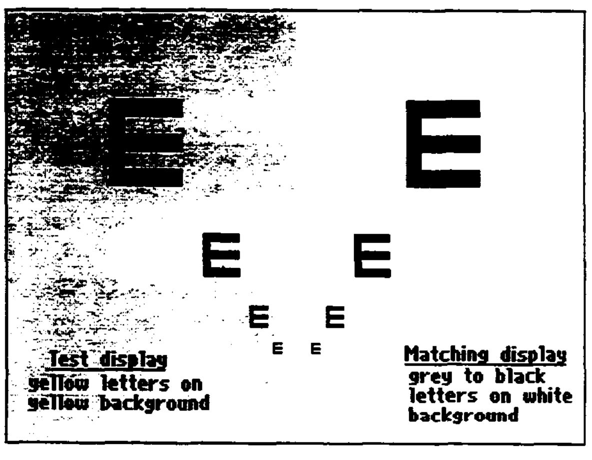

Figure 1. The contrast matching display. The left hemifield was yellow (red and green guns activated) and contrast of the 4-letter column was constant on any single trial (7.4, 15, 32.5 or 62.5%). The right hemifield was white (red, green and blue guns) and letter contrast was adjusted by the observer to match the perceived contrast of yellow letters on the left. For both hemifields, letter luminance was always lower than its background, but the chromaticity of each letter and its respective background was the same. From top to bottom, letter sizes corresponded to Snellen fractions of 20/600, 20/300, 20/150 and 20/75.

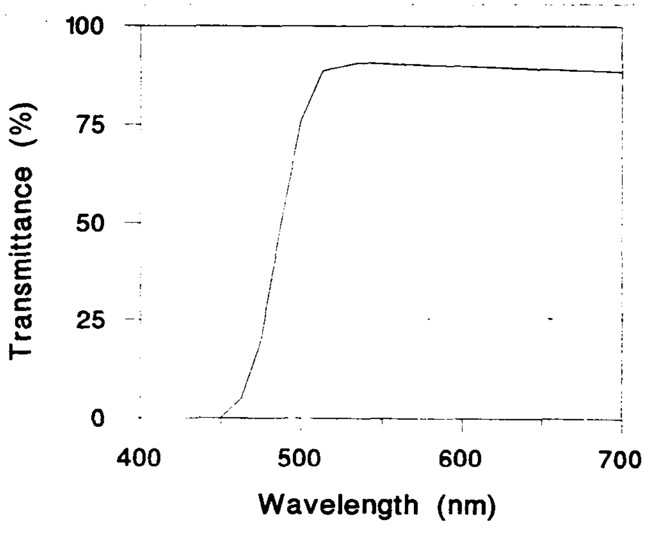

Figure 2. The transmittance of a spectrally broad, yellow filter (Kodak K2, # 8) as measured by a spectroradiometer (Humphery Instruments, *Spexan*). When viewed through this filter, the chromaticity of the white hemifield of the contrast matching display ($x = 0.398$, $y = 0.540$) was quite similar to the chromaticity of the (unfiltered) yellow hemifield of the display ($x = 0.391$, $y = 0.525$). Hence the results of our study may apply to spectrally broad yellow filters, but may not apply to spectrally restrictive longpass filters which appear orange or red.

depressing a keyboard. The subject started with the two largest letter pairs on the top, and then proceeded down the column adjusting contrast to achieve a match for each successive pair. This procedure was repeated 2–3 times and the mean setting was computed for each letter. Testing was conducted with four yellow contrasts (7.4%, 15%, 32.5%, 62.5%) which were presented in ascending order to reduce adaptation effects. The matching contrasts available with the black-on-white display ranged from 1.7 to 96.3% with each keyboard step, representing an average contrast change of 1.5%.

Seven subjects (ages 23–39 years, mean = 29 years) with normal visual acuity and ocular health were tested. Informed consent was obtained from all subjects after protocol approval by our institutional review committee.

Results

Figure 3 shows mean (± 1 SE; $n = 7$ subjects) apparent contrast of yellow-on-yellow letters plotted against the actual (physical) contrast for each of four letter sizes. Apparent contrast refers to the contrast to which the black-on-white display was adjusted to match the yellow display. The 1/1 line indicates exact agreement between perceived and physical contrast, while data falling above the line imply that the apparent contrast of yellow-on-yellow letters was enhanced relative to the black-on-white display.

The deviation from the 1/1 line was quantified for each subject by computing the ratio (apparent contrast/actual contrast), and evaluating these ratios in a two-way repeated measures ANOVA across *actual contrast* and *letter size*. This approach was used, rather than taking the difference between apparent and actual values, since a difference of, say 4%, would involve a greater perceptual difference at low than at high contrasts. As is evident in *Figure 3*, there was no significant effect of letter size ($F = 0.49$, $P > 0.69$) indicating that the perceived enhancement of the yellow display was independent of size for the range of letters tested. However, the ratio (apparent/actual contrast) was significantly related to the contrast of the yellow display ($F = 9.73$, $P < 0.0001$). At lower contrasts (7.4 and 15%), the apparent contrast of the yellow letters was 23% higher (mean ratio = 1.23), but as contrast increased the difference between apparent and actual contrast diminished with the ratio nearly unity for contrasts greater than 60%.

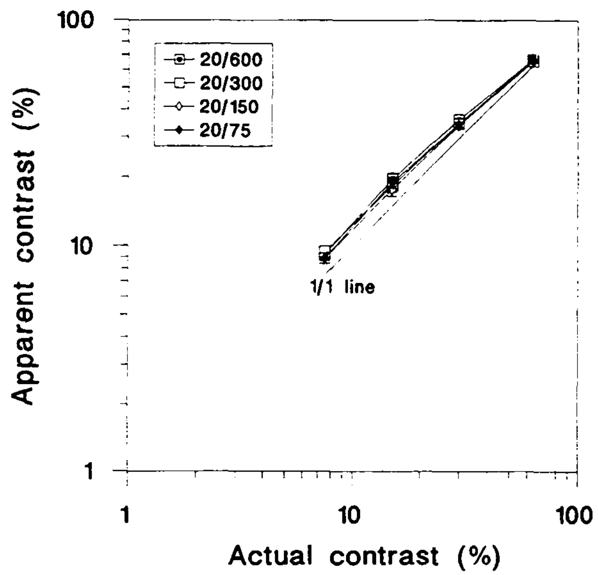

Figure 3. Mean (± 1 SE; $n = 7$ subjects) apparent contrast of yellow-on-yellow letters plotted against actual (physical) contrast for each of four letter sizes.

The slight, perceptual enhancement of yellow-on-yellow letters could not be atrributed to differences in luminance since the white ($113.2\,cd\,m^{-2}$) and yellow ($109.3\,cd\,m^{-2}$) luminances were nearly the same, and this slight difference was opposite to the direction of the perceptual effect. Kelly[12] found enhanced brightness perception through yellow filters that was maximal with large stimuli presented at moderate luminance ($10\,cd\,m^{-2}$), but absent at low and high luminance. To determine if luminance level affected the present results, contrast matching measurements were repeated on two subjects at low, medium and high luminance levels (approximately 1, 10 and $100\,cd\,m^{-2}$) with the two lowest letter contrasts. Mean enhancement with the yellow display, averaged across letter size, was largest at the highest luminance (33% at high luminance; 14% at low luminance) indicating that this effect is not limited to moderate luminances, but increases with luminance.

Chung and Pease[15] showed that the pupil is larger in yellow light compared with luminance-matched white light, and suggested that this effect may, in part, underlie perceptual enhancement with yellow lenses. To explore this possibility, measurements were repeated on two subjects who viewed the display monocularly through a 3 mm artificial pupil. Mean enhancement with the normal pupil (24%) was higher than with the artificial pupil (13%) suggesting that pupil size differences between white and yellow displays can influence the magnitude of the enhancement effect.

Discussion

This study demonstrates that the apparent contrast of letters is enhanced slightly when presented in yellow light as compared to white light. This effect is more prominent at lower letter contrasts, and cannot be attributed to differences in the luminance of yellow and white displays. Since the chromaticity of the yellow display in the present study was comparable to viewing through a spectrally broad yellow filter (*Figure 2*), the results reported here may relate to frequent subjective reports of enhanced vision with yellow (blue-blocking) lenses. The question of whether our results apply to filters that pass longer wavelengths and typically appear orange or red is a topic for further research.

Previous attempts to demonstrate enhancement with yellow filters primarily have involved threshold measurements under successive conditions of presentation. Most studies using acuity or detection tasks reported no measurable enhancement[1–5,8,9]. In the present study, this phenomenon was evaluated under suprathreshold conditions with simultaneous presentation of yellow and broad-band stimuli. It is conceivable that the suprathreshold nature of this task may relate more directly to enhancement with yellow filters reported subjectively. Kinney *et al.*[10,11] found a reduction in reaction time and enhanced depth discrimination in snowy terrain when viewing through yellow filters. Using a magnitude estimation technique, Kelly[12] found that brightness perception is enhanced with yellow filters. Since these studies also were conducted under suprathreshold viewing conditions with stimuli of low to moderate spatial frequencies, the findings are comparable to the contrast matching results reported here. However, the enhancement observed in the present study was slight (<0.1 log unit), limited to lower contrasts, and may have little effect on visual performance in real-world settings.

The origin of enhancement with yellow filters remains unclear. Kinney *et al.*[10,11] suggested that, since white light activates both luminance and colour channels, opponent (subtractive) output from colour channels may detract from the sense of brightness. Yellow filters, which absorb blue light and limit colour vision, reduce this opponent effect thereby enhancing brightness as compared to neutral filters which transmit broad-band, white light. Kelly[12] found that yellow filters enhance suprathreshold brightness perception at moderate luminances ($10\,cd\,m^{-2}$), but have no effect at higher luminances at which rod photoreceptors become saturated, nor at low luminances below the chromatic threshold. She suggests that the enhancement observed at moderate luminances reflects rod input to chromatic pathways. In the present study, the enhancement in apparent contrast was most prominent at the highest luminance tested (approximately $110\,cd\,m^{-2}$) suggesting that this effect is linked strongly to photopic function. In addition, no effect of letter size was observed, while a rod-mediated effect should be more apparent with larger letters (lower spatial frequencies).

Since the peak sensitivity of the pupillary response (530 nm) is, for some viewing conditions[13], lower in wavelength than the peak of the luminosity function (555 nm), yellow light, which lacks short wavelengths, is less effective in constricting the pupil than luminance-matched white light. Thus, the pupil tends to be larger in yellow light[14], and it has been suggested that this may underlie brightness enhancement with yellow lenses[15]. Two subjects did show a greater contrast enhancement effect when pupil size was allowed to vary normally as compared to their performance with a small, artificial pupil. While this indicates that differences in pupil size can contribute to this effect, yellow light enhancement was still present in these subjects when viewing through the artificial pupil suggesting that other factors also mediate this effect.

Although contrast was adjusted physically in the present study, it is likely that subjects used several dimensions to achieve perceptual matches including apparent contrast, clarity, and lightness of the letter pairs. Lightness and lightness induction effects are pervasive phenomena which transcend luminance and colour domains[16,17]. In view of the limited evidence for improvement in visual performance with yellow filters, the phenomenon is probably more related to appearance than to function, and may be explicable as a lightness induction effect. Since it is well established that yellow filters limit colour vision[9], this detrimental effect on visual function may far outweigh any slight gain in appearance.

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