The effects of yellow lenses on the human contrast sensitivity function

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Abstract
A review of the literature regarding visual performance with yellow lenses reveals little substantial evidence of visual enhancement with their use. However, several recent studies of contrast sensitivity with various filters have shown advantages for yellow over luminance-matched neutral filters. In this study, contrast threshold measurements were taken on 26 subjects using yellow, luminance-matched neutral, and clear control lenses using the Nic0let CS 2000 automated contrast sensitivity measuring system. No significant differences were found between any of the conditions at any of the six spatial frequencies tested. Suggestions for further investigation are made.

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THE EFFECTS OF YELLOW LENSES ON
THE HUMAN CONTRAST SENSITIVITY FUNCTION

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Spring, 1983

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ABSTRACT

A review of the literature regarding visual performance with yellow lenses reveals little substantial evidence of visual enhancement with their use. However, several recent studies of contrast sensitivity with various filters have shown advantages for yellow over luminance-matched neutral filters. In this study, contrast threshold measurements were taken on 26 subjects using yellow, luminance-matched neutral, and clear control lenses using the Nicolet CS 2000 automated contrast sensitivity measuring system. No significant differences were found between any of the conditions at any of the six spatial frequencies tested. Suggestions for further investigation are made.
Since colored lenses were first introduced in the 16th century, many therapeutic and vision-enhancing properties have been ascribed to various tints. Clark\(^1\) has published an extensive review of opinion and experimental evidence regarding colored lenses in general which aptly illustrates the large degree of confusion and disagreement regarding this subject found in the published literature. Of the many tints that have been produced, yellow appears to have generated the most controversy and the highest level of experimental activity relating to its claimed visual benefits. To date, the general consensus of most authorities is that yellow tints provide no tangible benefits over neutral density tints as sunglasses or for any other specific purpose.\(^2\)

Yellow lenses have been widely promoted and used as "shooting glasses", for use by aircraft pilots and skiers under certain weather conditions, and for night driving use, among other things. The visual enhancement reported for these lenses is generally described as an increase in "visibility" of targets or terrain (contours) in conjunction with an increase in apparent brightness of the visual display field. These properties, combined with a supposed glare-reducing effect, form the basis for most of the claims of improved visual discrimination associated with yellow lenses.
Unfortunately, the great majority of objective evidence has failed to support subjective reports. Visual acuity has been the most commonly measured indicator of performance experimentally. Although Berte\(^3\) reported slight acuity gains for certain luminance levels and target distances, Lauer,\(^4\) Stone and Lauer,\(^5\) Richards,\(^6\) Neumuller,\(^7\) Miles,\(^8\) and Depew and Jensen\(^9\) found no improvement or a decrease in acuity associated with wearing yellow lenses. The general conclusion reached by these authors and others has been that acuity is decreased in proportion to the loss in light transmission produced by any tinted lens, regardless of color. It must be stated that the majority of these studies found acuity losses under conditions of low luminance (such as night driving) while at higher luminances acuity was not significantly altered for yellow tints. The disproportional acuity loss at low luminance levels is explained theoretically by Richards\(^2\) as resulting from the Purkinje shift of maximal sensitivity from 555 to 510 nm, combined with the reduced short-wavelength transmission of yellow lenses.

The use of yellow filters to enhance vision in conditions of fog or haze has also been promoted. The theoretical basis is analogous to the use of yellow photographic haze filters which preferentially absorb the most easily scattered short wavelengths of light. However, Verplank\(^10\) and Luckiesh and Holladay\(^11\) found no increase in target visibility under haze conditions associated with use of yellow filters or yellow illumination, respectively. Richards\(^2\) attributes the lack of improvement under haze conditions to the lesser sensitivity of the retina to blue light (compared to photographic emulsions) and the greater chromatic aberration of the eye (compared to camera lenses).
Bierman\textsuperscript{12} and Ross\textsuperscript{13} evaluated marksmanship ability of shooters under various conditions with several lens tints, including yellow. Both reported no overall improvement in performance (with a few exceptions), although a significant number of shooters subjectively preferred yellow lenses over no lenses.

The search for objective corroboration of subjective reports regarding yellow lenses has also produced research in the area of color discrimination. Farnsworth\textsuperscript{14} and Newman and Toda\textsuperscript{15} found that colored filters (including yellow) generally lowered color discrimination ability, and both authors recommended neutral density tints whenever an absorptive lens is required for luminance or glare reduction. However, Luria\textsuperscript{16} in a study of color contrast and target detectability, reported a significant improvement in detection and increment thresholds for long wavelength targets against short wavelength backgrounds (e.g., a yellow target on blue surround) with yellow filters. The improved visibility was decreased by (a) increased background wavelength, (b) decreased target size, (c) increased age of observers, and (d) decreased luminance. The author attributes the effect to simple contrast enhancement resulting from the filtering out of the blue surround by the yellow lens. He presents a case for use of yellow goggles by scuba divers, since underwater conditions should be optimal for this effect. In a similar vein, Martin\textsuperscript{17} reported improved detectability of certain colored targets (but not gray targets) with yellow lenses, but only under conditions of simulated haze.

The impression that yellow lenses produce increased brightness of a visual scene is commonly reported. This phenomena has been attributed by Wright\textsuperscript{18} to a "psychological" effect in which yellow
is associated with sunlight and its high level of illumination. However, Septon has shown (with a brightness-matching procedure) that the effect is "real" to the observer under certain high-luminance conditions. In an attempt to correlate this phenomenon with a measurable physiological response, Dirks and Kajiwara were unable to show an increased amplitude of the visual evoked response (VER) with yellow filters compared to luminance-matched neutral filters.

The reported enhancement of color contrast and apparent brightness under certain conditions as cited above probably account for some of the subjective improvements in "seeing" experienced with yellow lenses. Yet these effects do not logically account for some situations for which yellow lenses have found widespread use. Most notable of these is the preferential use of yellow goggles by many skiers and aviators under conditions of low overcast or "arctic whiteout" to enhance visibility of low-contrast terrain. In recent years several studies have attempted to correlate the subjective reports with contrast sensitivity effects. (It is now widely accepted that luminous contrast sensitivity is a valid measure of visual function.) In an early theoretical analysis of contrast effects for various types of "depressions" found in snowy terrain, Wyszecki concluded that colored filters in general should not significantly improve visibility (contrast). However, his calculations predict a slight gain in contrast for filters transmitting the long wavelengths preferentially. He noted that the optimal contrast gain provided by a deep red filter would be more than offset by an overall luminance reduction. Burge, using a computer analysis of Wyszecki's theoretical assumptions,
similarly concluded that colored filters should not significantly enhance snowy terrain contrast.

A more recent approach to the question of contrast sensitivity with colored filters has produced some very interesting results. Kinney et. al.\(^25,28\) evaluated contrast sensitivity with yellow and luminance-matched neutral filters by measuring reaction times to suprathreshold sine and square-wave gratings of various spatial frequencies. The authors reported significantly faster reaction times with yellow filters for all but the highest spatial frequencies. Since the highest spatial frequencies correspond to acuity measurement, these results do not contradict the earlier literature showing no acuity enhancement. The greatest improvement was noted in the middle of the spatial frequency range (near 2 cycles per degree) in low contrast gratings with bright white surrounds. These conditions are very analogous to those found in snow-covered terrain in overcast or "whiteout" conditions. (The authors also conducted an extensive evaluation of stereoscopic acuity with yellow versus neutral filters and found no significant differences between them.)

Richards\(^26\) also measured grating contrast sensitivity for 11 different filters and reported enhancement of detection with yellow filters for square-wave (but not sine-wave) targets of less than 2 cycles per degree. Similarly, Everson and Levene\(^27\) utilized a grating detection procedure at various luminances and found enhanced sensitivity with yellow filters for gratings in the 1 to 5 cycles per degree range, with an optimal luminance range near 30 foot-Lamberts. The improved sensitivity occurred for both sine and square-wave targets but disappeared at very bright luminance levels.
Kinney and her co-workers proposed an intriguing theory to account for these contrast enhancement effects. Their theory relies on the possible contribution of the chromatic opponent system to luminous contrast sensitivity. By essentially reducing the short-wavelength cone receptor response, yellow filters may reduce the inhibitory effect of this channel in the chromatic opponent model.

The results of these recent studies have provided the major impetus for this research project. Since Kinney et. al. used reaction times to suprathreshold gratings as a measure of contrast sensitivity, it is our intention to further investigate this area by measuring contrast detection thresholds for various sine-wave gratings with spatial frequencies within the normal range of human sensitivity. This study was designed to compare and evaluate these thresholds with yellow lenses, luminance-matched neutral density lenses, and clear control lenses in an attempt to further corroborate and expand upon the recent research cited above.
METHODOLOGY

SUBJECTS

Twenty-six subjects were selected from the population of optometric interns at the Pacific University Forest Grove Optometry Clinic. The familiarity of this population with psychophysical testing procedures and concepts was considered desirable.

Criteria for subject selection included freedom from active pathology and 20/20 (or better) best-corrected visual acuity with each eye. Subjects with tinted corrective lenses were excluded from the study. Five females and twenty-one males ranging in age from twenty-four to thirty-five years were selected.

APPARATUS

The experimental apparatus consisted of a Nicolet CS 2000 automated contrast sensitivity testing system* and three pairs of plano optical filters: (1) non-absorptive trial lenses, (2) neutral density filters (Wratten #96) mounted in trial lens rings, and (3) yellow trial lenses (American Optical Corp. Noviol "C").

The neutral density filters and yellow lenses were matched photometrically for overall light transmission (82%). This was done so that the comparison would be based solely on the non-selective versus selective absorptive quality of each, respectively. The non-absorptive plano lenses were used in a "control" condition, primarily to familiarize subjects with the testing procedures.

Halberg trial clips were used to mount the experimental lenses on habitual spectacle frames. Uncorrected subjects and

* Nicolet Biomedical Instruments, 5225-4 Verona Road, Madison Wisconsin, 53711.
contact lens wearers wore the lenses in a trial frame.

The CS 2000 unit was used in the "standard setup" as recommended by the manufacturer. Subjects were seated three meters from the CRT screen on which the sinusoidal gratings were generated. The procedure was carried out in a light shielded room so that the only light present was generated by the CRT display itself.

The CS 2000 program contains four different psychophysical methods to choose from. The method of increasing contrasts was chosen for this study because preliminary trials indicated that data "scatter" was generally lower for this method than for the other three methods.

Six spatial frequencies (0.5, 1, 2, 3, 6, and 11.4 cycles per degree) were used for the experimental and control trials. Since the contrast sensitivity enhancement attributed to yellow lenses in prior studies has been in the midrange of spatial frequencies, we excluded frequencies lower than 0.5 C/D and higher than 11.4 C/D.

The CS 2000 unit was calibrated before each use using the standard calibration procedure incorporated by the manufacturer into the system. This procedure is carried out by placing the photodiode aperture of the "response box" upon the calibration stand in front of the CRT screen and instructing the unit to "scan" the CRT display after adequate warmup time (at least 15 minutes). The printer display instructs the user to make necessary adjustments for contrast and brightness until calibration is achieved. When calibrated, the display monitor is set for 100 candela/meter$^2$ average luminance and 0.50 peak contrast at the screen center.
The step-by-step program sequence used is given in Appendix A. For each spatial frequency tested, a brief pretrial preview was presented, followed by six trials in which the contrast increased from a random subthreshold level until a "just visible" criterion was met.

**PROCEDURE**

Subjects were screened and briefly informed of the nature of the experiment without a suggestion of any expected outcome (see Appendix B). Subjects were then seated three meters from the display screen, fitted with the non-absorptive control lenses, and instructed in the use of the "response box". The complete battery of 36 trials (6 trials for each of 6 frequencies) was run with the control lenses, primarily to familiarize subjects with the complete procedure.

Subjects were then fitted with either the neutral filters or yellow lenses and the complete trial battery repeated. Finally, the second set of experimental lenses/filters were fitted and the trial battery repeated a third time. The order in which neutral and yellow lenses were used was alternated for successive subjects to balance for practice and fatigue effects. The entire procedure required 20 to 30 minutes per subject.

The data printout for each spatial frequency tested included mean log contrast for the six trials, standard deviation, and mean sensitivity (mean contrast$^{-1}$). To minimize data scatter and maximize validity, a criterion for maximum allowable standard deviation of 0.11 log unit was arbitrarily selected. (Preliminary trials indicated this as a reasonable figure for the subject population.) Trial sets with standard deviations in excess of 0.11 log unit were repeated until the criterion was met.
RESULTS

Mean values for the sample population under the three conditions are shown graphically in Figure 1. A range of ± 2 standard errors of the mean is shown in the figure for each point.

It is evident in Figure 1 that the ranges for ± 2 standard errors are virtually completely overlapping for all three lens conditions at each and every frequency tested. Since the range of variation of each condition is clearly well within the range of variation of the other two conditions for each frequency, we can state that the three conditions represent samples drawn from the same population at all frequencies tested. In other words, no significant difference exists between the contrast thresholds for the yellow, neutral, and control lenses used in this study.

Due to the extent of the overlap of the descriptive statistics at all frequencies, it is plainly unnecessary to apply inferential statistical tests for significance to the data gathered.
FIGURE 1

Mean log contrast at threshold for 20 subjects

- C = C
- □ = Y
- △ = N

Spatial Frequency (Cycles/Degree)

20 Squares to the inch
DISCUSSION

The results of this study indicate that the threshold for contrast detection is not significantly different for yellow versus matched neutral density filters for any of the spatial frequencies tested. The fact that detection thresholds for yellow and neutral were not significantly different from the clear control lens thresholds indicates that the difference in overall light transmission (control = .92, yellow and neutral = .82) had no effect on the contrast threshold at the frequencies tested. This is not in disagreement with previous studies showing decrements in visual acuity with the use of colored filters, since the upper range of spatial frequencies corresponding to fine acuity targets was not tested in this study.

We are able to say conclusively then, based on this work and work by others cited in the Introduction, that yellow lenses neither enhance nor degrade threshold contrast sensitivity in the range of spatial frequencies between 0.5 and 11.4 cycles per degree.

The most promising direction for further investigation is in the area of suprathreshold testing. The strongest objective evidence to date in favor of yellow filters has come from Kinney and co-workers,25,28 who recently measured reaction times to suprathreshold gratings at varying contrasts. The greatest measurable advantage for yellow (over matched neutral density) occurred for midrange frequencies at low contrasts.

It seems likely that the "yellow effect" is not present at threshold contrasts, but instead becomes active at some
suprathreshold level. It also seems likely that reaction-time measures for suprathreshold targets are more precise than "first visible" threshold measurements. Regardless, there remains the need for corroboration and expansion of this recent work, which may very well lead to a resolution of the yellow lens controversy.
REFERENCES


