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Effects of Colored Filters on Visual Function

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14. ABSTRACT: The effects on visual performance of colored filters were investigated. Visual performance of 10 subjects (mean age = 30.5) was assessed while wearing yellow and pink tinted filters and compared to performance with transmission matched neutral filters and without any filter. Visual acuity was assessed with high (96%) and low (11%) contrast letter charts at mean luminance of 100 and 3 cd/m^2. Contrast sensitivity for blue/grey and green/grey gratings was assessed at 5 spatial frequencies (0.45, 0.9, 3, 6, 12cpd) at grating mean luminance of 36 cd/m^2. Visual search performance for grey targets on blue and green backgrounds viewed with and without the yellow and pink filters respectively, was assessed at moderate and low photopic ambient levels. Both the pink and yellow filters reduced contrast acuity compared to the no filter condition at 3 cd/m^2, but had no effect on acuity at 100 cd/m^2. Sensitivity to color contrast at mid spatial frequencies was improved with the pink filter, although the yellow filter did not change sensitivity at any frequency. Furthermore, both the pink and yellow filters improved search times at the moderate ambient level, and the pink filter improved search times at the low ambient level. Tinted filters can improve visual performance in situations where they significantly increase the luminance and or color contrast differences between targets and backgrounds.

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1. INTRODUCTION

Wearing colored filters has been reported to produce both gains and losses in visual function. Some of the gains include improved reading performance in persons with dyslexia[1] and low vision[2] and general visual performance in bright environments in persons with low vision.[3] In persons with normal vision, yellow filters have been reported to reduce glare and improve overall visual performance.[4-9] The claims of improved vision in dyslexia and low vision are based on anecdotal or marginal empirical evidence and remain largely unsubstantiated.[3,10] In contrast, there is an abundance of empirical evidence showing that colored filters can have adverse effects on color vision ranging from mild losses in color discrimination to symptoms similar to those found in dichromats.[11-13]

Yellow filters have received the most research attention because of numerous claims by users such as pilots and skiers that they improve visibility and reduce effects of glare, particularly in haze and snow environments.[4] However, there has been little objective evidence to support these claims.[5-9] The lack of empirical support for subjective claims may be due to the broad nature of the experimental questions that have been asked in previous studies. For example, the assumption has often been that any test related to visibility (e.g. acuity) should show improvement if the yellow filters do what users claim. As a result, numerous studies of acuity and contrast sensitivity, where targets and backgrounds are achromatic, showed little improvement with yellow filters. As Kelly[6] pointed out, and Luria[9] demonstrated experimentally, this is not a stimulus condition where yellow filters would be expected to enhance contrast and improve visibility. On the other hand, yellow filters could improve visibility if the background were blue like the sky. This occurs because the yellow filter removes the blue end of the spectrum making the sky appear darker and enhancing the contrast of overlaid lighter colored objects. In a recent study, a yellow filter had no effect on contrast sensitivity using white on black bar patterns, but significantly improved contrast sensitivity at low to mid spatial frequencies when the bars were white on blue.[7]

Hypothetically, this concept can be extended to other colored filters, for example red, which should enhance the contrast of lighter objects on a green background, such as grass, because it causes the grass to appear black or at least very dark. The extension finds some support in the literature on avian vision, where pigeons, for example, have yellow, orange and red oil droplets in their photoreceptors that act as selective chromatic filters. The distribution of these droplets is such that the yellow and orange ones are found in photoreceptors that view the sky and red ones in photoreceptors that view the ground during feeding.[14,15] Although it has never been empirically demonstrated, it has been suggested that the "yellow-field" may enhance contrast of objects seen against a blue sky and the "red-field" may enhance contrast of objects viewed against a green background such as seeds on the ground.

Yellow filters are also claimed to reduce the effects of glare. Multiple reasons have been postulated as to why this occurs but only recently has some experimental evidence been obtained that directly supports the claim. Kooi and Alferdinck, found that yellow lenses reduced discomfort glare with the most likely explanation being that this occurs because of reduced short wavelength cone stimulation.[16] Furthermore, the effect was larger at higher luminance levels, which may explain the benefit reported by pilots and skiers who often work in high luminance environments. Similar effects have been found for the naturally occurring yellow filter, the macular pigment. Stringham, Fuld and Wenzel found that subjects with more macular pigment were better able to tolerate more short wavelength light.[17] Stringham and Hammond later reported that increases in macular pigment density were related to lower glare disability and faster photostress recovery times.[18]

Other areas where yellow filters have shown some benefit is improved contrast sensitivity and low contrast acuity under mesopic conditions[19] and faster reaction times to low contrast, mid spatial frequencies.[20] What is interesting about these studies is that black and white rather than blue and white stimuli were used.

In the present study, we used different approaches to determine if yellow filters can be used to enhance vision. Compared to previous studies, we focused more on situations where colored filters would increase the contrast between targets and background compared to a no filter condition. We also assessed performance on a dynamic task, visual search, which tests speed of information processing. The effects of wearing a yellow filter on contrast acuity for achromatic stimuli as well as contrast sensitivity and visual search under test conditions where gratings and search stimuli contained blue and achromatic components were determined. The expected result was that wearing a yellow filter would not improve performance when stimuli were achromatic, but would improve performance for stimuli with a blue component because the yellow filter would selectively absorb the short wavelengths in the stimuli and enhance contrast. We extended this reasoning to another filter condition and tested the effects of wearing a pink tinted filter on the same visual functions. The difference being that the chromatic component in the contrast sensitivity and visual search tasks was green rather than blue.

2. METHODS

2.1 Subjects

The voluntary informed consent of 10 subjects was obtained as required by AFI 40-4021[21]. Nine of these individuals had binocular visual acuity of 20/20 or better and normal color vision. One subject had binocular acuity of 20/20 but was an anomalous trichromat (deutan). The average age of the sample was 32.3 years with a range of 23 to 57. Six of the subjects were males and 4 were females. Eight subjects completed all of the contrast acuity and contrast sensitivity testing. However of those eight subjects, one male subject dropped out of the study before his search data were collected and one of the female subjects completed only half of the search data prior to being re-assigned to another location. To fill the gap two subjects, both male and one a deutan, were recruited and complete sets of search data were obtained for these individuals. The deutan subject gave the same general pattern of results as the other subjects so his results were included in the group data.

2.2 Visual Function Tests

The visual function tests consisted of high and low contrast acuity, spatial contrast sensitivity and visual search. All tests were viewed binocularly. Contrast acuity was assessed with the

96% and 11% contrast Regan charts at 100 and 3 candelas/meter-squared (cd/m^2). The charts were illuminated by two fluorescent light sources. The luminance of the white area of the Regan charts was set at 100 cd/m^2 and the 3 cd/m^2 level was achieved by covering the light sources with neutral filters with an optical density of 1.5 log units. The total number of letters correctly identified was recorded; Snellen equivalent was determined and converted to the logarithm of the minimum angle of resolution (LogMAR).

Contrast sensitivity was assessed using a computerized test system. Targets were 5^o vertically oriented Gabor patches with spatial frequencies of 0.45, 0.9, 3, 6, and 12 cycles per degree (cpd). The patches were generated by a Cambridge visual stimulus generator and displayed on a Sony Trinitron color graphis display (model GDM-F520). The display size was 41 cm wide by 31 cm high and subtended 8^o by 6^o at the viewing distance of 3 m. Mean luminance of the Gabor patches was set at 36 cd/m^2. The gratings were isoluminant blue and grey or green and grey and the chromaticity coordinates are shown in Table 1. Contrast was based on the amount of the color difference between adjacent bars of the grating. When the bars were set to the color coordinates in Table 1, color difference and thus contrast were maximal for the combination and this was defined as 100% contrast. Reducing the color difference, and hence contrast, was achieved by presenting mixtures of the grey and blue (or green) component hues which moved the hue of adjacent bars closer to the point in color space mid-way between the two component hues. At the midpoint, adjacent bars had the same color coordinates and color contrast was 0%. Since luminance contrast was also zero, no pattern was visible. A staircase procedure was used to determine thresholds. During a trial, targets were presented for 500 msec, offset 1^o to the right or left of fixation, followed by a 900 msec response period. Subjects were instructed to indicate the right or left location using the right or left response keys on a keypad. They were instructed not to respond if they did not see a target. Each correct response resulted in a decrease in stimulus color contrast. Two consecutive no responses or incorrect responses resulted in an increase in color contrast. Threshold was taken as the average of 4 contrast reversals. The presentation of the target and pressing of a response key were signaled by a beep.

Table 1. Grating and search task background and target chromaticity coordinates in 1931 CIE color space.

	x	y
Grey Bars	0.3	0.34
Green Bars	0.28	0.57
Blue Bars	0.24	0.28
Grey Search Target	0.28	0.31
Green Search Background	0.28	0.61

Blue Search Background	0.20	0.16

The visual search task consisted of the presentation of grey targets on a blue or green background. The chromaticity coordinates of the grey targets and blue and green backgrounds are also shown in Table 1. The targets were small (0.5° x 0.5°) solid squares or triangles and were luminance matched as closely as possible to the colored backgrounds. The luminance of the grey targets and green background were 49 and 47 cd/m^2, respectively. The luminance of the grey targets and blue backgrounds were 58 and 56 cd/m^2, respectively. These stimuli were also tested in a low luminance condition created by covering the monitor with a 0.9 log unit neutral filter. Thus the grey targets on the green and blue backgrounds were reduced to 6.2 and 7.3 cd/m^2, respectively. One target was presented at a time at one of 16 possible locations (randomly selected) on major meridians at eccentricities of 4° and 8° (See Figure 1). A trial consisted of 32 target presentations. The subjects' task was to locate targets as quickly as possible, identify if the target was a square or triangle, and to respond by pressing either the S (for square) or T (for triangle) keys on a computer keyboard. Correct and incorrect responses were indicated immediately by different tones.

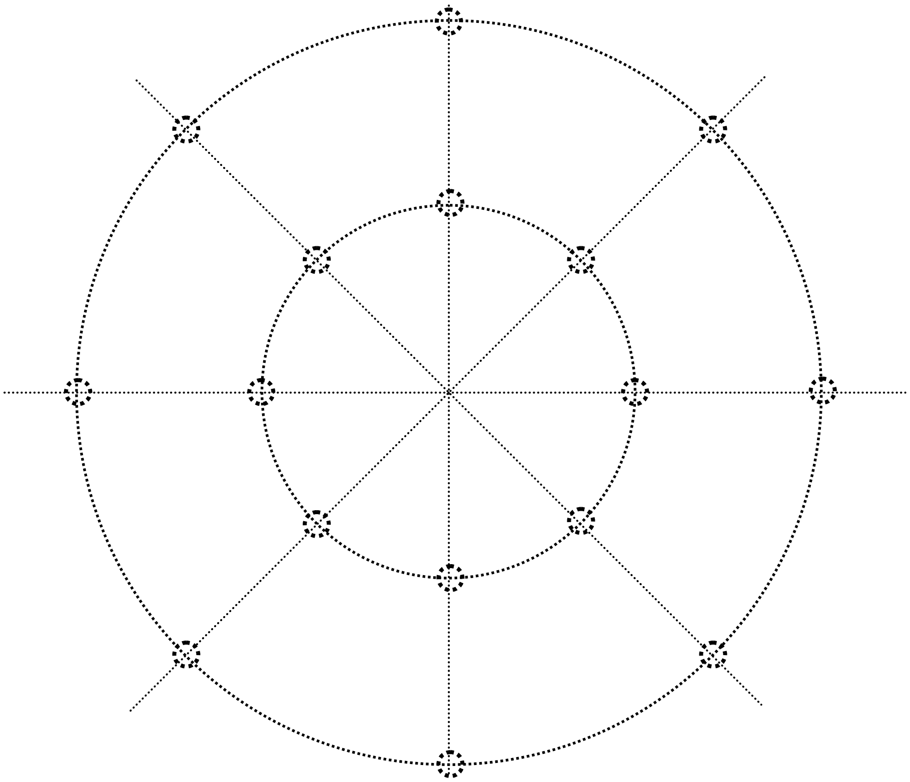


Figure 1. Test locations on the inner (4°) and outer (8°) rings of the visual search task.

2.3 Colored filters

Two colored filters were tested. One had a yellow tint and the other a pink tint. Both were based on a dye host liquid crystal (DHLC) technology developed by Alphamicron, Inc. With this technology the tint can be turned on or off. In the present study we only tested the tint in the on (darkest) state. Transmission in the on state was 40% for the yellow filter and 27% for the pink filter. The transmission curves for the two filters in the on state as a function of wavelength are shown in Figure 2.

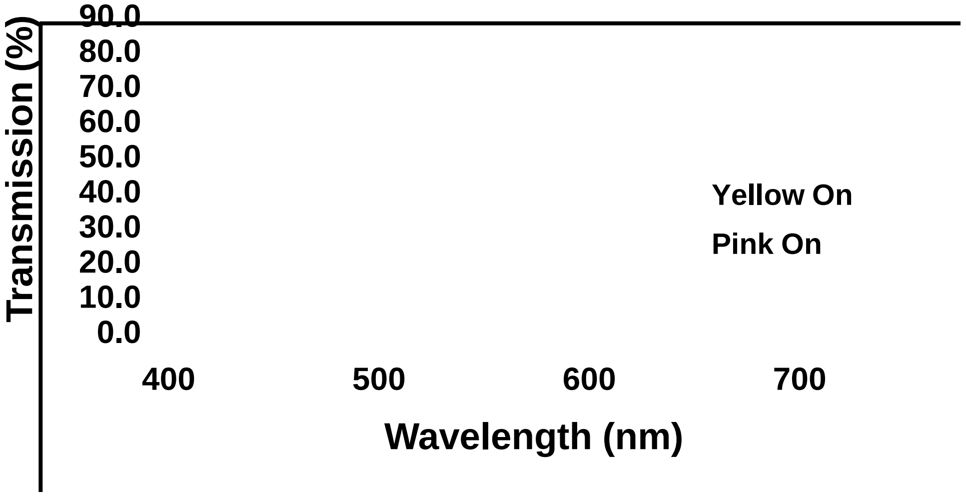


Figure 2. Transmission properties of the yellow and pink filters in the on state.

Luminance of the blue and grey and green and grey gratings and the grey targets on the blue and green backgrounds was measured without and through the colored filters with a Minolta Luminance Meter. Michelson contrast ([L1-L2/L1+L2) and Weber contrast ([L1-L2]/L1) were calculated for the grating and search targets, respectively and Table 2 lists the unfiltered and filtered values. Without the filters, grating and search target contrasts were on the order of 0.001-0.02. With the filters, grating and target luminance contrast increased by more than an order of magnitude.

Table 2. Unfiltered and Filtered Grating and Search Target Contrasts

	Unfiltered Contrast	Filtered Contrast
Grey Bar/Blue Bar &Yellow Filter	0.001	0.07
Grey Bar/Green Bar & Pink Filter	0.001	0.14
Grey Target/Blue Background & Yellow Filter	0.04	0.22
Grey Target/Green Background & Pink Filter	0.04	0.37

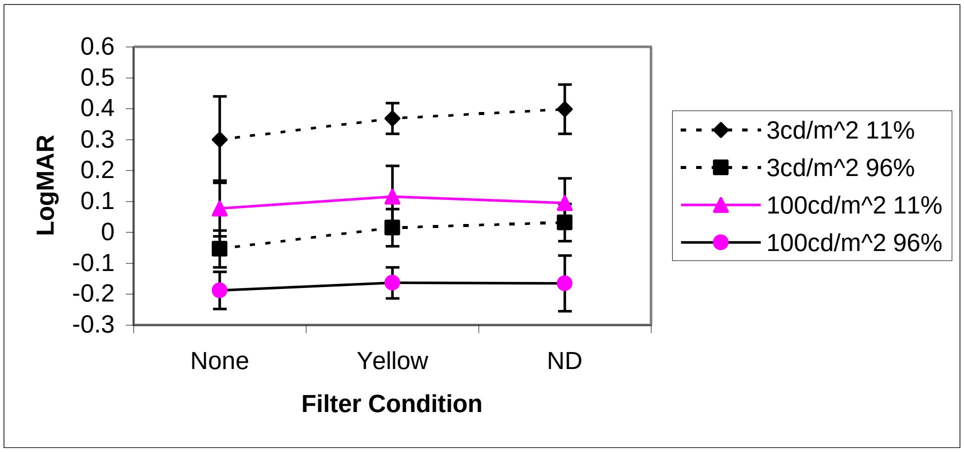
2.4 Procedure

There were a total of 5 test sessions, each approximately 45 minutes in duration. These were spread out over a 2-3 week time period. Baseline (no filter) testing was completed first on all tests, with tests completed in the order of contrast acuity, contrast sensitivity and then visual search. For the contrast sensitivity and visual search tests, subjects were given an initial trial run in the baseline condition to familiarize them with the tests. After baseline data were collected, subjects re-did the tests with the colored and neutral filters with half of the subjects starting with yellow and neutral filters and the other half with pink and neutral filters.

3. RESULTS

3.1 Contrast Acuity

Contrast acuity is measured in LogMAR so better contrast acuity is evidenced by smaller, including negative, values. Data for the yellow and pink filters was analyzed separately in 3 filter x 2 ambient x 2 letter contrast, repeated measures Analysis of Variance (ANOVAs). The independent variables were filter (none, tinted or neutral), ambient level (3 and 100 cd/m^2) and letter contrast (96% or 11%). The main effects and significant interactions that are described in the next two sections can be seen in Figure 3 for the yellow and pink filter conditions. In addition, comparison of the results for the yellow and pink filter conditions shows that the13% transmission advantage of the yellow and neutral filters in the yellow filter condition had little overall effect on Snellen equivalent acuity compare to the pink filter condition.



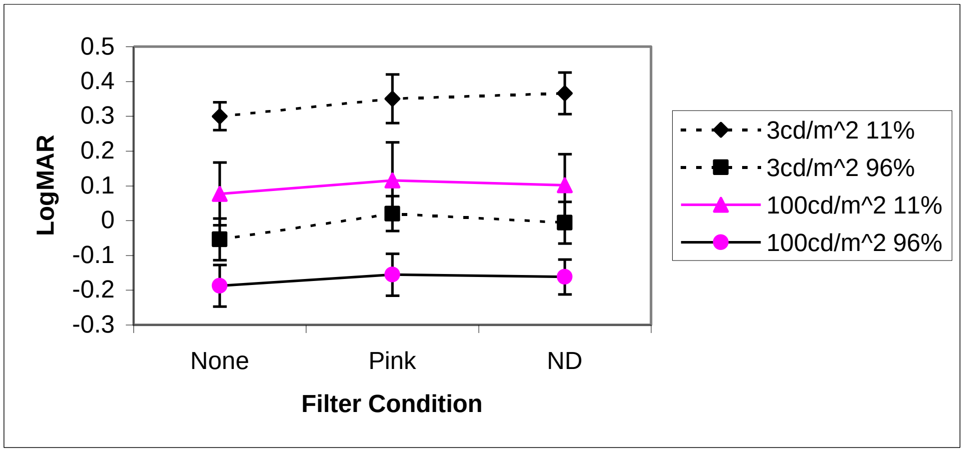


Figure 3. The effects of ambient and letter contrast level on LogMARfor the yellow (top) and pink (bottom) filter conditions and without a filter.

3.1.1 Yellow Filter

There was a significant effect of filter on acuity ($F = 75.0$, $p < 0 .001$). The mean LogMAR without a filter was smaller (better) than with the filters. As expected there were significant effects of ambient light level and letter contrast such that acuity was better at the higher ambient and contrast levels ($F = 200.1$, $p < 0.001$; $F = 815.8$, $p < 0.001$, respectively). Ambient level entered into a significant interaction with contrast ($F = 6.05$, $p = 0.043$) and there was less of an effect of ambient level on acuity for higher versus lower contrast targets. The interactions between filter and ambient as well as filter and contrast were not significant ($F = 4.52$, $p = 0.065$; $F = 0.20$, $p = 0.823$, respectively) and neither was the three-way interaction between filter, ambient and contrast ($F = 0.128$, $p = 0.744$).

Given the significant effect of ambient level on acuity and what appeared in Figure 3 to be a significant effect of filter on low contrast acuity at 3, but not 100, cd/m^2, the results were analyzed for each ambient condition. At 3 cd/m^2, wearing a filter resulted in a significant decline in acuity ($F = 28.07$, $p < 0.001$) that was not present at 100 cd/m^2 ($F = 1.98$, $p = 0.187$). As expected there were significant effects of target contrast on acuity at both light levels (p's < 0.001)`,but no significant interactions between filter and contrast (p's > 0.721) indicating that wearing the filters has similar effects on high and low contrast letter acuity.

3.1.2 Pink Filter

Results for the pink filter were similar to those for the yellow filter, except there was no significant interaction between ambient and contrast. The mean LogMAR without a filter was better than with filters ($F = 22.0$, $p = 0.002$) and acuity was better at the higher ambient and contrast levels ($F = 115.1$, $p < 0.001$; $F = 703.4$, $p < 0.001$). The interactions between filter and ambient ($F= 1.81$, $p = 0.262$), filter and contrast ($F = 1.48$, $p = 0.300$), and ambient and contrast were not significant ($F = 4.22$, $p = 0.079$) and neither was the three-way interaction between filter, ambient and contrast $F = 1.15$, $p = 0.534$).

The pink filter data were also analyzed separately for each ambient condition and this yielded the same pattern of results that were obtained for the yellow filter. Wearing a filter at 3 cd/m^2, resulted in a significant decline in acuity ($F = 14.98$, $p < 0.001$) that was not present at 100 cd/m^2 ($F = 2.59$, $p = 0.122$). In addition there were the expected effects of target contrast on acuity (p's < 0.001) and no interaction effects between filter and target (p's > 0.434).

3.2 Color Contrast Sensitivity

The proportion of color contrast required for detection out of the total available was analyzed separately for the yellow and pink filters in 3 Filter x 5 Spatial Frequency repeated measures ANOVAs. Independent variables were filter (none, tinted, neutral) and spatial frequency

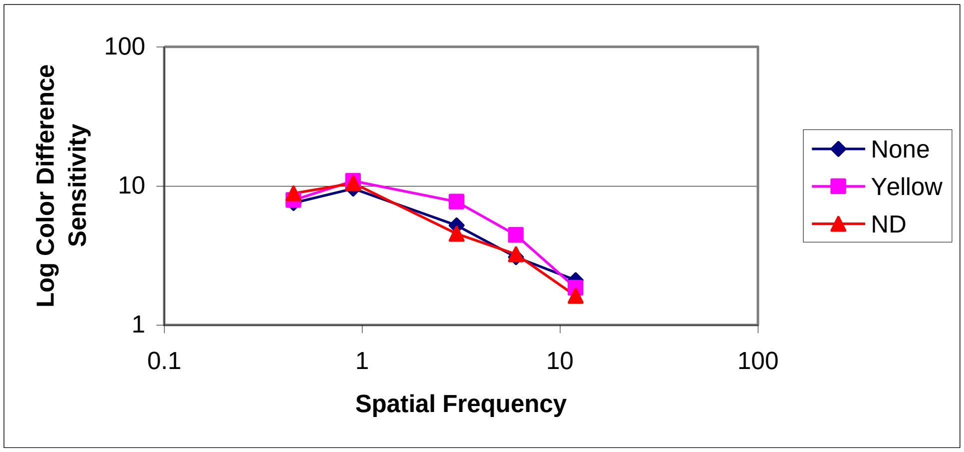
(0.45, 0.9, 3, 6 and 12 cpd). Contrast sensitivity (the reciprocal of threshold color contrast) was computed for each participant with each filter condition for each of the five Gabor spatial frequencies (0.45, 0.9, 3, 6, and 12 cpd) and those results are plotted for the yellow and pink filter conditions in the top and bottom graphs of Figure 4, respectively.

3.2.1 Yellow Filter

The effect of filter on the amount of color contrast required to detect the isoluminant gratings was not significant ($F = 0.26$, $p = 0.642$). Although there was an expected frequency effect ($F = 35.4$, $p < 0.001$) the interaction between filter and frequency was not significant ($F = 1.06$, $p = 0.372$) indicating that the frequency effect followed the same pattern for all of the filters. These effects can be seen in Figure 4 (top graph). It appears that the yellow filter yielded lower contrast sensitivity at 3 cpd, but the individual variability in the data was large at this and higher frequencies and the difference was not significant.

3.2.2 Pink Filter

For the pink filter condition there was a significant effect of filter on the amount of color contrast required to detect the isoluminant gratings ($F = 7.2$, $p = 0.016$). The mean contrast needed to detect the gratings was less (contrast sensitivity was higher) when the pink filter was worn. There was also the expected significant effect of frequency on contrast sensitivity ($F = 28.5$, $p < 0.001$), but in addition there was a significant interaction between frequency and filter which indicates the frequency effect was not the same for all of the filter conditions ($F = 4.3$, $p = 0.023$). This interaction effect is clearly evident in Figure 4 (bottom graph) where contrast sensitivity with the pink filter is higher than with the other two filters at mid frequencies. As a result the pink filter contrast sensitivity function has a more pronounced band pass shape than the baseline and neutral filter functions.



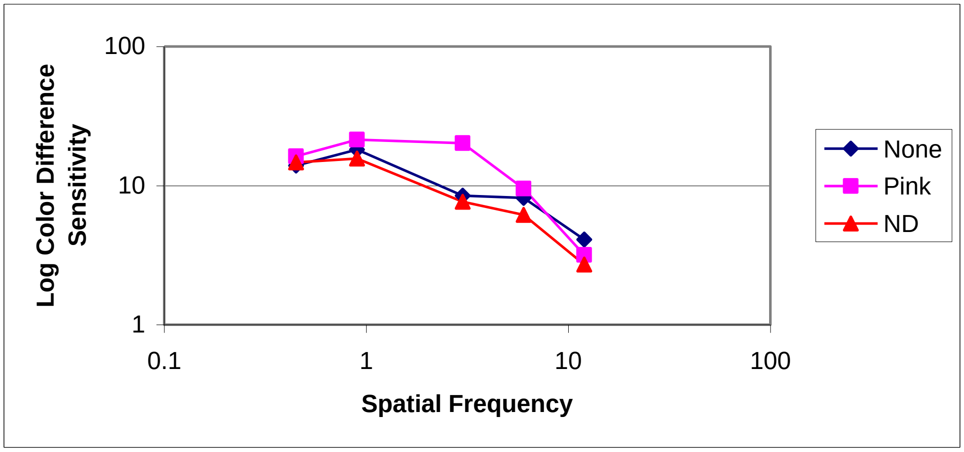


Figure 4. Mean color contrast sensitivity (+/- SD) through each of the filters and without the filter.

3.3 Visual Search

Average reaction time (RT) data for correct target identification within discrete trials of 32 target presentations were analyzed separately for the yellow and pink filters. The RT data were analyzed in 3 Filter x 2 Ambient repeated measures ANOVAs where the independent variables were filter (none, tinted, and neutral) and ambient light level (photopic = 47 and 56 cd/m^2 for the green and blue backgrounds and low photopic = 5.9 and 7.0 cd/m^2 for the green and blue backgrounds, respectively).

3.3.1 Yellow Filter

The RT data for the yellow filter are summarized in Figure 5. Overall there was a significant effect of filter on RT with RT being faster when the yellow filter was worn (F = 5.34, p = 0.036). There also the expected increase in RT at the lower ambient light level (F = 15.46, p = 0.006) but no significant interaction between filter and ambient level (F = 0.616, p = 0.548). Additional t-test comparisons revealed that significant filter condition effects occurred only at the higher light level between the yellow filter and the no filter (t = 2.55, p = 0.034) and neutral filter (t = 3.0, p = 0.017) conditions. At the lower light level, wearing the yellow filter did not change reaction times compared to the other filter conditions.

3.3.2 Pink Filter

Figure 5 also summarizes the RT data for the pink filter. First, there was a significant effect of filter on RT (F = 53.48, p < 0.001). When the red filter was worn, RT was faster than either the neutral filter or no filter test conditions. There was also the expected effect of ambient (F = 14.95, p = 0.006) on RT with slower search times at the lower light level. In addition there was a significant interaction between filter and ambient (F = 8.66, p = 0.006) indicating that the effect of changing ambient level on RT was not uniform across the three test conditions. This effect can be appreciated in Figure 5 where it can be observed that the relationship between the neutral filter RT's to the other two conditions is different at the two ambient levels. At the higher ambient level the difference in RT between the baseline and neutral filter conditions is negligible, but at the lower light level the neutral filter RT is much longer.

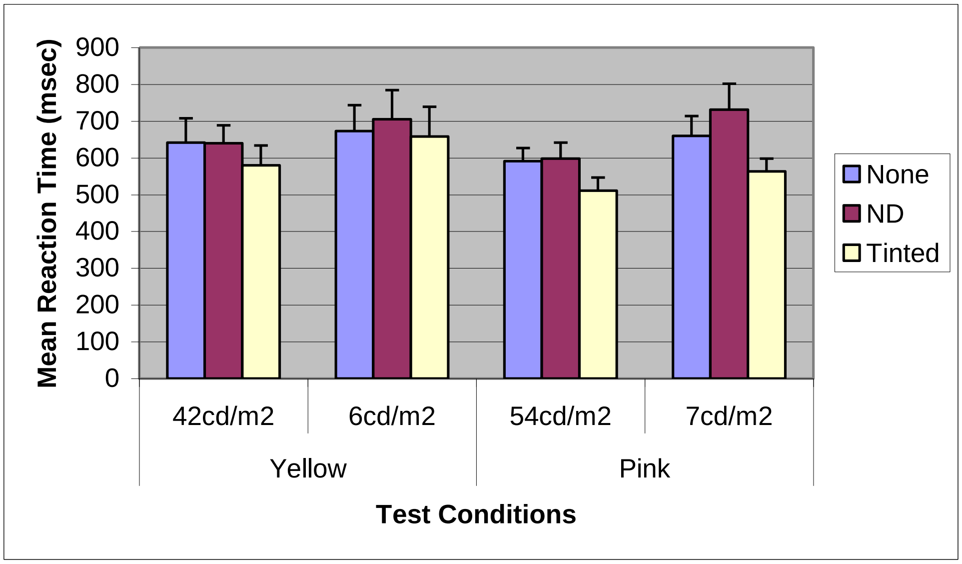


Figure 5. Search time for correct responses through each of the colored filters and without a filter at moderate and low photopic light levels.

4. DISCUSSION

We looked at the effect of wearing yellow or pink filters on contrast acuity for achromatic stimuli as well as contrast sensitivity and visual search under test conditions where gratings and search stimuli contained chromatic and achromatic components. The expected outcome was that wearing the colored filters would not improve performance when test stimuli were achromatic, but would improve performance when they had chromatic and achromatic components

The results with the yellow filter partially fulfilled expectations. Achromatic contrast acuity was not improved. However contrary to expectation neither was contrast sensitivity. Visual search results were mixed. There was a significant improvement in search times with the yellow filter at the higher ambient light level but not when light levels were reduced to near mesopic conditions. In contrast the results with the pink filter completely fulfilled expectations. Achromatic contrast acuity was not improved by wearing the pink filter but contrast sensitivity and visual search were.

In a recent study, Wolffsohn et al.,[4] reported a lack of an effect of wearing yellow filters on photopic contrast acuity at 90 and 10% contrast with acuity targets that were standard black letters on a white background. This was attributed to the fact that even though yellow filters increase perceived brightness, with achromatic stimuli they do not produce a change in contrast ratio between letters and background that might improve visibility. For the photopic adaptation condition we found no effect on contrast acuity at 96 and 11% contrast with the yellow or pink filters. At the mesopic adaptation level, using the tinted filters actually resulted in a decline in contrast acuity and the effect was greater with the low contrast targets. For the high contrast mesopic condition both of the tinted filters and their transmission matched neutral controls reduced acuity by approximately the same amounts. The similar effects suggest the decline in acuity with the tinted filters is simply the result of reduced light levels.

Our mesopic acuity results are not completely consistent with Perez et al.[12] At an intermediate letter contrast (50%) they found no difference in acuity between a yellow and no filter condition. This is in agreement with our findings for high letter contrasts (96%). However at 10% contrast they also found no difference in acuity with a yellow filter, whereas we found a decline in acuity with 11% contrast letters. In addition, when target contrast was reduced to 5%, they found the yellow filter improved acuity. Although we do not have comparable data at the 5% contrast level it seems unlikely in light of the significant decline in acuity at 11% contrast when the yellow filter was worn (see Figure 3), that this trend would be reversed if we had tested at a lower contrast level. We do not have an explanation for the difference in findings between studies. There were differences in the methods used to obtain acuity, and Perez's subjects were all emmetropes whereas ours were not, but it is not clear how those factors might account for the difference in direction of the effect.

The effects on contrast sensitivity of wearing the yellow and pink filters were very different. The yellow filter did not yield a significant improvement in contrast sensitivity at any of the frequencies tested. This finding seems to contradict results obtained by Wolffsohn et al.,[4] who found that yellow filters improved sensitivity to low and mid frequencies measured using a white on blue grating. On the other hand, wearing the pink filter produced the expected effect and contrast sensitivity improved when measured using the grey and green grating.

Wolffsohn et al.,[4] attributed the improved sensitivity with yellow filters to contrast enhancement due to selective reduction in short wavelength light. In the present study, there was a measurable change in contrast between the no filter and both the yellow and pink filter conditions. However, it was much smaller for the yellow filter condition, at approximately 7%, and this may not have been a large enough increase to affect contrast sensitivity. Another factor that may have contributed to the failure to find an effect with the yellow filters was the amount of color difference between the blue and grey bars of the grating. A calculation of color difference ($d = \sqrt{(\Delta u^2 + \Delta v^2)}$) between the grey and blue bars in CIE uv space was 0.05 compared with 0.10 for the difference between the grey and green bars. When the bar pattern is viewed through the yellow filter, the hue of both bars shifts toward the color of the filter. This is shown in Figure 6 for the unfiltered and filtered grating targets. In the figure the unfiltered grey and blue that make up the bars as well as the green are shown with arrows originating from them and pointing to the location where they shift in color space when viewed through the filters. The unfiltered grey stimulus has two arrows coming from it since it was viewed through both filters. It can be seen that the hue shifts caused by the filters are in the general direction of the locations of where the yellow and pink filters plot in color space, which are indicated by the solitary points in the yellow and pink color zones, respectively. It can also be seen that the separation in color space between the blue and grey bars in the filtered condition is less than in the unfiltered condition, indicating that the yellow filter, while it increased luminance contrast had the opposite effect on the color difference which declined slightly to 0.04. In the case of the green and grey bars, not only did the pink filter increase luminance contrast from near zero to 14% but the color difference also increased slightly, from 0.10 to 0.13. These factors working together likely contributed to the enhanced visibility of the gratings when wearing the pink filter.

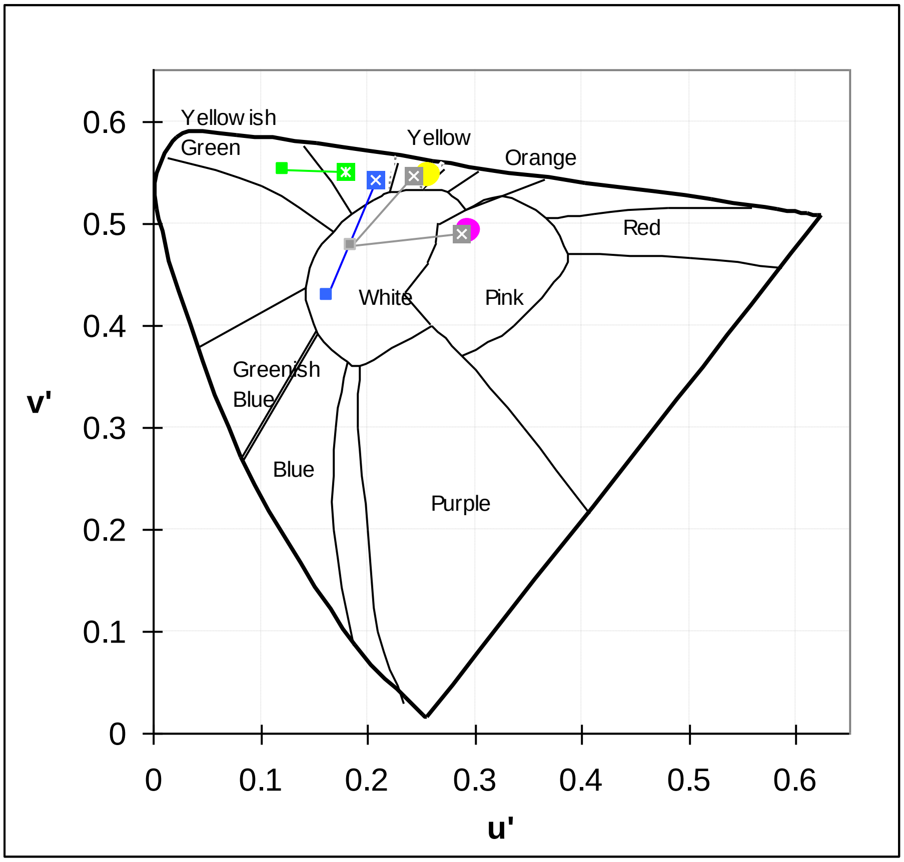


Figure 6. Locations of the filter colors (solid circles) and unfiltered (small squares) and filtered (large squares) stimulus components of the isoluminant gratings in CIE color space.

Visual search is the ability to rapidly look for and locate objects of interest in the environment. Unlike contrast acuity and contrast sensitivity, which are static measures of sensory function, visual search also involves perceptual, cognitive and occulomotor functions. This task was set up so that when targets and backgrounds were viewed without a filter there was only a small luminance contrast difference between them (see Table 2). With the filters, contrast increased by nearly an order of magnitude. For the moderate photopic light level, these contrast changes resulted in faster search times with the yellow and pink filters. However for the low photopic condition, only the pink filter yielded faster search times than the no filter condition. The lack of a significant improvement in search time with the yellow filter may have been caused by a lack of sufficient contrast in the stimulus to overcome the loss of sensitivity at the near mesopic light level (see Figure 7). That contrast sensitivity declines as light level changes from photopic to mesopic is a well known fact and the low contrast acuity data obtained in this study provide a good example (see Figure 2). A contributing factor may also have been a reduction of color contrast, which went reduced from 0.14 to 0.06. With the pink filter, luminance contrast also increased, but the absolute magnitude was larger than for the yellow filter. In addition, wearing the pink filter did not change color contrast and this is reflected in the chromaticity diagram (Figure 7) which shows the pink filtered stimuli maintained good separation in color space.

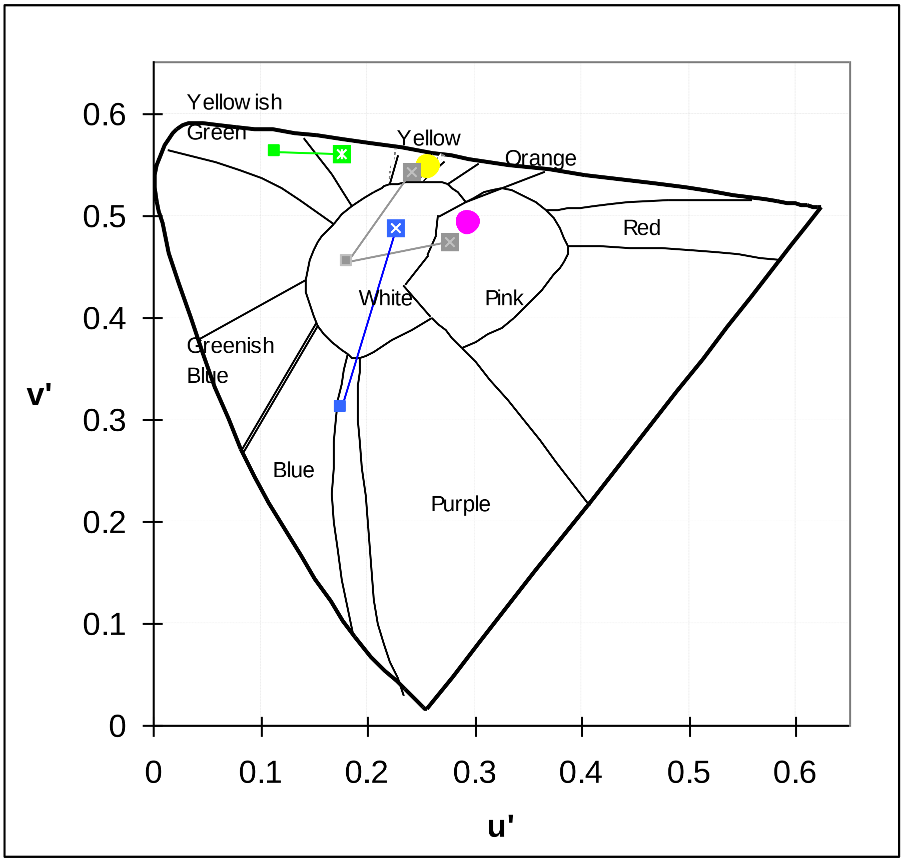


Figure 7. Locations of the filter colors (solid circles) and unfiltered (small squares) and filtered (large squares) stimulus components of the search task in CIE color space.

Much of the failure of the yellow filter to enhance contrast was likely due to the stimuli that were selected. In the case of the blue/grey gratings there simply was not enough blue in the stimulus to be removed by selective absorption to significantly increase contrast. This occurred because a trade off was made to generate isoluminant gratings with a luminance in the mid-photopic range that had an appearance similar to blue sky. Deeper blue targets could have been selected but luminance would have been considerably reduced and they would not have looked very realistic. Given results obtained by Wolffsohn et al.,[4] with a deep blue grating bars, it seems likely that using similar stimuli in the isoluminant situation would yield a better result. The yellow filter performed better on the search task because the blue background was darker. It might be possible to achieve saturated blues that still resemble the sky by using a projection system to achieve higher light levels.

5. CONCLUSIONS

Wearing colored filters can enhance contrast and improve visual performance. However, this will only occur when the stimulus or scene being viewed contain the appropriate color components. In terms of operational utility, colored filters may improve detection of overlaid light colored objects on colored backgrounds. Our search data for the pink filter suggests that if the changes in color difference and luminance contrast are of sufficient magnitude that performance can be enhanced over a range of lighting conditions. However, for optimal effect, filters need to be tailored to the situation.

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