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Preference for lighting chromaticity in migraine with aura

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Abstract

Objective

We studied the color of lighting chosen as comfortable for reading by individuals with migraine and controls. We explored the effects of the chosen color on visual performance.

Background

It has been reported that individuals who experience migraine with aura choose, as comfortable for reading, light that is more strongly saturated in color than that chosen by individuals without migraine.

Methods

A convenience sample of 18 individuals who experienced migraine with aura, 18 without aura, and 18 controls without migraine participated in a cross-sectional laboratory study at Anglia Ruskin University. We used an Intuitive Colorimeter that illuminated text with colored light and permitted the separate control of hue (color) and saturation (strength of color) without a change in luminance. We selected individuals with migraine and healthy controls from the general population. They were headache-free in the 48 hours prior to testing. We used a routine that permitted the selection of the most comfortable hue from 12 alternatives and then alternately optimized the saturation and hue using small changes, thereby allowing for color adaptation.

Visual performance at a word search task was measured under white light and under light of a color chosen as comfortable, using colored lenses.

Results

Healthy individuals chose light with chromaticity close to the Planckian locus, which approximates the chromaticities of daylight and most electric lighting. The distance from the locus averaged 0.029 (SD 0.021). Individuals who experienced migraine with aura chose strongly saturated colors well away from the Planckian locus (average distance 0.056, SD 0.022). Individuals who experienced migraine without aura chose intermediate chromaticities (average distance 0.034, SD 0.022). Overall there was a large statistically significant difference between participant groups that explained 24% variance.

Visual search time of individuals with migraine aura decreased from 22.5s to 16.8s when light of the chosen color was provided using tinted lenses (the average increase in search speed was 45.7%). The lenses had no statistically significant effect on the performance of individuals without migraine aura.

Conclusions

Individuals who experienced migraine with aura selected as comfortable colors that deviated from the lighting typically experienced in everyday life. Possibly, individuals who experience migraine with aura may be more susceptible to photophobia under typical lighting. Visual performance was improved using lenses that provided light of the chosen comfortable color.

The spectral power of that choice showed no evident relationship to melanopic energy (energy captured by the intrinsically photosensitive retinal ganglion cells).

Introduction

Photophobia is a common symptom of migraine with and without aura[1]. It is usually defined as an aversion to light, particularly bright light[2]. However, individuals with migraine are also averse to flicker, and to particular patterns, such as those that are epileptogenic in patients with photosensitive epilepsy[3]. Aversion has also been reported to particular colors of lighting[4]. Huang, et al.[5] found an elevated cortical haemodynamic response to aversive patterns in patients with migraine relative to controls. They later showed that this elevated response can be normalized by optimally selected colored filters[6]. Similarly, a small-scale randomized controlled trial[7] found that colored filters decreased headache frequency, photophobia, eye-pain and medication reliance in some patients.

When given the opportunity to select a color of light that is comfortable for viewing text, healthy controls selected a chromaticity close to the Planckian locus, i.e. they selected a color close to colors typically provided by daylight and artificial lighting[4]. Patients who experienced migraine with aura, however, tended to choose strongly saturated colors well away from the locus[4]. Although certain strongly saturated colors evidently make vision more comfortable for these individuals, little is known about the effect of such colors on visual performance. We examined the effect of the chosen color using a visual search task.

Methods

Participants

Fifty-four adults aged 18 - 53 years (mean 24 years) were recruited using convenience sampling via social media and advertisements on university campuses in Cambridge that sought participants who experienced migraine with and without aura, in addition to controls without migraine. Participation was incentivized by a system of course credits and an opportunity to win a £50 gift card. All participants had normal or corrected-to-normal vision measured by a Near Lighthouse chart, and self-reported no color vision anomaly. Participants were grouped according to the International Headache Society criteria for migraines with (MA) and without (MO) aura (IHS, 2018). These groups included 18 controls (3 male, 15 female), 18 migraine without aura (3 male, 15 female) and 18 migraine with aura (4 male, 14 female). There was no significant difference in age between groups (p = .528): migraine with aura (M = 26, SD = 10), migraine without aura (M = 23, SD = 6) and controls (M = 24, SD = 8). All participants with migraine were free of headache for at least 48 hours prior to testing. Three participants used colored filters for reading, two using colored overlays and one using tinted glasses. All participants were recruited and tested between January 2019 and May 2019 and provided written informed consent prior to testing. The study was approved by the Faculty of Science & Engineering research ethics panel at Anglia Ruskin University (approval code EHPGT18-02), and was conducted in accordance with the tenets of the Declaration of Helsinki.

Materials and Procedure

In the cross-sectional laboratory study participants were first assessed in a darkened room using the Intuitive Colorimeter[8] (Cerium Visual Technologies, Kent UK). The Intuitive

Colorimeter is an instrument that illuminates a page of text with colored light and allows the separate manipulation of hue (color) and saturation (strength of color; from gray to strongly coloured) without a change in brightness (or, more strictly, luminance, measured in candelas per square meter)[8]. The instrument uses a source of white light in the centre of a cylinder on the surfaces of which are colored filters. Light passes through the cylinder, then through a square aperture into a viewing chamber where the filtered light is mixed by multiple reflection. Ranged around the surface of the cylinder are seven colored filters, each of similar photopic transmission, covering its entire circumference and half its surface, see Figure 1. The remainder of the cylinder is covered by a grey filter of similar (photopic) transmission. The light entering the viewing chamber is filtered by a maximum of three filters, two colored and one grey. As the cylinder is rotated the color varies continually as the proportion of the two exposed colored filters varies. As the cylinder is slid along its axle the proportion of the grey filter changes, varying the saturation of color. In this way patients are able to vary the color of light in an intuitive manner. The color can be expressed in chromaticity coordinates in the CIE 1976 Uniform chromaticity scale diagram. Any position in this diagram specifies the ratio of energy captured by the three classes of cone photoreceptors in the retina. The plane of the diagram has a constant luminance (V-lambda).

INSERT FIGURE 1 ABOUT HERE

Any chosen color can be replicated using tinted trial lenses that have the same spectral transmission as the filters used in the colorimeter. The trial lenses have seven dyes. Each dye has (at least) five pairs of lenses in which the dye deposition increases as a geometric series[9]. As a result, each of the 32 combinations of the five trial lenses can be combined with each of 32 combinations of trial lenses having neighboring chromaticity, and can thereby replicate any selected color with precision. When the trial lenses are worn under a light source that is the same as that used in the colorimeter the spectral power distribution is closely similar[8].

The participants underwent a colorimeter assessment that followed the procedure recommended in the Manual for the Intuitive Colorimeter Mk. 2 (Cerium Visual Technologies, Kent UK). In brief, participants viewed 15 lines of randomly ordered words, printed in black ink in Times New Roman 12 point, arranged to resemble text. The text was illuminated initially by white light ($u' = 0.219$, $v' = 0.521$) and the saturation (s_{uv}) was gradually increased and then decreased. Participants reported whether the colored light was more or less comfortable than the white. The hue (h_{uv}) was then increased by about 30 degrees and the process repeated for a total of 12 hues. Having short-listed the hues that best improved comfort, these were compared two at a time until a single hue was selected. Afterward the saturation was optimized. The hue was then adjusted incrementally to further improve comfort. Combinations of Cerium tinted plano trial lenses were then selected to match the chosen chromaticity.

Participants then undertook a visual search task requiring them to search for a given word presented horizontally and embedded in a random position in a matrix of letters. Using MATLAB with the Psychtoolbox extensions[10], a 10-by-10 letter matrix (144 mm wide and 183 mm high) of black Courier New lower case letters with x-height 4mm, was presented at the centre of the touch-screen monitor (model ProLite T2250MTS; screen 270 mm high by 475 mm wide). Above the array, on the midline, was positioned a three-letter English word, with no repeated letters (e.g., get, ice, dog, new, air, sit, car, son). The word and array appeared simultaneously and remained in view until the participant found the target word, whereupon they touched the screen with their finger at the position of the first letter of the target word. No constraints on search strategy were recommended. A subsequent trial began after a delay of 1s.

The participants viewed the screen from a comfortable viewing distance, typically about 0.5m. Twenty trials were given when participants wore the colored trial lenses (in addition to any habitual optical correction), using a trial frame. A further 20 were run without the tinted lenses. The order of the conditions was counterbalanced across participants to reduce the effect of practice and fatigue. Upon completion of each word search the MATLAB program recorded the time elapsed from the presentation of the word to the finger press.

Statistical Analyses

All analyses were the primary analysis of the data and were conducted with a threshold *p*-value of .05, two-tailed, and effect size calculations with eta-squared (sum of squares for variable / total sum of squares), using SPSS and MATLAB. No statistical power calculation was conducted prior to the study because the sample size was based on data in the literature. A between-subjects design was used to evaluate differences in participants' color selection. The shortest distance of each selected chromaticity from the Planckian locus was calculated. A Shapiro-Wilks test found that the assumption of normality was met for MO ($p = .069$) but not for MA ($p = .035$) or controls ($p = .008$). No outliers were identified and homogeneity of variance was met, $F(2, 51) = .22$, $p = .802$. Due to the violations of normality a robust one-way, independent samples ANOVA with Bonferroni-corrected *post hoc* comparisons was run.

A 2×3 mixed two-way design was used to compare search time differences between lens condition across groups. There were two within-subject conditions, with colored lens and without lens. Participants' search times were recorded automatically in MATLAB after each word search. The distribution of search times was normalised by a log transformation (resulting in Lilliefors' k = 0.156, p=.113) and the geometric mean obtained for each lens condition for each participant (20 trials in all except 5 participants: 3 MA, 1 MO and 1 Control, where an average of 3.4 data points was missing). Sphericity was ignored as there were only two within-subject factors. To analyze search time differences the data were transformed to form normal distribution using a log transform and a 2×3 mixed factorial ANOVA, with Bonferroni-corrected pairwise comparisons, was undertaken on the geometric means. Raw (untransformed) data were also subject to equivalent confirmatory non-parametric statistics.

INSERT TABLE 1 & FIGURE 2 ABOUT HERE

Results

The chromaticities chosen as comfortable for viewing text are shown separately for each group in Figure 2, which also shows the Planckian locus. The locus is defined by Planck's law of black-body radiation in which the black body glows red hot, yellow, white and blue in sequence as its temperature increases, a sequence shown as the locus. (Most typical sources of daylight and artificial light have chromaticities close to the locus.) The shortest distance in the CIE UCS diagram between the chromaticity chosen and the Planckian locus was calculated and is shown in Table 1. A one-way, independent ANOVA revealed a statistically significant difference between groups, $F(2) = 8.05$, $p = .001$, $\eta^2 = .240$. A Bonferroni-corrected *post hoc* analysis revealed that chromaticities in the MA group were significantly further from the locus than MO ($p = .010$) and controls ($p = .001$). However, there was no difference between MO and controls ($p = .470$).

INSERT TABLE 2 ABOUT HERE

Table 2 shows the search times for the three groups with and without colored lenses. A log transformation rendered the distribution of search times normal, and Table 2 shows the mean of the participants' geometric mean search times for each condition. Three females who had migraine without aura and one control male failed to complete the visual search task. A mixed factorial ANOVA of each participants' geometric mean search times for the two lens conditions showed a statistically significant effect of viewing condition, $F(1,47)=8.41$, $p<.006$, $\eta^2 = .152$ and a statistically significant interaction between viewing condition and participant group, $F(2,47)=7.96$, $p<.001$, $\eta^2 = .253$. Pairwise comparisons, with Bonferroni correction for three comparisons, revealed that the MA group took significantly less time to find the target word when wearing colored lenses than without them ($p<.001$). The MO group was also quicker with the colored lenses than without, though the difference did not reach the threshold for statistical significance with Bonferroni correction ($p=.071$). No difference was seen with controls ($p=.230$). The three participants who had previous experience of colored filters all had migraine with aura. The difference in search times for this group remained statistically significant ($p<.001$) when these three participants were removed from the analysis. Wilcoxon non-parametric tests were also used in the above comparisons and gave a similar pattern of results. Figure 3 presents the results graphically for the three groups as average percentage increase in search speed with colored lenses.

INSERT FIGURE 3 ABOUT HERE

Discussion

When selecting light of a color comfortable for viewing text, healthy observers chose a chromaticity close to the Planckian locus, i.e. a color similar to those colors provided by typical illumination, whether daylight or artificial. In contrast, observers who experienced migraine with aura chose a chromaticity that was relatively high in saturation and further from the locus. In this respect the findings confirm those of Adrich et al[4]. Evidently individuals who have little discomfort choose lighting of a color with which they are familiar, whereas individuals with migraine, particularly those with aura, seldom experience lighting they find comfortable. This infrequent exposure to comfortable light could, perhaps, be related to the photophobia they experience. Photophobia has been linked to the melanopsin receptors[11,12]. The size of the points in Figure 4 is proportional to the energy captured by the intrinsically photosensitive retinal ganglion cells (ipRGCs) in the Intuitive Colorimeter. Comparison with Figure 2 makes it clear that participants were not choosing a comfortable chromaticity simply on the basis of the energy captured by the ipRGCs.

INSERT FIGURE 4 ABOUT HERE

When given colored glasses that provided a comfortable chromaticity, visual search performance of individuals with migraine improved. Improved performance with comfortable lighting has also been demonstrated with reading[13]. Aldrich et al.[4] have additionally shown that abnormal contrast discrimination of gratings can be reduced by colored filters. These results imply anomalous visual function in participants with migraine aura that can be normalized with colored lenses. It is possible that other neurological patients with cortical hyper-excitability may show similar benefit, but the present study did not address this issue.

The current study suggests that investigations into the clinical efficacy of colored filters for migraine need to consider the large individual differences between patients. In principle it is patients who select chromaticities distant from the Planckian locus that are likely to benefit from tinted lenses, and the majority of these patients have migraine with aura. The reliability of the colorimetry assessment is high in patients with similar symptoms[14]. Our findings confirm a link between color, migraine and discomfort, while establishing therapeutic possibilities that deserve further exploration. Previous studies have found evidence for the benefits of colored filters in migraine[7,15], but have selected participants on the basis of their response to colored filters. The present study recruited participants on the basis simply of their migraine symptoms in a sample of the general population, not neurological patients. Nevertheless, a clear effect of migraine on the choice of comfortable color and on visual performance was demonstrated. The effects first reported by Aldrich et al[4], have been replicated and extended here, suggesting that the effects are reliable and perhaps clinically significant.

The Intuitive Colorimeter used in this study filters the light from a compact fluorescent lamp with a high-frequency (~30kHz) electronic ballast. The light was therefore effectively steady. This is not always the case with gas discharge lighting, particularly when a magnetic ballast is used. With such a ballast the lamp can flicker continuously at twice the frequency of the electricity supply, varying not only in brightness but sometimes also in chromaticity[16], and this variation can cause headaches[17]. A patient's decision to wear tinted spectacles may therefore be the result not only of the preferences documented here, but a possible reduction in the effects of flicker from lighting, to which patients will have adapted[18], and which can be visible at very high frequencies[19].

Acknowledgements.

We thank the participants.

Declaration of interest.

Arnold Wilkins invented the Intuitive Colorimeter when employed by the British Medical Research Council and has received an Award to Inventors from the Council, based on sales. No colorimeter was purchased for this study. No royalties are received for tinted lenses.

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TABLES AND FIGURES

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Table 1. Mean distance from the Planckian locus for participants in each group

	MA (N=18)	**MO (N=18)**	**Controls (N=18)**
Mean	.056	.034	.029
SD	.022	.022	.021

.

Table 2. Mean and standard deviation of the participants' geometric mean search times in each condition.

		MA (N=18)	MO (N=15)	Control (N=17)
No lenses	Mean	22.5	19.9	16.5
	SD	5.8	6.8	8.6
Colored lenses	Mean	16.8	17.3	18.1
	SD	6.4	5.4	6.7

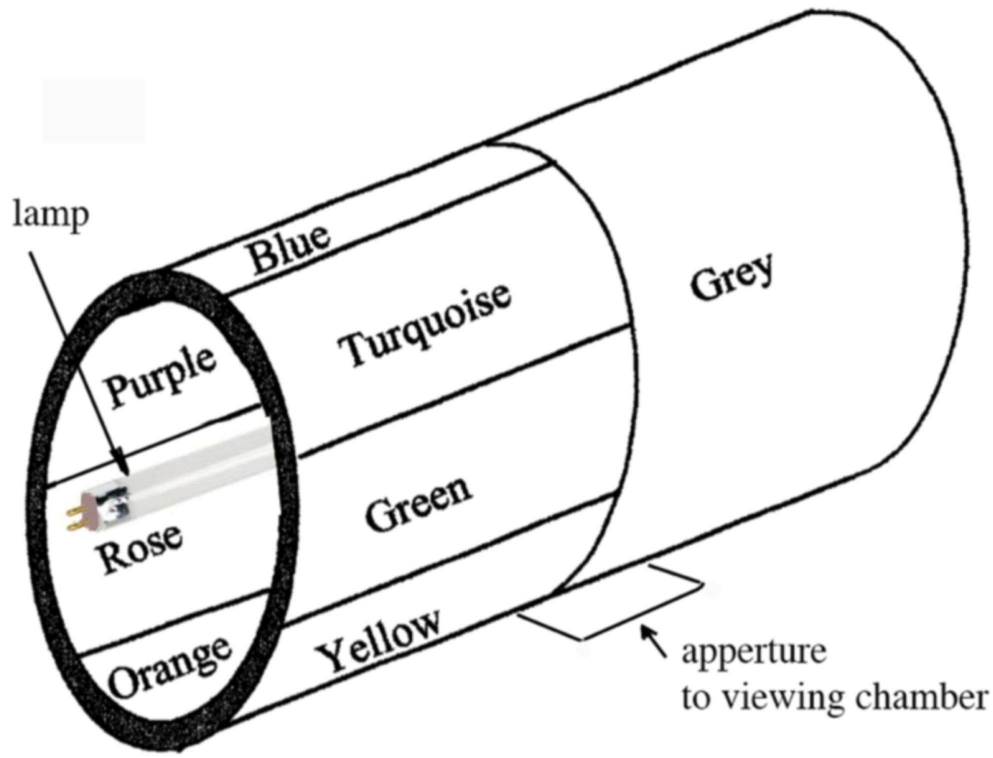
FIGURE LEGENDS

Figure 1. The principle of color mixing used in the Intuitive Colorimeter Mark 2. White light passes through a cylinder on which are mounted colored and gray filters of similar transmission. The light then passes through a square aperture into a viewing chamber (not shown) where it is mixed by multiple reflection. Rotation of the cylinder changes the color of the mixed light, and movement of the cylinder along its axle changes the saturation.

Figure 2. Top: Control group; Middle: MO group; Bottom: MA group. Each point represents the color chosen by a participant. The line shows the Planckian locus.

Figure 3. Percentage increase in search speed with colored lenses for participants in the three groups. Error bars show +/- 1 standard deviation.

Figure 4. Measurements of melanopic energy at various settings of the Intuitive Colorimeter. The diameter of the points is proportional to the melanopic energy as derived from spectrophotometric measurements. The melanopic sensitivity function used was symmetrical and had a peak at 490nm and a width at half-height of 85nm.



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271x221mm (144 x 144 DPI)

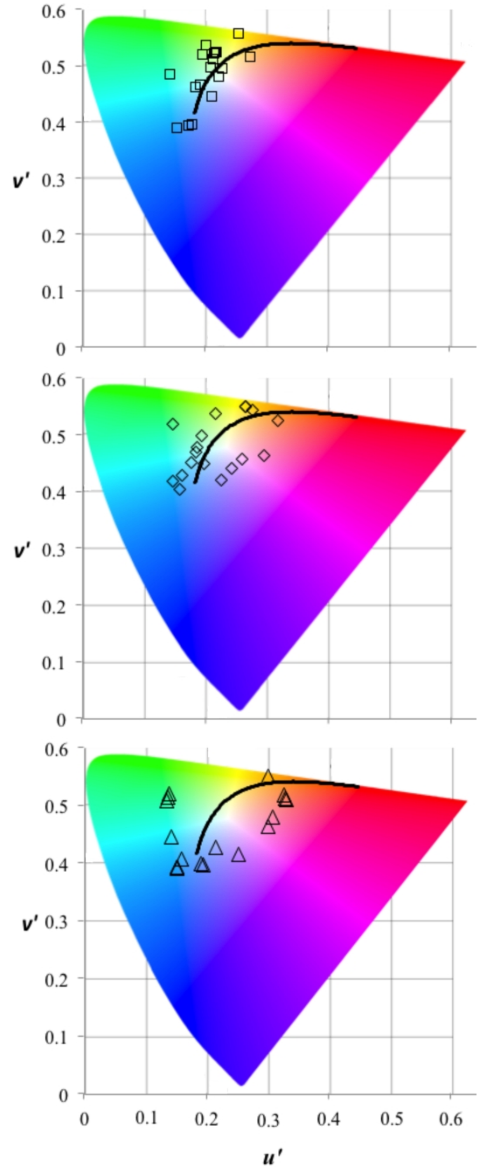

Figure 2. Top: Control group; Middle: MO group; Bottom: MA group. Each point represents the color chosen by a participant. The line shows the Planckian locus.

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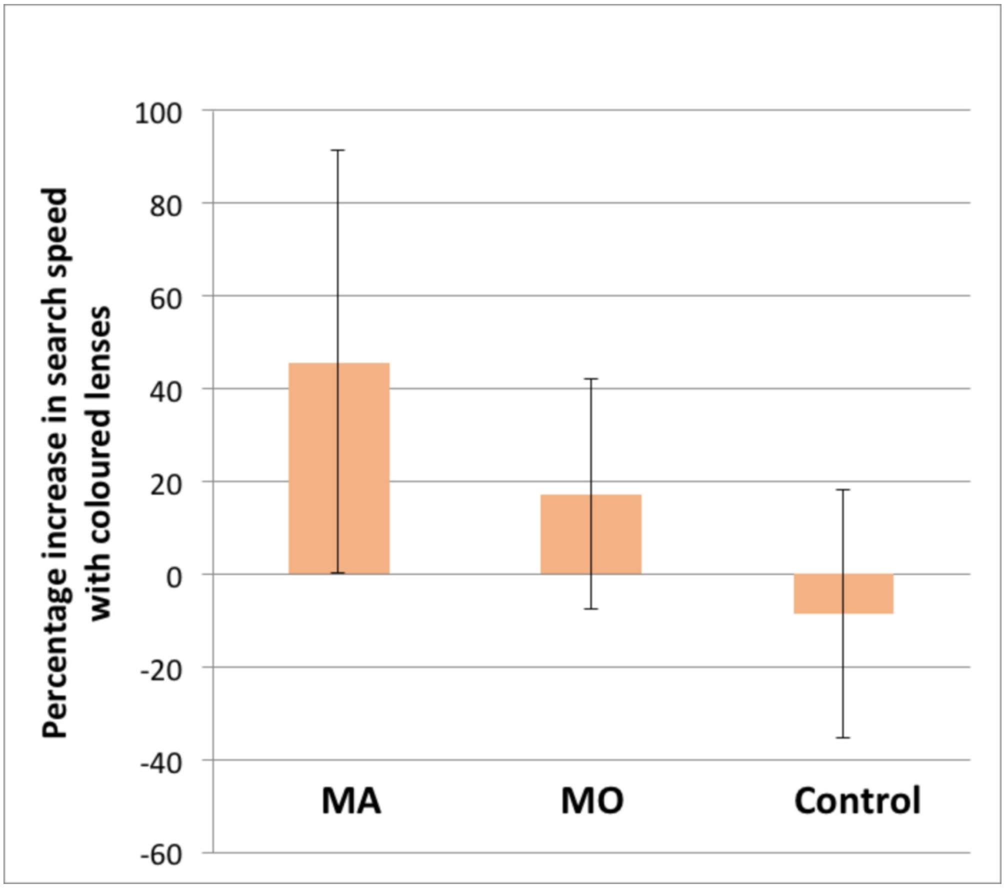
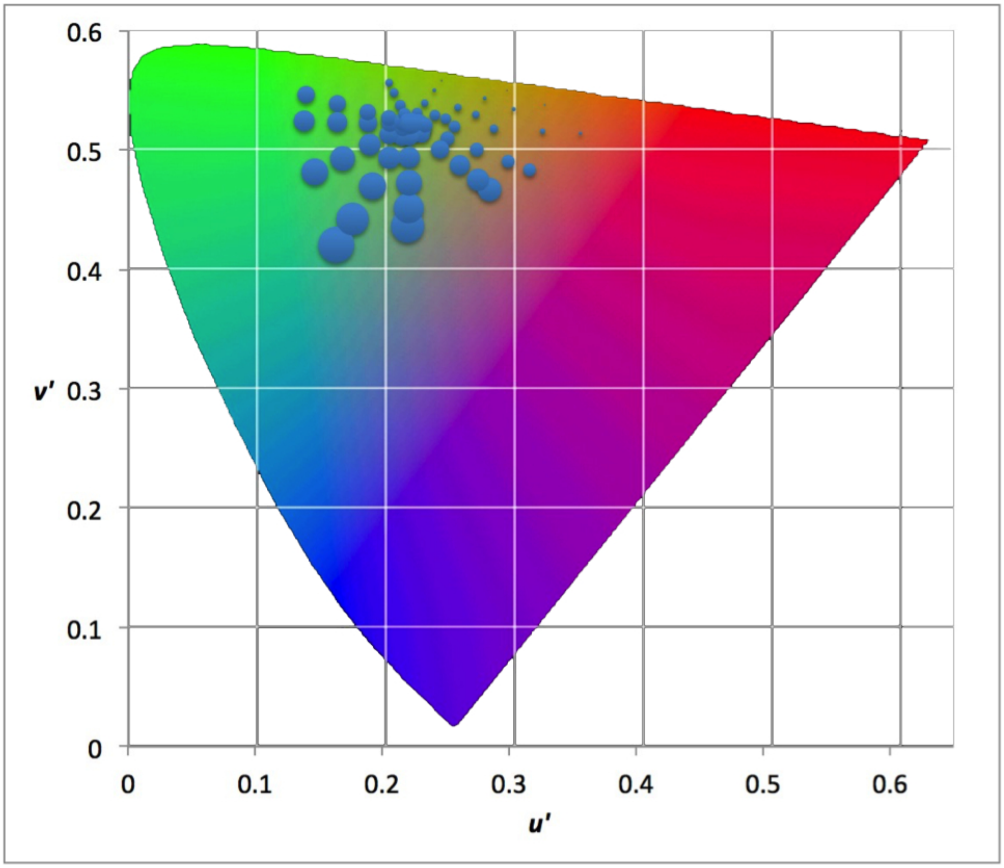


Figure 3. Percentage increase in search speed with colored lenses for participants in the three groups. Error bars show standard deviation.

254x224mm (144 x 144 DPI)



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