Effect of Perceived Contrast Enhancing Lens Technology on Traffic Signal Detection for Color-deficient Individuals

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Abstract. This study examined the effect of Perceived Contrast Enhancing (PCE) lens technology on traffic signal detection and recognition for color-normal and color-deficient observers compared to a neutral density lens. Eighteen color-normal and eighteen color-deficient participants performed a visual-motor task while wearing two different PCE lenses with specific spectral transmissions as well as a neutral-density lens. At random intervals, simulated traffic light signals were presented 5° to the right and left of the participant's focal point, to which participants identified signal color using a three-button input device. Response time and error rate were recorded. We found that lens tint did not have a significant main effect on response time and error rate. The data collected in this study lends considerable evidence to the assumption that PCE lenses will not impair driving.

Keywords: Human Factors · Color Deficiency · Visual-Motor Detection and Recognition

1 Introduction

Approximately 8 % of males and 0.4 % of females today are color-deficient, and a large majority of those are color-deficient in the red-green spectrum [1]. A majority (~75 %) of the color-deficient population is made up of anomalous trichromats, meaning one of their color receptors is altered as compared to normal. Nearly all of the rest of the color-deficient world are dichromats, meaning they completely lack one of the three color receptors and have two-dimensional color discrimination as opposed to three-dimensional. As a result of these deficiencies, the ability of the color-deficient population to discriminate between red, yellow, and green traffic signals is reduced or, in the case of dichromats, completely absent [2]. Participating in traffic depends on the detection of colors and colored signals. Because tinted sunglass lenses can negatively affect reaction time and recognition rates to those signals for color-deficient users [3], [4], and [5], it is important to determine which sunglass lenses are acceptable to use for the color-normal and color-deficient population. Due to these findings, sunglass standards around the world enforce coloration requirements on sunglasses with the goal of limiting color distortion. These properties are established to define the amount of chromatic influence of red, yellow, and green traffic signals as viewed with a background of average daylight. The American National Standards Institute (ANSI Z80.3-2018) [8] regulates these chromatic influences with three criteria: 1) *Color limits*: Each respective chromatic coordinate must reside within a specified region of the Commission Internationale de l'Eclairage (CIE) 1931 chromaticity diagram [9], 2) *Transmittance properties*: Each filter must allow a minimum amount of total light and respective colored light through, and 3) *Spectral Transmittance*: All attenuation must not fall below a set threshold.

The objective of our experiment was to assess the extent to which reaction time and error rate may be affected by PCE lens technology for color-deficient subjects when compared to a neutral density lens, using traffic signals that comply with US national standards laid out by the Institute of Traffic Engineers (ITE), Australian national standards, and ANSI guidelines [6], [7], [8], [9], and [10]. Our hypotheses are as follows:

H1: *Color-deficient subjects' reaction times and error rates are higher than their color-normal counterparts'.*

H2: *There is no effect of PCE lenses that fail and other lenses that currently pass ANSI standards on reaction time and error rate.*

2 Method

2.1 Study Design

Sport performance frames (Oakley® Radar EV) were used to cover a wide field of view and mitigate backside glare effects. Fig. 1 shows the three lenses used which consisted of a neutral density pair (16 % visible light transmission VLT, shown in *green*) and two pairs of PRIZM™ lenses (18 % VLT, shown in *red*, passes ANSI 4.10.2.3, and 34 % VLT, shown in *blue*, fails ANSI 4.10.2.3).

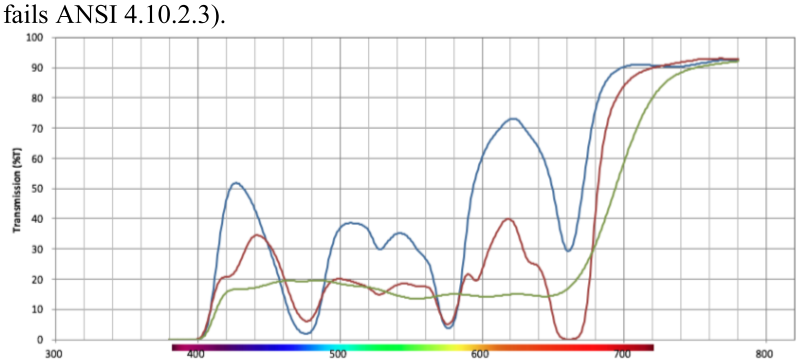

Fig. 1. Spectral Transmissions of PRIZM™ Golf (*blue*, 34%VLT, fail ANSI 4.10.2.3), PRIZM™ Road (*red*, 18%VLT, pass ANSI 4.10.2.3) and Dark Violet (*green*, 16%VLT, pass ANSI 4.10.2.3).

2.2 Sample

Our sample utilized thirty-six healthy males between the ages of 14 and 54 (M = 36.4 yrs, SD = 9.0 yrs), consisting of 18 color-normal males and 18 color-deficient males. Pre-study all participants conducted a color discrimination task using a light box and Farnsworth-Munsell 100 Hue Test to ensure their grouping in color-normal or color-deficient. Distinctions were not made between the different types of color deficiencies. All participants had a visual acuity of at least 20/25, and participants wore their non-tinted correctional lenses behind the experiment's tinted lenses if necessary, to achieve this visual acuity.

2.3 Apparatus

The general study apparatus was replicating parts of [5] with minor alterations, discussed below (see Fig. 2). Participants viewed a target in the center of a computer monitor at a 1.5 m working distance to be able to view the secondary task easily on a conventional computer monitor. Three separate bulbs were laid horizontally (spanning 1 cm) on either side in the same space on either side so intensity could be individually regulated. At the working distance of 1.5 m and angle 5º size constancy mandated the use of LED bulbs with 3 mm diameter. Following that, there were no significant positional cues for each of the bulbs that could influence the experiment. Additionally, we positioned our participants' eye level at 7 cm beneath the signal level rather than at the level of the bulbs. This corresponds to a 200 mm traffic light at 100 m being 4.572 m off the ground, which is the minimum height a traffic signal can be in the U.S. according to the ITE [10]. Signals were created using three differently colored, high-intensity LED bulbs (red, yellow, and green). We referenced standards outlined by ITE to find the minimum intensity of a traffic signal from the vantage point of -2.5º vertically and 5º horizontally, to mimic our study design. We converted this to lux at 100 m and used different resistors for our LED bulbs until we were able to match that lux from 1.5 m. For red, a 220 ohm resistor was used to achieve the luminous intensity of 0.033 cd. For yellow, a 47 ohm resistor was used to achieve 0.081 cd, and for green a 1.5 kohm resistor was used to achieve 0.021 cd. Each of these luminous intensities are the 1.5 m equivalent of the minimum allowed intensity of a 200 mm traffic signal at 100 m, which is the standard Australian practice utilized by Dain [4], [6], and [7]. Bulb rise time to full intensity was negligible. Table 1 references the respective ITE and CIE specifications.

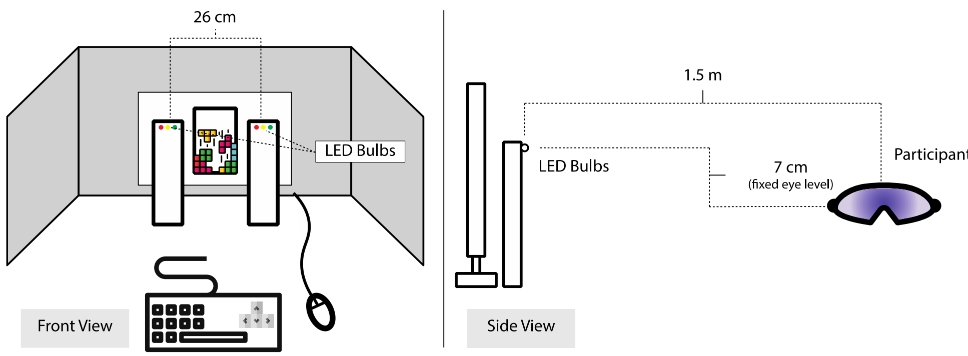

Fig. 2. Apparatus with computer monitor, keyboard, mouse, led bulbs, and measurements. Front view (left), side view (right).

Table 1. Minimum allowed luminous intensity of a traffic light as outlined by ITE and Chromaticity coordinates of each of bulb, from spectral radiance measurements made with an AsenseTek Essence telespectroradiometer, all fall within the required CIE 1931 specifications as laid out by ANSI.

Traffic Signals	**Red**	**Yellow**	**Green**
Minimum luminous intensity [cd]	150	373	196
Luminous emittance at 100 m [lx]	.015	.0373	.0196
Right LEDs			
Luminous intensity [cd]	.035	.081	.047
Luminous emittance at 1.5 m [lx]	.0135	.036	.021
Left LEDs			
Luminous intensity [cd]	.033	.08	.051
Luminous emittance at 1.5 m [lx]	.0146	.0355	.018
Bulb color			
x – coordinate	0.583	0.213	0.688
y – coordinate	0.413	0.688	0.309

2.4 Experiment

The experiment was divided into three distinct sections. The first section consisted of measuring reaction times for each finger on a three-click mouse. The reaction times from the first section were used to normalize our response data for the different dexterities among participants and among fingers of each participant. The participant was instructed to place the middle finger of their dominant hand on the center button of the mouse, and their other two fingers on the surrounding buttons. The left button corresponded to red, middle to yellow, and right to green. The lights flashed exclusively on the right-hand side for this section of the experiment, with the participant's gaze fixated directly upon them. The participant was instructed to look at the lights on the right-hand side only and respond as quickly and accurately as possible to the color of these flashing lights. Each light would stay on for 3 s, with a 1 s break in between each individual flash. To ensure we had a good measure of each participants' true reaction time, this task would not stop until the previous 9 responses were all correct and within ~150 ms of each other. The participant carried out this task twice to ensure good data was collected. For data analysis, response times for each button were normalized by subtracting the average reaction time of the last 9 responses for that button.

The second section consisted of a single run of the same procedure as section one, but while wearing a lens. This section served as an adaptation period for the lens in question before the participant moved onto section three. Lens order was randomized using a python code, and the participant would perform sections two and three in succession before switching to the next lens.

The third section consisted of the experiment proper, in which the secondary task was utilized. We used Tetris as our secondary task, as it is a well-recognized visual-motor secondary task. The Tetris was displayed on a monitor behind the LED lights. The center of the game was aligned in the middle of the two sets of LED lights, and was located 7 cm below the level of the lights so as to be even with the participant's eye level. To control the Tetris, the participant used their non-dominant hand on the arrow keys of a standard QWERTY keyboard. In cases where the participant was left-handed but used a mouse with their right hand, they used their left hand on the keyboard. The participant was instructed to play Tetris and keep their gaze fixated straight ahead on the task. As they played, an LED bulb would flash on either the left or the right side, and the participant would respond to the color of the flash with the input device, and their reaction times were recorded. The lights flashed in random intervals of between 6 and 12 s and stayed on for 3 s. Failure to respond to the light in the 3 s that it stayed on was recorded as an error. Each run consisted of 24 randomized presentations of the LED lights, so that each side and color combination was presented 4 times. This was done 3 times for each of the three lenses, for a total of 72 data points for each lens per participant. The participant was given the opportunity to take a short rest in between each trial, but most opted to not take the break. The participants informed the experimenter immediately if they had made a mistake in responding to a light and these data points were not used in analysis. Observers were not given feedback about which lights were correctly or incorrectly identified.

3 Results

We conducted a mixed 2 (*color vision*) x 3 (*lens color*) ANOVA to analyze the interaction of reaction time and error rate. The normality assumption was checked graphically using histograms and Q-Q plots as well as by applying the Shapiro-Wilk test. Effect sizes are classified using Cohen's benchmark: small (η^2, ω^2 = .01), medium (η^2, ω^2 = .06), and large (η^2, ω^2 = .14). Table 3 summarizes the descriptive results for *color vision* and *lens color*.

Table 3. Minimum allowed luminous intensity of a traffic light as outlined by ITE.

Lens	Color-normal				Color-deficient			
	M_{RT} [s]	SD_{RT} [s]	M_{error} [-]	SD_{error} [-]	M_{RT} [s]	SD_{RT} [s]	M_{error} [-]	SD_{error} [-]
Dark Violet	0.695	0.368	0.031	0.054	0.729	0.432	0.195	0.233
PRIZM™ Road	0.695	0.394	0.030	0.042	0.761	0.452	0.211	0.215
PRIZM™ Golf	0.695	0.374	0.040	0.040	0.723	0.453	0.216	0.224

There were significant main effects of color vision on response times ($F_{1, 102} = 11.93$, $p < .001$, $\eta = .105$, $\omega = .095$) and on error rate ($F_{1, 102} = 39.53$, $p < .001$, $\eta = .279$, $\omega = .27$), but this was expected. There were no significant main effects of lens on response times ($F_{2, 102} = 0.12$, $p = .89$, $\eta = .002$, $\omega < .001$) or on error rates ($F_{2, 102} = .099$, $p = .91$, $\eta = .002$, $\omega < .001$), which you can see in Fig. 3. There were no significant two-way interactions between lens tint and color vision for reaction time ($F_{2, 102} = .11$, $p = .892$, $\eta^2 = .002$, $\omega^2 < .001$) or for error rate ($F_{2, 102} = 0.03$, $p = .968$, $\eta^2 = .002$, $\omega^2 < .001$). Additional Bonferroni post-hoc tests revealed that there were no significant differences in response times or error rate between individual lenses.

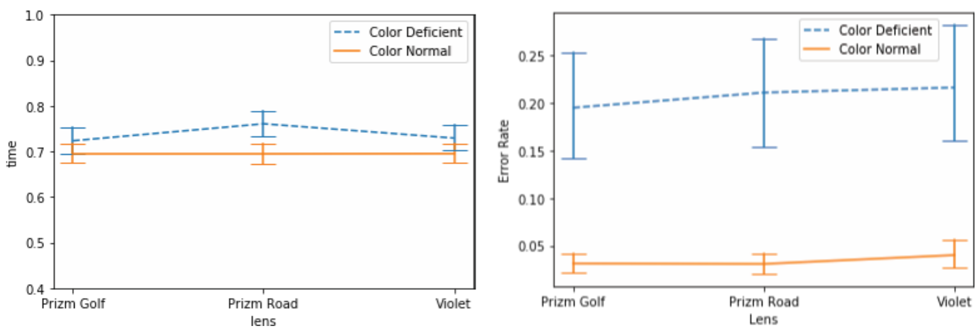

Fig. 3. Reaction times (left), error rates (right).

4 Discussion

There was no significant difference in mean reaction time or error rate across all lenses for color-normal participants. For color-deficient participants, although the difference was not statistically significant, the lens with the slowest mean adjusted reaction rates was the PRIZM™ Road lens, which currently passes the mentioned ANSI standards. PRIZM™ Golf (does not pass ANSI) yielded the fastest reaction times for color-deficient participants. Although the differences in these results were not statistically significant, the question remains as to whether they show any practical significance.

The fact that PRIZM™ Golf yielded the slowest mean adjusted reaction times raises questions about the validity of current standards regarding transmission rates.

The practical significance of our results is best illuminated by a simple rates problem. At 96.56 km/h (60 mph), it takes an average of 4.5 seconds and around 25 m to stop a car completely. According to our data, and by looking at reaction times (Fig. 3), the highest difference between lenses for color-deficient participants is ~30 ms or 0.81 m travelled distance. Therefore, if a color-deficient person was driving a car while wearing a pair of PCE lenses, they might expect to stop for a sudden red light change 0.81 m later than they would have if wearing a neutral density lens. This distance, when taking into account all of the other external factors that can influence the braking distance of a car, would have minimal effects on braking in time for an intersection as opposed to ending up in the middle of it.

In conclusion, according to the data we gathered, we believe that Oakley PCE lenses offer solely a subjective change in our perception, as they don't appear to cause any significant decrease in reaction time or error rate. Especially in the light of rapidly changing transportation paradigms (Level 5 automation and human-robot interaction) and novel communication between traffic participants (e.g., via external HMIs), additional studies have to be conducted around lens technology and signal perception.

References

1. Hunt, R.W.G., Pointer, M.R.: Measuring Colour; John Wiley & Sons: Hoboken, NJ, USA (2011)
2. Dain, S. J., & King-Smith, P. E.: Visual Thresholds in Dichromats and Normals: The Importance of Post-Receptoral Processes. Vision Research, 21, 573--580 (1981)
3. Atchison, D. A., Pedersen, C. A., Dain, S. J., Wood, J. M.: Traffic Signal Color Recognition Is a Problem for Both Protan and Deutan Color-Vision Deficients. Human Factors, 45, 3, 495 (2003).
4. Dain, S. J., Wood, J. M., Atchison, D. A.: Sunglasses, Traffic Signals, and Color Vision Deficiencies. Optometry and Vision Science, 86, 4, 296--305 (2009).
5. Australian Standards Association: Australian Standard AS 1067-1990. Sunglasses and Fashion Spectacles. Part 1: Safety Requirements. Sydney: Australian Standards Association (1990)
6. Standards Australia/Standards New Zealand: Australian/New Zealand Standard Traffic Signal Lanterns AS/NZS 2144:2002. Sydney: Standards Australia Ltd. (2002)
7. Fisher AJ, Cole BL: The photometric requirements of vehicular traffic signal lanterns. In: Proceedings of the Australian Road Research Board, vol 7. Melbourne: Australian Road Research Board, 246–-265 (1974)
8. American National Standards Institute: Ophthalmics: Nonprescription Sunglasses and Fashion Eyewear: Requirements: Z80.3-2018. New York: American National Standards Institute (2018).
9. Commission Internationale de l'Eclairage: Commission Internationale de l'Eclairage proceedings, 1931. Cambridge: Cambridge University Press (1932).
10. Institute of Transportation Engineers: Vehicle Traffic Signal Control Heads: Light Emitting Diode (LED) Circular Signal Supplement. Prepared by the Joint Industry and Traffic Engineering Council Committee (2005).