Eye (2020) 34:2347–2348
https://doi.org/10.1038/s41433-020-0793-4

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CORRESPONDENCE

Cool (blue) vs. warm (yellow) displays enhance visual function

Jeff Rabin[1] · Christopher Cha[1] · Minh Nguyen[1] · Liana Renteria[1] · Fortuna Abebe[1] · Arzoo Wastani[1]

Received: 11 January 2020 / Accepted: 26 January 2020 / Published online: 6 February 2020
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Displays emitting substantial blue light (phones, tablets, computers) can produce eyestrain (computer vision syndrome: CVS) [1, 2]. Yet findings have been challenged [3]. A metric to assess CVS is the highest detectable flicker rate (CFF). We compared the short-term effects of bluish ("cool") vs. yellowish ("warm") displays on high temporal frequency contrast sensitivity (TCS), which relates directly to the CFF.

The 5-degree foveal stimulus of the frequency-doubling perimeter (FDT®), which determines TCS for rapidly reversing sinewaves, was measured after 10 min of exposure to a bluish or yellowish iPad, which displayed *Memorama Classic*, a memorization game wherein pictures appeared, and subjects used touch interface to choose two pictures forming a pair. After baseline TCS, subjects played the game for 10 min followed by repeat measurement of TCS. Testing was conducted in one session with order (blue vs. yellow) randomized across subjects with 30 min between testing. iPad display settings were adjusted to present stimuli in bluish, cool format (x,y chromaticity: $x = 0.144$, $y = 0.061$, luminance 26.3 cd/m^2) and in luminance-matched yellowish, warm format (x,y chromaticity: $x = 0.473$, $y = 0.437$, luminance 26.4 cd/m^2, Fig. 1a).

After a written informed consent, 27 subjects (mean age [SD] 27 [3], 18 females, 9 males) participated. Baseline TCS was available for 23. Contrary to the results showing increased CFF (improved temporal vision) after blue-blocking filers, we found *increased* foveal TCS after bluish vs. yellowish displays (blue mean [SE] 3.11 [0.06] log CS, yellow mean [SE] 2.98 log CS [0.06]; mean increase 0.13 log units, 95% CI = 0.04–0.22, $P = 0.02$). Figure 1b shows TCS plotted for each subject after cool vs. warm light (some points overlap). Most values fall above the 1–1 line and 95% CI (dotted lines) illustrating higher TCS after cool light. Fifty percent showed higher TCS after cool vs. 20% after warm light (Wilcoxon, $P = 0.02$). Comparable results ensued by comparing TCS change from pre-exposure baseline to post exposure (cool mean difference [SE] .05 [0.10] log CS, warm mean difference [SE] −0.09 [0.13] log CS; mean increase after cool light: 0.14 log units, 95% CI = 0.04–0.25, $P = 0.03$).

Table 1 shows stimulation of red (L), green (M), and blue (S) cones by each display based on conversion to cone excitations and normalizing values to the maximum for each cone type. Changes in L and M cones were moderate, while stimulation of S cones was 70× greater with the cool display. Since the CFF is mediated by L and M cones, greater stimulation of S cones may have lessened the adaptation of L and M cones, leading to higher TCS after blue light. In addition, the blue display had a much greater stimulation of intrinsically photosensitive retinal ganglion cells (ipRGCs), which mediate circadian rhythms and enhance cognition and alertness possibly improving TCS [4, 5].

Contrary to reports of decreased flicker detection after blue light, short-term exposure improved TCS, possibly due to ipRGC- enhanced cognition/alertness, greater S-cone stimulation, and lesser L/M-cone adaptation. Future studies are needed to determine how these positive blue light findings may have clinical applications.

Author contributions The principal investigator, Dr. Jeff Rabin, had full access to all the data in the study, and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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✉ Jeff Rabin
rabin@uiwtx.edu

[1] University of the Incarnate Word Rosenberg School of Optometry, San Antonio, TX, USA

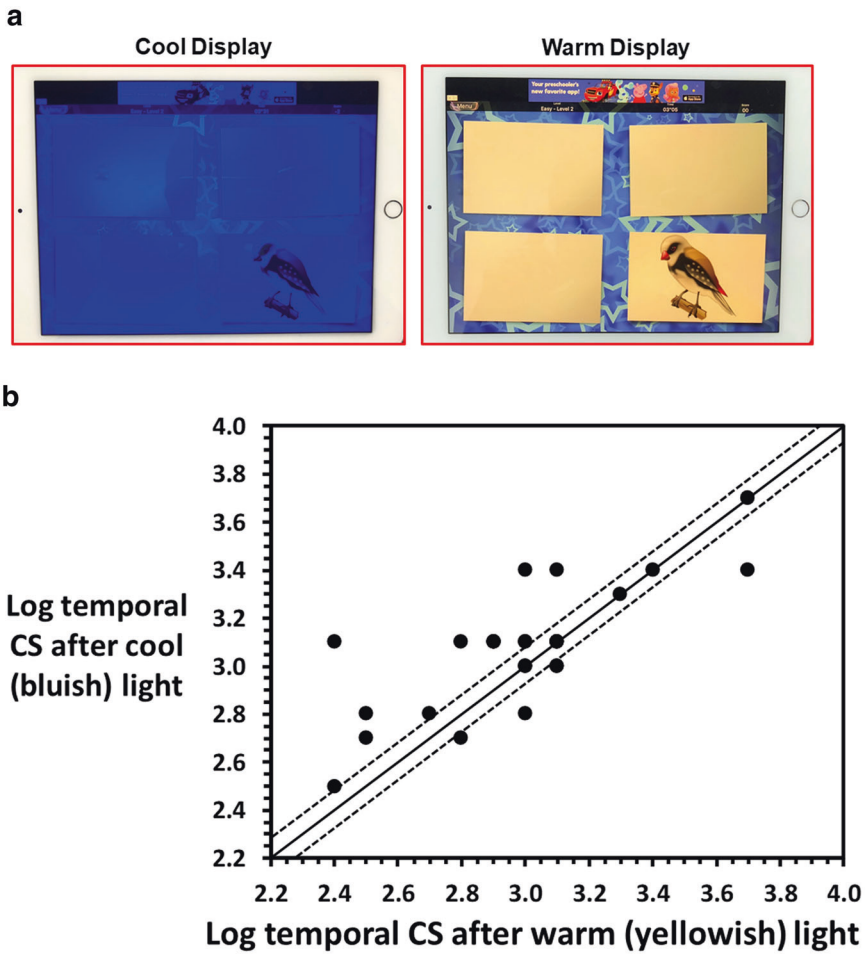

Fig. 1 **a** The bluish (cool) and yellowish (warm) iPad displays used in the memory game. **b** Temporal contrast sensitivity after viewing the cool display is plotted against the corresponding values after viewing the warm display. The bold 1-to-1 line represents no difference between values. The dotted lines represent the 95% confidence interval; values above this line show significantly higher temporal contrast sensitivity after cool light exposure ($n = 27$; some values overlap).

Table 1 Cone stimulation from warm (yellowish) and cool (bluish) displays (normalized relative to maximum stimulation for each cone type).

Cone type	L cone	M cone	S cone
Warm (yellowish)	100%	57%	1.4%
Cool (bluish)	68%	100%	100%
Change with cool display	1.5× decrease	1.8× increase	70× increase

Tabular results showing relative stimulation of each cone type. Luminance and CIE chromaticity were measured from displays set to luminance-matched white in blue (cool) and yellow (warm) formats, and converted to L, M, and S-cone excitations. Values were normalized in percentage based on the maximum stimulation to each cone type from the two displays.

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