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COMPARISON OF THE EFFECTS OF BRIGHT CHROMATIC STIMULI OF EQUI-LUMINANCE AND EQUI-RADIANCE ON THE PUPIL LIGHT REFLEX AND INVESTIGATION OF THE PERFORMANCES OF BLUE-GREEN BANDPASS SUNGLASSES

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COMPARISON OF THE EFFECTS OF BRIGHT CHROMATIC STIMULI OF EQUI-LUMINANCE AND EQUI-RADIANCE ON THE PUPIL LIGHT REFLEX AND INVESTIGATION OF THE PERFORMANCES OF BLUE-GREEN BANDPASS SUNGLASSES

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Abstract

The influence of intrinsically photosensitive retinal ganglion cells (ipRGCs) in the pupil light reflex (PLR) has been further investigated on young adults in this paper. We compared the influence of blue light and red light stimuli of both equi-luminances (100 and 200 cd/m²) and equi-radiance on the rapid pupil constriction and sustainability in photopic conditions. We confirmed the major implication of ipRGCs in the PLR, even under equi-radiance stimuli (lower amount of blue light compared to red light). Then, as the current sunglasses usually transmit less than 15% of blue-green wavelengths, we developed sunglasses with higher blue-green transmittance, while keeping the same overall protection. The associated study (PLR under white light stimuli) will only be disclosed during the poster session.

Keywords: melanopsin, pupil light reflex, chromatic pupillometry, photopic light

1 Introduction

1 to 3% of retinal ganglion cells (RGCs) express melanopsin, a photosensitive pigment discovered in the beginning of the 2000s (Hattar, 2002) that regulates non-visual functions such as sleep-wake cycles, cognitive performance, alertness or pupil light reflex (PLR) (Daneault, 2016) (Vandewalle, 2011). The maximal spectral sensitivity of human intrinsically photosensitive RGCs (ipRGCs) ranges between 460 nm and 510 nm (i.e blue-green wavelengths) with a peak around 480 nm (Brainard, 2001). Among the non-visual effects mediated by ipRGCs, the PLR is the most fast-acting and observable one. These cells are strongly involved in both the rapid phase pupil constriction and sustainability (Kawasaki, 2007) and their ablation almost completely eliminates the PLR in mice (Hatori, 2008).

Under photopic luminance-matched (cd/m²) red light (619 nm) and blue light (465 nm), rapid pupil constriction is induced by both chromatic lights, but the maximum amplitude of constriction is greater and more sustained under blue light (Park, 2011). However, as luminance (cd/m²) is weighted by the CIE photopic function V(λ), equi-luminance stimuli require a higher radiance (W/m²/sr) at 465 nm than 619 nm, which may explain the higher efficacy of blue light on the PLR linked to the cones, rather than the involvement of ipRGCs.

Thus, we compared the influence of red light and blue light stimuli of both equi-luminances (cd/m²) at two levels and equi-radiance (W/m²/sr) on the PLR on 22 young adults (44 eyes).

2 Material & methods

2.1 Chromatic pupillometry device

A Ganzfeld stimulator illuminated by chromatic LEDs (MonColor, Metrovision, France) was used to perform full-field chromatic pupillometry. The light stimulus is adjustable in duration, spectrum, and luminance (up to 4000 cd/m²) and can be repeated over a given period. (Figure 1 – left)

The participants' pupils are monitored and recorded with a 200 Hz infrared camera (Figure 1 - right) for the spectral bands centred at 465 nm and at 619 nm (Figure 2).

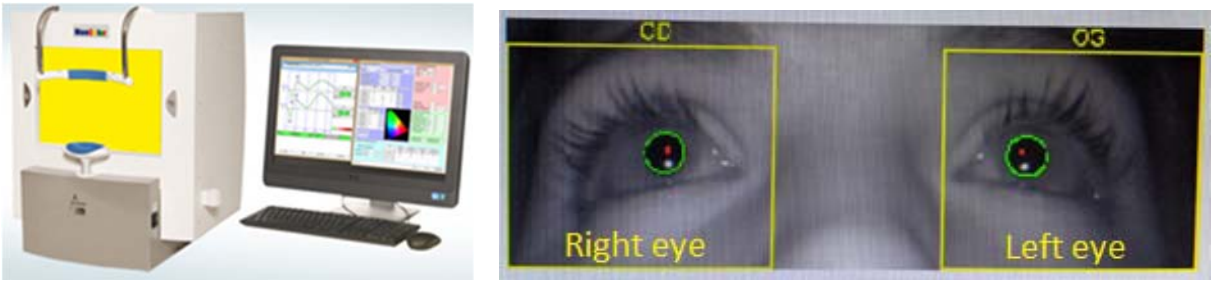

Figure 1 – MonColor chromatic pupillometry device (left), view of the participant's eyes with the infrared cameras (right)

Consistently with the results of Lei in his thesis, equi-luminances of 100 cd/m² and 200 cd/m² were tested for blue (465 nm) and red (619 nm) light flashes of 500 ms (Lei, 2016).

A calibrated spectroradiometer (Jaz, Ocean Optics, USA) was used to set the equi-(ir)radiance conditions (110 µW/cm² - 3 x 10^{14} ph/cm²/s): 18 cd/m² for the spectral band centred at 465 nm and 130 cd/m² for the spectral band centred at 619 nm.

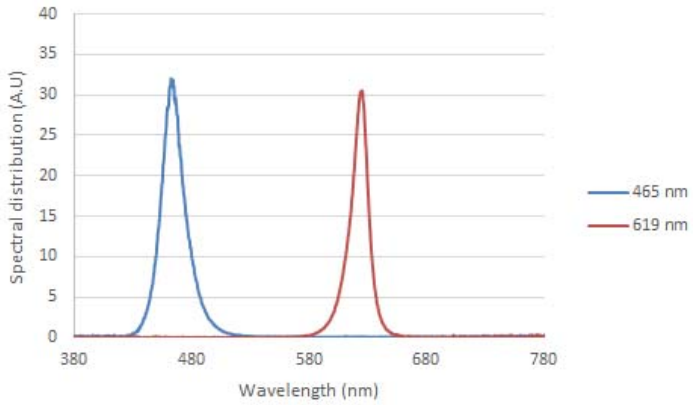

Figure 2 – Blue and red LED spectra centred at 465 nm and 619 nm respectively

2.2 Protocol

Table 1 – Summary of the population and lighting conditions

	Protocol
Population	22 young healthy participants 28 years old +/- 4 SD
λ	465 nm - 619 nm
Luminances	Equi-luminances: 100 and 200 cd/m² Equi-radiance: 18 cd/m² (465 nm) and 130 cd/m² (619 nm)
Flash durations	500 ms

22 young healthy participants (28 years old +/- 4 SD) took part in this study. Before the experiment, the participants were advised not to take any tea, coffee or to smoke for a couple hours. The respect of these guidelines was verified before starting the experiments.

After the signature of consent forms, the participants performed a dark adaptation inside the MonColor device to ensure a stable baseline pupil diameter. Then, the participants were randomly exposed to three 500 ms flashes of red light or blue light, separated by 50 s of darkness (Figure 3). This interval between the flashes was sufficient to ensure a full recovery to the baseline pupil diameter in darkness. The experiment was paused whenever the pupil sizes started to fluctuate.

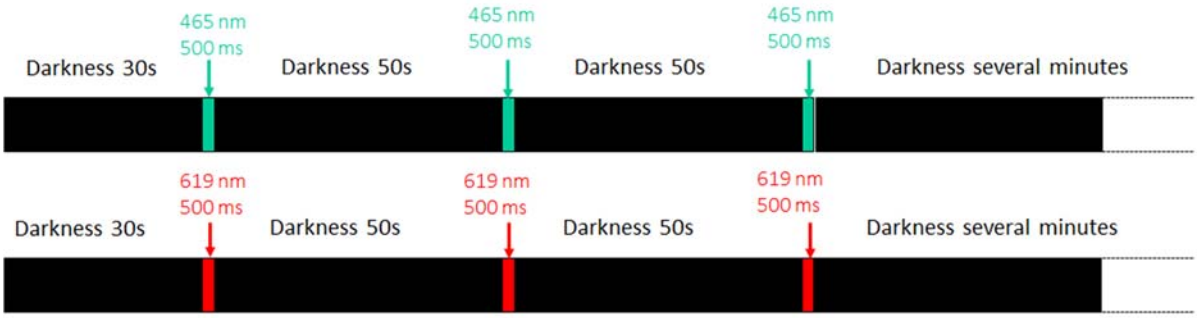

Figure 3– Light protocols inside the MonColor chromatic pupillometry device

Raw pupil size data from the MonColor were extracted and analysed with a custom Matlab software to compute the amplitude and sustainability of pupil constriction. The amplitude (mm) was defined as the difference between the baseline diameter in darkness and the minimum pupil size after a flash. The sustainability (s) was defined as the time needed after a flash to recover 90% of the baseline pupil diameter. (Figure 4)

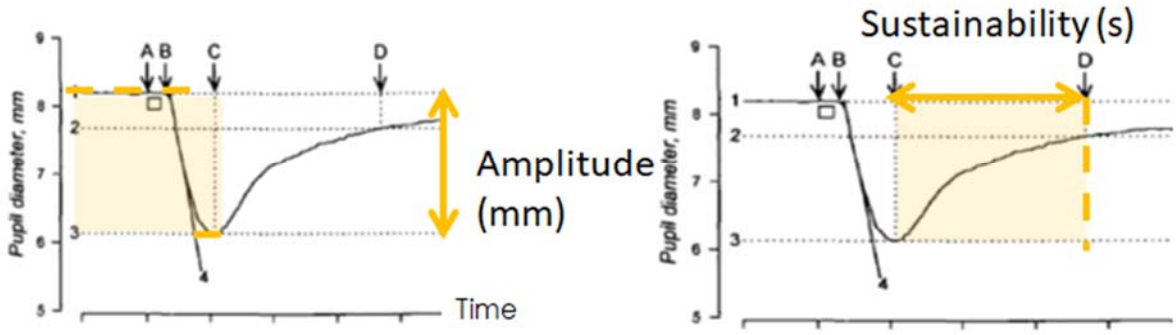

Figure 4 – Definition of amplitude (left) and sustainability (right) of the pupil light reflex under a flash

The data were represented as mean ± SEM. Statistical analyses were performed on Statistica 13.1 software (StatSoft, Tulsa, OK, USA). Two-way ANOVA with repeated measures followed by Tukey post-hoc tests were used to define the effects of the wavelength and of the luminance. Differences were considered to be significant when $p < 0,05$ (*).

3 Results

As previously reported in the literature, under luminance-matched stimuli, the amplitude of constriction and sustainability were significantly higher after blue light than red light stimuli ($p < 0,001$). The amplitude was at least 3,8 mm after blue flashes compared to below 2,8 mm under red light. Similarly, the sustainability lasted at least 32 s after blue light and was below 10 s after red light stimuli.

Interestingly, increasing the blue-green photopic luminance from 100 to 200 cd/m² did not significantly increase the amplitude of constriction ($p = 0,6$), but impacted the sustainability ($p < 0,02$). 200 cd/m² of blue light centred at 465 nm induced 4,6 times higher sustainability than 200 cd/m² of red light centred at 619 nm, whereas this ratio was only 3,4 times at 100 cd/m².

In addition, similar results were found with radiance-matched stimuli: blue light induced 1,3 times higher pupil constriction and up to 2,5 times higher sustainability than red light ($p < 0,001$). Thus, these results confirmed the strong involvement of ipRGCs in the rapid phase pupil constriction and especially the sustainability (Figure 5).

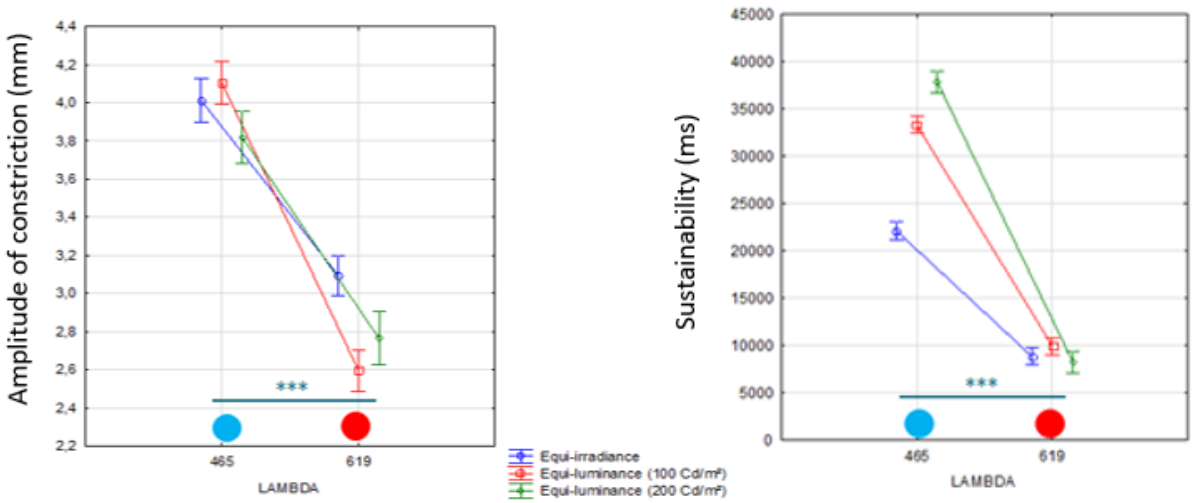

Figure 5 – Amplitude of constriction (left) and sustainability (right) for each wavelength and each light level

Table 2 – Ratios of amplitudes of constriction and sustainability between blue (465 nm) and red (619 nm)

	Equi-luminance 100 cd/m² (photometric)	Equi-luminance 200 cd/m² (photometric)	Equi-radiance (radiometric)
λ, light level	465 nm at 100 cd/m² 619 nm at 100 cd/m²	465 nm at 200 cd/m² 619 nm at 200 cd/m²	465 nm at 18 cd/m² 619 nm at 130 cd/m²
Amplitude	x 1,6	x 1,4	x 1,3
Sustainability	x 3,4	x 4,6	x 2,5

4 Conclusion

As previously reported in the literature, with photopic equi-luminances, blue-green stimulations convey significantly higher pupil constriction and sustainability compared to red light stimulations. In addition, complementary results obtained with radiometric-matched chromatic stimuli strongly confirm the major implication of ipRGCs. Even with lower luminance, blue light still induces higher pupil constriction and sustainability than red light.

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