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EFFECT OF METAMERIC WHITE LIGHTS ON VISUAL PERFORMANCE

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Abstract

Intrinsically photosensitive retinal ganglion cells (ipRGCs) are known to be involved in non-imaging functions of the eye, through a direct stimulation of a photopigment names melanopsin. Recent studies suggested that besides playing a role in circadian rhythm and cognitive functions such as alertness and working memory, they would modulate perceptual vision. However, the underlying mechanisms involved remain unclear. Our study further investigates whether this stimulating effect of light can be extended to light detection thresholds and how it varies with aging across the visual field. To this end, a perimetry task was designed and performed under two metameric white lights, opposed in melanopsin stimulation. Findings suggest that ipRGC stimulation does not interfere with light detection thresholds but may enhance visual functions by improving reaction time. Increased performances may be the consequence of non-imaging pathways stimulation and not likely the results of brightness or contrast perception.

Keywords: Light, Melanopsin, ipRGC, metamerism, perimetry

1 Introduction

Intrinsically photosensitive retinal ganglion cells (ipRGCs), commonly called the fourth photoreceptor in the human eye, play a crucial role in both visual and non-visual functions. Photosensitive pigment melanopsin has a maximal sensitivity around 480nm and subsequently regenerates by wavelengths between 590 and 620nm. Their implication in visual perception such as brightness or contrast perception is still under examination (Allen et al., 2019; Brown et al., 2012; Zele et al., 2018).

Recent studies (Allen et al, 2019) explored the direct implication of ipRGCs on contrast sensitivity and brightness perception. Combined with a sparse distribution across the retina and an uneven distribution (Esquiva et al., 2017), we may question the mechanism involved and how melanopsin stimulation impacts global and local light detection thresholds across the visual field.

Aging affects the eye's optical properties, including increased light absorption by the lens (particularly in the shortest visible wavelengths), pupil constriction (senile miosis), heightened intraocular scattering and optical aberrations. These changes impact the amount of light reaching the retina and, consequently, research on ipRGCs has shown that the spectral sensitivity of ipRGCs shifts with age, with the peak sensitivity shifting from 484 nm in younger individuals to 494 nm in older adults (Najjar et al., 2014). If perimetry was deeply explored across the lifespan, no data were found on the combined effect of the spectral nature of the background and age.

In our study, we explore the impact of metameric white backgrounds on light detection thresholds across the visual field in both young adults and seniors and investigate visual and attentional performances under short wavelength-enriched white light. We hypothesized that intrinsically photosensitive retinal ganglion cells through melanopsin stimulation impact contrast detection threshold and may induce shorter reaction time.

2 Experiment

A perimetry task was designed with a proper control of background spectra and melanopsin stimulation. Two metameric whites were developed, silencing cones with the silent substitution method ((Hung et al., 2017; Spitschan and Woelders, 2018) and increasing melanopsin contrast between both stimulation, to evaluate the impact on light detection thresholds. Reaction time was also recorded to assess attention and non-imagine pathway, along with a perceptual vision assessment.

2.1 Participants

40 healthy subjects, including 20 young adults from 20 to 37 years of age (mean of 28 ± 5), and 20 seniors from 71 to 84 (mean of 77 ± 4) with no ocular pathology, no history of neurological disorder, no color vision deficiencies and no extreme chronotype were included from the Silversight cohort.

2.2 Materials and procedures

Experimental set up was composed of a translucent screen in front of a light wall (Figure 1A). The wall is composed of 398 light units, each one of them containing 14 different LEDs, tunable independently, behind diffusers. The translucent screen Nexnovo NT10 is composed of 1cm spaced W, R, G, B LEDs.

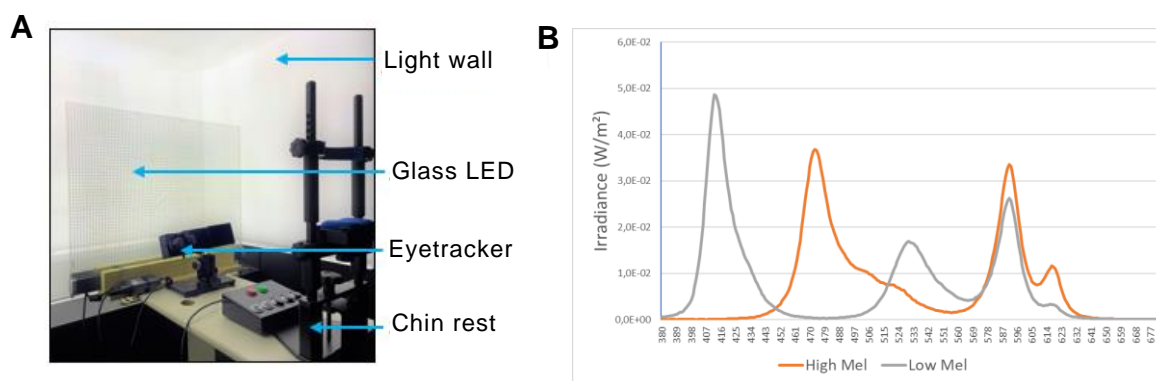


Figure 1 – A: Experimental setup, B: Spectral irradiance (W/m²) of metameric whites High Mel and Low Mel

Two metameric whites (Figure 1B) were calculated, maximizing melanopsin stimulation for High Mel light condition and minimizing it for Low Mel light condition. They were equalized in illuminance at 611 lux and density photonic flux and used as background light on the light wall. Amber light composed of 590 and 620 nm was used to initiate a comparable state of the retina before tasks.

The visit took about 2 hours, and was divided into 4 parts (Figure 2).

After preliminary measures to check visual acuity and normal color vision, participants were trained under amber light. They were then randomly exposed either to blue-enriched white background (High Mel) or to a metameric white background minimizing melanopsin stimulation (Low Mel) (Figure 1) and they had to perform perimetry and ocular movements tasks. The background was then switched, and the tasks were repeated. Order between both lights was balanced within the population. Results from perimetry tasks are presented in this paper.

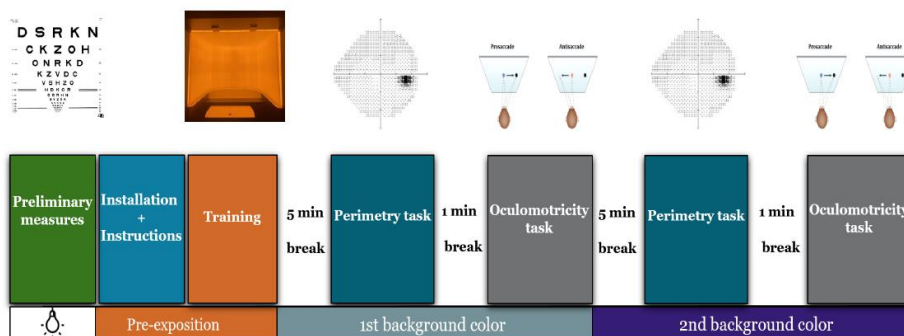


Figure 2 – Experimental design

Visual stimuli are composed of single pixels from the translucent screen. During perimetry task, 14 points across the visual field were measured monocularly and randomly, across 4 different visual angles (Figure 3A). Each point was on during 200ms to assure light detection and avoid saccadic reflex, spaced from 1 to 2 seconds. Each light detection threshold was measured three times through a staircase method (Figure 3B). The visual angle of one single LED was $0,18^\circ$, viewed from 65 cm distance. The participants had to constantly fixate the central point throughout the task and press a button at each light point detection.

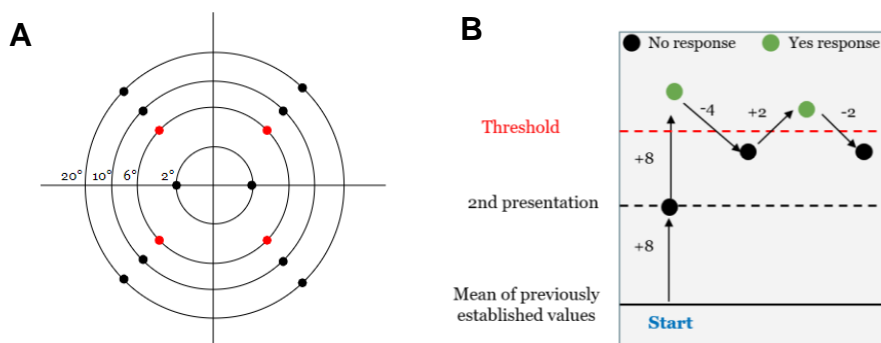


Figure 3: (A) Localization of light stimuli within visual field (B) Staircase method to measure light detection threshold

The Eyelink1000+ recorded eye movements during perimetry, saccades and anti-saccades tasks with gap paradigm. Visual tasks were similar as the one described in Bécu's thesis (Bécu, 2018). Synchronization was performed in Psychopy.

3 Results

3.1 Light detection thresholds

Experimental set-up successfully renders light sensitivity thresholds across the visual field, showing consistent results with existing data (Verriest and Israel, 1965), using up and down staircase strategy. Intra-individual variability of our system (Figure 4) was found close or better to standard perimeter used by ophthalmologists (Heijl et al., 1987) with a mean of 1,56dB. The main difference with a standard perimeter is the distance variation between the eye and visual stimulus, as the device is not a light dome.

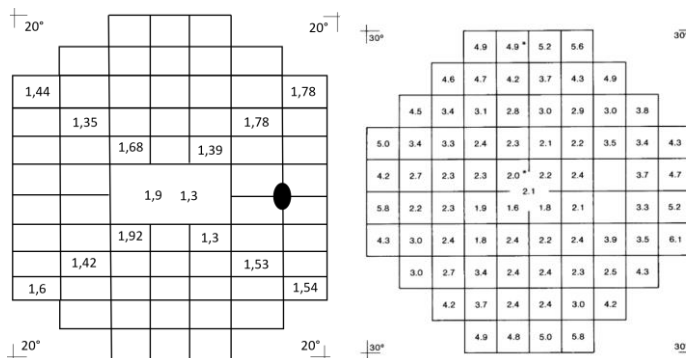


Figure 4 : Standard deviation of light detection thresholds in dB from our device (left), Standard deviation of Humphrey static perimeter in dB (Heijl et al., 1987)(right)

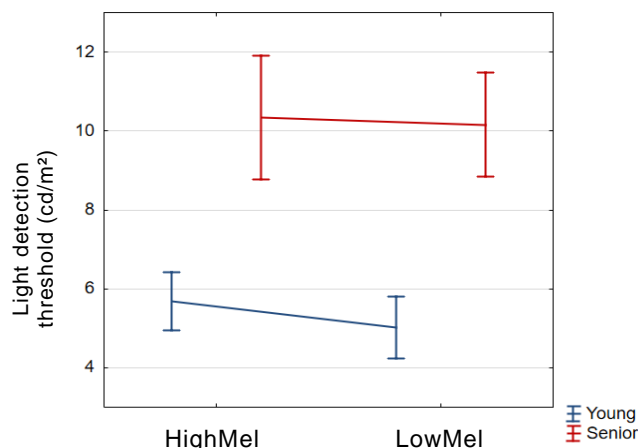


Figure 51 : Background spectrum effect on light detection thresholds, in young adults and seniors

Repeated measures ANOVA were performed on light detection thresholds to evaluate the difference between High Mel and Low Mel and the effect of the stimulation of ipRGCs within young adults and seniors. No statistical difference was found between the two light conditions, considering the entire set of local points and both age groups (Figure 5).

3.2 Reaction time

Results showed that young adults were significantly faster at performing the perimetry task under the High Melanopsin background compared to the Low Melanopsin background. (Paired T-test, $t=-2.26$, $p=.024$.) The mean difference was 16 ms, which is approximately 3% improvement. It represents the smallest difference the system is capable of measuring. The reaction time was not correlated with luminance (Pearson correlation: $r^2= 0.0304$ on High Mel background and $r^2 = 0.0050$ on Low Mel background), so the effect found is not related to an improved visibility. For seniors, effect was not significant suggesting that ageing may impact light detection thresholds and the potential effect of ipRGCs on attention and reaction time.

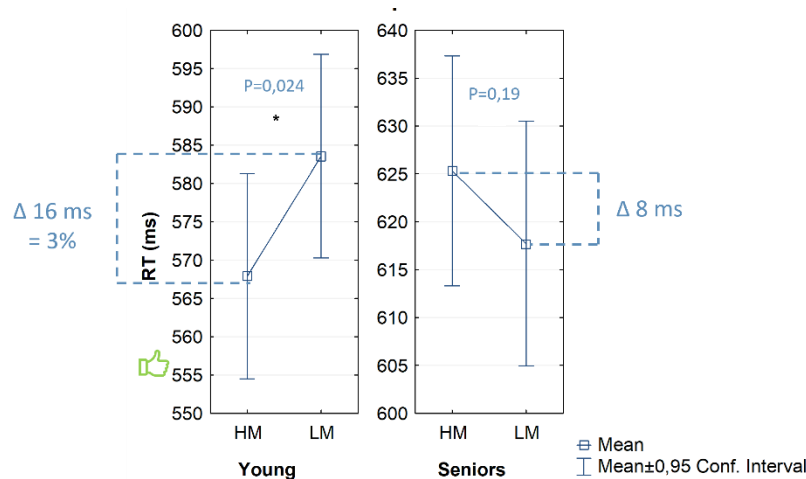


Figure 6: Background spectrum effect on reaction time during perimetry task in young adults and seniors.

4 Discussion

Light detection thresholds, when averaged across the visual field or analyzed individually, were not impacted by the spectral content of the background, which contradicts our initial hypothesis. Nevertheless, a significant effect of the background was found on reaction time during perimetry within young adults, confirming a positive role of ipRGCs stimulation on attention and a sufficient contrast between both metameric whites. Our results are consistent with results from a study from Tonetti and Natale, 2019, in which reaction time during a lexical task was assessed after one-minute short wavelength exposure. Decreased reaction time amplitude was similar (17ms vs 16ms in our study). As it could result from a training effect, randomization was effective, and no order effect was found. The absence of significant change of light detection threshold implies that the benefit on reaction time could result from non-imaging pathway and not direct stimulation of visual area in the brain. In the case of seniors, the results may be impacted by crystalline lens yellowing or ganglion cell loss with ageing. These hypotheses should be explored further, selecting preferably cataract-free population or compensating for short wavelength absorption, ideally with a proper measurement of the spectral transmission of the ocular media, which still needs to be developed.

5 Conclusion

The effect on local contrast perception across the visual field within a perimetry task remains unaffected by melanopsin stimulation, which could be too low to produce a lightness increase perception. Yet, performance during a task involving light detection and motor action is improved through reaction time decrease. The positive effect of ipRGC stimulation is here assumed to derive from non-imaging pathways, as reaction time is not correlated with stimulus luminance. Differences between age groups could be related to crystalline lens yellowing and should be explored further to better understand the relative benefit of short wavelength stimulation through ageing.

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