ORIGINAL ARTICLE

UDC: 617.7-089.24/.25
DOI: https://doi.org/10.2298/VSP190522082J

Clinical impact of nanophotonic blue-light filtering spectacles based on fullerene C_{60} and polymethyl methacrylate (PMMA)

Klinički efekat nanofotonskih naočara s plavim filterom na bazi fulerena C_{60} i polimetil metakrilata (PMMA)

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Abstract

Background/Aim. Blue light might be harmful to the retina. The nano-material based on fullerene C_{60} and polymethyl methacrylate (PMMA) transforms the light into harmonized light and absorbs violet, blue, and ultraviolet (UV) wavelength. The aim of the study was to evaluate the subjective and objective impact of the spectacles on daily activities. **Methods**. Twenty-five healthy participants were submitted to contrast sensitivity (CS) and visual field (VF) testing and a questionnaire about the influence of spectacles on daily activities: two spectacles with different concentrations of fullerene C_{60} vs. two commercially available blue-blocking spectacles. **Results.** There was no statistical difference in CS ($p = 0.83$), in VF parameters: mean deviation (MD) ($p = 0.36$), pattern standard deviation (PSD) ($p = 0.25$), number of relative scotomas ($p = 0.31$), while the number of absolute scotomas showed a statistically significant decrease ($p < 0.05$). Spectacles B (with a lower concentration of fullerene – 0.025%) had the best overall comfort mean score ($p < 0.00001$): four-fifths of participants performed better only during the day, while two-thirds performed better both during the day and night. Spectacles B were also superior in overall satisfaction regarding all combined daily activities (4.04 ± 1.1) ($p = 0.0008$). **Conclusion.** Blue-blocking filters with fullerene C_{60} increase the overall comfort of daily tasks during and after their use. These filters might be an effective mechanism that can protect us from ocular pathologies while providing better comfort in daily activities.

Key words:
spectacles; filter; colours; field of view.

Apstrakt

Uvod/Cilj. Plavo svetlo može da bude štetno za retinu. Nano-materijal od fulerena C_{60} i polimetil metakrilata (PMMA) transformiše svetlo u harmonizovano hiperpolarizovano svetlo upijajući plavu, ljubičastu i ultraljubičastu talasnu dužinu. Cilj ovog rada bio je da se oceni subjektivni i objektivni uticaj nošenja naočara na obavljanje dnevnih aktivnosti. **Metode.** Dvadeset pet zdravih dobrovoljaca podvrgnuto je kompletnom oftalmološkom pregledu, ispitivanju kontrastne senzitivnosti (KS) i perimetrije (PM). Popunjavan je upitnik o uticaju naočara na dnevne aktivosti: dvoje naočara sa različitim koncentracijama fulerena C_{60} upoređeno je sa dvoje komercijalno dostupnih naočara sa plavim filterom. **Rezultati**. Nije postojala statistička razlika u KS ($p = 0,83$), kod PM parametara: MD (*mean deviation*) ($p = 0,36$), PSD (*pattern standard deviation*) ($p = 0,25$), i kod broja relativnih skotoma ($p = 0,31$), dok je broj apsolutnih skotoma pokazao statistički značajno smanjenje ($p < 0,05$). Naočare B (sa manjom koncentracijom fulerena od 0,025%) imale su sveukupno najbolju srednju ocenu ($p < 0,00001$): oko četiri petine ispitanika je bolje funkcionisalo danju, dok je oko dve trećine njih osećalo boljitak i danju i noću. Naočare B su isto tako bile superiorne u sveukupnoj oceni zadovoljstva pri svim kombinovanim dnevnim aktivnostima (4,04 ± 1,1) ($p = 0,0008$). **Zaključak.** Naočare sa plavim filterom na bazi fulerena C_{60} povećavaju sveukupan komfor u obavljanju dnevnih aktivnosti pri njihovom nošenju i nakon nošenja. Ovi filteri mogu da budu efikasan način zaštite od očnih bolesti uzrokovanih plavim svetlom uz povećan komfor u obavljanju svakodnevnih aktivnosti.

Ključne reči:
naočare; filteri; boje; vidno polje.

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Introduction

The pigments in retinal photoreceptor cells absorb photons, initiating a chemical cascade of events known as phototransduction, thus converting light into electrical signals, sending them along the optical nerve to the upper neural structures for further analysis [1]. It has been documented that light causes apoptotic death of photoreceptors and retinal pigment epithelium (RPE) cells because of oxidative stress [2]. While excessive blue light is theoretically harmful, adequate blue light is necessary for normal visual function, such as colour discrimination and night vision, but also for circadian rhythm, which stimulates the brain to stay awake during the day, inhibiting melatonin secretion [3].

Artificial light sources, including light-emitting diode (LED) light bulbs and fluorescent light tubes, are the primary sources of blue light. With the increasing popularity of blue-rich LED-backlight display devices, such as smartphones, tablets, computer and television (TV) screens, our eyes are exposed to more blue light than in the past. Furthermore, not much is known about the safe levels of light exposure nor of the light spectrum for the retina and other ocular structures [4].

Blue light (short wavelength 400–455 nm) has been shown to be the most harmful to the retina [3–5]. It is known that the cornea and the lens are the structures that protect the eye from light-induced damage by preventing short wavelengths from reaching the retina. The cornea absorbs wavelengths below 295 nm, while the lens absorbs ultraviolet (UV) radiation (in the range of 300–400 nm) [6].

For this reason, many different filters which reduce that part of the visible spectrum have been developed in order to reduce the effect of blue light on the retina [7]. The nano-material based on fullerene C_{60} and polymethyl methacrylate (PMMA) has been used for nanophotonic contact lenses [8] and spectacles [9]. It has been shown that it transforms diffuse light into harmonized and hyper-polarized light, and these light photons have the same symmetry order (electrical and magnetic planes of photons in space and time) as biomolecules, which interact with light [10]. Moreover, these nanophotonic spectacles absorb the high-energy part of the visible light spectrum together with the UV light [11], resulting in a spectrum that is more comparable with the light sensitivity of the eye [12].

The aim of this prospective, interventional, comparative, non-randomized trial was to evaluate whether there is any subjective or objective impact on daily activities of the subjects during and after the use of the spectacles and any possible preference between them.

Methods

Spectacles A were commercially available lenses (Blue Glide, Pol Optic, Germany) with a narrow blue filter that blocks wavelengths below 410 nm. Spectacles B were nanophotonic lenses with a lower concentration of fullerene C_{60} (0.025%) that blocks wavelengths below 490 nm. Spectacles C were nanophotonic lenses with a higher concentration of fullerene C_{60} (0.034%) that blocks wavelengths below 530 nm. Spectacles D were commercially available lenses (Blue blocker Winter Sun, Pol Optic, Germany) with a broad blue filter that blocks wavelengths below 470 nm (Figure 1).

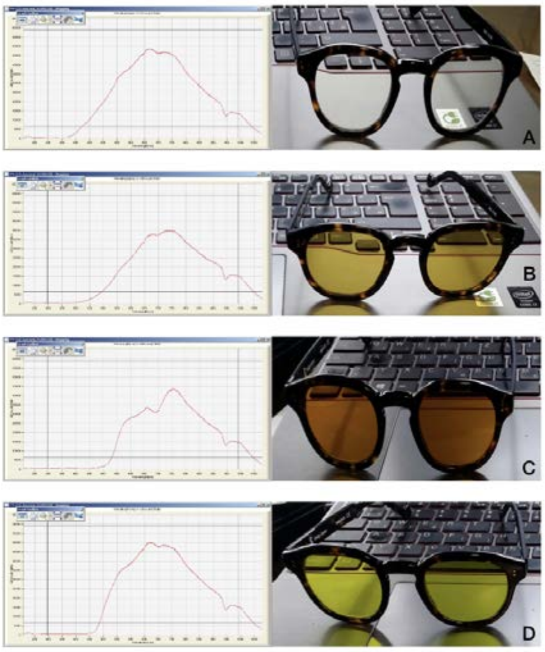

Fig. 1 – Lenses for different spectacles.
A – commercially available lenses with a narrow blue filter; B – nanophotonic lenses with concentration of fullerene (0.025); C – nanophotonic lenses with fullerene concentration of 0.034; D – commercially available lenses with a broad blue filter.

Table 1

Demographic characteristics of the study group (n = 25)

Characteristics	Values
Age (years), mean ± SD (range)	40 ± 11 (18–55)
Gender, n	
male	7
female	18
Dominant eye, n	
OD	21
OS	4
Refraction (D), mean ± SD (range)	
OD	0.23 ± 0.32 (-0.25 to 1.00)
OS	0.14 ± 0.24 (-0.25 to 0.50)
Tonometry (mmHg), mean ± SD (range)	
OD	11.84 ± 2.06 (9 to 16)
OS	11.72 ± 1.99 (9 to 16)

SD – standard deviation; OD – *oculus dexter* (right eye); OS – *oculus sinister* (left eye).

Twenty-five healthy participants (7 males and 18 females), aged 18–55 years (mean age 40 ± 11 years), were included in this pilot study. In twenty-one participants, the dominant eye was the right eye, while in four of them, the dominant eye was the left one (Table 1).

Exclusion criteria included the following: best corrected visual acuity worse than 1.0 in either eye, history of ocular diseases and surgeries, and abnormal colour vision based on the Ishihara colour vision test. All experimental procedures were approved by the Ethics Committee of the LaserFocus Centre for Eye Microsurgery (Belgrade, Serbia) and were conducted according to the principles expressed in the Declaration of Helsinki. Written informed consent was obtained from the participants, and all tests were conducted by one examiner (MJ) in the premises of the LaserFocus Centre for Eye Microsurgery.

On their first visit, the participants were subjected to a complete ophthalmological examination (distance and near visual acuity, refraction and eye dominance, slit lamp, tonometry, and fundus examination). Additionally, contrast sensitivity under standard conditions, colour discrimination, and visual field (24–2 program) were measured [13].

After four days of daily lens wear, subjective ratings of lens performance were collected by a Visual field (VF)-14 questionnaire regarding the quality of vision and comfort during different daily tasks without any spectacles. Questions about different situations, such as variable distances, object sizes, details, movement, and illumination, were combined.

All four pairs of spectacle lenses were delivered, with their identity hidden, as spectacles A, B, C, and D. The sequence of lens types was the same for each individual. All participants were asked to wear the assigned spectacles for a minimum of one day, 4 hours a day, for at least 15 minutes for each activity before assessing it in the questionnaire.

Spectacles A were commercially available lenses (Blue Glide, Pol Optic, Belgrade, Serbia) with a narrow blue filter, spectacles B were nanophotonic lenses with a lower concentration of fullerene C_{60} (0.025%), spectacles C were nanophotonic lenses with a higher concentration of fullerene C_{60} (0.034%), and spectacles D were commercially available lenses (Blue blocker Winter Sun, Pol Optic, Belgrade, Serbia) with a broad blue filter (Figure 1).

The participants were asked to use the spectacles in any daily situation, especially in the following situations: in a closed space with different types of illumination (computer, TV, tablet, mobile phone, books, newspapers and magazines); open space (walking in nature, on the streets, driving or being driven) during the day, at dusk and at night.

After the whole one-week wearing period, the visual performance and low light vision quality were assessed subjectively using a questionnaire (DA-16) and objectively - on visual acuity, contrast sensitivity, and visual field examination.

The participants would answer each of the 16 questions about how performing daily activities with a particular lens compared with the situation without the lens, and the mean score for each lens and each activity was calculated. Hence, the maximal score for all the participants for each lens would be 1.0 if all participants felt that this particular lens was better for a given activity, the minimal score would be 0 if none of the participants felt that this particular lens was better for a given activity, while the score would be 0.5 if the same number of participants stated that this particular lens was better or worse for a given activity than without using it.

The activity that was not performed by the participant was not statistically computed.

At the end of the study, the participants were asked to choose their preferred lens type among the four pairs of lenses, scoring them from 1 (very unsatisfactory) to 5 (very satisfactory).

Single-tailed paired Student's *t*-test and One-way repeated measures analysis of varience (ANOVA) were used for statistical analysis; the values of $p < 0.05$ were considered statistically significant.

Results

There was no statistical difference between the levels before and after wearing the spectacles measured by the Pelli-Robson contrast sensitivity chart with passive illumination both under artificial light (halogen source) or natural light (sunlight) ($p = 0.83$) (Table 2).

Regarding the comfort during different activities, while using the spectacles, a universal question for each activity was whether the specific spectacles help or not in a given activity compared with the ease of performing it without them. The participant scored 1 for positive and 0 for negative, while the score was not calculated in case the subject did not perform a specific activity.

As seen in Table 3, spectacles B had the best overall comfort mean score (0 to 1), where almost two-thirds of participants had the feeling that they performed better in their overall activities than without them ($p < 0.00001$).

The results, broken down into different activities, show that the majority of participants prefer spectacles B for near activities (print reading and fine near work), intermediate activities (computer), and distance ones (signpost and face recognition, driving); two-thirds of participants perform better both during the day and night, while four-fifths of them perform better only during the day.

More details on satisfaction scores (1 to 5) from DA-16 can be found in Table 4. Spectacles B were superior regarding the following daily activities: TV, computer, reading, and open space activities with a statistically high

Table 2

Visual field results

Statistics*	MD		PSD		Absolute scotomas		Relative scotomas	
	before	after	before	after	before	after	before	after
Mean	0.04	0.03	0.58	0.64	0.88	0.48	0.92	0.80
SD	0.14	0.11	0.46	0.43	0.97	0.51	0.91	0.82
min	-0.21	-0.22	0	0	0	0	0	0
max	0.27	0.24	1.3	1.44	3	1	4	2
p		0.36		0.25		**< 0.05**		0.31

***Single-tailed paired Student's *t*-test.**
MD – mean deviation; PSD – pattern standard deviation; SD – standard deviation; min – minimum; max – maximum.

Table 3

Comfort score during different activities

Statistics*	Spectacles†			
	A	B	C	D
Mean	0.55	**0.63**	0.28	0.61
SD	0.09	0.15	0.14	0.13
min	0.30	0.38	0.00	0.42
max	0.64	0.88	0.50	0.93
p	< 0.00001			

***One-way repeated measures analysis of variance (ANOVA).**
†For explanation see Figure 1.
SD – standard deviation; min – minimum; max – maximum.

Table 4

Satisfaction score during different daily activities One-Way repeated measures ANOVA

Parameters	Spectacles†				*p**
	A	B	C	D	
Television (TV)					
mean	3.68	**4.00**	2.32	3.24	**0.0001**
SD	1.28	1.29	1.25	1.56	
Reading					
mean	3.64	**3.84**	2.44	3.28	**0.0009**
SD	1.29	1.22	1.36	1.57	
Car					
mean	**3.68**	**3.68**	2.60	3.08	**0.002**
SD	1.28	1.18	1.26	1.44	
Fine work					
mean	3.41	3.65	**3.88**	3.41	**0.00356**
SD	1.37	1.37	1.27	1.54	
Outside					
mean	3.52	**4.04**	2.60	3.60	**0.0005**
SD	1.29	1.31	1.39	1.39	

***One-way repeated measures analysis of variance (ANOVA).**
†For explanation see Figure 1.
SD – standard deviation.

difference, while they were ranked 2nd for driving and fine manual work. Spectacles C were superior for fine manual work without reaching statistical significance.

Overall satisfaction scores (1 to 5) can be found in Table 5, where spectacles B were superior in terms of overall satisfaction regarding all combined daily activities (4.04 ± 1.1), which was statistically highly significant ($p = 0.0008$).

Table 5

Overall satisfaction score One-Way repeated measures ANOVA

Statistics*	Spectacles†				*p*
	A	B	C	D	
Mean	3.12	**4.04**	2.68	3.72	0.0008
SD	1.05	1.10	1.25	1.37	

***One-way repeated measures analysis of variance (ANOVA).**
†For explanation see Figure 1.
SD – standard deviation.

Discussion

Wavelengths can activate rhodopsin range from 400 nm to almost 600 nm [12]. Not all parts of the spectrum affect retinal cells equally: the one above 500 nm wavelengths excites rhodopsin and generates toxic waste but does not cause retinal degeneration; the other part of the spectrum, below 500 nm, causes retinal degeneration in addition to toxic waste. Rhodopsin and its sub-products of excitation seem to have a major role in retinal damage [5].

After photo-stress, cones and rods die by apoptosis, thus rendering irreversible loss of retinal function. A large number of photoreceptors could survive by using the filters which allow survival, but still, there will be morphological and functional alterations in the retina [2]. On the contrary, a full recovery of functional responses after nine months of light deprivation has also been reported, even after having suffered a 50% reduction caused by photo-stress [5]. The number of absolute scotomas in our study was statistically significantly decreased after the use of the spectacles. Considering the fact that the absolute scotoma means that there is a permanent decrease in sensitivity to the light stimulus of that area of the retina, differently from the relative one where there is a relative decrease, one could postulate that we could witness the full functional recovery after using protective blue-light filtering lenses, as suggested by Vicente-Tejedor et al. [5].

Therefore, it is reasonable to think that photo-stress injury could be mitigated enough for getting a full recovery later [5]. Moreover, protecting the photoreceptors by decreasing their exposure to the high-energy blue part of the spectrum in order to reduce the risk of age-related macular degeneration (AMD) would make sense. Blue-filtering intra-ocular lenses with a UV filter that are implanted after the cataract surgery have been used with such intention without conclusive results [14, 15].

However, AMD is a multifactorial eye disease, which has risk factors including age, smoking, nutritional status, sunlight exposure, and genetic background [16, 17]. Moreover, the disease takes years to develop and progress, which makes it difficult to directly comprehend the protective efficacy of the blue-light filtering lenses in human eyes. A large population prospective study might answer that question.

Indoor lighting or screens use LED lamps that may be of concern if used for extended viewing times and at a short distance. While we can protect ourselves from the natural blue light by wearing filtering glasses, it is more difficult to do so in internal lighting. One of the suggested solutions is to restrict its use to "white warmth" lamps (2700 K). As far as organic light emmiting diode (OLED) or active matrix organic light emmiting diode (AMOLED) screens are concerned, the only effective protection is to use them occasionally and only for a short period of time [18].

On the other hand, O'Hagan et al. [19] reported that even under extreme long-term viewing conditions, none of the assessed sources (fluorescent lamps and LED, computer screens, tablet computers, laptops, and smartphones) suggested a cause for concern for public health. In terms of blue light hazard, the domestic lamps had a range from 10–20% of the exposure limit, assuming intentional long-term viewing. At the same time, knowing that the percentage of blue light transmission from the corneal surface to the retina is higher for children than for adults, such sources could be distressing for children while for adults they are uncomfortable to view [19].

Our study showed that subjectively spectacles B with a lower concentration of fullerene C_{60} were statistically significantly superior in all different daily activities: for near (reading paper print or doing fine manual work), for mid-distance (computer work), and for distance (sing posts, street signs, face recognition, driving).

It is interesting to observe that static vision (e.g., street signs or face recognition) was good both during the day and at night, while dynamic vision (driving) was more comfortable only during the day. This would be in line with the studies by Leung et al. [7] and Spalton et al. [12] that point out that adequate blue light is necessary for normal visual function, such as in colour discrimination and night vision. Under low-light conditions, the overall number of photons is generally reduced. Therefore, any additional loss that happens in the high-energy blue light with these lenses might reduce them below the threshold of comfort. Spectacle lenses with an even lower concentration of fullerene might be useful under low-light conditions while driving, as well as during foggy weather.

Although day driving has been reported as significantly more comfortable with spectacles B, some participants complained about the internal reflections of the dashboard onto the windshield. Differently from traditional polarized spectacles that prevent diffuse light from the inside of the cabin to reflect from the windshield, the hyper-polarized light does not attain the same level of comfort in this task. A combination of hyper-polarizing fullerene filter and traditionally linearly polarizing coating might make a perfect combination.

It has been shown that nanophotonic glasses transform daily sunlight, LED white light, neon light, mobile phone and TV screen light into a light spectrum that is more comfortable to the human eye [11]. The efficiency of nanophotonic harmonized light and nanophotonic hyper-polarized light in medicine, compared to traditional light sources (linearly polarized, colour light, and laser), is 20–40% higher. The reason for this lies in the fact that nanophotonic harmonized and hyper-polarized lights affect the tissue not only from an energy point of view but because "structured light meets structured matter", as the resonance of the icosahedral (orientation-preserving) symmetry order of light (photons) and the order of structure-energy-information synergy of biomolecules.

A pilot study showed that the use of nanophotonic glasses also balances the serotonin/melatonin ratio, which also had a positive effect on behaviour, reducing anxiety and depression while meliorating sleep quality [11]. The harmonized light interacts with the biomolecules and may initiate the restoration of the disrupted symmetry. During this process, it might influence the brain waves through retinal ganglion cells rather than the photoreceptors pathway and thus influence the pineal gland function and the levels of neurotransmitters in the brain [3].

Further studies that are in progress include validation of the results presented herein in a larger sample of participants. They also include some specific modifications, such as different and longer wear regimes, diverse and more controlled ambient light sources. Moreover, these studies set with patients in whom the benefit of blue-blocking is expected, such as patients with corneal oedema and early cataract, with macular degeneration or glaucoma neural damage, in pseudophakic patientsm, or patients with low myopia or astigmatism.

Conclusion

It was shown that using blue-blocking filters with fullerene C_{60} can significantly decrease the high-energy blue part of the spectrum present in natural and artificial light sources. At the same time, they increase the overall comfort of daily tasks during and after their use. Therefore, these filters might be an effective mechanism to protect us from ocular pathologies alleviating the functional loss of retinal photosensitive cells if the expected exposure to the blue-rich light in the living ambient is high and long enough.

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Received on February 19, 2019.
Accepted on July 18, 2019.
Online First September, 2019.