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KLINIČKI EFEKAT NANOFOTONSKIH NAOČARA S PLAVIM FILTROM NA BAZI FULERENA C60 I PMMA

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Clinical Impact of Nanophotonic Blue-Light Filtering Spectacle Lenses based on fullerene C60 and PMMA

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Nanophotonic fullerene C60/PMMA Lenses
Nanofotonske naočare s fulerenum C60/PMMA

Jankov: study design, study execution, writing, correcting
Jaksic: study design, writing, correcting
Koruga: study design, writing, correcting
Koruga holds a patent for the method of manufacturing an optical filter with fullerene C60.
Other authors have no conflict of interest to disclose

Clinical Impact of Nanophotonic Blue-Light Filtering Spectacle Lenses based on fullerene C60 and PMMA
Abstract

Background / Aim. Blue light might be harmful to the retina. The nano-material fullerene C60 and PMMA transforms light into harmonised light and absorbs violet, blue and UV wavelength. The aim was to evaluate subjective or objective impact on daily activities using the spectacles. Methods. Twenty-five healthy participants have been submitted to contrast sensitivity (CS) and visual field (VF) testing, and a questionnaire about the influence of spectacles on daily activities: two with different concentration of fullerene C60 vs. two commercially available blue-blocking spectacles. Results. There was no statistical difference in CS (p=0.83), in VF parameters MD (mean deviation )(p=0.36), PSD (pattern standard deviation) (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 lower concentration of fullerene 0.025%) had the best overall comfort mean score (p<0.00001): four-fifths of them performs better only during the day, while two-thirds both day and night. Spectacles B were also superior in overall satisfaction regarding all the combined daily activities (4.04 +/- 1.1) (p=0.0008). Conclusions. Blue-blocking filters with fullerene C60 increases the overall comfort of daily tasks while and after using them. These filters might be an effective mechanism to protect us from ocular pathologies while providing a better comfort in daily activities.

Key words: phototoxicity, blue-light hazard, fullerene C60, lens filter, visual field, contrast sensitivity.

Apstrakt

Uvod / Cilj. Plavo svetlo može da bude štetno za retinu. Nano-materijal od fulerena C60 i 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 je podvrgnuto kompletnom oftalmološkom pregledu, ispitivanju kontrastne senzitivnosti (KS) i perimetrije (PM). Popunjava se upitnik o uticaju naočara na dnevne aktivnosti: dvoje naočara sa različitim koncentracija fulerena C60 upoređeno je sa dvoje komercijalno dostupnim naočarima sa plavim filtrom. Rezultati. Nije postojala statistička razlika u KS (p=0.83), kod PM parametri MD (mean deviation)(p=0.36), PSD (pattern standard deviation) (p=0.25), i kod broj 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%) su imali 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 filtrom na bazi fulerena C60 povećava sveukupan komfor u obavljanju dnevih aktivnosti pri i posle njihovih nošenja. Ova sočiva mogu da budu efikasan način zaštite od očnih bolesti uzrokovanih plavim svetlom uz povećan komfor u obavljanju svakodnevnih aktivnosti.

**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 RPE cells because of the oxidative stress. [2] While excessive blue light is theoretically harmful, adequate blue light is necessary for normal visual function, such as in colour discrimination and night vision, as well as for circadian rhythm by stimulating the brain to stay awake during the day inhibiting melatonin secretion. [3]

Artificial light sources, including LED (light-emitting diode) 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 mobile smartphones, tablets, and computer and TV screens, our eyes are exposed to more blue light than in the past, while not much is known about the safe levels of light exposure nor of 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 UV radiation (in the range of 300–400 nm). [6]
For this reason, many different filters that reduce that part of the visible spectrum have been developed in order to reduce the effect of blue light on the retina. [7] The nanomaterial based on fullerene C60 and PMMA has been used for nanophotonic contact lenses [8] and spectacles. [9] It has been shown to transform diffuse light into harmonised and hyper-polarised 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-randomised 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

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

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

Exclusion criteria included: 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 LaserFocus 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 LaserFocus - Centre for Eye Microsurgery.

On their first visit the participants were subject 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 questionnaire VF-14 regarding the quality of vision and comfort during different daily tasks without any spectacles. Questions regarding different situations meaning variable distances, object sizes, details, movement and illumination have been 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 of daily use and for a minimum of 15 minutes for each activity before assessing it in the questionnaire.

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

The participants were asked to use the spectacles in any daily situation, especially: in a closed space with different types of illumination (computer, TV, tablet, mobile telephone, books, newspapers and magazines); open space (walking in the nature, on the streets, driving of being driven) during the day, at dusk and at night.
After the whole weekly wearing period, the visual performance and low light vision quality were assessed subjectively using a questionnaire (DA-16), as well as 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 compares with the situation without the lens, and the mean score for each lens and each activity was calculated. Hence, maximal score for all the participants for each lens was 1.0 (if all the participants felt that this particular lens was better for a given activity), 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 there was the same number participants stating that this particular lens was better and worse than without it.

The activity that the participant did not perform 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 t-test i One-Way repeated measures ANOVA were used for statistical analysis, and the values of p<0.05 were considered for statistical significance.

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

There was no statistical difference in MD (mean deviation) (p=0.36), PSD (pattern standard deviation) (p=0.25) and number of relative scotomas (p=0.31), while the number of absolute scotomas showed a statistically significant decrease (p<0.05), as shown on Table 2.

Regarding the comfort during different activities while using the spectacles, a universal question for each activity was if the specific spectacles do or do not help in a given activity.
compared with the ease of performing it without them. The participant scored 1 for positive, 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), having almost two-thirds of participants feeling they performed better in their overall activities than without them (p<0.00001).

The results broken down into different activities show that 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 them performs better both during the day and night, while four-fifths of them performs better only during the day.

More details of the satisfaction scores (1 to 5) from DA-16 can be appreciated in Table 4. Spectacles B were superior regarding the following daily activities: TV, computer, reading and open space activities with statistically high difference, while they were placed 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 appreciated on Table 5, where Spectacles B were superior in the terms of overall satisfaction regarding all the combined daily activities (4.04 +/- 1.1), which was statistically highly significant (p=0.0008).

**Discussion**

Wavelengths that can activate rhodopsin range from 400 nm to almost 600 nm [12]. Not all parts of the spectrum affect equally retinal cells: 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]

Cones and rods after photo-stress die by apoptosis rendering thus irreversible loss of retinal function. A large number of photoreceptors could survive by using the filters allows the survival, but still there will be morphological and functional alterations in the retina. [2] On the contrary, it has been also reported a full recovery of functional responses after a deprivation of light for nine months, 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 mean that there is a permanent decrease in sensitivity to the light stimulus of that area of retina, differently from the relative one where there is a relative decrease, one could postulate that we could witness the full functional recovery after the use of protective blue-light filtering lenses, as suggested by Vicente 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 it would make sense to protect the photoreceptors by decreasing their exposure to the high energy blue part of spectrum with the intention of reducing the risk of age-related macular degeneration (AMD). Blue-filtering intra-ocular lenses with UV filter that are implanted after the cataract surgery have been used with such intention without conclusive results. [14]-[15]

However, AMD is a multi-factorial 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 they are used for extended viewing times and at short distance. While we can protect ourselves from natural blue light by wearing filtering glasses, it is more difficult to do so in internal lighting. One of the suggested solutions is that its use should be restricted to “white warmth” lamps
(2700 K). As far as OLED or AMOLED screens are concerned, the only effective protection consists of using them occasionally and only for a short period of time. [18]

On the other hand, O’Hagan et al. 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 cause for concern for public health. In terms of blue light hazard the domestic lamps ranged from 10 to 20\% of the exposure limit, assuming intentional long-term viewing. At the same time, knowing that the percentage of transmission of blue light from the corneal surface to the retina is higher for children than for adults, where such sources are uncomfortable to view for adults, they could be distressing for children. [19]

Our study showed that subjectively the Spectacles B with lower concentration of fullerene 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 (sign posts, street signs, facial recognition, driving).

It is interesting to observe that static vision (ex. street signs or facial recognition) was both good during the day and at night, while dynamic vision (driving) was more comfortable only during the day. This would be in line with Leung et al. pointing out that adequate blue light is necessary for normal visual function, such as in colour discrimination and night vision. [12] Under the 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 even lower concentration of fullerene might be useful under the low-light conditions while driving, as well as during foggy weather.

Although day driving has been reported as significantly more comfortable with the Spectacles B, some participants complained about the internal reflections of the dashboard onto the windshield. Differently from traditional polarised spectacles that prevent diffuse light from inside the cabin to reflect from the windshield, the hyper-polarised light does not
attain the same level of comfort in this task. A combination of hyper-polarising fullerene filter and traditionally linearly polarising 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 light spectrum which is more comfortable to human eye. [11] The efficiency of nanophotonic harmonised light and nanophotonic hyper-polarised light in medicine, compared to traditional light sources (linearly polarised, colour light and laser), is 20-40% higher. The reason for this lies in the fact that nanophotonic harmonised and hyper-polarised lights affect the tissue not only from energy point of view, but because “structured light meets structured matter”, as the resonance of the icosahedral symmetry order of light (photons) and the order of structure-energy-information synergy of biomolecules. [11]

A pilot study showed that the use of nanophotonic glasses also balances the serotonin/melatonin ratio, which also had a positive effect on their behaviour, reducing their anxiety and depression, while meliorating their sleep quality. [11] The harmonised 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 course include validation of herein presented results in a larger sample of participants, as well as some specific modifications, such as different and longer wear regimes, diverse and more controlled ambient light sources, and also set with patients where benefit of blue-blocking is expected, such as in patients with corneal oedema and early cataract, with macular degeneration or glaucoma neural damage, in pseudophakic patients or in patients with low myopia or astigmatism.

**Conclusions**

In summary, it was shown that the use of blue-blocking filters with fullerene C60 can significantly decrease the high-energy blue part of the spectrum present in natural and artificial light sources, and at the same time increase the overall comfort of daily tasks while and after using them. 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.

References


### TABLE 1. DEMOGRAPHIC CHARACTERISTICS OF THE STUDY GROUP

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<td>Tonometry</td>
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<td>OS: 11.72 +/- 1.99 (9 to 16) mmHg</td>
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### TABLE 2. VISUAL FIELD RESULTS

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single-tailed paired Student t-test
### TABLE 3. COMFORT SCORE DURING DIFFERENT ACTIVITIES

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*p < 0.00001

One-Way repeated measures ANOVA

### TABLE 4. SATISFACTION SCORE DURING DIFFERENT DAILY ACTIVITIES

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*p = 0.0001
*p = 0.0009
*p = 0.002
*p = 0.00356
*p = 0.187803
*p = 0.0005

### TABLE 5. OVERALL SATISFACTION SCORE

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*p = 0.0008
One-Way repeated measures ANOVA

Fig 1

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