IL NUOVO CIMENTO **46 C** (2023) 176
DOI 10.1393/ncc/i2023-23176-8

Communications: SIF Congress 2022

Photochromic contact lenses: Optical analysis and visual effects of their transition dynamics

E. Sartoretto, F. Kryeziu, A. Rossetti, P. Gheller and G. Ruffato(*)
Department of Physics and Astronomy "G. Galilei", University of Padova - Padova, Italy

received 20 February 2023

Summary. — Since their introduction, the evolution of contact lenses has been mainly routed by criteria of wearing comfort, increased oxygen permeability, and correction of refractive errors, while less attention has been paid to the improvement of visual functions. More recently, a new type of contact lenses has been designed and marketed. This type of lenses contain photochromic additives that enable filtering in the visible range depending on the intensity and spectrum of environmental light. In this work, we have characterized the dynamics over time of commercial photochromic contact lenses in order to quantify their filtering effect in the visible as a function of the input wavelength and estimate the transition time necessary for their activation and deactivation. In addition, we have investigated the influence of photochromic contact lenses on visual functions during specific indoor and outdoor activities. The present research encompasses an optical characterization of the constituent photosensitive material and a preliminary investigation of the expected visual benefits provided by the use of this new type of optical devices.

1. – Introduction

Despite the filtering action of the atmosphere, a non-negligible amount of UV rays, especially UVA and UVB, reaches the surface of the Earth. Such wavelengths are filtered out by the outer parts of the eye, especially by cornea and lens, however, an excessive exposure to UV radiation has been demonstrated to be correlated to conjunctival diseases such as pinguecola and pterygium, photokeratitis, cataracts, and solar retinopathy [1]. Also the cumulative exposure to short-wavelengths in the visible, *i.e.*, blue light, can be harmful and damage the eye, promoting age-related macular degeneracy and other retinal diseases [2, 3]. In addition, exposure to blue light before bedtime can interfere with sleep-wake cycle, stimulating ganglion cells to produce melanopsin which regulates

(*) E-mail: gianluca.ruffato@unipd.it

Creative Commons Attribution 4.0 License (https://creativecommons.org/licenses/by/4.0)

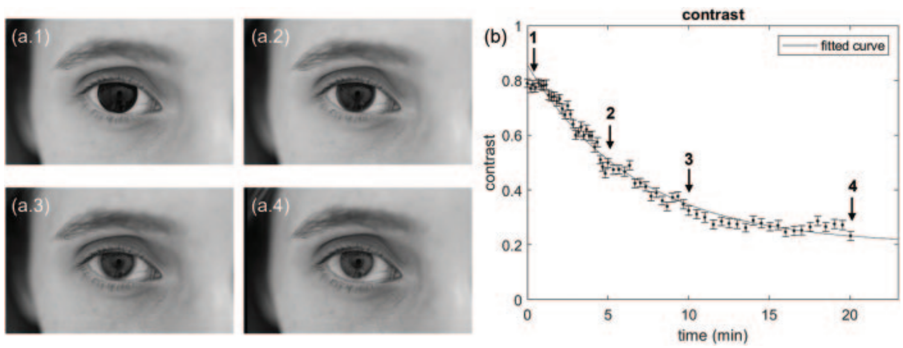

Fig. 1. – Pictures of a subject under test wearing an activated photochromic contact lens during lens deactivation. (a) Evolution in time of the activated photochromic contact lens (maximum activation using a UV pointer) (a.1), after 5 min (a.2), 10 min (a.3), and 20 min (a.4). (b) Calculated contrast between coated and uncoated zones of the sclera and fit using an exponential curve. Estimated relaxation time: (6.69 ± 0.41) min.

the circadian rhythm [4]. For all the above reasons, wearing light filters can influence the visual related functions or be recommended for the safety of our eyes [3, 5].

A smart solution combining both types of protections is provided by Johnson & Johnson. ACUVUE® OASYS with Transitions™ contact lenses [6] are spherical contact lenses [7] made of silicone hydrogel material (senofilcon A) with an internal wetting agent, including two different UV-absorbing molecules: Benzotriazole monomers, absorbing UV light so to achieve a transmission of less than 1% in the UVB range (280–315 nm) and less than 10% in the UVA (315–380 nm), and a photochromic additive represented by naphthopyran monomers, which quickly change their molecular structure from a closed to an open form in the presence of UV light, activating absorption in the visible range. The reaction is reversible, then the lens becomes transparent again when no longer exposed to UV light, as shown in fig. 1(a). Taking a sequence of pictures and analysing the contrast between coated and uncoated zones of the sclera, it is possibile to obtain a rough estimate of the deactivation time. The influence of photochromic contact lenses on visual performances has been recently investigated [8] [9].

In this work, we have characterized the transmittance of such contact lenses between 420 and 800 nm in order to compare the optical response between the transparent and the maximum activated configurations. In particular, we have studied their transition dynamics during both the activation and deactivation processes to infer an estimate of their typical relaxation time. Finally, we conducted preliminary visual tests on a group of subjects to analyse the influence on visual acuity and contrast sensitivity.

2. – Optical characterization

2·1. *Experimental setup.* – The transmission of a photochromic contact lens (−1.0 D) has been characterized in the laboratory as a function of time during the activation and deactivation processes. A specific characterization setup was arranged on an optical table (fig. 2). A supercontinuum laser (SuperK Compact, NKT Photonics) was used, emitting coherent white light, followed by a monochromator in the visible range (SuperK Varia, NKT Photonics, 400–840 nm) with a minimum bandwidth of 10 nm. The lens was sandwiched between two thin cover glasses (CG15XH1, Thorlabs) and fixed into a

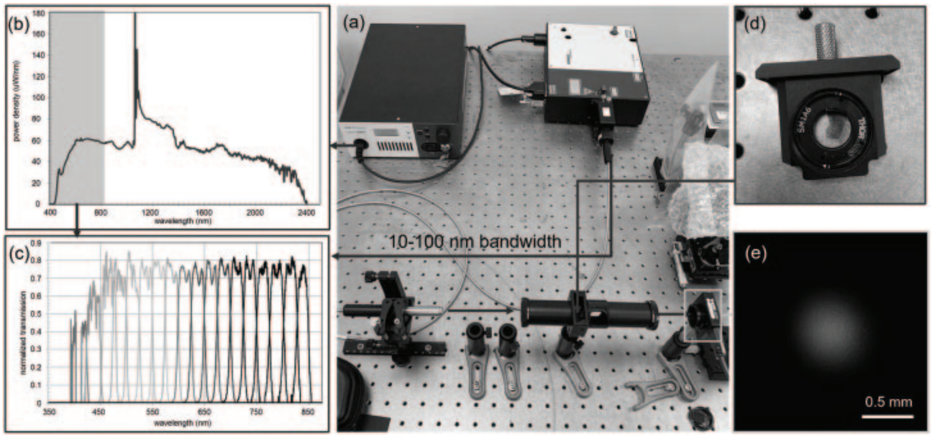

Fig. 2. – (a) Experimental setup for indoor characterization of photochromic contact lenses: supercontinuum laser (SuperK Varia, NKT Photonics) power output (μW/nm) (b) and normalized intensity with 10 nm bandwidth selection (c) using a monochromator in the visible range (SuperK Varia, minimum bandwidth 10 nm). The lens is cut, sandwiched between two glasses (c), and inserted inside a lens tube setup (a). The transmitted beam (e) is collected using a 10-bit colour camera (Zelux CMOS Camera).

filter holder (CFH2R/M, Thorlabs), which could be easily inserted and removed with high repeatability. Two lens tubes were connected at the two sides of the cage plate and closed with two iris diaphragms to protect the lens from environmental light during measurements. In particular, one of the two tubes had a slot (SM1L10C, Thorlabs), closable by a rotable slip shield, in order to open a temporary access for lens activation using an external UV pointer (for activation analysis). Finally, the transmitted beam was collected by a CMOS camera (Zelux CMOS camera 1080×1440 pixels, 3.45 μm, 10 bit).

2˙2. *Transmission analyses*. – The transmission of the activated lens was analysed in the visible range between 420 and 800 nm, with a wavelength step of 20 nm. After activating the lens for 30 s under the exposure to 4 Xenon lamps (365 nm, 36 W in total), it was quickly inserted inside the lens tube setup and the acquisition started, collecting the transmitted beam over 22 minutes every 20 s. In fig. 3(a) the transmitted energy (a.u.) is reported for $\lambda = 520$ nm. In particular, the figure shows the integrated energy over a region of interest (ROI) of the whole camera including the beam. As expected, the intensity increases as a function of time, then it is possible to obtain an estimate of the relaxation time from an exponential fit. The average time is 7.17 ± 0.02 min. The result is consistent with the trend and estimate in fig. 1(b) based on contrast analysis between two different points of the eye. In a similar way, we studied the activation dynamics within the same range, which resulted to be a much faster process. In this case, the acquisition started before lens activation, then the lens was exposed to a UV pointer (405 nm). As shown in fig. 3(b) for the wavelength of 600 nm, as soon as the lens is exposed, the transmission drops abruptly in a few seconds, with a characteristic time lower than 0.5 s for all the wavelengths.

In fig. 4(b) the whole deactivation plot in the visible is reported as a function of time for all the wavelengths under consideration. In particular, the energy collected with the activated/deactivated lens is normalized by the energy collected over the same ROI and

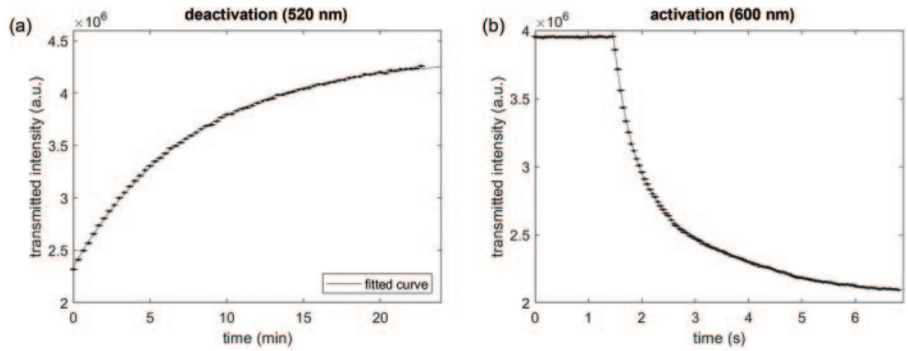

Fig. 3. – Examples of beam acquisitions in time for deactivation (a) and deactivation (b). Data refer to the energy integrated over a region of interest (ROI) of the camera including the transmitted beam (fig. 2(e)).

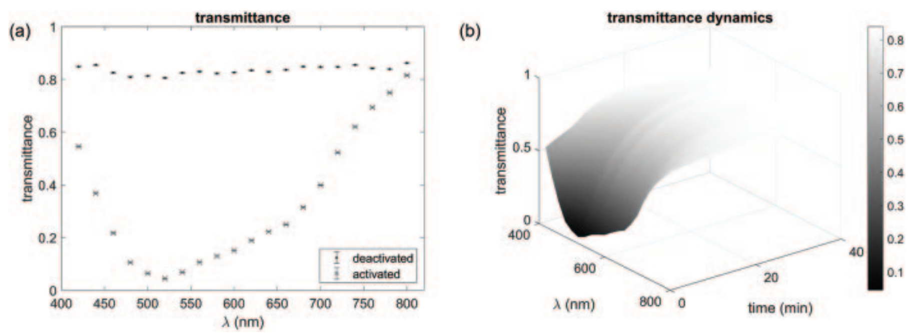

Fig. 4. – (a) Transmittance of activated and deactivated photochromic contact lens in the range under consideration, and whole deactivation dynamics in time (b).

time interval without the lens mounted on the holder (normalized transmission). For the completely activated lens, the transmission exhibits a sort of double-U shape (fig. 4(a)), with an absolute minimum around 520 nm. There is a good absorption in the blue range, while the transmission increases for increasing wavelengths towards the near infrared.

3. – Visual tests

3·1. *Protocols.* – Then, we investigated the influence of activation and deactivation on the visual performance. Visual tests were performed on a group of 10 people of different age (between 22 and 57), sex (50% men, 50% women), and refractive errors. The free software FrACT (`https://michaelbach.de/fract/`) was used, placing a laptop at a distance of 3 m from the observer. The software implements optimized psychophysical tests to converge quickly (15 trials) to an estimate of the visual acuity and contrast sensitivity of the subject. The progression of optotypes relies on a Bayesian approach and is determined by a modified Best-PEST strategy [10, 11]. For visual acuity, Sloan letters were selected, while for contrast sensitivity 4 random orientations of tumbling Landolt C were used. All the participants were recruited after explanation and informed consent. The research was carried out in accordance with the Declaration of Helsinki.

TABLE I. – *Indoor tests during photochromic contact lenses deactivation: Pearson's correlation coefficient ρ for visual acuity (VA, (dec)) and contrast sensitivity (CS, (%Weber)) as a function of time for the 10 subjects under test.*

ρ	GM	MF	M	MM	GR	ES	FK	LK	DT	AF
VA	0.21	0.63	0.48	0.21	0.29	0.23	0.14	0.45	0.42	0.34
CS	−0.19	−0.34	−0.24	−0.27	−0.37	−0.08	−0.28	−0.38	−0.22	−0.09

3˙2. *Indoor tests (deactivation).* – The subjects were required to wear the photochromic contact lenses (with their usual correction) just after activation by means of a UV pen (405 nm), and to repeat the tests indoor every one minute for twenty minutes and for three times. In fig. 5 the results for three subjects are reported. There is substantially a good stability of the visual performance in time. For all the ten subjects, a slight improvement of both visual acuity and contrast sensitivity can be noticed during activation, however the Pearson's correlation coefficient $|\rho|$ is generally weak ($|\rho| < 0.3$) or moderate ($0.3 < |\rho| < 0.7$) (table I) [12].

3˙3. *Outdoor tests (activation).* – The group was required to repeat the same tests outdoor in the morning (9 a.m.), at midday, and in the late afternoon (around 5 p.m.),

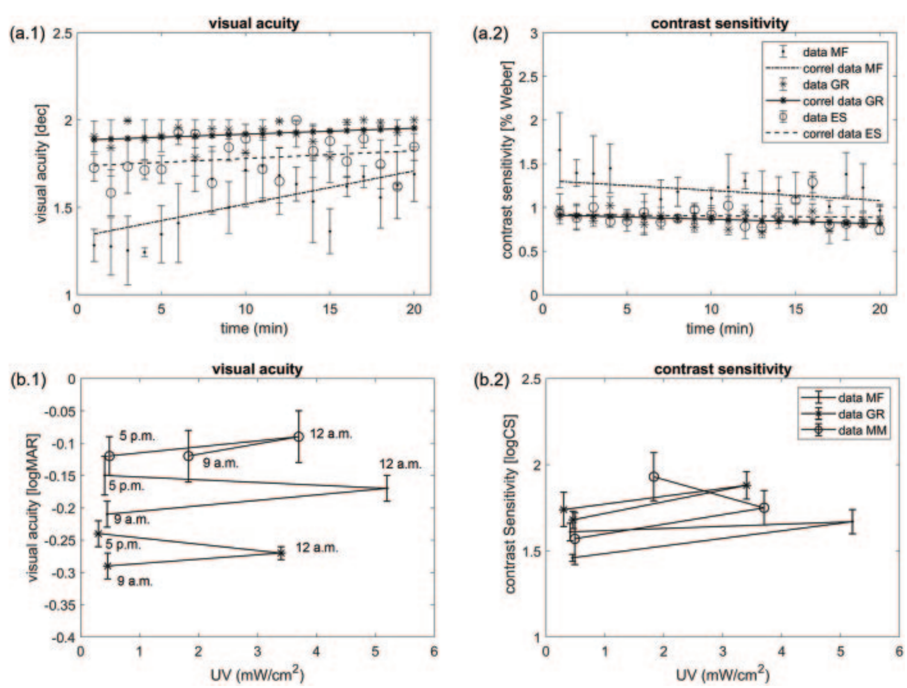

Fig. 5. – Examples of visual performance for subjects wearing photochromic contact lenses during indoor deactivation (a.1,2), and outdoor activity (b.1,2). Analysis of visual acuity (a.1, b.1) and contrast sensitivity (a.2, b.2).

during a sunny day in mid-July in Padova, for three times in sequence. In fig. 5, the plot of the visual performances for three subjects is reported as a function of the UV solar intensity, measured using a UV sensor (GY/ML8511, 280–390 nm) connected to an ARDUINO board. Again, preliminary results suggest no significant influence on visual performance for all the individuals, while the lens adapted promptly to the outdoor UV intensity, as declared by the subjects and as verified by visual inspection.

4. – Conclusions

We considered the commercial photochromic contact lenses ACUVUE® OASYS with Transitions™ marketed by Johnson & Johnson. We characterized the (de)activation process and performed preliminary tests on visual performances in terms of visual acuity and contrast sensitivity. The lenses indeed adapt promptly to the UV level in order to filter the visible spectrum. High protection from UVA, UVB, and shorter visible wavelengths (blue light) is provided. The lens activates in a few seconds when exposed to UV radiation, while the deactivation process is quite longer, with an average characteristic time around 7 minutes. The influence on visual acuity and contrast sensitivity is not significant in constant conditions, showing a weak improvement during deactivation. The results are limited to the test conditions described above. In particular, it is worth noting that the lens has been activated using artificial UV illumination in order to achieve the maximum activation level possible.

* * *

The authors acknowledge all the subjects who spent their time for their visual tests.

REFERENCES

[1] Ivanov I. V., Mappes T., Schaupp P., Lappe C. and Wahl S., *J. Biophoton.*, **11** (2018) e201700377.
[2] Liang L., Cui Z., Lu C., Hao Q. and Zheng Y., *BMC Ophthalmol.*, **17** (2017) 49.
[3] Margrain T. H., Boulton M., Marshall J. and Sliney D. H., *Prog. Retin. Eye Res.*, **23** (2004) 523.
[4] Wahl S., Engelhardt M., Schaupp P., Lappe C. and Ivanov I. V., *J. Biophoton.*, **12** (2019) e201900102.
[5] Backes C., Religi A., Moccozet L., Behar-Cohen F., Vuilleumier L., Bulliard J. L. and Vernez D., *J. Expo. Sci. Environ. Epidemiol.*, **29** (2019) 753.
[6] Buch J., Hammond B. R. and Ruston D., *Johnson & Johnson Vision Care* (2018), URL `https://jnjvisionpro.co.uk/sites/uk/files/public/content/en-GB/resource-library/pp2021aot4136_-_the_contact_lens_with_seven_dimensions_for_exceptional_visual_performance.pdf`.
[7] Key J. E., *Eye Contact Lens*, **33** (2007) 343.
[8] Renzi-Hammond L. M., Buch J. R., Cannon J., Hacker L., Toubouti Y. and Hammond B. R., *Contact Lens Anterior Eye*, **43** (2020) 250.
[9] Renzi-Hammond L. M., Buch J. R., Hacker L., Cannon J. and Hammond B. R., *Optom. Vis. Sci.*, **97** (2020) 526.
[10] Bach M., *Optom. Vis. Sci.*, **73** (1996) 49.
[11] Bach M., *Graefes Arch. Clin. Exp. Ophthalmol.*, **245** (2007) 965.
[12] Ratner B., *J. Target. Meas. Anal. Mark.*, **17** (2009) 139.