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Brain correlates of adaptation to multifocal contact lenses

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Summary. — One common option to correct presbyopia is providing simultaneous images with multifocal contact lenses (MCLs). However, patient satisfaction with MCLs is not uniform and fully predictable and it might be modulated by neuroadaptation mechanisms. Using another technique to correct presbyopia with CLs called monovision, the visual evoked potential (VEP) evidenced, after a short period of adaptation to monovision, a compensatory activity in anterior cortical areas used to counteract the degraded V1 signal induced by this kind of correction. This compensatory activity was considered cognitive rather than sensorial. The purpose of the present study was to explore, with the use of VEP with a high-density electrode array, whether this kind of compensation in anterior cortical areas of the brain is present in presbyopes corrected with MCLs too. Multifocal presbyopia corrections produced a loss of feedforward activity in the primary visual cortex but no modulation over anterior cortical areas as the one recorded in monovision. This result suggests that the possible nature of neural compensation for MCLs is not cognitive as in monovision.

1. – Introduction

It has been estimated that by the year 2050 presbyopia will affect about 2 billion people worldwide [1]. Multifocal Contact Lens (MCL) can correct presbyopia using a certain amount of spherical aberration which generates simultaneous images on the retina, for far and near distances [2]. Despite the increase of depth of focus which helps presbyopia correction, spherical aberration induces a decrease of the retinal image at the best focus [3]. Patient satisfaction with MCLs is not uniform and fully predictable [4]. Some forms of neural adaptation may compensate for the visual disturbances due to the drawbacks of these devices. Using another technique to correct presbyopia with CLs called monovision, in which one eye is optically corrected for far distance and the other for near distance [5, 6], the visual evoked potential (VEP) evidenced a compensatory activity in anterior cortical areas used to counteract the degraded V1 signal [7]. The purpose of the present study is to explore whether this kind of compensation in anterior cortical areas of the brain is present in presbyopes corrected with MCLs too.

2. – Materials and methods

2˙1. *Participants.* – Fifteen healthy presbyopes (mean age 51.8±2.6 years; range 45.3–55.4 years; six males) who had previously not been fitted with MCLs were enrolled if non MCLs, with good binocular vision (no strabismus and stereoacuity no lower than 160 sec of arc) and no anomalies in ocular motility were enrolled. The study was conducted in accordance with the Declaration of Helsinki, all participants gave written informed consent, and the study was approved by the Ethics Committee of Fondazione Santa Lucia (Rome, Italy) Prot. CE/PROG.798.

2˙2. *Materials.* – Silicone hydrogel daily disposable CLs in multifocal and monofocal design (Dailies TOTAL1TM; Alcon Laboratories, Fort Worth, TX, USA), were used throughout the study. These CLs are made in delefilcon A, with a back optic zone radius of 8.5 mm and a total diameter of 14.1 mm. Their core equilibrium water content is 33% and Dk/t of 156 Fatt units (at −3.00 DS). The far distance power of the MCLs was determined for each participant equal to the Mean Spherical Equivalent worked out on the monocular subjective refraction least minus/most plus adjusted for the vertex distance. Two additions (low and medium) were selected for the MCLs.

2˙3. *Preliminary visual assessment and MCLs assessment.* – A comprehensive optometric examination of each participant was performed before the VEP experiment. Participants were required to fill the Italian version of the Near Activity Vision Questionnaire (NAVQ) [8], which provides a measure of the subjective satisfaction with the quality of vision at near without the use of any correction. A non-cycloplegic subjective refraction was carried out monocularly to determine the subjective refraction least minus/most plus. Addition for a distance of 40 cm was firstly determined according to the expected age procedure [9] and then adjusted subjectively. Monocular and binocular best corrected visual acuity (both at far and near distance), binocular functionality (vergence fusional status, fixation disparity, stereopsis and central suppression; [10]) ocular motility, accommodation, and reading performance (Radner test; [11] were assessed with the appropriate correction for the examination distance arranged on a trial frame. After a preliminary visual assessment, monofocal for near distance (Mean Spherical Equivalent of the subjective refraction plus addition) and MCLs with the two additions were fitted

Fig. 1. – Letter array used as stimulus in the VEP experiment.

in a random order. BCVA near distance, stereoacuity, central suppression, and reading performance were assessed.

2˙4. *VEP experiment*. – In a dimly lit (average light level of 200 ± 25 lux) and quiet room, visual stimuli were presented on a CRT monitor (Philips 201B, resolution 1200 × 1600 pixels, refresh rate: 120 Hz). The stimulus was a string of b/w of 0.5 logMAR Sloan letters with high contrast (94% ± 0.8). Letters were arranged in a rectangular array of 176 letters distributed onto 11 rows (fig. 1) subtending a visual angle of 15 × 10 degrees at a distance of 40 cm. A fixation dot (diameter 0.3 degrees) was presented at the center of the letters array and participants were instructed to maintain stable fixation on the central dot during the recording session.

Participants looked at the visual stimuli binocularly in three conditions of correction:
1) Monofocal CLs with a power for near distance (Mean Spherical Equivalent of the subjective refraction plus addition).
2) MCLs with “Low addition”.
3) MCLs with “Medium addition”.
The experimental sessions consisted of five 90 s runs for each of the three experimental conditions for a total of 300 stimuli for each condition. Pauses were allowed between runs. Electroencephalographic (EEG) recording of each condition started after 10 minutes CLs wear.

2˙5. *Electrophysiological recording and data analysis*. – The EEG was recorded using 64 active non-polarizable sintered Ag/AgCl scalp sensors (ActiCapTM) mounted according to the 10-10 International System. EEG recording was digitized at 250 Hz with an amplifier band-pass (0.01–100 Hz) including a 50 Hz notch filter. Offline analysis was performed utilizing the BrainVisionTM Analyzer 2.2 software (BrainProducts GmbH., Munich, Germany). Horizontal eye movements were monitored from electrodes at the left and right outer canthi using a bipolar recording, whereas blinks and vertical eye movements were recorded with an electrode below and one above the left eye using a bipolar recording. Epochs in raw EEG data contaminated with eye movement artefacts were discharged from the analysis. The EEG signal was separately segmented for each condition into 400 ms epochs (from 50 ms before to 350 ms after stimulus onset. The 0–350 ms VEP interval in which the global field power peaks (obtained collapsing all the experimental recording) were larger than 80% of its maximum value was used for further analysis. Several main VEP components were studied. The frontal activity of the pN1 and pP1 components were represented by a frontal pool containing 13 electrodes (Fp1, Fpz, Fp2, AF7, AF3, AFz, AF4, AF8, F3, F1, Fz, F2, F4). The C1 component was represented by a medial parieto-occipital pool containing 6 electrodes (CPz, P1, Pz, P2, POz, Oz). The P1, N1, and P2 were represented by a bilateral parieto-occipital pool containing 12 electrodes (P7, P3, PO9, PO7, PO3, O1, O2, PO4, PO8, PO10, P4, P8). Data were analyzed using a repeated measure analysis of variance (ANOVA) separately for each component. For all analyses, the alpha level was fixed at 0.05.

3. – Results

3˙1. *Visual assessment.* – Results of visual assessment show a typical functional profile of a mid-presbyopic condition for the people enrolled in the sample that presented low amplitude of accommodation, a significant level of addition required at near, and poor subjective satisfaction for near vision without presbyopic correction. The addition for near was of 1.50 ± 0.09 D (range 1.25 to 1.75 D). The amplitude of accommodation was 2.29 ± 0.35 D (range 1.85 to 2.94 D) and 2.34 ± 0.41 D (range 1.85 to 3.13 D) in the right and left one respectively. The NAVQ score resulted in 63 ± 14 (range 33 to 85), a value higher than the cut off value for symptomatic presbyopes [8,12]. MCLs allowed achieving a good level of high contrast visual acuity both at far distance (Binocular level of -0.10 logMAR $\pm$ 0.06 for low addition MCLs and -0.04 logMAR $\pm$ 0.08 for medium addition MCLs) and at near distance (Binocular level of 0.03 logMAR $\pm$ 0.08 for low addition MCLs and -0.03 logMAR $\pm$ 0.05 for medium addition MCLs). However, the binocular BCVA at near distance with correction at near provided with monofocal CLs was significantly better (-0.10 ± 0.06 logMAR). Stereopsis resulted significantly better with near correction with spectacles (55 ± 36 arcsec) than MCLs both for low (71 ± 42 arcsec) and medium addition (83 ± 74 arcsec) (p-values 0.014 and 0.020 respectively), but no differences were found between the two CLs. However, fixation disparity and central suppression did not result significantly different between near correction with spectacles and MCLs both for low and medium addition, and also between the two MCLs (Wilcoxon-Signed Rank test). Concerning reading performance, the two kinds of MCLs significantly improved reading acuity measured by the Radner test (0.14 ± 0.06 and 0.06 ± 0.06 logMAr respectively) compared to the simple correction at far distance (without reading correction 0.28 ± 0.09 logMAR) (Wilcoxon test; $p = 0.002$ and $p = 0.001$ for low-and medium addition MCLs, respectively). Also, for the critical print size (CPS) the same results were achieved (Wilcoxon-Signed Rank test; $p = 0.001$).

3˙2. *VEP data.* – In fig. 2 are reported VEP waveforms at the selected pools for the three corrections. C1 is the earliest visible VEP component with onset at 60 ms and peak at 85–95 ms on medial centroparietal sites. P1, N1, and P2 peaked at 100, 140, and 240–250 ms, respectively, over bilateral parieto-occipital sites. The prefrontal pN1 and the pP1 peaked at 105 and 130 ms, on frontal and prefrontal sites.

ANOVA for the C1 component showed a significant difference between the three conditions (different CLs) ($p < 0.001$). Bonferroni post-hoc comparisons showed larger amplitudes ($p < 0.001$) for the monofocal condition than for the multifocal low and medium addition conditions, which did not differ from each other. The N1 component showed a significant effect of the condition ($p < 0.0001$). Bonferroni post-hoc comparisons showed larger amplitudes ($p < 0.001$) for the monofocal condition than for the multifocal low addition and multifocal medium addition conditions, which did not differ from each other. Also, the P1 component showed a significant difference between the conditions ($p < 0.001$). Bonferroni post-hoc comparison showed smaller amplitudes ($p < 0.0001$) for the monofocal condition than for the multifocal low addition and multifocal medium

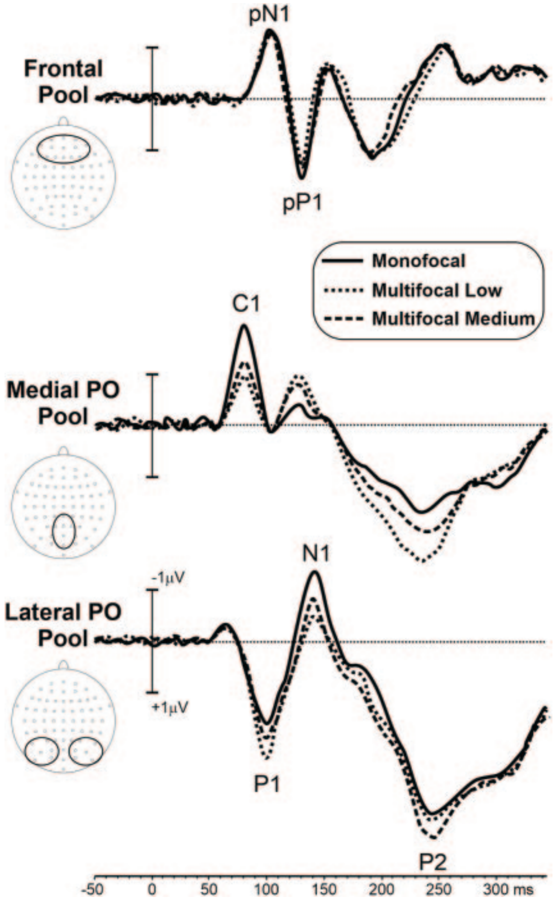

Fig. 2. – Grand-averaged VEP waveforms for the three conditions (Monofocal CL, Low addition MCLs, and Medium addition MCLs) overlapped and displayed on electrodes pools selected over frontal, medial, and bilateral parieto-occipital (PO) sites. Time zero represents the stimulus onset.

addition conditions, which did not differ from each other. The P2 component showed a significant main effect of condition ($p = 0.01$). Bonferroni post-hoc comparisons showed smaller amplitudes ($p < 0.0001$) for the monofocal condition than for the multifocal low addition and multifocal medium addition conditions, which did not differ from each other. Finally, ANOVA on the pN1 and pP1 showed no significant results.

4. – Discussion

The preliminary results of this study allow looking at the brain correlates of initial adaptation to multifocal optics through a high-density EEG array and VEP measures. The aim was to evaluate if, in the case of initial adaptation of MCLs, it exists a compensatory activity in anterior cortical areas such as the one evidenced in monovision CLs to counteract the degraded V1 signal [7]. Firstly, it should be noticed that BCVA with MCLs showed a slight reduction compared to the visual acuity achieved with monofocal correction provided by spectacles or monofocal CLs. This outcome is expected considering the reduction of the modulation transfer function of the optical system at the best focus due to the spherical aberration created by multifocality [3]. The brain correlates of this decrease in visual acuity induced by the simultaneous images generated by MCLs are detected in the significant reduction of amplitude of the C1 and N1 component. C1 represents the afferent volley in the primary visual area V1 or Broadmann area 17 [13,14]. N1 was previously localized in extrastriate visual areas and the posterior intraparietal sulcus; [14-16] it is known to be related to the encoding of visual stimuli [17] and it represents the feed-forward visual signal from earlier areas [14,15]. However, no modulation over anterior cortical areas as the ones recorded in monovision and interpreted as a compensatory activity in non-visual cognitive areas [7] was found in MCLs. This result suggests that neural compensation for MCLs, in an immediate phase of wear, is not cognitive as in monovision and could be exclusively sensorial, since P1 and P2 components enhance their amplitude.

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