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The effect of centesimal prismatic lenses on attention orienting processes: neuroscientific evidence

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Abstract

Prismatic Adaptation has different clinical applications but, given its association with attention orienting mechanisms, it might hold a potential even for neurocognitive empowerment. The present study aimed at investigating the empowerment effect of a protocol based on centesimal prismatic lenses (SiXDEVICE™) on attention orientation processes and their electrophysiological markers (event-related potentials, ERPs) by using a spatial cueing paradigm. Twenty participants were divided into an experimental group, training with SiXDEVICE™, and an active control group, performing traditional visual training. The comparison of pre/post-training performance measures and ERP markers of attention orienting – namely, the P300 component – highlighted qualitatively different patterns of performance modulation between the groups and a significant reduction of P300 amplitude over parietal areas in response to invalid cue trials in experimental participants. Preliminary results hint at the potential of the tested optical device and protocol as supportive tools to foster attention skills even in healthy people.

Keywords: sensory prisms; attention orienting; visual training; neurocognitive empowerment; visual harmonization

1. Introduction

Prismatic adaptation (PA) is a sensory-motor adjustment process, which occurs after a visuo-proprioceptive conflict that fosters implicit adaptation mechanisms (Michel et al., 2003). Adaptation might be triggered by cognitive and motor compensation behaviours, which could be seen as consequence of an alteration of the visual information flow. Effects of PA are thought to ground on the association between vision, proprioception, sensorimotor integration, and attention orientation, which reflects in a complex network of interdependent cortico-subcortical structures and feedback mechanisms and, in particular, in the contribution of the superior colliculus and the sensory nuclei of the trigeminal nerve together with the cerebellum and the temporal, prefrontal, and posterior parietal cortices (Panico et al., 2020).

Prismatic lenses of different power and orientation were initially used to obtain clinical effects on altered postural patterns (Padula, 1988), with applications even to dysfunctions concerning environmental vision (Kaplan, 1987; Kraskin, 1982) and, later, sensory integration deficiency (Allison et al., 2007) and unilateral spatial neglect (Jacquin-Courtois et al., 2013). Possible positive outcomes derived from prismatic lenses might, however, not fall only on clinical grounds. In fact, it has been proposed that their effect might ground on the modulation of attention orienting mechanisms (Striemer et al., 2006). Therefore, while research on the potential of prismatic lenses as empowerment tools is, to date, still scant, available findings suggest that PA might positively influence the way attention is oriented across the visual field even in healthy people.

Considered the relationship between vision and attention mechanisms and the potential implications of PA empowering effects on the healthy population, the present study aimed at investigating the effect of an empowerment protocol based on long-term use of centesimal prismatic lenses on attention orientation processes and their electrophysiological markers (event-related potentials, ERPs) by using a spatial cueing paradigm. Indeed, the spatial cueing paradigm (Petersen & Posner, 2012; Posner, 1980) is a well-established experimental task devised to assess exogenous and endogenous shifts of attention focus. Furthermore, the cueing task was also largely investigated by electrophysiological studies, which corroborated its informativity with regard to the efficiency of attention orientation mechanisms (Proskovec et al., 2018; Thiery et al., 2016). In particular, the P300 event-related potential (ERP) – generally thought to mirror attention orientation to novel stimuli and/or updating of the mental representation of the context (Polich, 2007) – proved to be a convenient physiological marker of a re-orienting attention response that includes both spatial and non-spatial (e.g. arousal modulations) processes associated with infrequent events (Capotosto et al., 2012; Chica & Lupiáñez, 2009; Eimer, 1994; Gómez et al., 2008).

Given such premises, we expected to observe: (i) better post-training that pre-training performances (higher accuracy and shorter reaction times) at the cueing task in participants undergoing the experimental empowerment protocol with respect to active control participants; and (ii) a consistent post-training modulation of the P300 ERP marker, specifically, in the experimental group, mirroring fine-graded signs of optimized orientation of attention resources.

2. Method

2.1 Sample

20 healthy volunteers took part in the study (M_{age} = 23.30, SD_{age} = 1.82). Exclusion criteria were: history of psychiatric or neurological disorders; history of strabismus or other disorders of the visual and oculomotor system; sensory, motor or cognitive deficits; concomitant therapies based on drugs that could modulate central nervous system functioning. None of participants reported ongoing concurrent therapies based on psychoactive drugs, nor history of oculomotor, neurology or psychiatric disorders. They had normal or corrected-to normal vision. Participants were equally and randomly divided into an experimental (EXP) group – which underwent the empowerment training based on SiXDEVICE™ – and an active control (CONT) group – which completed a traditional visual training protocol. EXP and CONT groups were comparable in terms of age ($p > .05$). All participants gave their written consent to participate in the study. The study and relative procedures followed the principles of the Declaration of Helsinki and were reviewed and approved by the competent ethics committee.

2.2 Procedure

The research was designed as a two-arm controlled longitudinal study with pre- and post-training assessment steps. The assessment protocol included a spatial cueing computerized task together with the analysis of electrophysiological markers of attention skills in order to investigate training effects on attention orienting processes. During the cueing task (Petersen & Posner, 2012; Posner, 1980), participants are, indeed, presented with a series of targets, which can appear in one of two possible locations, and have to rapidly indicate the stimulus position. Prior to the presentation of the stimulus, a peripheral cue might indicate the probable location of the target, with a certain level of validity. The task included 180 trials, of which 120 were preceded by a valid cue, 30 were preceded by an invalid cue, and 30 were not preceded by cues (i.e. neutral trials). Performance at the task has been quantified in terms of response times (RTs, i.e. the amount of time, in milliseconds, between the onset of a stimulus and the response to such stimulus) and detection accuracy (Acc, i.e. the percentage of correct responses over the total number of trials).

Electrophysiological markers of attention processes were also collected during task execution, with a specific focus on the P300 ERP component. EEG data have been recorded by means of a V-Amp system with a 15-channel montage (10-20 International System: F7, F3, Fz, F4, F8, C3, Cz, C4, P3, Pz, P4, T7, T8, O1, O2; reference to linked earlobes) and then processed offline via Vision Analyzer2 software (Brain Products GmbH, Gilching, Germany). Electrodes impedance was kept under 5 kΩ and vEOG was recorded in order to keep track of ocular artifacts for subsequent rejection. Data were sampled at 1000 Hz (input filters: 0.01-250 Hz bandpass and 50 Hz notch). After offline filtering (IIR 0.1-30 Hz bandpass filter, 24db/octave), data were segmented according to experimental conditions, visually inspected for artifacts, and averaged to obtain condition-specific waveforms. Midline (Fz, Cz, Pz) P300 peak and latency data were finally extracted for each experimental condition (Valid, Invalid and Neutral trials) following a weighted peak-detection algorithm (Crivelli & Balconi, 2017).

As for the training procedure, the experimental group completed an empowerment protocol based on the repeated use of SiXDEVICE™ centesimal prismatic lenses (Family Vision Center – VTE srl, Sesto San Giovanni, Milan; see Figure 1). The protocol lasted 4 weeks, with daily activity sessions to be planned in conjunction with everyday activities, such as studying, training or working at the computer (three 1-hour sessions a day, interspersed with periods of pause). The active control group has, instead, completed an alternative protocol based on traditional visual training exercises – such as target tracking, saccadic jumps, and accommodative flexibility – which acted as a gold standard reference for the evaluation of training effects. The control protocol, as the experimental one, lasted 4 weeks, with daily training sessions.

Figure 1. Representation of the optical device used in the experimental empowerment protocol – i.e. SiXDEVICE™, centesimal prismatic lenses with elastic band and rods by Family Vision Center – VTE, Sesto San Giovanni (MI), Italy

3. Results

Pre- and post-training data concerning behavioural (RTs, Acc) and ERPs (P300 amplitude and latency at Fz, Cz, and Pz sites for Valid, Invalid and Neutral trials) measures in the EXP and CONT groups were compared via paired-samples *t-tests* (PASW Statistics 18, SPSS Inc., Quarry Bay, HK). Threshold for statistical significance was set to $\alpha = 0.05$. Cohen's d values were calculated and reported as a measure of within-group effect size for significant comparisons. Effect sizes have been deemed as small when ≥ 0.2, medium when ≥ 0.5, and large when ≥ 0.8, in agreement with Cohen's norms (1988).

Statistical comparisons highlighted some minimally-significant pre-/post-

training differences for Acc (EXP: M_{pre} = .94, SD_{pre} = .16, M_{post} = .99, SD_{post} = .01, p > .050; CONT: M_{pre} = .99, SD_{pre} = .01, M_{post} = .98, SD_{post} = .01, p > .050; see Figure 2a) and RTs (EXP: M_{pre} = 423.66, SD_{pre} = 34.60, M_{post} = 398.61, SD_{post} = 55.74, p > .050; CONT: M_{pre} = 406.32, SD_{pre} = 36.54, M_{post} = 379.03, SD_{post} = 58.17, p > .050; see Figure 2b).
Analysis of P300 data highlighted a significant reduction of post-training peak amplitude during Invalid trials at Pz in the EXP group alone (EXP: M_{pre} = 10.53, SD_{pre} = 4.56, M_{post} = 7.86, SD_{post} = 6.15, t = 2.79, p = .032, *Cohen's d* = 1.05; CONT: M_{pre} = 9.22, SD_{pre} = 2.00, M_{post} = 9.26, SD_{post} = 3.70, p > .050; see Figure 2c).

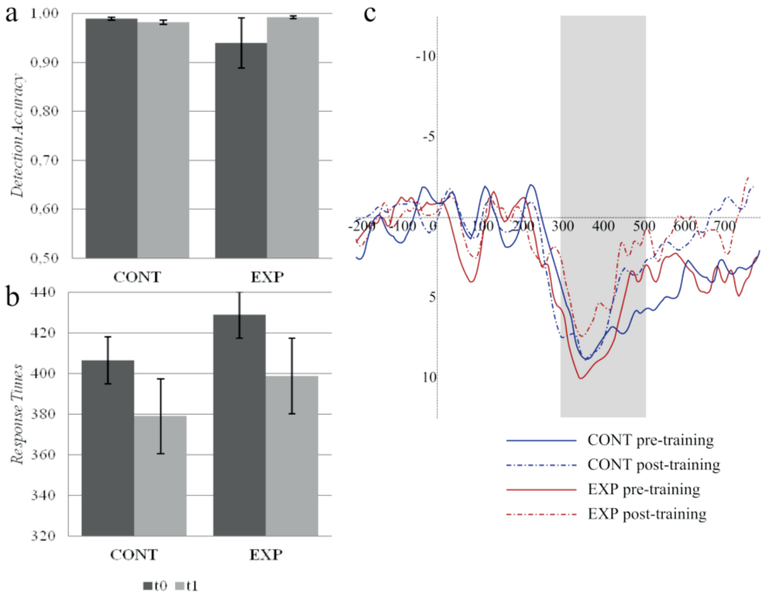

Figure 2. (a) Pre-training and post-training accuracy at the spatial cueing task for the experimental and control groups. Bars represent ±1 SE. (b) Pre-training and post-training response times at the spatial cueing task for the experimental and control groups. Bars represent ±1 SE. (c) Group waveforms as recorded in response to invalid cue trials at Pz site during the spatial cueing task. The grey-shaded box marks the reference period for the P300 ERP component. t0: pre-training data; t1: post-training data; CONT: active control group; EXP: experimental group

4. Discussion and conclusions

In order to explore the potential of low-power prismatic lenses as empowerment tools to improve attention orientation processes, healthy volunteers were asked to complete a 4-week experimental protocol using a dedicated optical device (EXP group) or an active control protocol based on traditional visual training (CONT group), while behavioural and electrophysiological correlates of attention orienting performance were tested before and at the end of the training period. Preliminary results highlighted: (i) qualitatively different patterns of performance modulation at the spatial cueing task in EXP and CONT participants; (ii) a significant post-training reduction of P300 amplitude collected during the spatial cueing task over parietal areas in response to invalid cue trials in the EXP group alone.

Going down to specifics, at the behavioural level the CONT group qualitatively showed a reduction of RTs without a notable change of accuracy at the spatial cueing task, whereas the EXP group showed reduced RTs paired with increased accuracy. Specifically, qualitative difference between groups' responses to EXP and CONT protocols can prompt valuable remarks. In particular, the pattern of optimized performance at the cueing task (increased Acc and reduced RTs) showed by the EXP group suggests that the protocol might have strengthened participants' attention orienting and control skills even if it was merely based on passive use of the prismatic lenses. Such effect might be traced back to implicit sensorimotor and cognitive adaptation mechanisms that, as suggested by Striemer and colleagues (2006), influence the way in which covert attention is oriented and re-oriented across the visual scene and that are thought to systematically affect even higher spatial and cognitive processes (Michel et al., 2003).

The remarks on behavioural effects of training with centesimal prismatic lenses are further supported by the observed modulation of electrophysiological markers of attention orientation – namely, the P300 ERP – in the EXP group alone.

The P300 ERP is typically observed as a positive deflection over midline posterior scalp areas starting from 300 ms from the onset of a relevant stimuli, and is thought to mirror context updating processes and orientation of attention to significant events (Polich, 2007). A reduction of the P300 component collected during spatial cueing tasks was associated to behavioural facilitation for cued as compared to uncued trials (Chica & Lupiáñez, 2009; Eimer, 1994) and, consistently, P300 amplitude is known to mirror the amount of attention resources employed in a given task (Polich, 2007; Wickens et al., 1983). Based on such accounts and evidence, the observed reduction of P300 amplitude in response to invalid trials might mark a lower investment of attention resources in disengaging attention from invalidly cued locations and reorienting it toward the correct location, thus suggesting that the training has improved the efficiency of attention control and orienting processes.

As a final general note, it has to be underlined that the experimental empowerment protocol was based on the use of centesimal prismatic lenses – i.e. prismatic lenses with extremely low optical power – in contrast to the current evidence base, which is focused on vertical or horizontal prismatic lenses with remarkable refractive power. Conventional prisms change the light direction in a specific retinal area versus the entire retinal and are used with 15-280 times stronger powers than the SiXDEVICE™. When prisms of low power are used (from 1 to 3 Pd), the changes are unconscious, that is reflexive, and proprioceptive changes precede visual ones. When high powers are used (from 4 Pd to up) the changes are conscious and an immediate reorganization of the neuromotor system is forced to meet the new transformed demands of the environment (Kaplan, 2005). With their light diffusion feature, the centesimal power creates an instantaneous sensory effect along the trigeminal pathway, and trigeminal sensory nuclei complex (TSNC). This slight power aligns itself with the threshold of the acceptance of any rigidly organized sensory system (dysfunctional) to regulate and harmonize visual information management (best interaction between localized and environmental/spatial information) and to reorganize basic function.

The SiXDEVICE™ prisms modulate the sensory information leading to a new perceptual organization and sensory learning experience without adaptation due to visuo-proprioceptive incoherence and without affecting structural change (from refractive prisms to sensory prisms).

Therefore, to our best knowledge, present preliminary findings firstly suggest that even centesimal prismatic lenses might actually modulate the efficiency of attention orienting and control in the healthy brain. In addition, the limited refractive power of the tested optical device allowed users to wear it during daily activities - such as studying, reading, working at the computer, training or performing non-contact sports, and so on apart from driving, due to safety precautions – with no relevant unwanted effects and nor side after-effects.

To sum up, while present preliminary findings would still benefit from corroboration via further investigation with larger samples, maybe representative of different age groups, they begin to hint at the potential of the tested optical device (SiXDEVICE™) and protocol as supportive tools to foster attention skills even in healthy people. In addition, the inclusion of further integrative measures, i.e. neuropsychological testing, might improve the extent of present results, thus adopting a multilevel assessment approach.

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