ORIGINAL ARTICLE

Amblyopic-related frontal changes in an orientation discrimination task: a research of P3a event-related potentials in anisometropic amblyopia

Zhao J[1],Yang XB[1], Wang JL[1], Wang SJ[2], Gong R[1], Zheng Z[3], Liu LQ[1]

[1]Department of Optometry and Visual Science
[2]Department of Medical Engineering
[3]Neurobiological Laboratory Center
West China School of Medicine, Sichuan University, Chengdu, China

Abstract

Background: Amblyopic deficits in the primary and secondary visual cortex have been demonstrated broadly. However, the cognitive process at late stage originating in higher brain area in amblyopes hasn't been studied yet. The aim of this study was to investigate the late cognitive process at the frontal lobe in anisometropic amblyopes of a distinct degree, using visual event-related potential (ERP) techniques.

Methods: Thirteen severe anisometropic amblyopes, 14 mild-to-moderate anisometropic amblyopes, and 13 control subjects participated in this study. Oddball paradigm (three stimuli: target, novel, and non-target stimuli) of low spatial frequency (1 cycle per degree, CPD) was used to elicit brain ERP waves. Reaction time, accuracy, latency, and amplitude of P3a waves evoked by novel stimuli at Fz electrode (the central electrode at frontal lobe), were analyzed statistically.

Results: Neither accuracy nor reaction time showed significant difference among the three groups. The latency of N200 wave showed no significant difference. The latency of P3a wave was delayed in the amblyopes compared with healthy controls, but there was no significant difference between severe and mild-to-moderate amblyopes. P3a amplitude in mild-to-moderate amblyopes was significantly higher than in controls and severe amblyopes.

Conclusions: Our findings indicated that the cognitive process in anisometropic amblyopes was impaired, and the compensative effect of P3a amplitude was shown in mild-to-moderate amblyopes. P3a visual ERP could become a useful tool to investigate cognitive processing in amblyopes. Hippokratia 2016, 20(1): 60-66

Keywords: Anisometropic amblyopia, event-related potentials, P3a, Gabor patches, latency, amplitude

Corresponding Authors: Longqian Liu, Department of Optometry and Visual Science, West China School of Medicine, Sichuan University, Chengdu, China, address: 37 Guoxue Xiang, Chengdu, 610041, China, e-mail: b.q15651@hotmail.com and Zhong Zheng, Neurobiological Laboratory Center, West China School of Medicine, Sichuan University, Chengdu, China, address: 28 Dianxin Street, Chengdu, 610041, China, e-mail: 345244784@qq.com

Introduction

Amblyopia is a visual disorder caused by anomalous early visual experience (e.g., anisometropia and strabismus) and characterized by abnormal foveal vision. It is the leading cause of unilateral visual impairment in pediatric patients. It not only results in low visual acuity but also impairs contrast sensitivity, binocular function, and other advanced visual functions, which adversely affect the patient's occupation choice and life convenience. The prevalence of amblyopia was reported to be 1.0% in year-1 primary school students in central China and 2.8% in a rural adult Chinese population in Handan, Hebei province. Anisometropia is the most common cause of amblyopia[1,2].

Many studies have confirmed deficits in the primary visual cortex at the early stage of message processing in amblyopes. Heravian et al recorded pattern visual evoked potentials and pattern electroretinogram simultaneously in 40 amblyopes (20 strabismics and 20 anisometropics) and 20 normal controls and found that the P100 latency was increased, and amplitude was reduced in the anisometropic group[3]. Other electrophysiological studies also found similar changes of P100 wave in amblyopes[4]. Although visual evoked potentials were broadly used in earlier times, it merely reflects processing of visual information at an early stage.

Event-related brain potential (ERP) is an excellent noninvasive tool to investigate brain activity due to its high temporal resolution to the millisecond. It represents voltage oscillations in the electroencephalogram (EEG) that are time-locked with the occurrence of a specific event such as stimulus onset. Components of ERP are identified in the average ERP waveforms that are associated with subprocesses involved in the perceptual or cognitive processing. By investigating N170 wave of ERP using foveal face stimuli, Koertvelyes et al revealed that

Table 1: Characteristics of subjects of the study (13 severe and 14 mild-to-moderate anisometropic amblyopes, and 13 control subjects). Age, sex, tested eyes, refraction state, and LogMAR visual acuity are listed.

Subject	Age	Sex	AE/NDE	Refraction		VA(logMAR)	
				RE	LE	RE	LE
Control Subjects							
N1	20	M	RE	-3.0DS	-2.0DS/-1.0×15	0.00	0.00
N2	21	M	RE	-2.5DS/-1.5DC×170	-2.75DS/-1.5DC×170	0.10	0.10
N3	20	M	LE	-1.5DS/-2.5DC×180	-0.5DS/-2.0×165	0.10	0.00
N4	23	F	LE	-5.75DS	-5.5DS	0.00	0.00
N5	24	F	RE	-1.75DS	-2.75DS	0.00	0.00
N6	19	F	LE	-2.5DS	-2.75DS	0.00	0.00
N7	18	F	RE	-5.5DS	-4.75DS/-0.5DC×150	0.00	0.00
N8	20	F	LE	PL	PL	0.00	0.00
N9	20	M	RE	-2.75DS	-2.5DS	0.00	0.00
N10	19	F	LE	-3.75DS	-4.75DS	0.00	0.00
N11	24	F	LE	-6.0DS	-5.5DS/-0.75DC×160	0.00	0.00
N12	19	M	RE	-5.0DS/-0.75DC×180	-5.0DS/-1.0DC×180	-0.10	0.00
N13	22	M	LE	PL	PL	-0.20	-0.20
Severe Anisometropic Amblyopes							
S1	15	M	LE	+4.5DS/+0.5DC×110	PL	0.00	1.0
S2	14	F	RE	+5.0DS/-2.25DC×180	-0.5DS	0.00	0.80
S3	15	F	LE	-3.5DS/-0.5DC×180	+2.0DS/+2.0DC×90	0.00	0.70
S4	19	F	LE	+4.25DS/+1.0DC×75	+6.5DS/+1.0DC×90	0.00	0.70
S5	21	F	RE	+7.0DS	-0.5DS	1.0	0.00
S6	15	M	RE	-4.0DS/-3.0DC×165	-3.5DS/-0.5DC×180	1.0	0.00
S7	13	M	RE	-1.0DS	-0.5DS/+4.0DC×90	0.00	0.70
S8	16	F	LE	-0.75DS	+5.0DS/+2.0DC×105	0.00	0.70
S9	27	F	RE	+4.0DS/+1.5DC×80	+0.5DS	0.80	0.00
S10	15	M	LE	-1.0DS	+4.0DS/+1.75DC×90	0.00	1.10
S11	15	F	LE	PL	+7.5DS/+1.0DC×100	0.00	1.0
S12	19	M	RE	+4.5DS/+2.75DC×90	-0.75DC×90	0.70	0.00
S13	30	M	LE	+6.5DS/-0.5DC×10	+8.5DS/-0.75DC×170	0.10	0.70
Mild-to-moderate Anisometropic Amblyopes							
M1	13	F	RE	+1.0DS/+2.0DC×85	-0.5DS/-1.0DC×10	0.40	0.04
M2	14	M	LE	PL	+3.5DS/+1.0DC×90	0.00	0.40
M3	16	M	RE	+4.25DS	-2.0DS/-1.0DC×170	0.40	0.00
M4	21	F	LE	-1.00DC×7	+8.0DS/+1.0DC×180	0.00	0.4
M5	20	F	LE	PL	+1.0DS/+1.5DC×75	0.00	0.15
M6	19	F	RE	+2.0DS/+1.0DC×35	-7.5DS	0.52	0.00
M7	25	F	RE	+7.0DS/+1.0DC×65	-0.75DS	0.52	0.00
M8	25	M	LE	-0.75DS	+2.5DS	0.00	0.50
M9	25	M	RE	+0.75DS/+3.0DC×75	+0.5DS/+0.50DC×90	0.30	0.00
M10	25	M	LE	+0.75.0DC×85	+3.0DC×90	0.00	0.4
M11	13	F	LE	-1.5DS/-0.5DC×180	+1.0DS/+1.0DC×90	0.05	0.6
M12	13	M	RE	+5.5DS/+3.0DC×90	PL	0.15	-0.10
M13	24	F	RE	+5.0DS/+1.25DC×45	PL	0.52	0.00
M14	33	F	LE	-0.5DS/-1.50DC×5	-1.5DS/-5.0DC×175	0.00	0.60

N: control subjects, S: severe anisometropic amblyopes, M: mild-to-moderate anisometropic amblyopes, AE: amblyopic eye, NDE: non-dominant eye, RE: right eye, LE: left eye, VA: visual acuity, LogMAR: log minimum angle of resolution, DC: cylindrical diopter, DS: spherical diopter, PL: plane lens.

the latency of this early component was delayed, and the amplitude was reduced, which also indicated the abnormal visual cortical processing at the earliest stage[5].

P300 ERP is a late positive component between 350 ms and 600 ms time window, related to the processing of human beings' consciousness or cognitive psychological functions (attention, memory) and has been widely used in the field of cognitive studies. It has been broadly adopted as a means to assess cognitive dysfunction in various diseases[6-9]. In Alzheimer's disease, Chang et al found pre- to post-treatment difference of P300 latency significantly correlated with the difference incognitive ability screening instrument score, and P300 latency decreased as cognitive capability improved[9].

In target and novel distractor stimuli processing, distinct attentional subsystems are involved, indicated by different origins between P3a and P3b. The classical P300 (or P3b), is elicited by the target stimuli in a classic oddball paradigm and mainly originates from parietal and inferior temporal areas, associated with revision of working

Table 2: The behavioral data of accuracy and reaction time (millisecond) expressed in mean, standard deviation, median, upper and lower quartiles.

		N	mean	SD	median	Q25	Q75
ACC	control subjects	13	99.23	1.88	100.00	100.00	100.00
	Severe amblyopes	13	98.00	3.11	100.00	95.50	100.00
	mild-to-moderate amblyopes	14	98.29	4.03	100.00	97.00	100.00
RT	control subjects	13	332.17	69.47	325.20	271.51	372.08
	Severe amblyopes	13	326.74	60.26	310.13	266.70	386.77
	mild-to-moderate amblyopes	14	309.60	68.29	324.15	243.85	361.08

AC: accuracy, RT: reaction time, N: number of subjects, SD: standard deviation, Q25: lower quartile,Q75: upper quartile.

memory within the stimulus environment. Whereas the P3a ERP, mainly evoked by novel distractor stimuli, has an intense frontal distribution and correlates with selection of stimulus information governed by attentional orienting[10].

A large variety of stimuli has been adopted to elicit ERP waveforms, such as facial images[11], Vernier stimulus[12], pattern-reversal and motion-onset stimuli[13] and Gabor patches[14]. Gabor patches which consist of sine-wave gratings with peripheral Gaussian decreasing, are mainly used in vision laboratories because they have characteristics that match with the receptive field properties of neurons in the primary visual cortex[15]. On the other hand, directions and spatial frequencies of Gabor patches could be easily modulated to study brain activity at different task loads. Therefore, we chose Gabor patches as visual stimuli in the present study.

Although abnormal visual processing at early stages in amblyopes has been confirmed, little is known about the cognitive processing of visual attention at late stages. Therefore, we utilized the visual Oddball task with novel stimuli to elicit P3a ERPs and investigated cognitive processing at the frontal lobe in anisometropic amblyopes of distinct degree.

Methods

Subjects

In this study conducted between October 2014 and January 2015, 40 subjects participated (age rang 13-33 years). We recruited 13 severe anisometropic amblyopes [mean age ± standard deviation (SD): 18.00 ± 5.21 years, 6 males, 7 females] and 14 age and sex matched mild-to-moderate amblyopes (mean age ± SD: 20.42 ± 6.09 years, 6 males, 8 females) from the ophthalmology department of the West China Hospital. The diagnosis of anisometropic amblyopia was defined as astigmatic anisometropia of more than 1.50 diopters and/or hyperopic anisometropia of more than 1.00 diopter. Severe anisometropic amblyopia was defined as best corrected LogMAR visual acuity above or equal to 0.7 and mild-to-moderate amblyopia between 0.1 and 0.7 in the amblyopic eye. Exclusion criteria included the existence of systemic diseases or other ocular abnormalities; strabismus or history of strabismus surgery and eccentric fixation. We also recruited 13 healthy subjects (mean age ± SD: 20.69 ± 1.97 years, 6 males, 7 females) for controls who were age and sex matched to the other two groups. Best corrected LogMAR visual acuity of the healthy controls was below 0.1 with absence of other ocular abnormalities or systemic diseases. All subjects were right-handed and were examined by an ophthalmologist and anoptometrist, and were fitted with the optimal correction (Table 1). In addition, the non dominant eye of the control subjects was determined by the hole-in-card test to facilitate comparison of the amblyopic and control subjects. An additional 14 amblyopic patients and five control subjects were tested, but not included in the final analysis due to issues related to high levels of movement artifacts in the ERP waves.

Approval for this study was obtained from the institutional review board of West China Hospital of Sichuan University [No 2014 (33), 1-6-2015]. Informed consent

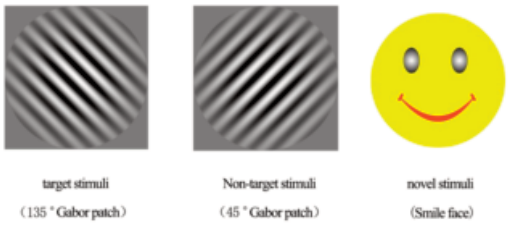

Figure 1: Three patterns of stimuli randomly presented into the amblyopic eye or the nondominant eye (controls). Gabor patches directed at 135° are target stimuli which require responses from the subjects (pressing the ENTER button) while 45° Gabor patches and smiling faces serve as non-target stimuli and novel stimuli requiring no physical responses.

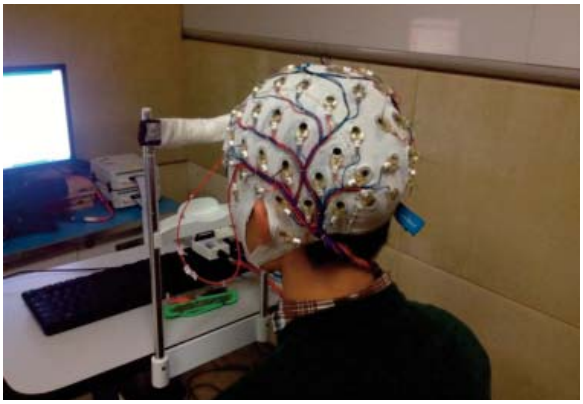

Figure 2: The 64 Ag/Agcl scalp electrodes mounted on theelastic cap (Easycap GmBH, Herrsching-Breitbrunn, Germany). After wearing the Easycap, subjects placed their chins on a chin rest and viewed the central display horizontally with the amblyopic eye or the nondominant eye (controls).

Table 3: Latency of P3a and N200 waves and amplitude of P3a event-related potential (ERP) at Fz electrode (the central electrode at frontal lobe), expressed in mean, standard deviation, median, upper and lower quartiles.

		N	mean	SD	median	Q25	Q75
Latency of P3a(ms)	control subjects	13	427.69	54.47	406.00	388.00	493.00
	Severe amblyopes	13	482.92	66.08	490.00	435.00	548.00
	mild-to-moderate amblyopes	14	471.71	50.58	475.00	429.00	506.00
Amplitude of P3a(μV)	control subjects	13	7.33	6.56	6.24	3.32	10.91
	Severe amblyopes	13	7.46	8.18	6.49	2.16	8.68
	mild-to-moderate amblyopes	14	14.16	7.82	9.81	9.06	21.85
Latency of N200(ms)	control subjects	13	267.69	37.52	250.00	240.00	297.00
	Severe amblyopes	13	275.08	38.47	276.00	241.00	302.00
	mild-to-moderate amblyopes	14	269.00	26.07	261.00	245.50	293.00

N: number of subjects, SD: standard deviation, Q25: lower quartile, Q75: upper quartile.

was obtained from all subjects or their parents.

Visual stimuli and procedure

Gabor patches at alow spatial frequency (1 cycle per degree, CPD) directed at 45° and 135° with 0.5° half-Gaussian ramp in the periphery area and a smiling face, were randomly presented in the center of a Sony G220 monitor (Sony, Tokyo, Japan) with 1024×768 pixel resolution, a frame rate of 60 Hz, and 128 cd/m² background luminance. Patterns of stimuli are shown in Figure 1.

The experimental procedure was controlled on a computer using the E-Prime 2.0 software (Brain Products GmbH, Munich, Germany), which sent the experimental events to the Net station and utilized a single-clock system to time-lock these experimental events with the EEG data. Each block consisted of 200 stimuli, of which 70% were Gabor patches directed at 45° (Non-target stimuli), 20% at 135° (target stimuli) and 10% smiling faces (novel stimuli). All stimuli subtended to 9°×9° diameter at a testing distance of 1 m. Each stimulus lasted for 200 ms and the interval between successive stimuli onsets varied between 1000 and 2000 ms randomly. A black cross was continuously visible in the center of the display during the interval to keep eyes' fixation. Observers were required to press the ENTER button as soon as the target stimuli were presented. Behavioral data and ERP waves were recorded simultaneously.

ERP acquisition and analysis

Acquisition and processing techniques of visual ERPs were described by Banko et al[11]. ERPs were recorded using a Brain Products MR amplifier (Brain Products GmbH, Munich, Germany) from 64 Ag/Agcl scalp electrodes mounted on an elastic cap (Easycap GmBH, Herrsching-Breitbrunn, Germany) using a modified 10-20 placement system, with sample rate at 1000Hz and bandpass filtering at 0.5-30Hz. One additional electrode was placed above the left eye for the purpose of recording the electrooculogram.

All subjects rested adequately before the test and were kept alerted during the separate blocks of the study. They placed their chins on a chin rest and viewed the central display horizontally with the amblyopic eye or the non-dominant eye (controls) at a distance of one meter. The other eye was completely patched with a black cloth during testing. Electro-gel was applied to keep all electrodes impedance below 10 kΩ (Figure 2). Processing of recorded ERP waves was done using Brain Vision Analyzer 2.0 (Brain Products GmbH, Munich, Germany) off-line.

Statistical analysis

Behavioral data: Reaction time was calculated as the time from the stimulus onset to correct response. Accuracy was defined as the percentage of correct responses. One-way ANOVA or Kruskal-Wallis test was used depending on the normality or not of data distribution. A p value of <0.05 was considered significant.

ERP data: ERP averages elicited by novel stimuli were calculated from 200 ms before stimulus presentation to 1000 ms post onsetand the largest positive peak within the 350-600 ms time window was labeled as P3a peak. N200 peak was determined as the negative peak within the 240-360 ms time window. One-way ANOVA or Kruskal-Wallis

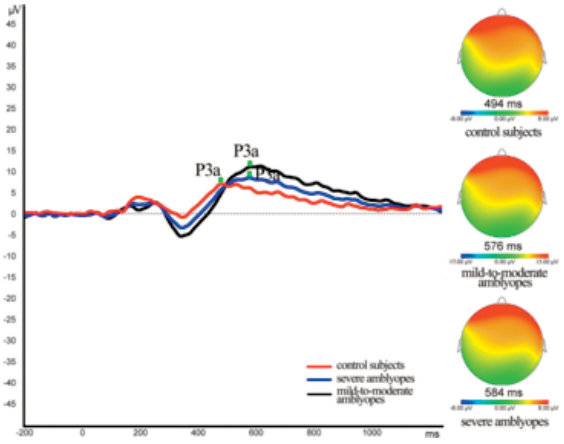

Figure 3: Left panel: Grand average ERP waveforms elicited by novel stimuli at Fz electrode in control subjects (red line), severe anisometropic amblyopes (blue line) and mild-to-moderate anisometropic amblyopes (black line). Right panel: Scalp potential maps at 494, 576 and 584 ms after novel stimuli onset (corresponding to the respective peak latencies in grand average ERP waves) in control subjects (top), mild-to-moderate anisometropic amblyopes (middle) and severe amblyopes (bottom). Dots indicate electrode positions on the scalp.

test was used to examine the latency and amplitude of P3a wave and the latency of N200 wave at Fz electrode (the central electrode at frontal lobe), depending on the normality or not of data distribution. A p value of <0.05 was considered significant.

Results

Behavioral data

The behavioral data regarding accuracy and reaction time (millisecond) are presented in Table 2 as mean, standard deviation, median, Q25, and Q75. The Shapiro-Wilk test revealed that accuracy data didn't follow normal distribution and Kruskal-Wallis test showed no significant difference in accuracy among the three groups (p =0.464). Also, ANOVA revealed no significant difference inreaction time among the three groups (F =0.0431, p =0.653).

ERP grand averages

Grand average ERP waveforms elicited by novel stimuli at Fz electrode are shown in Figure 3. Latencies of P3a and N200 waves and amplitudes of P3a wave are presented in Table 3 as mean, standard deviation, median, Q25, and Q75. Latencies of P3a and N200 wave followed normal distribution. In our study, the group that patients belonged was a significant factor for the latency of P3a ERP (F =3.395, p =0.044). The latency of P3a ERP was significantly longer in amblyopes compared with the controls (severe amblyopes vs. control subjects: p =0.019; mild-to-moderate amblyopes vs. control subjects: p =0.043), but no significant difference was found between the mild-to-moderate and severe amblyopes (p =0.614). The latency of N200 wave among the three groups demonstrated no significant difference (F =0.173, p =0.842). P3a amplitude in severe amblyopes didn't follow a normal distribution. Kruskal-Wallis test for P3a amplitude revealed significant difference among the three groups (p =0.011) while mild-to-moderate amblyopes exhibited significantly higher P3a amplitude compared with the other two groups (mild-to-moderate amblyopes vs. severe amblyopes: p =0.009; mild-to-moderate amblyopes vs. control subjects: p =0.034). However, there was no significant difference between the control subjects and the severe amblyopes (p =0.998).

Discussion

To our knowledge, no previous published studies exist regarding the advanced cognitive process of anisometropic amblyopes. The major findings of this study were the significant delay in the P3a latency in both groups of anisometropic amblyopes and the increase in P3a amplitude in mild-to-moderate amblyopes. However, no significant difference in P3a amplitude was found between severe amblyopes and controls.

Two kinds of behavioral tasks are employed in ERP detection. One is mental counting task[16], and the other is button pressing task[13]. We adopted the latter for its feasibility and simplicity. Counting and memorizing the number may induce unwanted mental activity to mix up with cognitive processing of visual attention. Furthermore, to enhance the reliability of our research in P300, we controlled for age, sex, and handedness which might influence the cognitive processing as reported by Polich and Kok[17].

In our study, no significant difference was found in accuracy among the controls, mild-to-moderate, and severe amblyopes. This result is different from previous studies in which amblyopic eyes exhibited lower accuracy than the fellow eyes or eyes of control subjects[5]. This difference might be due to the different task loads and different requirements for waveforms studied in various studies. In the study of P300 waveform, stimuli should be easily discriminated[18]. Without this precondition that target stimuli could be correctly discriminated, P300 waves may not accurately reflect the cognitive status. We ensured the accuracy by testing all subjects at a low spatial frequency (1 CPD).

Amblyopic deficits in the primary visual centers (V1, V2) and the secondary extrastriate temporooccipital associated areas have been demonstrated by functional magnetic resonance imaging (fMRI) and electrophysiological measurements broadly[19,20]. It has been reported that recognition of visual tasks is completed after activation of parietal, and frontocentral associated cognitive areas of the brain[21] and intrusive or novel stimuli can produce an earlier, positive potential, which is typical over the frontal electrodes and believed to reflect an altering process[10].

P300 latency is directly associated with cognitive capability and an index of information processing speed[22,23]. It is independent of behavioral reaction time[24], which makes it a valuable tool for assessing cognitive function. It was reported that the pre- to post-treatment difference of P300 latency significantly correlated with the screening instrument score in Alzheimer's Disease, with shorter latencies been associated with superior cognitive function and increased latencies indicated the cognitive capability decline[9]. Therefore, P300 latency is directly associated with the cognitive ability. In the present study, amblyopes exhibited significantly longer P3a latency compared with the control subjects, but no significant difference was found between the severe and mild-to-moderate amblyopes. To exclude an influence of previous waves on P3a latency, we also analyzed the latency of N200 wave and found no significant delay in the amblyopes, indicating that the prolonged P3a latency in amblyopes didn't result from delay of previous waves. We speculated that amblyopes spend longer time to shift from previous attention to novel stimuli at the late stage, indicating that the ability to select stimuli information is damaged in amblyopes. Besides P3a ERP in our study, latencies of other waveforms such as P100, N170, N270, and N450 are also found delayed in special tasks in amblyopes according to previous reports[3,4,25]. However, these waves were cognitive independent.

P300 amplitude is proportional to the amount of attentional resources devoted to a given task[26,27] and a favorable index of central nervous system (CNS) activity. The amplitude of P300 wave varies with the degree or quality of neuronal activity incorporated in the information process-

ing[28]. Based on the concepts of compensation-related utilization of neural circuits hypothesis (CRUNCH)[29], van Dinteren et al found the frontal P300 wave steadily increased in magnitude with advanced aging, reflecting an increase in recruitment of compensatory frontal neural circuits that predominantly weighed on the frontal P300[30]. In our study, the amplitude of P3a ERP in the mild-to-moderate amblyopes exhibited a significantly higher amplitude at Fz electrode. This might be explained by the frontal compensative effect of mild-to-moderate amblyopes in cognitive visual processing. Although severe amblyopes exhibited higher amplitude than the controls, no significance was found. We speculated that the following two reasons are accounting for this result: firstly, the compensative ability in severe amblyopes might be down-regulated; secondly, the severe amblyopes gave up to discriminate more details of the stimuli due to their limited visual acuity, and less neural resources were activated in the cognitive process.

Neurophysiological and fMRI studies provided sufficient evidence that the frontoparietal networks played important roles in top-down cognitive and bottom-up sensory-driven ways during visual attention[10,31]. Studies in monkey and human electrophysiology suggested that the frontal and parietal cortices were differentially engaged in the bottom-up and top-down control of visual attention, with frontal cortices more involved in top-down control of visual attention and parietal cortex more involved in bottom-up perceptual processes[32]. Although these systems could be called upon independently, they might interact to carry out two distinct attentional processes flexibly. One was bottom-up attentional process activated early and decaying quickly, and the other was top-down attentional process activated late and lasting longer[33]. We inferred that the top-down effect activated in the frontal lobe was strengthened in mild-to-moderate amblyopes, resulting in the same behavioral reaction time in our study.

Amblyopic deficits are different at different spatial frequencies. Li et al discovered in anisometropic amblyopia that the blood oxygenation level-dependent (BOLD) signal magnitude in V1 and V2 visual cortex in the amblyopic eye was significantly lower than the fellow eyes at low spatial frequencies (0.4-2 CPD) but significantly higher than the fellow eyes at high spatial frequency (8 CPD)[19], indicating that the spatial frequency of visual stimuli might influence neuronal reaction differently in anisometropic amblyopes. We adopted the low spatial frequency to ensure correct discrimination of all subjects in this study. For further investigation, larger samples and more task loads could be tested to compare neural activity at different spatial frequencies using different stimuli.

Limitation

Although we tried to ensure the baseline data to be equivalent during the test for all subjects to avoid P300 variation, larger samples might be necessary to counterbalance for individual fluctuations. Also, due to the low spatial resolution provided by ERP, it would be of significance to combine high-temporal-resolution ERP with high-spatial-resolution neuroimaging to investigate the cognitive process of amblyopia further.

Conclusions

In conclusion, anisometropic amblyopes exhibited distinct neural activity from control subjects at a late stage of the cognitive process, demonstrated by the delayed latency of P3a wave in the frontal lobe. Cognitive visual processing in anisometropic amblyopes was impaired, and the compensative effect of P3a wave was shown in mild-to-moderate anisometropic amblyopes.

Conflict of interest

Authors declare no conflict of interests.

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Zhao J and Yang XB contributed equally to this work and should be considered as co-first authors. This work was funded by Sichuan Province Scientific Support Plan "The influence of visual display terminal to visual quality and function": 2012SZ0138.

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