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The automatic processing of visual information at different visual acuity levels: An ERP study

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ABSTRACT

This study investigated the subjective visual acuity by recording ERPs elicited by task-irrelevant visual changes. Optotypes stimuli were presented in the center of the visual field at three threshold levels (supra-threshold, threshold and sub-threshold) while participants were listening to stories. The results showed that neither vMMN nor P3a component was elicited by optotypes stimuli on the sub-threshold condition, whereas, vMMN was elicited under supra-threshold and threshold conditions, with no significant differences between those vMMN amplitudes of two conditions. The P3a amplitude was larger for supra-threshold condition than that for threshold condition. These data demonstrated that the emergence of vMMN could only reflect the automatic detection of orientation-changes in the supra-threshold and threshold conditions compared to the sub-threshold condition, whereas the P3a amplitude could reflect the difference in processing of supra-threshold and threshold stimuli.

1. Introduction

Although visual acuity (VA) that represents the ability to detect visual stimuli in the minimum angle has been assessed subjectively by visual testing chart in clinic, there are several anthropogenic factors affecting the validity of test results (Ramachandran et al., 2013), and for the low rate of repetition of optotypes in one line of the chart, the chance of guessing becomes key factor to reduce the objectivity and reality of the testing (Hoffmann, 1997; Paliaga, 1993). As one of objective and automatic tools to test the visual acuity, the computer-based vision assessment could test the patient's acuity threshold relying on the reaction to the changes of optotypes in direction and size (Bach, 1996; Crossman et al., 1970; Hoffmann and Menozzi, 1997; Moke et al., 2001; Rolkosky et al., 2009). In addition, electrophysiological test played an important role in accessing the visual function. For example, VEP (visual evoked potentials) is generated from the occipital cortex in response to the visual stimuli received by the retina and has been generally regarded as an objective indicator for assessing clinical visual impairment without considering verbal, motor or behavioral response from the patients (Chen et al., 2012; Good et al., 2001; Sokol, 1976; Tyler et al., 1979), especially in young or minimally cooperative participants. However, the cases of cortical blindness with normal VEP waveforms (Aldrich et al., 1987; Bodis-Wollner et al., 1977) indicated that VEP, indeed, could not totally access the higher-level (beyond the primary visual cortex) processing in the cortical pathways (Heinrich et al., 2010; Saitoh et al., 2001). Besides, due to the lower correlation between VEP and visual acuity, especially, when there are small differences in VA and when the participants are patients with good/high VA level (Kromer et al., 2014), visual acuity of patients could not be measured accurately by the VEP test. Hence, in the present study our aim is to find a more suitable experimental method to test visual acuity.

Relevant to the present study, recent studies explored the correlation between the late-latency ERP components and visual acuity. For example, Heinrich and colleagues investigated the visual acuity estimation based on P3 component by using normal visible gratings and blurred visible gratings in a visual oddball paradigm and found that the P3 component was sensitive to identify the resolution threshold and thus could be used as a tool for measuring acuity in cases of visual impairments (Heinrich et al., 2010). In addition to infrequent target stimuli-relevant P3 component (i.e., P3b component), interestingly, in the three-stimuli oddball paradigm (including infrequent target stimuli and frequent non-target stimuli as well as infrequent novel stimuli), novel stimuli elicited P3a component with a frontal-central scalp distribution, reflecting automatic orientation of attention (Katayama and Polich, 1998; Polich, 2007). Several researches have reported that P3a can be obtained with visual stimuli under passive viewing conditions (Bennington and Polich, 1999; Jeon and Polich, 2001), which is positively correlated with stimulus discriminability. As an important cognitive function for human survival, the pre-attentive change detection occurs at the very early stage of information processing. To date, ample

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evidence indicated that the mismatch negativity (MMN) of event-related potential (ERP) components is a reliable indicator for exploring pre-attentive processing (Näätänen et al., 2007). Generally, MMN can be elicited by infrequent deviant stimuli inserted randomly in a sequence of frequent standard stimuli presented outside of the focus of attention. MMN is thought to reflect memory-comparison-based automatic processing. Although the MMN component has been widely investigated in auditory modality, analogue of auditory MMN was also found in response to visual deviants such as color (Czigler et al., 2002), size (Kimura et al., 2008), shape (Grimm et al., 2009), duration (Qiu et al., 2011), even complex visual stimuli such as facial expressions (Zhao and Li, 2006) and especially orientation (Czigler and Pato, 2009; Flynn et al., 2009; Kimura et al., 2010; Sulykos and Czigler, 2011). Since vMMN is elicited by discriminable changes in vision irrespective of the participants' attention, it is not surprising that the vMMN has recently received considerable attention as a tool of visual cognitive sciences (see for a review (Kimura, 2012; Kimura et al., 2011) and clinical research (Maekawa et al., 2013). To this end, the vMMN might be the biomarker ‘we've been waiting for’ since it represents a unique window into the non-attentional automatic processing of brain and it is necessary to clarify the correlation between vMMN and VA.

In the present study, we attempted to address whether the brain could automatically distinguish the changes of visual optotypes and whether vMMN and/or P3a components could estimate visual acuity optotypes.

2. Material and methods

2.1. Ethics statement

The committee of Soochow University approved the experiments and the informed consent was obtained from all participants. The methods were conducted in accordance with the approved guidelines (http://www.nature.com/srep/policies/index.html#experimental-subjects).

2.2. Participants

Fifteen right-handed students (9 females) in Soochow University with ages of 19–30 years (Mean = 23.8) volunteered to participate in the present experiment, with normal self-reported hearing and no history of psychiatric or neurological diseases. Their monocular visual acuities (0.2–0.8) were appropriate for this study.

2.3. Stimuli

The uncorrected monocular visual acuities of all the participants were measured with the tumbling E visual acuity optotypes and then, the corresponding visual acuity values were presented for each participant. In the present study, we defined that: (a) the line indicating participant's visual acuity was threshold visual acuity level (the E icons of the line were considered as threshold stimuli); (b) the line above was supra-threshold visual acuity level (the optotypes in this line were supra-threshold stimuli); (c) the line below of the threshold level was sub-threshold visual level (the “E” optotypes of this line were regarded as sub-threshold stimuli). All participants participated in three levels of test, including threshold visual acuity level, supra-threshold level and sub-threshold level consisted of various sizes of optotypes. The three levels were deemed to be representative for their personal monocular visual acuity, under and below the perceptual threshold, respectively.

The “tumbling E” acuity chart is comprised of 11 groups of optotypes with size of progressive decreasing from 0.1 to 1.5. According to the principle of the chart, each kind of visual acuity value (0.1–1.0) corresponds with a definite visual angle (Table 1). All the stimuli were standardized “E” optotypes with three directions (upturned, leftwards and rightwards) based on the visual acuity chart, and also consistent with the homologous visual acuity and visual angle.

2.4. Procedure

Every visual level is consisted of one oddball condition block, in which the icons were the same size and three orientations. The standard stimuli were upturned “E” icons, and the deviant stimuli were optotypes with orientation in left and right. In each block, standard stimuli occurred 180 times (75%), and two kinds of deviant stimuli were respectively presented 30 times (12.5%). In addition, stimuli were presented for 300 ms and followed by an inter-stimulus interval of 500 ms. All the stimulus optotypes were shown in a white color with a black background at a distance of 2 m in front of the participants. In order to effectively avoid the successive emergence of deviants, there were at least two standards between two deviants.

During the experiments, the participants were instructed to look at the screen and to pay attention to the radio and count the number of /nə/ (one of modal particles in Chinese) silently, simultaneously looking at the front of the monitor horizontally without voluntary attention to the optotypes and avoiding extraneous movement. The radio presented an audio narration via a loudspeaker placed at about 50 cm next to the participant, in which the volume of the recording equaled that of a normal speaking voice. The stories were three excerpts from the Chinese history, and each excerpt includes 16–19 task-relevant stimuli (/nə/). After each condition, participants were instructed to report the counting result to the experimenter. Sequence effects due to the three different visual acuity condition blocks were already considered and eliminated by equilibrating the sequence of three conditions in each participant.

2.5. EEG recording and data analysis

The electroencephalogram (EEG) was continuously recorded with NeuroLab Amplifier with 32-channel Ag/AgCl electrodes according to the extended international 10–20 system. The ground and reference electrode were placed on the frontal area and nose tip, respectively. Vertical EOG was recorded with two electrodes above and below the right eye. Horizontal EOG was recorded with two electrodes at the right and left outer canthi of the eyes. The impedances of the electrodes were kept below 5 kΩ throughout the experiment. EEG and EOG signals were amplified with a band pass of 0.1–100 Hz at a sampling rate of 500 Hz.

After EOG artifact correction, the EEG was segmented into the epoch from 200 ms pre-stimulus to 800 ms post-stimulus. After the baseline correction (200 ms pre-stimulus), the trials contaminated with artifacts greater than ± 100 μV were rejected before averaging. The EEG segments were averaged separately for standard and deviant stimuli in different conditions. Both vMMN and/or P3a were obtained by subtracting ERPs to standard stimuli from ERPs to deviant stimuli for each visual feature, respectively.

Table 1
The tumbling E visual acuity chart and the corresponding of visual angle.

	The corresponded value										
Visual acuity	0.1	0.12	0.15	0.2	0.25	0.3	0.4	0.5	0.6	0.8	1.0
Visual angle	10.000′	7.943′	6.310′	5.012′	3.981′	3.162′	2.512′	1.995′	1.585′	1.259′	1.000′