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The event-related low-frequency activity of highly and average intelligent children

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Using time-frequency analysis techniques to investigate the event-related low-frequency (delta: 0.5–4 Hz; theta: 4–8 Hz) activity of auditory event-related potentials (ERPs) data of highly and average intelligent children, 18 intellectually gifted children, and 18 intellectually average children participated the present study. Present findings show that intellectually gifted children had significantly larger delta activity than their normal peers in mismatch negativity (MMN) component, while in P3a component, which originates from stimulus-driven frontal attention mechanisms during task processing, intellectually gifted children had both significantly larger delta and theta activities than their normal peers. The present findings further supported that low-frequency brain activity could be regarded as the basis of intelligence and cognitive functions, and spectral EEG time-frequency analysis technique should be used to explore some new aspects of brain activity relating to intelligence.

Keywords: electroencephalogram (EEG); event-related potentials (ERPs); time-frequency analysis; intelligence; automatic processing; children

Introduction

Studies show that intellectually gifted individuals have fast brains, and use much less time to accomplish cognitive tasks with much better performances than average individuals (Chalke & Ertl, 1965). Intellectually gifted individuals also have much better attention focus and memory abilities (Schweizer & Moosbrugger, 2004), and the neural mechanisms of high intelligence are regarded as the specific ability to catch tiny changes with attention (Jaušovec & Jaušovec, 2000a). Intellectually gifted individuals have faster neural processing speed and more efficient neural activation functions (Robaey, Cansino, Dugas, & Reault, 1995).

Some researches have studied the relationship between IQ and electroencephalogram (EEG) (Schmid, Tirsch, & Scherb, 2002), and it is reported that theta power (4–6 Hz) had close relationship with episodic memory processes and working memory performances (Klimesch, 1996). Most previous studies concentrated on the relationship between EEG activity and complex cognitive processing, and few studies explored the connection between EEG and brain automatic processing.

While in auditory event-related potentials (ERPs), mismatch negativity (MMN) is one of the most important and sensitive indices for the automatic processing (Näätänen, 1992; Näätänen, Gaillard, & Mäntysalo, 1978; Näätänen & Winkler, 1999), and it can be elicited even when participants do not pay attention to the sound

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stimuli (Näätänen, Paavilainen, Tiitinen, Jian, & Alho, 1993). When participants make their involuntary attention to novel sound stimuli, it elicits another ERP component termed P3a. P3a is a large positive deflection peaking at 200–300 ms (Squires, Squires, & Hillyard, 1975) and it reflects an involuntary attention switch towards distinct sound stimuli changes (Alho, Escera, Diaz, Yago, & Serra, 1997; Escera, Alho, Winkler, & Näätänen, 1998; Escera Alho, Schröger, & Winkler, 2000).

Time-frequency analysis of ERPs contributes to separate different event-related frequency components, which are superimposed in the time domain ERP (Basar, 1998), and the techniques help to differentiate the different frequency channels in specific time courses of perceptual and cognitive processing (Basar & Stampfer, 1985). It is suggested that event-related delta activity might reflect the neural processes of signal matching, while theta activity links to the neural processes of focused attention (Basar-Eroglu, Basar, Demiralp, & Schuermann, 1992). In the present study, we tried to use time-frequency analysis to explore the event-related low-frequency activity (delta activity: 0.5–4 Hz and theta activity: 4–8 Hz) during human brain automatic processing in both highly and average intelligent groups.

Materials and methods

Participants

Thirty-six children participated in the present study. Eighteen of them are intellectually gifted children (11 boys and seven girls; ages ranged from 11.4 to 12.4 years; mean age 11.8). These children were recruited from an experimental gifted class of a middle school in Beijing. In this experimental gifted class, 30 children were identified and selected from about 1500 candidates by using multiple criteria and multiple methods (Shi & Zha, 2000). Children's intelligence test scores and achievement scores (mainly for Chinese, English and mathematics) were above the 95th percentile. The rest of the participants were intellectually average children ($n=18$, nine boys and nine girls; age ranged from 11.2 to 12.2 years; mean age 11.7). Children in this group were from among those who responded to an advertisement placed in a primary school in Beijing.

Before the EEG being recorded, all participants were tested by Cattell's Culture Fair Test (CCFT, children's edition; Cattell & Cattell, 1960) and Test of Nonverbal Intelligence (TONI-2, a Language-Free Measure of Cognitive Ability, Picture Book Form A; Brown, Sherbenou, & Johnsen, 1982). The mean IQs of the intellectually gifted and average groups were 122.1 and 98.6, respectively. None of the children had neurological or psychiatric problems. Their visions were normal or corrected to normal, and all were right-handed and were naïve to electrophysiological procedures. Consent was obtained from the teachers and parents of the participants.

Stimuli and procedure

We revised the research paradigm of Lepistö et al. (2004), and the stimuli were Chinese consonant-vowel (CV) syllables /ka/ and /ta/. In addition, 120 different novel sounds were used during the experiment, and they ranged from pure and complex tones to natural vowels. The syllables were presented for 100 ms (including 5 ms rise and fall times) with the intensity of 59 dB SPL (sound-pressure level), and the intensity of novel sounds ranged from 55 to 79 dB SPL (mean 61.9 dB SPL). There were three stimulus blocks of 400 stimuli using a 1000-ms inter-stimulus interval (ISI). The probabilities for standard syllable /ka/, deviant syllable /ta/ and the novel sounds were 0.8, 0.1 and 0.1, respectively. Each stimulus block began with at least four standard sounds, and at least two standard syllables preceded each deviant syllable or novel sound. The stimuli were presented to the ears through insert earphones at a level of 75 dB SPL.

During the electrophysiological acquisition period, participants sat comfortably in a reclining chair within an electrically shielded, sound-attenuated booth and watched self-chosen soundless videos. The auditory stimuli were presented to each participant's ears through insert earphones, and in order to obtain brain automatic processing, all participants were instructed to ignore the sounds and to sit as quietly as possible. None of the participants experienced difficulty complying with this instruction. The duration of the recording session was approximately 35 minutes.

ERP recording and data analysis

Nose-referenced EEG (amplified by SynAmps 2 online bandpass filtering: 0.05–100 Hz, sampling rate 1000 Hz) was recorded with Ag–AgCl electrodes attached to the scalp sites F3–Fz–F4, FC3–FCz–FC4, C3–Cz–C4, CP3–CPz–CP4, P3–Pz–P4, and O1–Oz–O2 according to the International 10–20 system (Jasper, 1958). The vertical electro-oculogram (EOG) was recorded with electrodes placed above and below the left eye, and two active electrodes were placed at the right and left mastoids. EEG epochs of 900 ms, including 100 ms of pre-stimulus time, were offline averaged separately for each stimulus class. Epochs with artifacts exceeding 100 μV at any electrode were omitted from further analysis.

The MMN was measured from the deviant-minus-standard ERP-difference waveforms, and the P3a was from the novel-minus-standard ERP-difference waveforms. The visual inspection of the data revealed that the distributions of the MMN and P3a peak latencies differed. The MMN peak amplitude was calculated at the negative maximum between 200 and 400 ms, and the P3a was defined at the largest positive peak between 250–450 ms.

The ERP waveforms were subjected to bandpass ranges of 0.5–4 Hz (delta activity) and 4–8 Hz (theta activity) with a roll-off 24 dB/octave. Thus, the two sets of components represent accurately the original ERP waveforms without any loss or distortion of original signals. The between-group differences in the amplitudes, latencies, and scalp distributions of the ERP components were analyzed with three-way analysis of variance (ANOVA): Group (children with high intelligence vs. average children) × Anterior–posterior distribution (anterior, posterior) × Laterality (left, middle, right). Frontal-central electrodes were included as anterior distribution (F3–Fz–F4, FC3–FCz–FC4 and C3–Cz–C4), and parietal–occipital electrodes were included as posterior distribution (CP3–CPz–CP4, P3–Pz–P4 and O1–Oz–O2). Left laterality contained electrodes F3, FC3, C3, CP3, P3, and O1. Middle laterality contained electrodes Fz, FCz, Cz, CPz, Pz, and Oz. Right laterality included electrodes F4, FC4, C4, CP4, P4, and O2.

Results

In order to compare the patterns of the neural activities of the intellectually gifted and average children, a descriptive statistics of latencies and amplitudes of different EEG bands and a three-way ANOVA were conducted. The results of descriptive statistics were listed in Table 1.

Table 1. Mean amplitudes and latencies of delta and theta activities in MMN and P3a components in both groups.

	Delta (MMN)		Theta (MMN)		Delta (P3a)		Theta (P3a)	
Group	Latency	Amplitude	Latency	Amplitude	Latency	Amplitude	Latency	Amplitude
High intelligent	−1.53 (0.21)	415.17 (52.56)	−0.68 (0.07)	253.72 (25.74)	1.60 (1.85)	336.72 (27.99)	0.72 (0.17)	324.94 (13.62)
Average	−1.26 (0.20)	415.5 (55.42)	−0.67 (0.13)	245.83 (13.17)	1.01 (1.99)	338.83 (42.41)	0.42 (0.17)	311.78 (21.80)

Note: MMN=mismatch negativity.

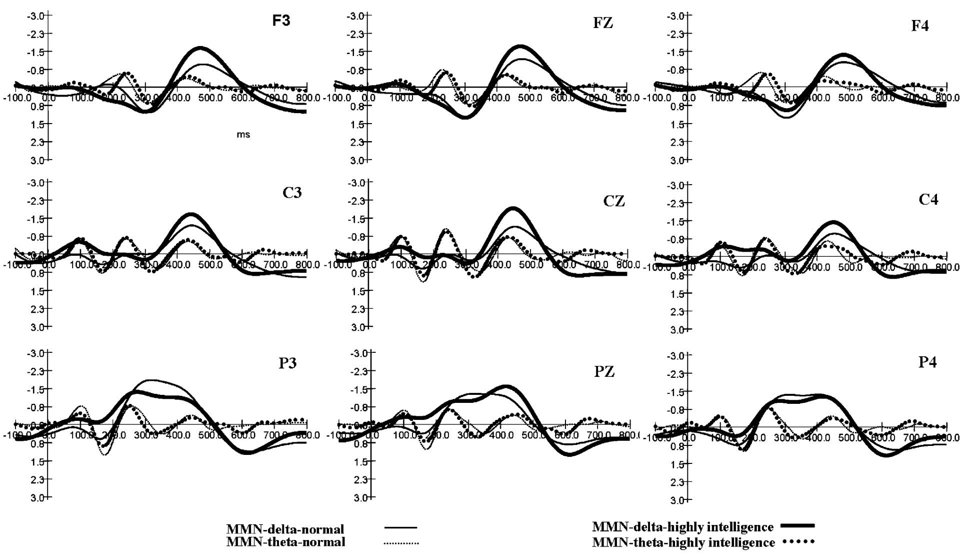

Figure 1. Delta activity and theta activity in the mismatch negativity (MMN) component of both the groups.

Delta activity and theta activity in the MMN component of both the groups were presented in Figure 1. According to the three-way ANOVA, it was found that as to MMN, intellectually gifted children had larger delta activity amplitude than average children ($F(1, 34)=5.15$, $P=.057$), and there were no significant differences in theta activity between the two groups. The delta activity also had Anterior–posterior effect on activity latency ($F(1, 34)=137.19$, $p<.001$): Delta activity had shorter peak latency in brain posterior distribution than that in anterior area. There were also significant interactions between Group effect and Anterior–posterior effect on delta activity amplitude ($F(1,34)=6.04$, $p<.05$) and latency ($F(1,34)=25.95$, $p<.001$) in MMN component: Intellectually gifted children had significantly shorter peak latency in brain anterior area and longer delta peak latency in posterior area than that of average children, and intellectually gifted children had larger delta activity amplitude in anterior area than that in posterior area but average children had larger delta activity amplitude in posterior area than that in anterior area.

Delta activity and theta activity in the P3a component of both the groups are presented in Figure 2. As to P3a component, intellectually gifted children had larger delta activity in amplitude than their average peers ($F(1,34)=11.61$, $p<.05$). The delta activity also had significant Anterior–posterior effect on peak latency ($F(1, 34)=114$, $p<.001$) and activity amplitude ($F(1, 34)=380.65$, $p<.001$): There were much shorter delta peak latency in anterior area that in posterior area and there were larger delta activity amplitude in anterior area than that in posterior area. Laterality also had significant main effect in delta activity amplitude ($F(2, 34)=10.47$, $p<.01$). There were also significant interactions between Group effect and Anterior–posterior effect on delta activity amplitude ($F(1,34)=37.98$, $p<.001$) and delta peak latency ($F(1,34)=50.11$, $p<.001$) in P3a component: Intellectually gifted children had much shorter peak latency in brain posterior area and longer peak latency in anterior area than that of average children, and they had larger delta activity amplitude in anterior area and smaller delta activity amplitude in the posterior area than average children.

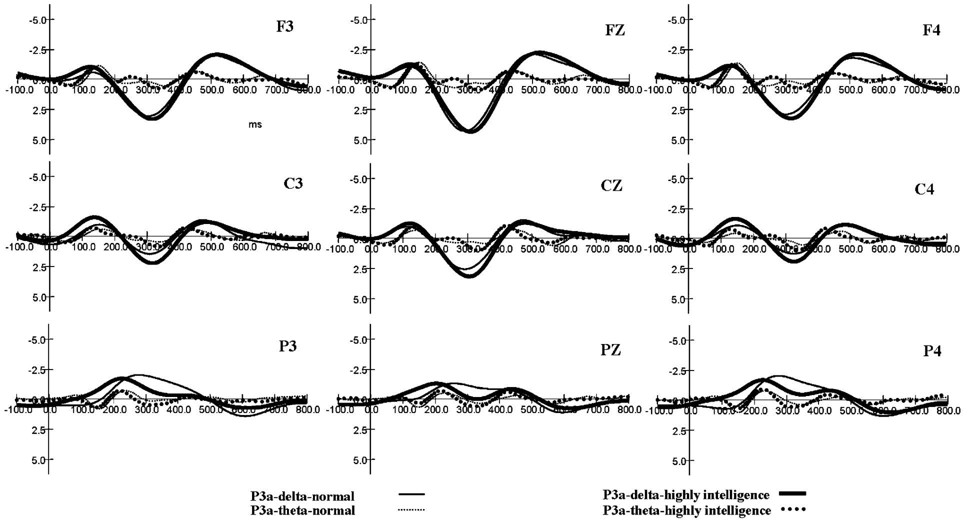

Figure 2. Delta activity and theta activity in the P3a component of both the groups.

As to P3a component, intellectually gifted children had larger theta activity of amplitude than their average peers ($F(1,34)=129.18$, $p<.001$). The theta activity also had significant Anterior–posterior effect on activity amplitude ($F(1, 34)=122.76$, $p<.001$): There was much larger peak amplitude in anterior area than that in posterior area. Laterality also had significant main effect in theta activity amplitude ($F(2, 34)=7.02$, $p<.05$). There were also significant interactions between Group effect and Anterior–posterior effect on theta activity amplitude ($F(1,34)=32.28$, $p<.001$) and latency ($F(1,34)=8.14$, $p<.01$): Intellectually gifted group had much shorter theta latency in brain posterior area and longer theta latency in anterior distribution than their average peers.

Discussion

Delta and theta activity in MMN component

In MMN component, intellectually gifted children had larger delta activity amplitude than average children, but there were no significant differences in theta activity between the two groups. The present finding further supported that brain low-frequency activity had close relationship with neural automatic processing and event-related delta activity was more sensitive to oddball paradigms (Johnstone, Barry, & Dimoska, 2003). According to our present results, intellectually gifted children had significantly shorter delta peak latency in brain anterior area, and might have better and more efficient frontal functions than average children (Duncan et al., 2000; Gray, Chabris & Braver, 2003; Jaušovec, 2000). The low-frequency brain activity could be regarded as the basis of intelligence and cognitive functions.

Delta and theta activity in P3a component

For delta activity, intellectually gifted children had larger delta activity amplitude than their average peers. Intellectually gifted children had much shorter delta peak latency in posterior area and longer delta peak latency in anterior area and had larger activity amplitude in anterior area and smaller activity amplitude in the posterior area than the average children, and these results were similar with previous findings (Basar, Basar-Eroglu, Karaks, & Schürmann, 1999).

For theta activity, intellectually gifted children had larger theta activity amplitude than their average peers, and there was much larger peak amplitude in anterior area than that in posterior area. Intellectually gifted children had shorter theta peak latency in posterior area and longer peak latency in anterior area comparing to average children, and these results might indicate that intellectually gifted individuals use more frontal functions to process the novel stimuli (Duncan et al., 2000; Gray et al., 2003; Jaušovec, 2000).

General discussion

Present results supposed that individuals with high intelligence might have high degree of maturation in brain structure and synapses action systems (Schmid et al., 2002) and more efficient engagement of neural networks (Jaušovec & Jaušovec, 2000b). It is reported that intellectually gifted individuals had significantly larger theta activity than less intelligent individuals in the cognitive tasks (Doppelmayr et al., 2005), and it is also suggested that theta band induced desynchronization/ synchronization (ERD/ERS) in working memory tasks (Jaušovec & Jaušovec, 2004). On the contrary, Gevins and Smith (2000) did not find any significant relationships between theta power activity and their cognitive performance in a spatial memory task. These divergent findings might be due to the different difficulty of cognitive tasks (Doppelmayr et al., 2005). Since the event-related low-frequency activity was more likely induced in oddball paradigms, the findings in our present study showed that delta activity significantly correlated with intelligence in both MMN and P3a components and theta activity linked closely with intelligence in P3a component.

In conclusion, the present findings confirmed the significant correlations between activities of EEG low-frequency band power and intelligence: Intellectually gifted children had significantly larger delta activity than their normal peers in automatic processing, while in neural responses to novelty information, intellectually gifted children had both significantly larger delta and theta activities than their normal peers. Our present findings further supported the importance of relationship between EEG low-frequency power and intelligence, and particular importance should be given to the use of spectral EEG time-frequency analysis technique, which could reveal new aspects of brain activity relating to intelligence.

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