Intelligence and information processing during a visual search task in children: an event-related potential study

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To investigate the differences in event-related potential parameters related to children's intelligence, we selected 15 individuals from an experimental class of intellectually gifted children and 13 intellectually average children as control to finish three types of visual search tasks (Chinese words, English letters and Arabic numbers). We recorded the electroencephalogram and calculated the peak latencies and amplitudes. Our results suggest comparatively increased P3 amplitudes and shorter P3 latencies in brighter individuals than in less intelligent individuals, but this expected neural efficiency effect interacted with task content. The differences were explained by a more spatially and temporally coordinated neural network for more intelligent children. *NeuroReport* 17:747–752 © 2006 Lippincott Williams & Wilkins.

Keywords: event-related potentials, intelligence, speed of information processing, visual search

Introduction

Endeavors focusing on the relationship between event-related potentials (ERPs) and psychometrical intelligence found consistently negative correlation between ERP latencies and IQ, which could be interpreted by the neural efficiency hypothesis that 'high-IQ subjects' brains work more efficiently' [1]. In these studies, elementary cognitive tasks have always been used in their classical form; for example, letter pairs used in Posner's task and digits used in Sternberg's short-term memory scanning task. A couple of studies reported that the physiological indices of cortical activation patterns were sensitive for different types of stimulus material [2–4]. A question that remains is whether this is equally true for children. Here, we selected children with different intelligence levels to see whether the same degree of content specificity on the Elementary Cognitive Task–intelligence relationship reported in adults would be found in a distinctly different sample.

We employed tasks consisting of Chinese word, English word and Arabic number stimulus elements. We used the classical approach by recording ERPs elicited in a varied visual search task [5,6]. The task was similar to Sternberg's memory scan task except that the target was presented concurrently with the distractors rather than subsequent to the distractors. It was reported to be sensitive to the cognitive processes underlying fluid intelligence [7], and thus was expected to yield ERP differentiations associated with intelligence. According to the neural efficiency hypothesis, we expected that the more intelligent group would display higher efficiency than less intelligent individuals when comparing Elementary Cognitive Tasks using three different types of stimulus materials.

Materials and methods

Participants

Twenty-eight participants were selected for the present study. The entire sample consisted of two groups: (1) An intellectually gifted group [n=15, nine boys and six girls; ages ranged from 11.5 to 12 years (11.7±0.2 years)]. These children were recruited from an experimental gifted class of a middle school in Beijing. Thirty children were identified and selected from 1500 peers by using multiple criteria and multiple methods. Children's intelligence test scores and achievement scores (mainly for Chinese and mathematics) were above the 95th percentile. After being identified, they received the so-called accelerated education, spending 4 years for 6-year middle-school courses. (2) An intellectually average group (n=13, seven boys and six girls; age 11.7±0.3 years). The children in this group were from among those who responded to an advertisement placed in a primary school in Beijing.

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Before the electroencephalogram (EEG) recording, all participants were tested by Cattell's Culture Fair Test (CCFT, children's edition) [8]. A *t*-test showed that the two groups were significantly different in CCFT raw score (43.5 vs. 32, $P<0.01$). No significant differences of age ($P=0.863$) and male/female ratio ($P=0.246$) were found. All children were free from neurological or psychiatric problems, vision was normal or corrected-to-normal, and all were right-handed and were naive to electrophysiological procedures. Informed consent was obtained from all teachers and parents of the children.

Stimuli and procedure

All stimuli were presented as white characters on a black background in the center of the screen, each extending to a visual angle of approximately 1.5° vertical, 3.42° horizontal. Each type of stimulus consisted of a single probe-like word (or letter or number) that appeared with another string of four words (or letters or numbers). Three types of stimuli were presented separately in Chinese words (CW), English letters (EL), and Arabic numbers (AN). Chinese words were presented by using a 'Song' font and were high-frequency words including a maximum of two to four strokes. All letters and numbers were presented by using a 'Times New Roman' font. The target stimulus appeared in the words (or letters or numbers) string in 50% of all the trials (Fig. 1). The participants were instructed to judge whether the target was among the distractors.

The experimental paradigm is illustrated in Fig. 1. At the beginning of each trial, a visual fixation stimulus ('+') was presented for 300 ms on the computer monitor; then, the test stimulus was presented for 400 ms and the participants had to respond to the stimulus by pressing either the 'yes' button or the 'no' button, with the interstimulus interval being varied randomly between 250 and 550 ms. Twenty practice trials and 120 trials were presented for each experimental condition. The order of presentation of six experimental blocks for three experimental conditions and the order of trials within each block were pseudo-randomized. Instructions stressed speed and accuracy.

Participants were seated individually in a dimly lit, electrically shielded and sound attenuated room. They were seated 1 m from the computer screen and were instructed to respond via a game pad. Half of them were told to press one key with their left index finger for the 'yes' response and another key for the 'no' response. For the other half of the participants, the assignment of the response hand was reversed. The experiment was controlled by an HP-compatible microcomputer, and stimuli were generated using the Windows-based evoke (Advanced Neuro Technology BV, Enschede, The Netherlands) program. Stimuli were displayed on a 17-inch HP color monitor (with refresh rate 85 Hz, resolution 1024 × 768).

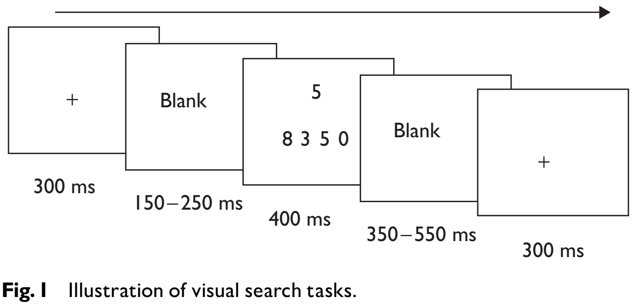

Fig. 1 Illustration of visual search tasks.

Event-related potential recording and data analysis

Brain electrical activity was continuously recorded from 64 scalp sites using tin electrodes mounted in an elastic cap (NeuroScan Inc., Sterling, Virginia, USA), the vertical electrooculogram (EOG) was recorded with electrodes placed above and below the left eye, and all electrodes were referenced to the left and right mastoids. Impedances were maintained below 5 kΩ at all sites. The EEG and EOG were amplified by an ANT (Advanced Neuro Technology BV) amplifier system with a gain of 20 and were stored without filtering (DC recording) and continuously sampled at 500 Hz/channel. Offline analysis included bandpass finite impulse response filtering of 0.01–30 Hz using a filter order of 4001. Prior to averaging, epochs were screened for eye movement and other artifacts, which were rejected in a semi-automatic procedure. During averaging, these EOG artifacts were corrected using a PCA-based algorithm [9].

The EEG data were epoched into periods of 1000 ms, from 200 ms before the onset of the stimuli to 800 ms after the stimuli onset. The following sites were chosen for statistical analysis: AF3, AF4, F5, F1, Fz, F2, F6, C3, C1, Cz, C2, C4, Pz and Oz. The grand-averaged ERP waveforms from selected electrodes superimposed for the three types of tasks of the two groups are displayed in Fig. 2 (Chinese words, left; English letters, middle; Arabic numbers, right). All types of stimulus elicited an anteriorly distributed, negative-going component peaking at approximately 125 ms (N125), followed by a positive-going component peaking at approximately 220 ms (P220), also most apparent at anterior sites. Following the typical N125-P220 complex, a negative-going, frontal-centrally maximal but widely distributed component peaking between 300 and 500 ms was evident, which may be referred to as an N370. Following the so-called N370, at anterior sites, a late positive-going component (LPC) or P600 was evident, and the latency and amplitude of LPC peaking at approximately 600 ms. At occipital sites, a positive peaking at approximately 125 ms (occipital P125) was apparent, followed by a negative-directed component peaking at approximately 200 ms (occipital N200).

Peak latencies were detected before the analyses of amplitudes. Mean amplitudes were measured in three time windows: first time window (between 200 and 300 ms after the stimulus onset, during which a positive slope was observed), second time window (between 300 and 500 ms after the stimulus onset) and third time window (between 500 and 800 ms after the stimulus onset). Peak latencies and mean amplitudes were calculated in each condition for each participant of each group. Repeated-measures analyses of variance were conducted for latencies and mean amplitudes with group (intellectually gifted vs. intellectually average) as a between-subjects factor, and stimuli type (Chinese words vs. English letters vs. Arabic numbers) and electrode sites (anterior 12, posterior 2) as within-subjects factors. Greenhouse–Geisser correction was used when appropriate.

Results

Behavioral data

Reaction time medians and accuracy are summarized in Table 1. A mixed-design analysis of variance was carried

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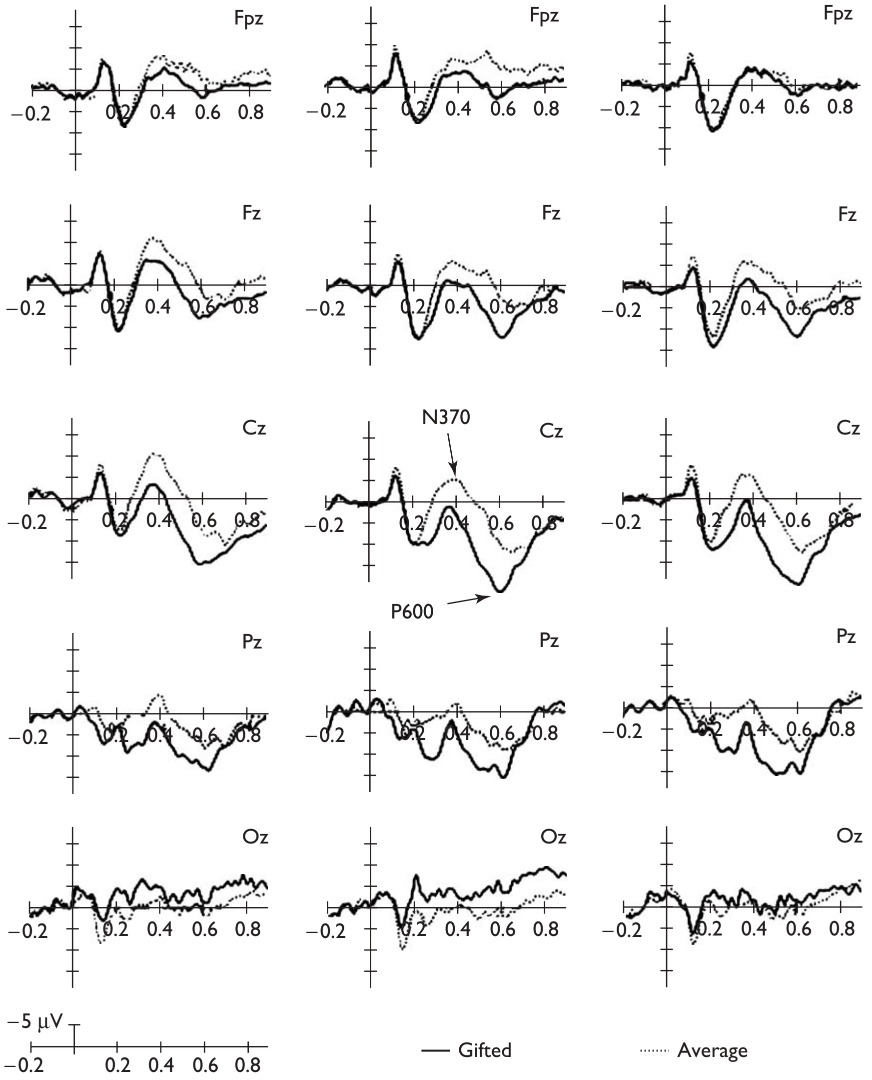

Fig. 2 Children's grand average event-related potential waveforms to Chinese words (the first column), English letters (the second column), Arabic numbers (the third column). Stimulus onset is the vertical calibration bar, and negative is plotted up. Solid line: gifted group; dotted line: average group.

out, with intelligence level as the between-subject factor and stimulus type as the within-subject factor. The main group effect on reaction time was not significant [F(1,26)=1.212]. The main effect of type was significant [F(2,52)=11.793, $P<0.001$]. Post-hoc comparison (Newman–Keuls test) revealed significant differences between the three types of stimulus material ($P<0.05$). No significant effect was observed on the interaction between type and group [F(2,52)=1.333].

As for accuracy, a significant main effect of type [F(2,52)=16.584, $P<0.001$] was yielded. Post-hoc comparison (Newman–Keuls test) revealed no significant differences between EL and AN, but both differed significantly from CW ($P<0.01$). The main effect of group [F(1,26)=10.394, $P<0.01$] reached significance, reflecting that the intellectually gifted group performed more accurately than the average group. No significant effect was observed in the interaction between type and group [F(2,52)=1.333].

P600 latency

The main effect of type [F(2,52)=25.000, $P<0.05$] was significant. Post-hoc comparison (Newman–Keuls test) revealed no significant differences between the EL and AN conditions but both types of stimulus material differed significantly from CW ($P<0.05$). The group effect on P600 (or LPC) latency was also significant [F(1,26)=10.562, $P<0.01$], with the latency of the intellectually gifted group being shorter than that of the intellectually average group. No significant main effect of electrode [F(11,286)=16.000] or interaction of group × type × electrode [F(22,572)=5.000] was noted.

Mean amplitude

In the first time windows (200–300 ms), there were significant main effects of electrode [F(11,286)=16, $P<0.01$] and type [F(2,52)=16.909, $P<0.001$]. Post-hoc comparisons by means of the Newman–Keuls test revealed no significant

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Table 1 Mean and standard deviation reaction times (ms) and accuracy (%) for gifted and average children

	Chinese		Letters		Numbers	
	Reaction time	Accuracy	Reaction time	Accuracy	Reaction time	Accuracy
Gifted	741.48 (125.87)	0.87 (0.11)	707.40 (104.23)	0.93 (0.09)	686.03 (103.59)	0.95 (0.06)
Average	665.60 (126.49)	0.75 (0.15)	653.28 (120.58)	0.80 (0.11)	644.61 (98.26)	0.81 (0.13)

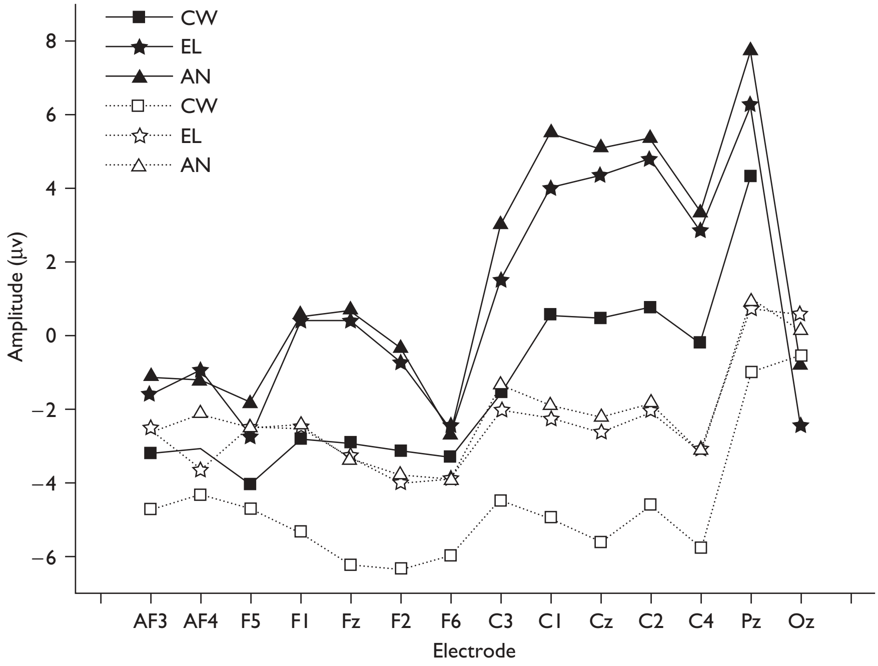

Fig. 3 Scalp distribution of the mean amplitudes of time window 300–500 ms. Solid lines: gifted group; dotted lines: average group. CW, Chinese words; EL, English letters; AN, Arabic numbers.

differences between the EL and the AN conditions but both types differed significantly from CW ($P < 0.01$). A main effect of group did not reach significance [F(1,26)=2.586]. No significant interaction of group × type × electrode [F(22,572)=5.000] was observed.

In the second time windows (300–500 ms), there were significant main effects of type [F(2,52)=21.695, $P < 0.001$] and electrode [F(11,286)=16, $P < 0.05$]. Post-hoc comparisons by means of the Newman–Keuls test revealed no significant differences between the EL and the AN conditions but both types differed significantly from CW ($P < 0.01$). Group effect reached significance [F(1,26)=10.519, $P < 0.01$]. The mean amplitudes of the ERPs in the second time window were smaller in the gifted children than in the average children. No significant interaction of group × type × electrode [F(22,572)=5.000] was observed.

In the third time windows (500–800 ms), no significant main effect of type [F(2,52)=2.347] was found. Significant main effects of electrode [F(11,286)=16, $P < 0.01$] and group [F(1,26)=13.708, $P < 0.001$] were found. The mean amplitudes of the ERPs in the third time windows were larger in the gifted children than in the average children. No significant interaction of group × type × electrode [F(22,572)=5.000] was noted.

Figures 3 and 4 illustrate the scalp distributions of mean amplitude in the time windows 300–500 and 500–800 ms. For the 300–500 ms window, both groups showed a frontal–central maximum of negativity, while for the 500–800 ms window, both groups showed a central maximum of positivity.

Discussion

The ERP results confirmed our expectations. The main effect of group successfully reached statistical significance especially on N370 and P600. Most likely, the current P600 represents the P3 component found in adult participants. The P600 latency across tasks was consistently faster for the gifted group than for the average group. The salient group effect is consistent with a number of previous studies [10,11]. Given the fact that P3 latency is a measure of the duration of the stimulus evaluation process [12], the present P600 latency decrements with increasing IQ might be taken to support the speed intelligence hypothesis or 'faster brains have higher IQs' as suggested by Chalke and Ertl [13]. The neural efficiency hypothesis of intelligence states that brighter individuals use fewer neurons and specific neuronal circuits in performing a specific task as compared with less bright individuals. Increased P600 amplitudes might be due to a more specific and focused use of neurons and neural circuits with a similar function. The higher level of

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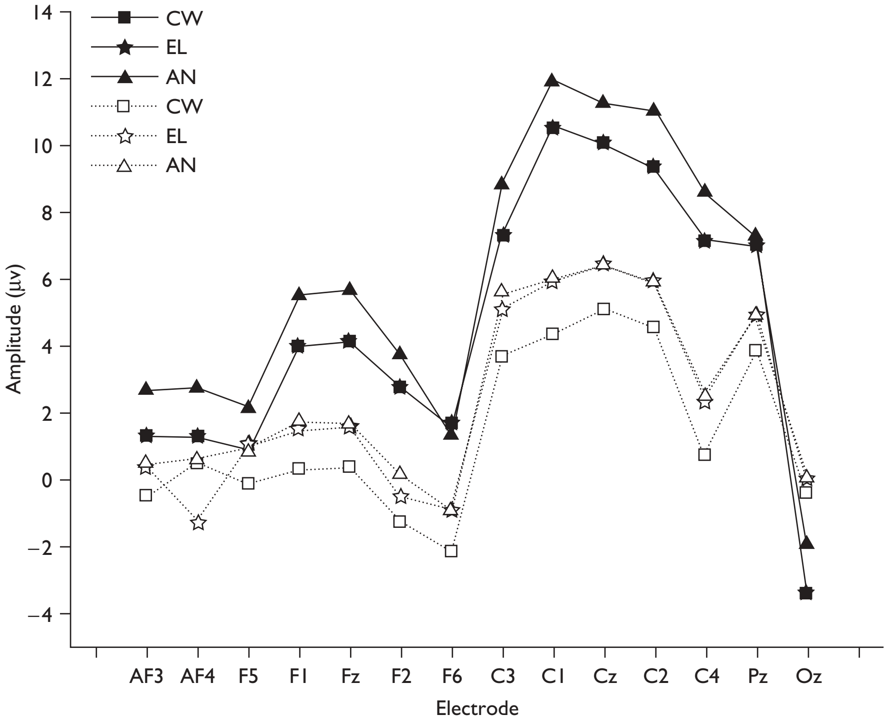

Fig. 4 Scalp distribution of the mean amplitudes of time window 500–800 ms. Solid lines: gifted group; dotted lines: average group. CW, Chinese words; EL, English letters; AN, Arabic numbers.

intelligence might be related to a spatially and temporally coordinated neural network [10].

As for the main effect of group on N370 amplitude, the explanation might be that a slow wave activity occurred early enough in the average group, leading to a relatively larger N370 and a smaller P600. The N370 component might be an N2. Previous studies suggested that N2 reflects the activity of a response inhibition system of the brain [14,15], which increased in amplitude when a greater effort was required. The three tasks in this study require the participants to preprocess stimulus, extract stimulus features, identify targets or search through a visual displayed sequential and choose responses, which also need an upper level control of inhibiting interference of distraction [16]. When gifted participants were finishing the choice reaction time task, they mobilized comparatively fewer resources [17].

The effect of different types of stimulus material on late components presents some evidence for content-specific patterns of cortical activation. In line with the task content effect of the reaction time–intelligence relationship, our results provide a corroboration of the relationship between physiological indices and intelligence. Our results, however, showed that the Chinese words condition differed significantly from the letters and numbers, which could be a result of basic cognition of different language elements, but the contamination of their complexity could not be excluded.

In this study, although no significant group effect on reaction time was found, a significant difference between their accuracy rates was found, which suggested that average and gifted children tended to adopt a strategy favoring speed and accuracy, separately. The effects of this type of response bias could imply the different processing efficiencies of different groups.

Conclusion

The results of the present study support the neural efficiency hypothesis, suggesting that the previously found pattern of relationship between intelligence and brain activity in adults also exists in children. The interpretation of the task content effects is problematic because of a contamination with task complexity.

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