Neural mechanisms of 1-back working memory in intellectually gifted children

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***Abstract*—To investigate the neural mechanisms underlying intellectually gifted children, electroencephalograms (EEG) were recorded while 13 intellectually gifted children and 13 average children accomplished a 1-back working memory task. The results showed that intellectually gifted children elicited significantly shorter P3 latency than their intellectually average peers. These results support the neural efficiency theory that intellectually gifted individual can use their brain more efficiently.**

Keywords-Event-related potential; Intelligence; 1-back, Working memory, Gifted

I. INTRODUCTION

What is the major difference between intellectually gifted and average people is a very important question to the public as well as to the researchers especially developmental psychologists. The behavioral research of intellectually gifted children has got consistent results. Intellectually gifted children outperformed intellectually average children in many domains, such as reasoning [1], memory [2], executive tests [3], self-regulation [4] and so on. Concerning the above cognitive functions, working memory might be the essential difference between these two groups of children [5]. After reviewed many researches, Schweizer also thought working memory was one of the most promising starting points in the research of the cognitive basis of intelligence [6].

Many researches concerned with brain features and their relations to intelligence. From an evolutional point of view, a high conduction velocity of cortex fibers together with cortex neurons correlates best with intelligence [7]. Racial studies found that variables related to brain size could mediate the relationship between race and intelligence [8]. It was proved that head circumference and brain volume are positively associated with intelligence [9]. Genetic studies found that biological determinants of intelligence may be translated into biochemical and neurophysiological processes in the central nervous system [10]. And this will influence the brain function and information processing.

In the relation between brain activity and intelligence, the neural efficiency theory proposed that intelligence is not a function of how hard the brain works but rather how efficiently it works [11-13]. Event-related potentials (ERPs) are sensitive indices of brain information processing and have been widely used in cognitive researches. Researches found that P3 latency negatively related with intelligence and intellectually gifted individuals showed shorter P3 latency than average individuals [14, 15].

Concerning the importance of working memory and ERP in the intelligence research, the aim of the present study is to investigate the difference of brain activity between intellectually gifted and average children with ERP method employing a classical working memory task. We expected that intellectually gifted children elicited shorter P3 latency than intellectually average children as the neural efficiency theory predicted.

II. MATERIALS AND METHODS

A. *Participants*

Twenty-six healthy right-handed children participated in this study. The intellectually gifted children were recruited from an experimental gifted class of a middle school (4 girls and 9 boys, age 11.95 ± 0.25 years (mean ± S.D.)). And the intellectually average children were from normal class in a primary school (5 girls and 8 boys, age 11.91 ± 0.25 years). The groups were matched on age [$t = 0.43$, $p = 0.675$]. Before the electroencephalogram (EEG) recording, all participants were tested by Raven's Standard Progressive Matrices. The mean scores of intellectually gifted and intellectually average group were 54.62 ± 2.14 and 43.77 ± 4.55 respectively. There was a statistically significant difference between groups on the Raven scores [$t = 7.78$, $p < 0.001$]. All participants had normal or corrected-to-normal vision, and free from neurological or psychiatric disorders. Informed consent was obtained from participants' teacher and parents.

B. *Stimuli and procedure*

The Participants responded to a numerical 1-back task (number 1 to 9 with same probability). Participants were asked to decide whether the present number was identical to the number previously or not. Stimuli were presented in the center of the screen with a visual angle of approximately 2.6° vertical, 1.8° horizontal. Stimulus duration was 300 ms and ISI was 1700-2000 ms. There were 144 trials totally and divided in two blocks with 1-2 min breaks between blocks.

The work was supported by Natural Science Foundation of China (Grant No. 30670716) and by Key Project of Knowledge Innovation Engineering of Chinese Academy of Sciences (Grant No.KKCX1-YW-05).

978-1-4244-2902-8/09/$25.00 ©2009 IEEE

Participants were seated individually in a dimly lit, electrically shielded and sound attenuated room. Half of the participants were instructed to press one key with their left hand for the 'identical' response and another key with their right hand for the 'different' response. For the other half of the participants, the assignment of response hand was reversed. Before task, participants were informed about the nature of the task, and 36 practice trials were performed. Stimulus presentation and data acquisition were used the E-prime software system.

C. Event-related potential recording and data analysis

EEG (amplified by SynAmps 2 online, bandpass filtering: 0.05-100 Hz, sampling rate 500 Hz) was recorded with Ag-AgCl electrodes according to the 10-20 international placement system. All sites were referred to the left mastoid and re-referenced to linked mastoids offline. The vertical electro-oculogram was recorded with electrodes placed above and below the left eye. Electrode impedances were kept below 5 kΩ. Ocular artifacts were removed from the EEG signal using a regression procedure implemented in the Neuroscan software [16]. EEG epochs of 1200 ms, including 200 ms of prestimulus time as baseline, were offline-average only using correct trials. Epochs with artifacts exceeding 50 μV at any electrode were omitted from further analysis.

Behavioral data were analyzed using t-test. The following sites were chosen for statistical analysis: F3-Fz-F4, C3-Cz-C4, P3-Pz-P4. ERP amplitudes and latencies were analyzed using a repeated measures analysis of variance (ANOVA) with Anterior-Posterior (frontal/central/parietal) × Lateral (left/midline/right) electrode sites as within-subject factors and Intelligence Group (gifted/average) as a between-subjects factor. Greenhouse–Geisser correction was used when appropriate.

III. RESULTS

A. Behavioral data

For reaction time (RT), the main Intelligence Group effect was significant [$t(24) = -2.509$, $p = 0.019 < 0.05$]. RTs for the gifted children were significantly shorter than those for the average children (561.04 ± 147.34 vs. 712.76 ± 160.66). However, the main effect of Intelligence Group did not reach statistical significance on accuracy [$t(24) = 0.96$, $p = 0.346$] (0.86 ± 0.09 vs. 0.81 ± 0.15).

B. ERP data

Fig. 1 displays the grand-average ERP data at Fz, Cz and Pz electrode sites as a function of Intelligence Group. Table 1 displays the significant effects from the mixed ANOVA analyses that were performed on amplitude and latency of N1, P2, N2 and P3.

The main effect of Intelligence was significant on P3 latency. Intellectually gifted children had shorter P3 latency than average children. However, no significant main effect of Intelligence or interactions involving Intelligence were obtained on the amplitudes and latencies of N1, P2, and N2 components and the P3 amplitude, *ps* > 0.05.

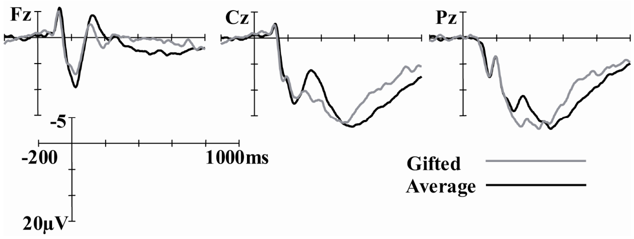

Figure 1. Children's grand-average event-related potential waveforms at Fz, Cz and Pz.

TABLE I. SIGNIFICANT EFFECTS FROM THE ANOVA ANALYSES OF EACH ERP MEASURE

	Factor	F	ε	P
N1 Latency	AP*LR	F(4,96) = 4.72	.41	.020
N1 Amplitude	AP	F(2,48) = 19.82	.70	.000
P2 Latency	AP	F(2,48) = 12.96	.77	.000
	LR	F(2,48) = 3.39		.042
P2 Amplitude	AP	F(2,48) = 11.03	.70	.001
	LR	F(2,48) = 10.22	.72	.001
N2 Latency	AP	F(2,48) = 50.12	.81	.000
N2 Amplitude	AP	F(2,48) = 25.40	.81	.000
	AP*LR	F(4,96) = 4.58		.002
P3 Latency	AP	F(2,48) = 32.91	.78	.000
	AP*LR	F(4,96) = 5.44		.001
	Intelligence	F(1,24) = 4.32		.049
P3 Amplitude	AP	F(2,48) = 35.85	.75	.000
	LR	F(2,48) = 9.11		.000
	AP*LR	F(4,96) = 8.53		.000

Note. AP = anterior/posterior electrode placement factor in the analysis, LR = left/right electrode placement factor in the analysis

IV. DISCUSSION

Present study concerned the difference of brain activities of intellectually gifted and average children while performing a numerical 1-back working memory task. The results showed that intellectually gifted children had shorter P3 latency than intellectually average children.

The intellectually gifted children performed more quickly than the average children. This was consistent with earlier studies [3, 17]. Although the intellectually gifted children performed more accurately than average children, the main effect of intelligence on accuracy was not significant statistically. Specifically, the prolonged reaction time may account for the absence of a lower accuracy in the average group because of a trade-off between accuracy and reaction time.

P3 is relatively independent of stimulus modality and represents brain activity related to late stage of information processing. And here, it approximately corresponds to the transfer of information into working memory and the completion of decision-making about the stimulus [18]. Our present results indicated that intellectually gifted children could make faster decision and supported that P3 latency was closely related to intelligence [19].

Considering the result of N1, P2 and N2 components together, maybe the intelligence-related differences only apparent at the later information processing stage [20]. As compared to intellectually average children, gifted children have a more temporarily coordinated brain activity [18, 21]. Intellectually gifted children distribute the cognitive resources needed to dealing with 1-back task more efficiently.

These results can be interpreted in the sense of the neural efficiency theory. Intellectually gifted children's reduced latency during our working memory task might be due to a more intensive and optimized use of neurons and neural circuits [11, 15]. Present study is a contribution to the more comprehensive understanding of neural efficiency theory.

The superiority of intellectually gifted children may be due to the enhancement of central nervous system synapse and myelination. Because high degree of myelinization brings better isolation and hence faster nerve conduction velocity and the myelinization processs seem to parallel intellectual development [22, 23].

To sum up, this study indicated that intellectually gifted children had shorter P3 latency than average children during a 1-back working memory task. It was also suggested that intelligence can influence initial stages of information processing as early as about 500 ms after stimulus onset. Our findings supported the neural efficiency hypothesis and made a contribution to the literature on neurophysiological differences between intellectually gifted and average children.

ACKNOWLEDGMENT

We thank all the children for their participation.

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