Effect of task complexity on intelligence and neural efficiency in children: an event-related potential study

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Received 29 June 2007; accepted 11 July 2007

The present study investigates the effects of task complexity, intelligence and neural efficiency on children's performance on an Elementary Cognitive Task. Twenty-three children were divided into two groups on the basis of their Raven Progressive Matrix scores and were then asked to complete a choice reaction task with two test conditions. We recorded the electroencephalogram and calculated the peak latencies and amplitudes for anteriorly distributed P225, N380 and late positive component. Our results suggested shorter late positive component latencies in brighter children, possibly reflecting a higher processing speed in these individuals. Increased P225 amplitude and increased N380 amplitudes for brighter children may indicate a more efficient allocation of attention for brighter children. No moderating effect of task complexity on brain–intelligence relationship was found. *NeuroReport* 18:1599–1602 © 2007 Wolters Kluwer Health | Lippincott Williams & Wilkins.

Keywords: complexity, event-related potentials, intelligence, neural efficiency

Introduction

In the relationship between cortical activation and intelligence, there is a considerable body of evidence showing that event-related potential (ERP) latencies correlate negatively with psychometrical intelligence. This could be explained by a neural efficiency hypothesis, which proposes that good performers use the brain more efficiently than poor performers [1–4]. Several recent studies suggested that the brain–intelligence relationship was sensitive to the complexity of Elementary Cognitive Tasks [5,6].

Earlier studies exploring task complexity effects on the brain–intelligence relationship were conducted in adults. These results have not yet been replicated in children. Here, we used the Raven Progressive Matrix (RAPM) test [7] to divide children into groups on the basis of intelligence with the goal of assessing the effects of task complexity on the Elementary Cognitive Task–intelligence relationship.

To manipulate the complexity of information processing, we used a modified version of Stauder's task [8] consisting of two complexity levels. We used the classical approach by recording ERPs elicited in this task. In this task, participants were instructed to judge whether a union of colored rectangles corresponded to another set of colored rectangles. It has been reported to yield good ERP differentiations associated with intelligence [8]. Another advantage of using this task in ERP research is that this approach may yield additional information about accuracy and information processing speed. In this study, the primary hypothesis was that the higher intelligence group would display greater efficiency than the average intelligence group. It was also predicted that the IQ–brain activation relationship would not be affected by task complexity.

Materials and methods

Participants

Twenty-three children were divided into two groups on the basis of their Raven's Progressive Matrices score. The intellectually gifted group consisted of six boys and six girls with RAPM scores above the 95th percentile, their ages ranged from 10.1 to 10.7 years (10.4 ± 0.3 years). The intellectually average group consisted of six boys and five girls with RAPM scores at the 50th percentile, their ages ranged from 10.2 to 10.6 years (age 10.4 ± 0.2 years). All children in this study were recruited using an advertisement placed in a primary school in Beijing. All participants were free from neurological or psychiatric problems, had normal or corrected-to-normal vision, were right-handed, and were naive to electrophysiological procedures. Informed consent was obtained from all parents and the children's teachers.

Stimuli and procedure

The choice reaction task consisted of two upper squares and a lower rectangle, each filled with three rectangles (Fig. 1).

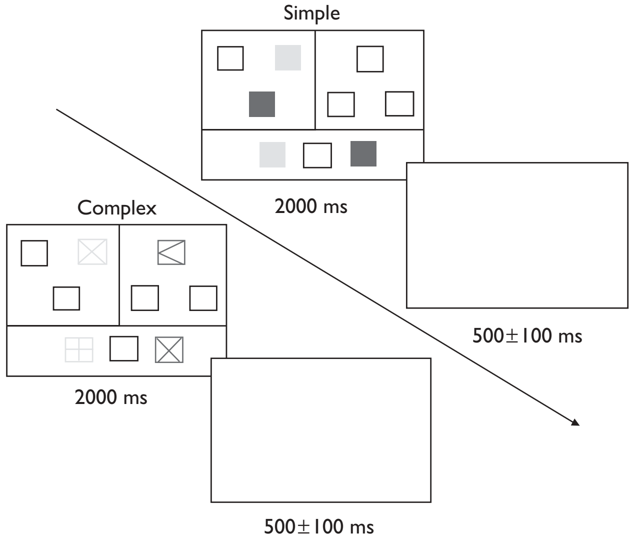

Fig. 1 Illustration of tasks and procedures.

Participants were asked to decide whether the total set of the colored rectangles in the left and right squares corresponded to the set of the colored rectangles contained by the lower rectangle. Two levels of complexity existed. In the simple level, the target rectangles were colored but otherwise featureless; for the complex level, the target rectangles contained colors and geometric shapes. For the examples shown in Fig. 1, the correct answer for the simple level task was 'yes', the correct answer for the complex level task was 'no'. All stimuli were presented in the center of the screen against a black background, each extending to a visual angle of approximately 2.72° vertical, 4° horizontal. The test stimulus was presented for 2000 ms and the participants responded by pressing one of the two buttons, one representing 'yes' and one representing 'no'. The interstimulus interval varied randomly between 400 and 600 ms. Each task condition was presented in five trial blocks each consisting of eight replications of eight different stimuli for each complexity level (a total of 640 trials for each task condition). For each condition, 20 practice trials were presented before electroencephalogram (EEG) recording began. The presentation order of trials within each block were pseudorandomized. Instructions stressed speed and accuracy.

Participants were seated individually in a dimly lit, electrically shielded and sound attenuated room. The computer screen was viewed from a distance of 1 m. Half of the participants were instructed to press one key with their left 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. Stimuli were generated using the Window-based Evoke program (Advanced Neuro Technology BV, Enschede, The Netherlands). Stimuli were displayed on a 17-inch HP color monitor (85 Hz refresh rate, 1024 × 768 resolution).

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. 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 Advanced Neuro Technology (Advanced Neuro Technology BV) amplifier system with a gain of 20 and were stored without filtering (DC recording) and were continuously sampled at 500 Hz/channel. Off-line analysis included bandpass finite impulse response filtering of 0.01–30 Hz using a filter order of 4001. Before averaging, epochs were screened for eye movements and other artifacts, which were rejected using a semiautomatic procedure. During averaging these EOG artifacts were corrected using a PCA-based algorithm [9].

The EEG data were epoched into periods of 2100 ms, from 100 ms before the onset of the stimuli to 2000 ms after the stimuli onset. The following sites were chosen for statistical analysis: AF3, AF4, F3, F4, FC3, FC4, Fz, FCz, Cz, CPz. Figure 2 shows the grand-averaged ERP waveforms from selected electrodes, superimposed for the two levels of task complexity for the two groups. All levels of tasks elicited an anteriorly distributed, negative-going component peaking at approximately 125 ms (N125), followed by a positive-going component peaking at approximately 225 ms (P225), also most apparent at anterior sites. Following the typical N125–P225 complex, a negative-going, frontal-centrally maximal but widely distributed component peaking at about 380 ms was found, which may be referred to as an N380. Following N380, at anterior sites, a late positive-going component (LPC) was evident, and the latency and amplitude of LPC peaking at approximately 800 ms. At occipital sites, a positive component peaking at approximately 150 ms was apparent (occipital P150), followed by a negative-directed component peaking at approximately 220 ms (occipital N220). Following occipital N220, a late positive-going component (occipital LPC) was found. The differences between the two task complexity levels and two groups of children could be found anteriorly in P225, N380 and LPC.

Peak latencies were detected before the analysis of amplitudes. Mean amplitudes were measured in two time windows: The first (N380) consisted of the period between 300 and 450 ms after stimulus onset (during this period, a negative potential was observed). The second (LPC) consisted of the period between 450 and 2000 ms after stimulus onset (during this period, a positive slope was observed). Peak latencies and mean amplitudes were then calculated for each complexity level for each participant in each group. Repeated measures analyses of variance (ANOVAs) were conducted for latencies and mean amplitudes with group (intellectually gifted vs. intellectually average) as a between-participants factor. Task complexity (simple vs. complex) and electrode site (anterior 10) were within-participants factors. Greenhouse–Geisser correction was used when appropriate.

Results

Behavioral data

Median values for reaction time (RT) and accuracy are shown in Table 1. A mixed-design analysis of variance was carried out, with group as the between-participants factor and task complexity as the within-participants factor. The

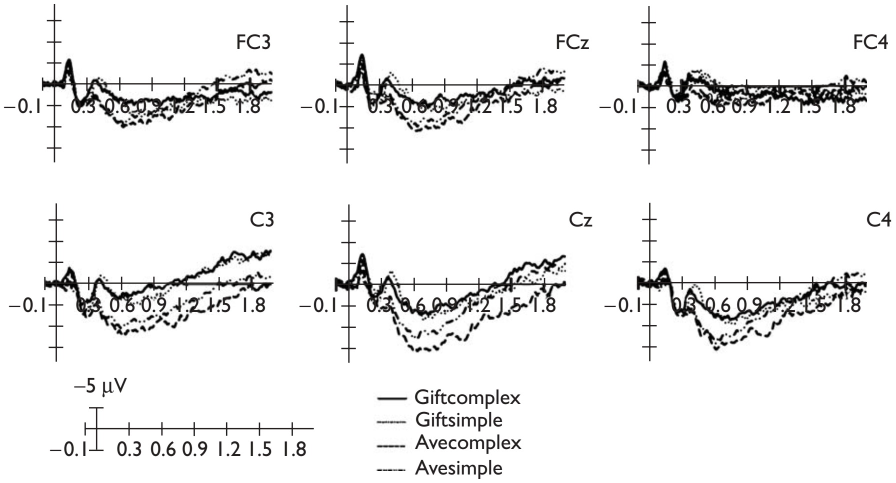

Fig. 2 Children's grand average event-related potential waveforms. Stimulus onset is shown by the vertical calibration bar. Upward deflections of these traces represent negative values. Solid and dotted lines show data obtained from intellectually gifted participants in the complex and simple conditions, respectively. Dashed and dash-dotted lines show data obtained from intellectually average participants in the complex and simple conditions, respectively.

Table 1 Descriptive statistics of median RTs (ms) and accuracy (%) for gifted and average groups of children

	Reaction time		Accuracy	
	Simple	Complex	Simple	Complex
Gifted group	1158.02 (44.61)	1236.24 (45.10)	0.94 (0.03)	0.91 (0.02)
Average group	1170.78 (46.60)	1257.52 (47.11)	0.81 (0.03)	0.79 (0.02)

RT, reaction time.

main group effect on RT was not significant [F(1,21)=0.057]. The main effect of task complexity was significant [F(1,21)=24.806, $P<0.01$]. RTs for the simple level of the task were significantly shorter than those for the complex level. No significant interaction between task complexity and group [F(1,21)=0.063] was found.

For accuracy, the main effect of group [F(1,21)=10.202, $P<0.01$] reached statistical significance, suggesting that the gifted group performed more accurately than the average group. No significant main effect of task complexity [F(1,21)=3.165] was found. No significant interaction between task complexity and group [F(1,21)=2.886] was found.

Late positive component latency

The main effect of task complexity [F(1,21)=4.391, $P<0.01$] was significant, with shorter latencies for the simple level. The main effect of group was significant [F(1,21)=6.217, $P<0.01$], with shorter latencies found for the gifted group. A main effect of electrode was also found [F(9,189)=7.660, $P<0.01$]. The remaining ANOVA effects did not reach statistical significance.

P225 amplitude

The main effect of task complexity [F(1,21)=4.619, $P<0.05$] was significant, with smaller amplitudes found for the simple level. The main group effect reached significance [F(1,21)=5.838, $P<0.05$], with the P225 amplitude of the average group significantly smaller than that of the gifted group. A significant main effect of electrode [F(9,189)=9.864, $P<0.01$] was found. A significant complexity × electrode interaction [F(9,189)=15.795, $P<0.01$] was also found. No significant group × complexity [F(1,21)=3.221], group-electrode [F(9,189)=0.985], group × complexity × electrode [F(9,189)=2.556] interactions were noted.

Mean amplitude

In the first time window (N380, 300–450 ms), the main effect of task complexity [F(1,21)=5.593, $P<0.05$] was significant, with larger amplitudes found for the simple level. The main effect of group reached significance [F(1,21)=8.560, $P<0.01$], with larger amplitudes found for the gifted group. A significant main effect of electrode [F(9,189)=12.491, $P<0.01$] was also found. A significant complexity × electrode interaction [F(9,189)=7.799, $P<0.01$] was also found. No significant group × complexity [F(1,21)=4.010], group × electrode [F(9,189)=1.260], group × complexity × electrode interactions [F(9,189)=1.425] were noted.

For the second time window (LPC, 450–2000 ms), there was a significant main effect of electrode [F(9,189)=25.896, $P<0.01$]. A significant complexity × electrode interaction [F(9,189)=16.873, $P<0.01$] was also found. The remaining ANOVA effects of task complexity [F(1,21)=1.490], group [F(1,21)=1.053], group × complexity [F(1,21)=0.021], group × electrode [F(9,189)=2.401] and group × complexity × electrode [F(9,189)=1.528] were not statistically significant.

Discussion

The present study had two major goals: first, we tried to test the neural efficiency hypothesis in high-IQ vs. average-IQ children. Second, we sought to examine the effects of task complexity (simple vs. complex) on the temporal aspects of brain cognition. These findings are summarized as follows:

(1) As anticipated, the main effect for intelligence level reached statistical significance on P225, N380 and LPC. The present LPC might represent the P3 component found in adult participants. The LPC latency across task conditions was shorter for the intellectually gifted group than for the intellectually average group. This finding is in line with earlier studies [10,11]. The negative latency–intelligence relationship could provide support for 'neural efficiency hypothesis' or the notion that 'brighter individuals have faster brains' [12].

The present P225 might be a P2. Earlier studies have found that the P2 component is a reflection of attention allocation [13]. In this study, the task demand of the simple task condition was less than that of the complex one, and this contributed to a smaller P225 amplitude. As for the intellectually average group, children might mobilize less attention resource for task execution, leading to a smaller amplitude of the P225 component. The present N380 component might be an N2. Earlier studies suggested that N2 reflects the efficiency of attention allocation [14]. In this study, a larger N380 amplitude for the simple condition might represent more efficient allocation of attention resource. A larger N380 amplitude for more intelligent individuals might mean more efficient allocation of attention.

Surprisingly, no between-group difference was found for either task condition for LPC amplitude, although the group-average potential showed that there is a difference between the two groups. One possible explanation of the observed amplitude differences in P225 and N380 might be that the difference in the two groups is liable to affect the earlier stage of information processing efficiency when performing the present task. Another potential explanation is that different children might use different cognitive strategies even within an age group. ERP data cannot tell us what kind of strategy was used by different individuals [15,16], and this may have resulted in later waveforms with an unsatisfactory signal-to-noise ratio.

(2) As expected, RTs in the simple task were shorter than in the complex task, which suggested that task complexity was manipulated successfully [5]. Neither the main effect for intelligence level nor the interaction reached significance (probably because of the small sample size). It should be mentioned, however, that the means conformed to expectation: the intellectually average children displayed longer median RTs than children in the gifted group. This intelligence level difference was much larger in the more demanding task (1257.52 vs. 1236.24 ms, respectively) than for the simple task (1170.78 vs. 1158.02 ms, respectively). The significant difference between accuracy rates suggested that average and gifted children adopted different strategies, implying different information processing efficiencies. This was consistent with an earlier study [17].

(3) We found a general influence of task complexity on the brain activation: the more complex task condition, which required more time to solve, were associated with larger P225 amplitude and smaller N380 amplitude. We, however, found no evidence in favor of a moderating influence of task complexity on the relationship between psychometric intelligence and brain activation. This finding conformed to an earlier study [5]. Not only under the easy test condition but also under the complex test condition was there intelligence-related difference with respect to the level of cortical activation.

Conclusion

The results of this study support the neural efficiency hypothesis, suggesting that the previously reported relationship between intelligence and brain activity in adults also exists in children. A general influence of task complexity on the brain activation was observed, no moderating influence of task complexity on the ERP–intelligence relationship was found.

Acknowledgements

This research was supported by grants from the National Natural Science Foundation of China (no. 30670716), the Key Project of Knowledge Innovation Engineering of Chinese Academy of Sciences (no. KSCXZ-SW-211) and the Research Center of Language and Cognition, Zhejiang University.

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