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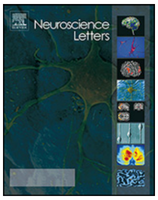

Electrophysiological correlates for response inhibition in intellectually gifted children: A Go/NoGo study

Xiaoju Duan[a,b], Jiannong Shi[a,*], Jianhui Wu[a], Yi Mou[c], Hairong Cui[d], Guiqing Wang[e]

[a] *Institute of Psychology, Chinese Academy of Sciences, 4A Datun Road, Chaoyang District, Beijing, 100101, China*
[b] *Graduate School of the Chinese Academy of Sciences, Beijing, China*
[c] *University of Missouri, Columbia, MO, United States*
[d] *QiSeGuang School, Handan, China*
[e] *NorthEast YuCai School, Shenyang, China*

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ABSTRACT

Superior response inhibition is an essential component of the advanced cognitive abilities of gifted children. This study investigated response inhibition in intellectually gifted children by recording event-related brain potentials (ERPs) during a Go/NoGo task. Fifteen intellectually gifted children and 15 intellectually average children participated. Our present findings showed that intellectually gifted children had shorter Go-P3 latency, indicating faster processing of Go stimuli, a finding consistent with previous studies. We focused on the two inhibition-related components, NoGo-N2 and NoGo-P3. The results showed that NoGo-P3 latency was shorter for intellectually gifted children compared to their average peers. N2 latency did not indicate the intelligence difference. These results suggested that intellectually gifted children showed faster inhibition when dealing with NoGo stimuli, and this superiority came from the later stages of inhibition, i.e., response evaluation or the success of inhibiting a response, as indexed by the shorter P3 latency.

Intellectually gifted children score higher than average children in information processing domains such as visual search [30], memory [24], reasoning [29], and executive tests [1]. For example, the results by Zhang et al. revealed that gifted children showed a shorter latency of P3 and faster reaction time (RT) as compared with the average control group during a visual search task [30]. The difference between the two intelligence groups, however, stems not only from the ability to process relevant information but also from the ability to inhibit irrelevant information or inappropriate preponderant response [14,22]. Also, as Dempster [7] has addressed, inhibitory ability is essential to intelligence. Previous studies have often utilized paradigms such as that of Stroop in which irrelevant information must be suppressed or ignored [8,14] and usually mixed with cognitive inhibition and response inhibition [11]. The present study aimed to investigate the response inhibition of intellectually gifted children.

Response inhibition has been generally assessed by the Go/NoGo task, which always consists of two stimuli: a Go stimulus which requires a response (usually a button press) and a NoGo stimulus that requires the inhibition of the response [17,18]. Two major event-related potentials (ERPs) components have been consistently linked with the response inhibition of Go/NoGo task. The first component is an enhanced negativity (NoGo-N2) at approximately 200–300 ms post-stimulus onset in response to NoGo stimuli and is maximal in the frontal areas [4]. The N2 may represent response inhibition [27] or the process of conflict monitoring [10,26]. The second major ERP component is an enhanced wave (NoGo-P3) that is elicited within a 300–500 ms time window [2,4,5]. NoGo-P3 showed a fronto-central maximum as opposed to the centro-parietal maximum of the Go-P3 [2,4]. NoGo-P3 was thought to be related to response inhibition and to index a later stage of the inhibitory process, i.e., response evaluation or the success of inhibiting a response [5,10,26,31].

In the relation between brain activity and intelligence, the speed intelligence hypothesis supposed that "faster brains have higher IQs" [6]. There is also the neural efficiency theory which states that intelligence is not a function of how hard the brain works but rather how efficiently it works [12,13]. Both of these hypotheses emphasize the faster processing speed of intellectually gifted individuals.

The aim of the present study was to find a neural index underlying the response inhibition difference between intellectually gifted and average children by using an ERP technique. We expected intellectually gifted children to elicit shorter N2 and P3 latency than intellectually average children.

Thirty healthy right-handed children participated in this study. The intellectually gifted group was recruited from an experimental

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[*] Corresponding author. Tel.: +86 10 6485 5744.
E-mail address: shijn@psych.ac.cn (J. Shi).

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middle school gifted class (5 girls and 10 boys, age 11.98 ± 0.24 years (mean ± S.D.). The intellectually average group was from a typical class in a primary school (4 girls and 11 boys, age 11.92 ± 0.29 years). The groups were matched on age ($F(1,28) = 0.44$, $P > .05$). Before the electroencephalogram (EEG) recording, all participants were tested by Raven's Standard Progressive Matrices. The intellectually gifted group scored significantly high than the intellectually average group (54.60 ± 2.29 vs. 43.20 ± 3.97, $F(1,28) = 92.83$, $P < .01$). All participants had normal or corrected-to-normal vision and were free from neurological or psychiatric disorders. Informed consent was obtained from participants' teachers and parents.

Stimuli for the Go/NoGo task were the two digits "1" and "9". Stimuli were presented in the center of the screen with a visual angle of approximately 2.6° vertically, 1.8° horizontally. Stimuli were presented for 50 ms with a random interstimulus interval of 1000–1300 ms. During each trial, one of the two digits was presented, and either a response (Go) or the withholding of a response (NoGo) was required. After an initial practice block of 20 stimuli, two experimental blocks each consisting of 72 stimuli (50% NoGo probability) were completed with 1–2 min breaks between blocks. Stimulus presentation and behavioral data acquisition were collected using the E-prime software system.

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 'Go' response, and the assignment of response hand for the other half of the participants was reversed.

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 online and re-referenced to linked mastoids offline. The vertical electrooculogram (VEOG) and horizontal electrooculogram (HEOG) were recorded with two pairs of electrodes, one placed above and below the left eye, and another was placed 10 mm from the outer canthi of both eyes. Electrode impedances were kept below 5 kΩ. Ocular artifacts were removed from the EEG signal using a regression procedure implemented in the Neuroscan software [23]. EEG epochs of 1200 ms, including 200 ms of prestimulus time as baseline, were offline-average only using correct trials according to the stimuli (Go, NoGo). Epochs with artifacts exceeding ±50 μV at any electrode were omitted from further analysis.

The N2 amplitude was calculated at the negative maximum between 200 and 380 ms and the P3 amplitude was calculated at the positive maximum between 300 and 500 ms.

Psychometric and behavioral data were analyzed using ANOVAs. The following sites were chosen for statistical analysis: F3, Fz, F4, C3, Cz, C4, P3, Pz, and P4. ERP amplitudes and latencies were analyzed using repeated measures ANOVA with lateral (left/midline/right) × anterior–posterior electrode sites (frontal/central/parietal) × stimulus (Go/NoGo) as within-subject factors and intelligence group (gifted/average) as a between-subjects factor. Greenhouse–Geisser correction was used when appropriate.

The RT, the rate of omission errors (OE) in Go trials, and commission errors (CE) in NoGo trials from both groups were subjected to one-way ANOVAs. There was no difference between the two groups in RT ($F(1,28) = 0.82$, $P = 0.37$). Intellectually gifted children committed significantly fewer omission errors in Go trials ($F(1,28) = 6.28$, $P < .05$) and significantly fewer commission errors in NoGo trials than did the intellectually average group ($F(1,28) = 5.07$, $P < .05$). All behavioral data are given for performance across stimuli in Table 1.

Fig. 1 shows the ERP waveforms at selected electrode sites. The significant stimulus main effect ($F(1,28) = 26.74$, $P < .01$) indicated that the amplitude of N2 was larger for NoGo (−1.76 ± 0.47 μV) than for Go stimuli (0.83 ± 0.46 μV). The significant stimulus by anterior–posterior interactions ($F(2,56) = 11.50$, $P < .001$) suggested that the stimulus difference effect was largest at the

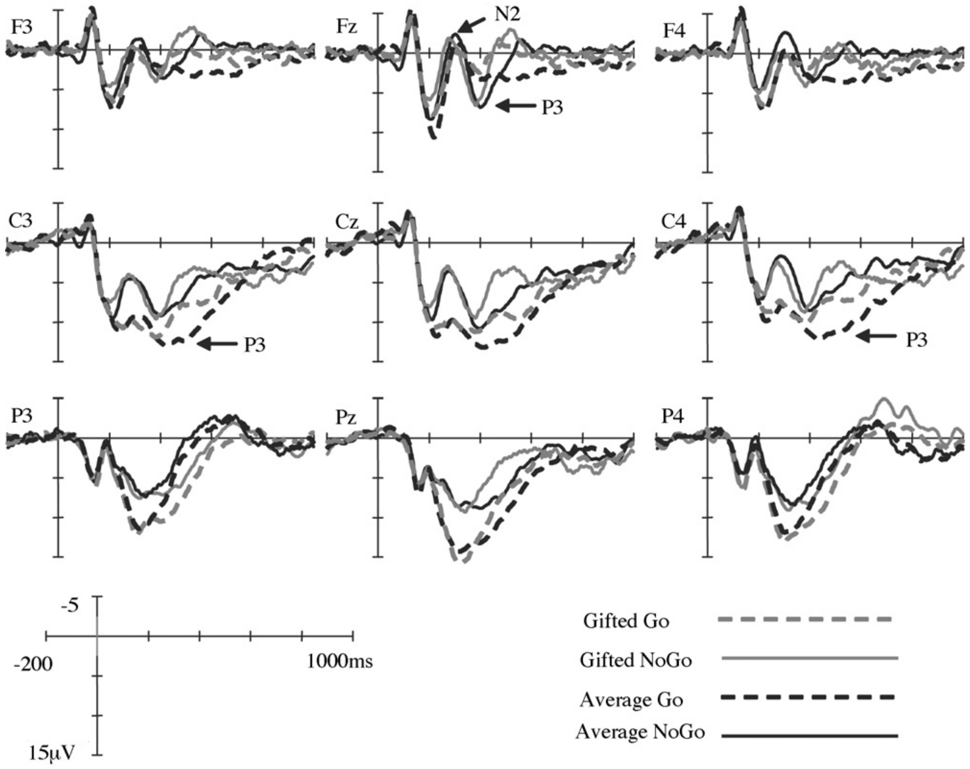

Fig. 1. The grand-average ERP data at selected electrode sites as a function of stimulus and intelligence group. The intellectually gifted group elicited shorter P3 latency to both Go and NoGo stimuli than did the average group.

Table 1
Behavioral performance data compared between intellectually gifted and intellectually average group.

	OE (%)	CE (%)	RT (ms)
Intellectually gifted	0.20 (0.78)	5.63 (3.17)	365.19 (44.78)
Intellectually average	1.47 (1.80)	10.87 (8.42)	380.30 (46.54)

OE: rate of omission error; CE: rate of commission error; RT: reaction time. Standard deviations are presented in parentheses. Intellectually gifted children committed significantly fewer errors in both Go and NoGo trials than did the average group.

central electrode sites ($t = 3.53$, $P < .001$, Go: $3.95 \pm 0.73\,\mu V$; NoGo: $-0.68 \pm 0.68\,\mu V$), as compared with both frontal ($t = 2.98$, $P < .01$, Go: $-2.59 \pm 0.68\,\mu V$; NoGo: $-4.26 \pm 0.80\,\mu V$) and parietal ($t = 3.17$, $P < .01$, Go: $1.12 \pm 0.90\,\mu V$; NoGo: $-0.35 \pm 0.89\,\mu V$). The difference between the two intelligence groups ($F(1,28) = 0.45$, $P = 0.51$) and the interaction of intelligence and stimulus was not significant ($F(1,28) = 0.44$, $P = 0.51$).

The main effect of intelligence was not significant ($F(1,28) = 0.45$, $P = 0.51$). The ANOVA revealed a significant interaction of stimulus and anterior–posterior ($F(2,56) = 3.42$, $P < .05$). The interaction may come from the shorter NoGo latency at the frontal area (Go: 298.31 ± 7.68 ms; NoGo: 284.18 ± 7.37 ms) and a longer NoGo latency at the central (Go: 252.58 ± 10.62 ms; NoGo: 270.96 ± 6.95 ms) and parietal sites (Go: 205.00 ± 4.63 ms; NoGo: 211.64 ± 5.36 ms) compared to the Go stimulus. The main effect of stimulus ($F(1,28) = 0.49$, $P = 0.49$) and the interaction of intelligence and stimulus were not significant ($F(1,28) = 0.13$, $P = 0.72$).

The significant main effect of stimulus ($F(1,28) = 8.63$, $P < .05$) indicated P3 amplitude was larger for the Go ($12.22 \pm 0.61\,\mu V$) than the NoGo stimulus ($10.60 \pm 0.62\,\mu V$). The stimulus and anterior–posterior interaction ($F(2,56) = 29.04$, $P < .001$) suggested that at frontal sites the NoGo stimulus elicited larger P3 amplitudes than did the Go stimulus ($t = -2.42$, $P < .05$, Go: $6.16 \pm 0.83\,\mu V$; NoGo: $8.08 \pm 1.08\,\mu V$), whereas at central ($t = 3.53$, $P < .01$, Go: $15.34 \pm 0.74\,\mu V$; NoGo: $12.50 \pm 0.84\,\mu V$) and parietal sites ($t = 3.17$, $P < .01$, Go: $15.15 \pm 1.04\,\mu V$; NoGo: $11.22 \pm 0.96\,\mu V$), the P3 amplitudes elicited by the Go stimulus were larger. The main effect of intelligence ($F(1,28) = 1.83$, $P = 0.19$) and the interaction of intelligence and stimulus was not significant ($F(1,28) = 0.85$, $P = 0.37$).

The significant intelligence effect ($F(1,28) = 4.67$, $P < .05$) indicated that intellectually gifted children (377.24 ± 34.76 ms) elicited significantly shorter P3 latency than average children (422.95 ± 74.12 ms) for both Go and NoGo stimuli. The stimulus by anterior–posterior interaction was significant ($F(2,56) = 5.41$, $P < .01$). The interaction may come from the shorter NoGo latency at frontal area (Go: 449.51 ± 19.75 ms; NoGo: 419.73 ± 18.61 ms) and the longer latency at central (Go: 406.16 ± 16.71 ms; NoGo: 423.73 ± 18.33 ms) and parietal sites (Go: 340.39 ± 8.34 ms; NoGo: 361.13 ± 17.87 ms) compared to the Go stimulus. The main effect of stimulus ($F(1,28) = 0.03$, $P = 0.88$) and the interaction of intelligence and stimulus were not significant ($F(1,28) = 1.18$, $P = 0.29$).

The present study used ERPs to investigate the response inhibition differences during a Go/NoGo task between intellectually gifted and average children, by focusing on the response inhibition-related NoGo-N2 and NoGo-P3 component. The main findings of the present study can be summarized as follows. The intellectually gifted children had significantly lower rates of omission and commission errors as expected. The P3 latency was shorter for intellectually gifted children compared to their average peers for both the Go and the NoGo stimuli.

The present ERP findings replicated previous results in three ways. Firstly, all children displayed a distinct NoGo-N2 effect, that is, the NoGo stimuli elicited larger N2 amplitude compared to Go stimuli. The NoGo-N2 effect reported here was consistent with previous studies [10,15,16].

Secondly, NoGo stimuli elicited significantly smaller P3 amplitude than Go stimuli in centro-parietal areas and larger P3 in the frontal regions. Our results were in agreement with the study employing similarly aged children which showed a trend towards a more positive P3 for Go than NoGo stimuli [16]. Developmental studies have also suggested that the dominant distribution of NoGo-P3 shifted to more anterior areas compared with that of Go-P3 as age increased [21].

Thirdly, the Go-P3 latency was shorter in intellectually gifted children as compared with average children. It is well established that P3 latency is an indicator of processing speed [19]. There was also a study showing that gifted children elicited shorter latency of P3 as compared with average children in a visual search task, suggesting gifted children can process information faster [30]. Our present study utilized a Go/NoGo task and the results obtained replicated this previous result, showing intellectually gifted children could process information of Go stimuli faster. The present results of P3 latency decreasing with increasing intelligence also supported that P3 latency is closely related to intelligence [28].

The most significant finding of the present study was that gifted children had shorter latency of the NoGo-P3 compared with average children. NoGo-P3 is thought to be an index of response inhibition [5,10,26,31]. Our present findings suggested that intellectually gifted children could make faster inhibition of NoGo stimuli and have higher inhibitory ability. Our results provided evidence to the assumption that inhibitory ability is closely related to intelligence [7] and its importance in gifted children's better cognitive performance [14]. These results also provide new content to the speed intelligence hypothesis and the neural efficiency theory [6,13]. This theory posits that is intellectually gifted children display a more efficient brain function not only with respect to information processing but also with respect to response inhibition. Other evidence was from patients studies which found that the PTSD and the Parkinson's disease groups had longer NoGo-P3 latency compared with control group to indicate an impaired inhibitory ability [3,25].

Out of expectation, there was no intelligence-related difference on N2 latency. These findings supported the hypothesis of a functional dissociation between NoGo-N2 and NoGo-P3 (i.e., these two components might reflect different stages of response inhibition) [3,20]. The N2 may represent the detection of response conflict [10] or the recognition of the need for inhibition [26]. NoGo-P3 was associated with response evaluation [5] or the success of inhibiting a response [9]. The superior response inhibition function of the intellectually gifted children might come from the later stage of inhibition as indexed by shorter P3 latency.

One limitation of the present research was that all of the participants were limited to right-handed children as is the case in most ERP studies. As a result, our present findings can only apply to right-handed individuals and how the brains of left-handed people work still requires further investigation.

In summary, our present findings showed that gifted children have faster inhibitory speed as indexed by shorter NoGo-P3 latency, which underlies the better behavioral performance related to response inhibition. The ERP results further suggested that the superior response inhibition ability of the intellectually gifted children might come from the later stages of inhibition, that is, response evaluation or the success of inhibiting a response.

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