An event-related brain potential study of children's conservation

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Abstract

To investigate the relationship between cortical activation and conservation ability, 22 children were divided into two groups based on their performance on a standard Piagetian Conservation test. Visual evoked potentials were recorded while children performed a weight conservation task. A bilateral, frontal-distributed, broad late positive component at 900 ms differed between non-conserving and conserving children, with non-conservers having a larger amplitude. The significant interaction between conservation ability and hemisphere on the amplitude of this component suggests that inferior generators gradually move from central to right frontal-central while conservation level increases. The results indicate the existence of an ERP component that reflects weight conservation ability in children and a possible relationship between conservation ability and brain activation.
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In recent years, event-related potentials (ERPs) have been adopted to study conservation ability. In a study by Molfese et al. [8], adults were asked to report whether a pair of blocks of arrays had equal numbers. The block arrays were then spatially transformed and the participants were asked to report whether the transformed pairs were equal to the original pairs. After the presentation of the transformed pair of arrays, participants were asked to press a key to indicate whether they agreed with the display ("same" vs. "different") on the computer screen. ERPs recorded during the key pressing were analyzed, revealing a bilateral frontal negativity that peaked at 90 ms and a left hemisphere distributed positive component at 250 ms, which discriminated participants' "agreement" or "disagreement" to the screen-displayed words. Molfese et al. thus concluded that several kinds of brain activity are involved in conservation judgment. McGlasson [7] then conducted an auditory ERP study in children performing a number conservation task. Conservers differed from non-conservers in a bilateral distributed positive component at 500 ms and a right hemisphere negative component at 300 ms, supporting the hypothesis that ERP components reflect children's conservation abilities, just as in adults. One limitation in this study, however, was the possibility that the ERPs were not elicited by the stimulus requiring conservation judgment but a tone discriminating children's thinking about the answer. Very recently, Stauder et al. [11,12] developed a choice reaction time task analogue of the typical liquid conservation task for children 5–7 years old. Two broad positivities (an early and late positivity, both before 1000 ms) and one broad negativity (after 1000 ms) were reported. Conservers differed from non-conservers in an anteriorly-distributed broad late positive component, which was supposed to reflect the emergence of cognitive capacity during development.

Because it is still unclear whether children display specific ERP components during conservation tasks, in the present study, we adapted a weight conservation task and investigated brain activation patterns in children. We predicted that group differences would be associated with an increase in the proportion of correct answers to the test stimuli. We also predicted that

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the ERPs could be used to discriminate when children made different judgments.

Participants in the present study were recruited from primary schools in Beijing. Informed consent was obtained from all parents and teachers. The children were healthy and had normal or corrected-to-normal vision, were right-handed and were naïve to electrophysiological procedures. Before the experimental session, the children were tested with a liquid and a weight conservation test from the Inventory of Piaget's Developmental Tasks (IPDT) [3]. Children who finished the liquid conservation task successfully were then required to finish the weight conservation task. Children who gave a correct answer and explanation were labeled "conservers" while children who failed to give a correct answer or failed to give a correct explanation were labeled "non-conservers". Twenty-two children underwent EEG recordings, including 13 conservers and 9 non-conservers. There were six boys and seven girls in the conserver group with a mean age of 9.48 years old (S.D. = 0.90, range = 8.48–10.38 years old). There were four boys and five girls in the non-conserver group with a mean age of 8.84 years old (S.D. = 0.50, range = 8.34–9.44 years old). The two groups did not differ significantly in age ($t = 0.121$).

Children were then asked to perform an adapted weight conservation task (Fig. 1). Each trial started with a warning display of a balance with round plasticine in each side. The child was told that the balance was balanced. The plasticine in one side of the balance was then transformed and put back. In the response display, there were two balances. The child's task was to indicate which balance was accurate by pressing a button corresponding to the left or a right balance. The correct answer for the example shown in Fig. 1 would be "right". Task stimuli were presented in the center of the screen against a black background extending to a visual angle of approximately 1.7° vertical, 5.3° horizontal. The warning display was presented for 1000 ms, followed by a response display with a randomized delay of 150–250 ms. The response display showed two balances for 2500 ms followed by the next warning stimulus 450–550 ms later. The choice reaction time task was presented in four blocks, each consisting of five replications of 12 different stimuli (a total of 240 trials). Among the 12 stimuli, the transformation consisted of six changes in shape and six changes in size. Before starting, there was an explanation of the task, emphasizing speed and accuracy, and a presentation of practice trials until the child understood the task

requirements. The order of trials was pseudo-randomized. After the experiment, the child received a small gift for participation.

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. 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).

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 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. Offline analysis included band-pass finite impulse response filtering of 0.01–30 Hz using a filter order of 4001. Before 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 2600 ms, from 100 ms before the onset of the stimuli to 2500 ms after the stimulus onset. The following sites were chosen for statistical analysis: F3/F4, FC1/FC2, C1/C2, Fz, FCz, Cz. Fig. 2 shows the grand-averaged ERP waveforms from selected electrodes superimposed for the two groups of children. All stimuli elicited an anteriorly-distributed negative component peaking at 100 ms (N100), followed by a positive component peaking at 200 ms (P200). Following the typical N100-P200 complex, a negative component peaking at 280 ms was found (N280). This was followed at anterior sites by a broad late positive (LP) component peaking at approximately 900 ms. At occipital sites, a positive component peaking at 150 ms was apparent (occipital P150), followed by a negative component peaking at approximately 270 ms (occipital N270). This was followed by a positive component peaking at 400 ms and a negative component peaking at 600 ms. Finally, a slow late positive component was present. The
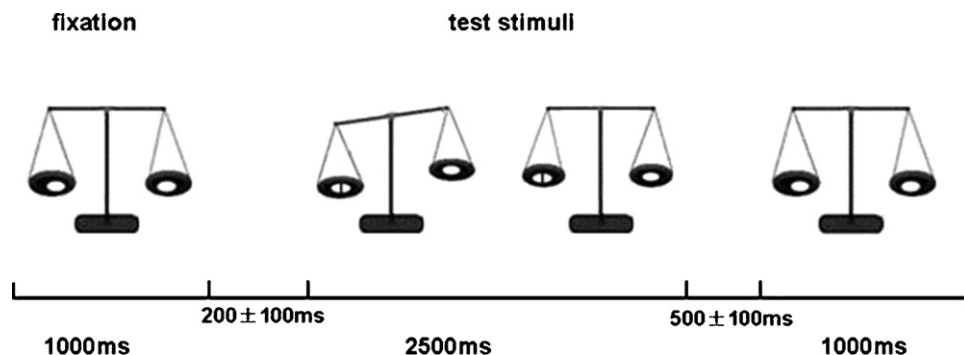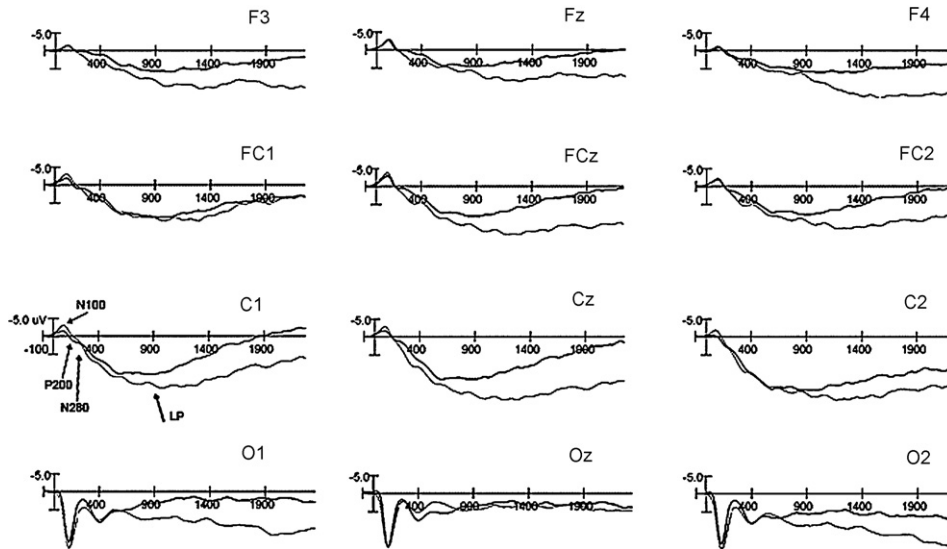

Fig. 1. Illustration of stimulus presentation.

Fig. 2. Grand average potentials of selected electrode positions for conserver (solid line) and non-conserver (dotted line) groups of children. Stimulus onset is indicated by the vertical calibration bar, and negative is plotted up.

difference between the two groups of children could be found in the anteriorly LP.

Peak latencies were detected before the analysis of amplitudes. Mean amplitudes of the LP were measured in two time windows: first time window (between 400 and 900 ms after the stimulus onset) and second time window (between 900 and 2000 ms after the stimulus onset). Peak latencies and mean amplitudes were then calculated for each participant in each group. Repeated-measures analyses of variance (ANOVAs) were conducted for latencies and mean amplitudes with group (conservers vs. non-conservers) as a between-subjects factor, hemisphere (frontal, fronto-central, central) and laterality (left, midline, right) as within-subjects factors. Greenhouse–Geisser correction was used when appropriate.

Reaction time medians and accuracy are shown in Table 1. Repeated-measures analysis of variance was carried out, with group as between-subject factor and stimulus items as the within-subject factor. Reaction time was not affected by group ($F(1, 20) = 0.18$) indicating that conservers and non-conservers answered equally quickly. However, the stimulus item significantly affected reaction time ($F(11, 220) = 4.19$, $p < 0.01$). Post-hoc comparisons by means of Newman–Keuls test revealed that the reaction time for item 12 was significantly shorter than for other items while the reaction time for item 6 was significantly longer than for other items. There was no interaction between group and stimulus item on reaction time ($F(11, 220) = 1.74$).

Whether a child was a conserver or non-conserver did significantly affect their accuracy ($F(1, 20) = 8.55$, $p < 0.01$). Conserving children performed more accurately than non-conserving children. Stimulus item also significantly affected accuracy ($F(11, 220) = 3.38$, $p < 0.05$). Post-hoc analyses revealed that accuracy on item 7 was significantly higher than on other items while accuracy on item 11 was significantly lower than on other items. There was no interaction between group and stimulus item on accuracy ($F(11, 220) = 1.69$). Because of the effects of stimulus item on reaction time and accuracy, the ERP data derived from these items (6, 7, 11 and 12) was not included in our analysis. The grand averages of ERPs were based on the waveforms from trials with correct responses (i.e., a maximum of 160 trials).

For the mean amplitude of the first time window (400–900 ms), the repeated-measures of variance indicated a significant effect of hemisphere ($F(2, 40) = 33.35$, $p < 0.01$) was yielded. The remaining ANOVA effect of group ($F(1, 20) = 0.59$), main effect of laterality ($F(2, 40) = 0.97$), interaction between hemisphere and group ($F(2, 40) = 0.15$), interaction between laterality and group ($F(2, 40) = 0.72$) were not statistically significant.

For the mean amplitude during the second time window (900–2000 ms), there was significant main effect of group ($F(1, 20) = 5.95$, $p < 0.05$). The amplitude of non-conservers was larger than conservers (7.501 µV vs. 4.484 µV). Amplitude was also significantly affected by hemisphere ($F(2, 40) = 15.80$, $p < 0.01$) and laterality ($F(2, 40) = 4.78$, $p < 0.05$). There was a significant interaction between hemisphere and group ($F(2, 40) = 5.95$, $p < 0.05$) and post-hoc comparisons by means of Newman–Keuls test revealed that conservers have the smallest amplitude ERPs centrally while non-conservers have the smallest amplitude in the frontal area. Both groups have the highest amplitude in the frontal-central region. A significant interaction between laterality and group ($F(2, 40) = 6.68$, $p < 0.01$) was noted and post-hoc analyses by means of Newman–Keuls test

Table 1
Median reaction time (RT; ms) and accuracy (AC) for the two groups of children

	RT (S.D.)	AC (S.D.)
Non-conservers	1244.06 (104.76)	0.66 (0.07)
Conservers	1301.95 (387.17)	0.84 (0.06)

Values are given with standard deviations (S.D.).

revealed that the largest amplitude was yielded on the right for conservers and along the midline for non-conservers.

The primary aim of the present study was to examine ERPs elicited by stimuli requiring conservation judgment. The task was an adaptation of Piaget's conservation task of weight quantity and we collected both behavioral and ERP data through a choice reaction time task paradigm. Consistent with other ERP studies, our tasks had repeated trials, short trial durations and discrete stimulus onsets [6]. The validity of the task was proven by the behavioral data of accuracy.

As anticipated, the ERP data reflected children's conservation ability. The N100 that we recorded was consistent with what Molfese et al. [8] found. The ERPs from conservers and non-conservers began to diverge at the P200 and N280. Slow wave activity might have occurred here, leading to a relatively larger P200, smaller N280 and a larger late positivity in the non-conserving group. This suggests that different components in different study are related only to the processing of a specific task. The difference between non-conservers and conservers was seen in the amplitude of the broad late positivity, with the mean amplitude of conservers being smaller than that of non-conservers. This finding is consistent with other studies [11,12] suggesting that a reduced amplitude of the broad late positivity could be a reflection of children's achievement of conservational judgment. In addition, the behavioral data suggested that the performance accuracy increased significantly from non-conservers to conservers, which also showed the acquisition of conservation ability [1,13–15].

Surprisingly, the interactions between conservation ability and hemisphere on the amplitude of the broad late positivity suggested altered scalp topography from the central (for non-conservers) to the right frontal hemisphere (for conservers). This is consistent with previous findings that showed that conservers utilize their right hemisphere more than non-conservers while processing conservation tasks [7]. It would be impudent to conclude qualitative changes of brain sources or information processing mode, but the data suggest an important role for frontal cortex maturation, which is consistent with theories on frontal cortex maturation [5,12]. The frontal lobe is viewed as the substrate for many higher cognitive functions, such as the organization of behavior and strategy of prompting. According to Piaget, during the course of development, behavior schemes are re-organized. Another major function of frontal lobe is inhibitory control and/or response interfering [4,5], while conservation tasks are supposed to involve perceptual conflicts [2].

ERP analysis of conservation tasks is still somewhat rudimentary. The present and future studies would benefit from some restructuring. For example, children may use different strategies when executing the conservation task in this study, a factor that ERPs would not detect. In future studies, we will group children by the strategies they use. Additionally, compared with adults,

the signal-to-noise ratio of children's electrocortical signal is much lower [10], requiring a more detailed analysis for each individual. Regardless, the present study revealed a correlation between ERP and conservation ability. This study goes one step further in that it provided a useful procedure in studies of the onset of conservation abilities.

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