The neural basis of conditional reasoning: An event-related potential study

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Abstract

The spatiotemporal analysis of brain activation during the execution of conditional reasoning tasks (the four inference forms: Modus Ponens (MP), Modus Tollens (MT), affirming the consequent (AC), and denying the antecedent (DA)) and one baseline task (BS) was performed in 12 normal young adult participants using high-density event-related brain potentials (ERPs). Results showed that the early components elicited by the five task types were not significantly different. Reasoning tasks elicited a more negative EPR deflection (N600) than did the BS task in the time window of 500–700 ms after onset of the minor premise. Dipole source analysis of the difference wave (MP − BS) suggested that a generator localized in the left anterior cingulate cortex (BA 24) was involved in the activation and the application of the inference rules. ERP components of the five tasks were similar in the subsequent time period between 700 and 1700 ms. Following that period, a greater negativity in the reasoning tasks, in comparison to the BS task, developed between 1700 and 2000 ms poststimulus over the left fronto-central scalp regions. A generator of this effect was located in the right anterior cingulate cortex (BA 24) and was possibly related to cognitive control. The results indicate that the cingulate cortex was activated by conditional reasoning tasks with purely abstract materials and support the view that human reasoning is not a unified phenomenon but is content-sensitive.
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1. Introduction

Conditional statements such as *If A then C* are the most studied of the connectives. A typical experiment contains an ordinary conditional as a major premise and then its antecedent or consequent (or a negation of its antecedent or consequent) as the minor premise (Evans & Simon, 2003). Participants are asked to assume these premises to be true and are then asked whether they endorse a conclusion that may validly follow. For example, participants can be given conditionals of the form *If A then C* as the major premise and *A* as the minor premise (Modus Ponens, MP). The frequency of endorsement of the conclusion *C* is then recorded. Other participants can be given the same major premise but *not-C* as the minor premise (Modus Tollens, MT), and the frequency of endorsement of the conclusion *not-A* in the valid inference is recorded. Simple MP arguments are correctly

endorsed at rates of at least 90%, whereas correct responses for MT inferences are at rates of approximately 60% (Johnson-Laird & Byrne, 2002). Thus, different logical inferences yield different behavioral results.

There are two non-valid inference forms related to the conditional rule. One is called the "Denial of the Antecedent" (DA). As the name suggests, this arises when the antecedent of a conditional is negated, as in *If A then C* along with *not-A*, which often leads one to conclude *not-C*. In the event that a participant is presented with these two kinds of premises, the logically appropriate response is to say *Inconclusive* (Cannot Tell). The other non-valid inference form, the Affirmation of the Consequent (AC), where one is confronted with *if A then C* and the information *C*, is also *Inconclusive* (Johnson-Laird & Byrne, 2002).

Three major psychology theories of the ordinary indicative conditional in natural language were developed to try to explain the results of experiments with these conditionals. Mental logic theories propose that the participant has an underlying knowledge of the inferential role of the closed-form, or log-

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ical terms, of the language (e.g. 'all', 'some', 'if–then') and uses this knowledge to infer the conclusion (Braine & O'Brien, 1998; Rips, 1994). Such theories explain the differing results with MP and MT by pointing out that MP is the basic rule of if-elimination, whereas MT is a derived rule requiring more computational steps and thus more mental resources (Braine & O'Brien, 1998; Rips, 1994). Mental model theories explain human inference, not by hypothesizing that there is a mental natural deduction system, but rather by suggesting that people manipulate 'mental models' (Johnson-Laird, 1983, 1994; Johnson-Laird & Byrne, 2002). Only one explicit model construction is required for MP, whereas one or two implicit models based on the explicit model are required for MT, AC, and DA. According to this theory, participants draw incorrect conclusions for MT, AC, and DA because implicit models cannot be constructed contemporarily within the limits of working memory capability. The theory of dual-process reasoning suggests that there are two sets of different reasoning process systems with relevant neurobiological foundation, in which System 1 is a rapid, parallel, and automatic process mainly in the frontal–temporal pathway, and System 2 is a slow, serial process together with working memory in the parietal–occipital pathway (Evans, 2003; Goel, 2003).

Neuroimaging techniques provide new methods of examining these issues in ways that transcend the differences among the models (Goel, Buchel, Frith, & Dolan, 2000; Goel & Dolan, 2003; Goel, Gold, Kapur, & Houle, 1998; Knauff, Mulack, & Greenlee, 2002; Noveck, Goel, & Smith, 2004; Osherson et al., 1998; Ruff, Knauff, & Spreer, 2003). Goel (2003) suggest that, if the mental model theory is correct, then the reasoning trials should result in right hemisphere and parietal activation (visuo-spatial areas), but if the mental logical theory is correct, the left frontal and temporal lobe regions (language areas) should be activated. In fact, Goel and Dolan's experiments have found that a parietal–frontal pathway is activated when participants reason with arbitrary materials, whereas a temporal–frontal system, linked to language areas, is activated when participants reason with syllogisms using realistic statements (Goel & Dolan, 2003). Thus, it appears that the reasoning activity is exclusively linked neither to language areas nor to visual–spatial areas. Noveck et al. (2004) used brain imaging to study conditional reasoning with arbitrary materials, such as "If there is a black triangle, then there is a red square". They found that the left superior parietal lobule, the left temporal lobe, and language areas were activated with MP in comparison to BS and that the left superior parietal lobe and the left frontal and prefrontal gyrus were activated with MT in comparison to BS. In the analysis of MT minus MP, the left dorsal lateral prefrontal cortex, the left inferior parietal lobe temporal lobe, and the inferior prefrontal cortex were activated, findings which are not consistent with rule theory or model theory.

Overall, it is unknown whether people solve reasoning problems by means of a set of inference rules or by means of visual–spatial models. In addition, although PET and fMRI studies provide important results, the time course of brain activity using such techniques lacks good temporal resolution. Many of these studies examined the brain activation during the whole reasoning process in a blocked fashion and thus could not distinguish reasoning-related processes during different stages of problem processing. For example, Fangmeier, Knauff, Ruff, and Sloutsky (2006) assumed that the reasoning process proceeds in three temporally separable phases: (1) the premise processing phase, (2) the premise integration phase, and (3) the validation phase in which reasoners decide whether a conclusion logically follows from the premises. Event-related potentials (ERPs) may provide a means to evaluate timing of cognitive processes prior to a response. In the ERP technique, recordings are made of the electrical activity of the brain that is time-locked to the presentation of an external stimulus. Thus, ERP data allow for more precise examinations of the time course of activation for different stages of reasoning and provide more valuable results for determining whether people solve reasoning problems by means of a set of inference rules or by means of visual–spatial models.

The purpose of the present study was to investigate the spatiotemporal pattern of brain activation in the performance of four different formats of conditional reasoning tasks and one BS task (memory retrieval) using high-density (64 channels) ERP recording and dipole source analysis (BESA software). Although a previous study found that different brain areas are activated by comparing MP with MT (Noveck et al., 2004), it is not known which ERP components are involved in different conditional reasoning tasks (MP, MT, AC, and DA) and whether there are differences among these components. Additionally, an fMRI study found activation of different brain areas to be involved in cognitive processes of reasoning and, thus, supported the theory of dual-process reasoning (Goel et al., 2000; Noveck et al., 2004). The methods of high-density (64 channel) ERP recordings and the dipole source analysis provide critical spatiotemporal information for analyzing the functional neuroanatomy of cognitive process of different inference forms, thereby enabling the testing of the different hypotheses.

2. Methods

2.1. Participants

Twelve healthy undergraduate students at a university in China (mean age: 20.2; range: 18–24; six men, six women) participated in the study. All participants were healthy and right-handed and had normal or corrected-to-normal vision.

2.2. Stimuli

Eighty items for each condition's arguments were presented along with 80 of the BS condition. Conclusions were both affirmative and negative to prevent creating expectations among participants. The materials used colored shapes. For example, one MP item looked like below:

If the figure is a square then it is red	[*major premise*].
It is a square	[*minor premise*].
So, it is red (or not red)	[*conclusion*].

Eighteen different colors (red, blue, green, yellow, black, white, etc.) and 18 different shapes (square, circle, triangle, cross, star, rectangle, etc.) were used. There was no repetition of a major premise in the formal test.
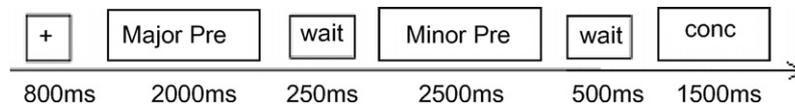
Fig. 1. Timeline of stimuli. Minor premise was the target events to which five different tasks ERP data were time-locked, respectively.

The BS condition was carried out with a prepositional syllogism having a trivially true conclusion. The following is an example:

If the figure is a square then it is red	[*major premise*].
It is a big figure	[*minor premise*].
So, it is big (or little)	[*conclusion*].

If the minor premise is true, then the conclusion is true as well. For the BS task, the minor premise does not have any relationship with the major premise. Test participants, therefore, judge whether the conclusion is right on the basis of minor premise, and they do not need to draw any conclusion based on the major premise and minor premise together. It is known that integration of information from various sources is an essential part of reasoning about the conditional reasoning problems. Such integration is not required for solving the BS task. In addition, the task forces participants to remain engaged throughout the problem, even as they see that the minor premise does not produce the means for a logical inference based on the major premise.

2.3. Procedure

Before the actual recording, participants were given a training session in which the task and the material to be presented were described. They were told to assume that the two premises (major and minor premise) would be true and were informed that they would need to determine whether the provided conclusion logically follows from them. They were further told that, if the conclusion follows, they were to respond *true*, and that, if the conclusion is false, they were to respond *false*. If they were unable to determine, they were told to choose *inconclusive*.

A given reasoning item was presented in the following way (see Fig. 1). The beginning of the trial was signaled by a "*" in the center of screen for 800 ms, followed by the appearance of the sentences on the screen one line at a time. The major premise (including 14 Chinese characters, each character's height and length were 1-cm, $5.73°$ (horizontal) $\times 0.81°$ (vertical)) appeared at 2000 ms. The minor premise (including seven or eight Chinese characters) appeared at 2500 ms, and the conclusion (including five or six Chinese characters) appeared 1500 ms after the minor premise. When the minor premise appeared in the center of screen, participants were asked to draw a logical conclusion immediately in order to judge whether the subsequent conclusion was true, false, or inconclusive. Test participants were asked to respond quickly. They responded by pressing one of three buttons on a keypad after the appearance of the last sentence. Participants were instructed to respond naturally and efficiently in order to be prepared to read the next trial. If they were unable to respond quickly enough, they were told to allow the trial to pass and to focus on the upcoming problem.

2.4. ERP recording and analysis

Brain electrical activity was recorded at 64 scalp sites using tin electrodes mounted in an elastic cap (Brain Product), with the reference electrodes on the left and right mastoids. Ocular artifacts were monitored by electrodes placed below and above the eyes (VEOG) and outside of both canthi (HEOG). All interelectrode impedances were maintained below 5 kΩ. The EEG and EOG were amplified using a 0.01–100 Hz bandpass and continuously sampled at 500 Hz/channel for off-line analysis. Trials with EOG artifacts (mean EOG voltage exceeding $\pm 80 \mu V$) and those contaminated with artifacts due to amplifier clipping, bursts of electromyographic (EMG) activity, or peak-to-peak deflection exceeding $\pm 80 \mu V$ were excluded from averaging.

The ERP waveforms were time-locked to the onset of the minor premise. The averaged epoch for ERP, including a 200-ms pre-answer baseline, was 2700 ms. The ERP waves for each condition were obtained after the ERP for the five types of tasks (MP, AC, DA, MT, and BS) were overlapped and averaged, respectively, and after trials with incorrect answers had been eliminated. On the basis of the

ERPs' grand averaged map and topographical map, the following nine electrode points (including an anterior frontal site, a central site, and a parietal site) were chosen for statistical analysis: F3, F4, Fz, C3, C4, Cz, P3, P4, and Pz. Mean amplitudes were analyzed using two-way repeated-measures analyses of variance (ANOVA). The ANOVA factors were task types (five levels: MP, AC, DA, MT, and BS) and electrode site. For all analyses, the *P*-value was corrected for deviations according to Greenhouse Geisser.

2.5. Dipole source analysis

The Brain Electrical Source Analysis program (BESA, Version, 5.0, Software) was used to perform dipole source analysis. For dipole source analysis, the four-shell ellipsoidal head model was used. In order to focus on the scalp electrical activity related to the processing of conditional reasoning, the averaged ERPs evoked by the reasoning tasks were subtracted from the ERPs evoked by the BS. When the dipole points were determined, the software automatically determined the dipoles' location. The relevant residual variance criterion was used.

3. Results

3.1. Behavioral performance

The percentage of correct judgments for each task was greater than 90% (see Table 1) because participants were selected for their abilities to reason logically and because they were given a training session before the formal test. No significant effect of task type was found. There were more than 45 trials for each type of event for each participant. Mean reaction times (RTs) to conclusion for AC (403 ± 137 ms) and DA (392 ± 169 ms) were shorter than RTs were for MP (707 ± 93 ms), MT (654 ± 279 ms), and BS (630 ± 273 ms) ($P < 0.001$) most likely because the correct responses for AC and DA were inconclusive. In inconclusive cases, the participants can determine the correct response without seeing the conclusion.

3.2. ERP waveforms analysis

ERP waveforms evoked by the MP, AC, DA, MT, and BS tasks are shown in Fig. 2. Conditional reasoning tasks elicited a more negative EPR deflection than the BS task did in the 500–800 and 1400–2500 ms time windows. The early difference (500–800 ms) was examined in 100 ms time windows, and the

Table 1
Summary of performance data

Tasks	Correct response (%)	Mean time (ms)
MP	94.8 ± 5.3	707 ± 93
AC	94.9 ± 6.0	403 ± 137
DA	92.5 ± 6.5	392 ± 169
MT	93.5 ± 6.5	654 ± 279
BS	97.6 ± 1.5	630 ± 273

Group mean reaction time and standard deviation for the five tasks, and correct ratio responses.
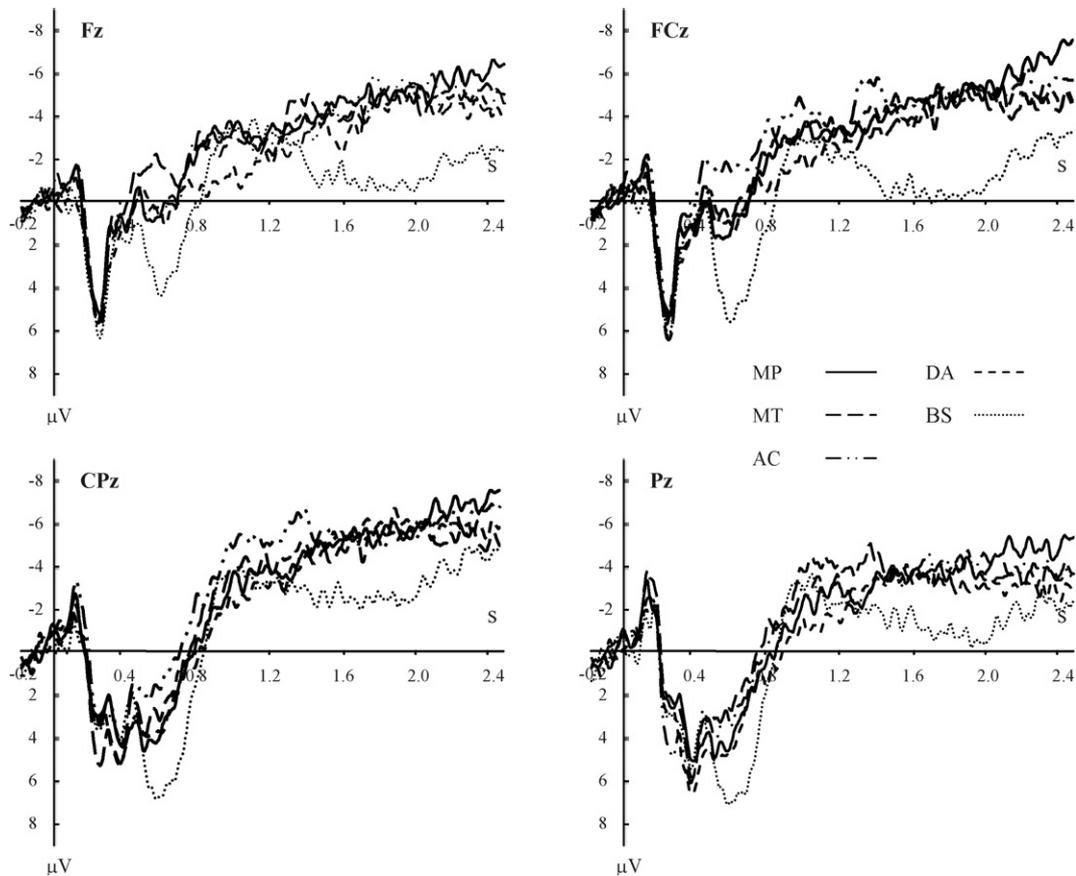
Fig. 2. Grand average ERPs at Fz, FCz, CPz, and Pz for five tasks.

late difference (1400–2000 ms) was examined in 300 ms time windows. Mean amplitudes in the time windows of 500–600, 600–700, 700–800, 1400–1700, and 1700–2000 ms were analyzed using two-way repeated-measures ANOVAs, with task types and electrode site as factors.

In the time window of 500–600 ms, there was a main effect of task type ($F(4,44) = 9.91$, $P < 0.001$). The mean amplitude was more negative for the four conditional reasoning tasks than for the BS task ($P < 0.05$). In addition, the interaction between task type and electrode location was significant ($F(32,352) = 4.13$, $P < 0.01$). Subsequently, a two-way repeated-measures ANOVA showed that the main effect of task type between 600 and 700 ms was also significant ($F(4,44) = 5.67$, $P < 0.01$). The mean amplitude was more negative for conditional reasoning tasks than for the BS task ($P < 0.05$). The analysis of mean amplitude by ANOVAs showed the main effect of task type was marginally not significant in the time window from 1700 to 2000 ms ($F(4,44) = 2.76$, $P = 0.08$). In the time windows of 800–1400, 1400–1700 and 2000–2500 ms, repeated-measures ANOVA showed that the main effects of task types and the electrode site were not significant.

To gain further information about the scalp electrical activity related to the process of conditional reasoning, source analysis using BESA software was performed on the ERP difference wave of MP and BS (see Fig. 3) because the ERP components elicited by the four conditional reasoning tasks were similar to each other.

Based on the statistical results and the topography of the difference waves, principal component analyses (PCA) were employed in the two time windows (500–700, 1700–2000 ms) in which the main effect of task type was significant. In the 500–700 ms time window, PCA indicated that one principal component was needed to explain 93.6% of the variance in the data. The results indicated that a dipole located near the left anterior cingulate cortex (ACC: BA 24) was able to account for the variance (location according to Talairach coordinates: x, y, $z = -6.6$, 15.8, 19.2) and revealed a maximal dipole moment strength at about 680 ms. This model explained the data best and accounted for most of the variance with a residual variance (RV) of 13.2% at the peak activity of this dipole (see Fig. 4). In the time window of 1700–2000 ms, PCA indicated that one principal component was needed to explain 97.1% of the variance in the data. Therefore, one dipole was fitted with no restriction to the direction and location of dipole. The results indicated that the dipole was located near the right ACC (BA 24) (location according to Talairach coordinates: x, y, $z = 5.7$, 19.6, 22.5) and revealed a maximal dipole moment strength at about 1730 ms. This model explained the data best and accounted for most of the variance, with a residual variance (RV) of 11.9% at the peak activity of the dipole (see Fig. 4).

The validities of these models were tested through the following steps. First, the display of the residual maps in the time windows (500–700, 1700–2000 ms) showed no further dipolar
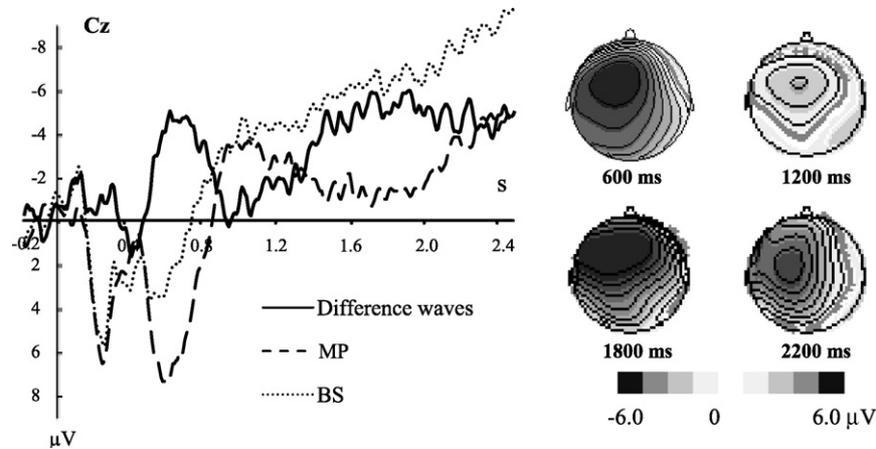
Fig. 3. (Left) Grand average ERP to MP, BS and the difference wave (MP − BS) at Cz. (Right) Topographical maps of the voltage amplitudes for the MP vs. BS difference wave in the 600, 1200, 1800, and 2200 ms.
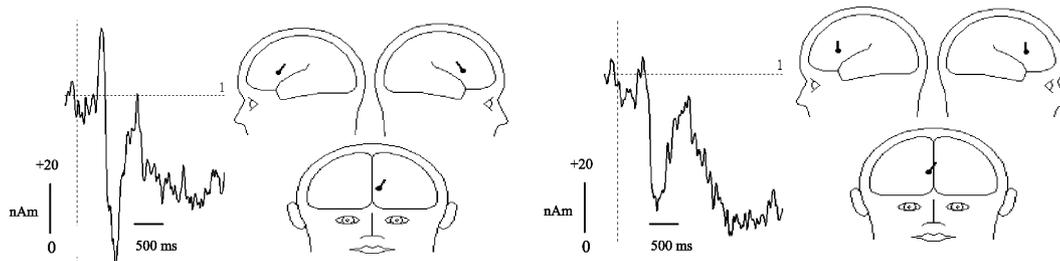

Fig. 4. Results of the dipole source analysis of the difference wave (MP vs. BS) in the time range of 500–700 and 1700–2000 ms. The left shows the source activity waveforms, whereas the right figure displays the mean locations of the dipole. (Left) In the time range of 500–700 ms, the dipole is located approximately in the left anterior cingulate cortex ($x = -6.6$, $y = 15.8$, $z = 19.2$). (Right) In the time range of 1700–2000 ms, the dipole is located in near the right anterior cingulate cortex ($x = 5.7$, $y = 19.6$, $z = 22.5$).

activity; second, no other dipoles could be fitted in the investigated time windows by comparing the solution with other plausible alternatives (e.g. bilaterally symmetric dipoles). These tests suggest that the models explained the data in the best manner for the time windows.

4. Discussion

In the present study, observations from the voltage map and the results of dipole analysis performed on the difference wave (reasoning tasks minus BS task) indicate activation of brain areas related to conditional reasoning. The results suggest that the ERP components elicited by the BS task were different from those of the four conditional reasoning tasks. Specifically, the findings suggest that left frontal–central areas, especially dorsal ACC, are involved in inferential processing.

The conditional reasoning tasks elicited a more negative EPR deflection between 500 and 700 ms than the BS task. A generator of this effect was located in the left ACC. When the minor premises made reference to the size of the figures (BS task), participants needed to memorize it but were not required to make any further deduction. However, when the premises provided information about the shapes and colors of the figures (conditional reasoning tasks), the participants had to activate the relevant reasoning rules to make an adequate inference,

in addition to memorizing this information. Thus, the negative component (located in the ACC) of the difference wave (MP − BS) was probably involved in the activation and the application of the inference rules to premise integration.

Previous work indicates that reasoning, in comparison with maintenance, is associated with greater activation in anterior cortical areas, comprising parts of the ACC (Ruff et al., 2003). The cluster of ACC/medial frontal activation is located anterior to the areas known to be involved in mere preparation and execution of motor responses (Petit, Courtney, Ungerleider, & Haxby, 1998). Some researchers suggest that the medial frontal gyri activation during reasoning reflects processes related to the integration of information from various sources (Kroger et al., 2002; Ruff et al., 2003). For example, Waltz et al. (1999) found that patients with damage to the prefrontal cortex are strongly impaired on deductive reasoning tasks only when the tasks require relational integration. In the present study, the activation of the left ACC also suggested that the abstract logic rule might be activated and applied in the left hemisphere.

Previous work indicates that the left hemisphere executes the function of formal logic manipulation, whereas the right hemisphere focuses on activating the relevant knowledge and experience with reasoning tasks (Deglin & Kinsbourne, 1996). Wharton and Grafman (1998) found that it is not difficult for right hemisphere-trauma patients to do logic reasoning,

whereas such reasoning is problematic for left hemisphere-trauma patients (Wharton & Grafman, 1998). In addition, the activity in the ACC gyrus found in the present study was in agreement with the findings of other studies on reasoning that likewise found activation in this area (Goel et al., 2000; Ruff et al., 2003). Recently, Fangmeier et al. (2006) investigated the neurocognitive processes underlying logical thinking with event-related fMRI. They found activation of the anterior prefrontal cortex and the ACC during the reasoning process, which supported their hypothesis of premise integration. Based on their findings, the integration processes are not necessary during pure maintenance problems, for which they found significantly lower the anterior prefrontal cortex (APFC) activation during the premise maintenance phase (Fangmeier et al., 2006). The present results support the importance of activation of the left ACC in the integration of information during deductive reasoning.

Dipole source analysis of the difference wave (MP − BS) between 1700 and 2000 ms indicated that a generator was located in right ACC. If participants inferred the corresponding conclusions, they had to hold them in working memory for a short time in order to give a quick and correct judgment when the conclusion appeared later. Thus, it might be expected that the cognitive process of working memory during the reasoning task would activate the dorsolateral prefrontal cortex (Fletcher & Henson, 2001). However, dipole source analysis of difference wave (MP − BS) indicated that the dorsolateral prefrontal cortex was not activated. This most likely occurred because participants also kept minor premises in working memory for the BS task.

In contrast, compared with the BS task, the conditional reasoning tasks activated the right ACC. In the present study, the greater negativity (MP − BS) that developed between 1700 and 2000 ms might reflect cognitive control because participants had to verify automatically whether their deductive conclusions were correct. For the BS task, the size of the figures was certain, and, thus, the participants did not spend any cognitive resources proving the BS tasks' validity. Botvinick suggests that ACC activation can be explained by the single function of the detection of conflict and puts forth the hypothesis that conflict might serve as an index of the demand for mental effort (Botvinick, Cohen, & Carter, 2004; Rushworth, Walton, Kennerley, & Bannerman, 2004). Consistent with this, it has been noted that the ACC becomes active in only those task settings that are experienced as cognitively difficult (Botvinick et al., 2004; Paus, Koski, Caramanos, & Westbury, 1998).

Previous work indicates that the ACC has also been shown to be the generator of the midline theta rhythm, an EEG oscillation that is characteristically observed during intense concentration (Gevins, Smith, McEvoy, & Yu, 1997). Other studies suggest that the ACC is involved in linking mental effort to the autonomic changes that typically accompany it (Critchley et al., 2003; Walton, Bannerman, Alterescu, & Rushworth, 2003). Prior research indicates that subjects have significantly shorter reaction times, increased N1 amplitudes, and increased ACC activity during the high effort condition, compared to those found in the relaxed condition (Mulert, Menzinger, Leicht, Pogarell, & Hegerl, 2005). These results provide direct evidence for a close relationship between conscious effort and ACC activ-

ity. The ACC activity has been described as a critical locus for "conscious effort" in "complex effortful tasks that presumably cannot be performed without conscious guidance" (Dehaene & Naccache, 2001; Mulert et al., 2005). Other findings suggest that the validation phase, in which participants decide whether a conclusion logically follows from the premises, activates three clusters: two in the prefrontal cortex and one in the posterior parietal cortex (Fangmeier et al., 2006). More precisely, the clusters in the prefrontal cortex are located in the middle frontal gyrus (BA 9, 8, and 6), extending into the medial frontal and the cingulate gyrus (BA 32) in the right hemisphere (Fangmeier et al., 2006). The present results, together with the prior findings, suggest that the right ACC is involved in cognitive control as an index of the mental effort it demands (Botvinick et al., 2004), particularly the validation of conclusions during reasoning processes.

In the present study, the ACC was activated by conditional reasoning tasks, as determined by the method of dipole source localization. However, it should be stressed that dipole source analysis is an inverse problem because there is no unique solution. Due to inherent limitations of source localization, the brain areas implicated by source localization are only tentative. The results of dipole source analysis, therefore, should be considered with caution, as the difference wave (MP − BS) may embody complex brain processes accomplished by multiple areas and their interactions. Thus, it is speculative to suggest that there is only one generator to account for a high-level cognitive process such as inference processing. Regarding the involvement of brain regions in response to conditional reasoning, the current results provide only a model rather than empirical data.

In sum, the results of the present study indicate that the cingulate cortex was activated by conditional reasoning tasks with purely abstract materials. The present results indicate that the language processing network and visual–spatial processing network were not activated solely for deductive reasoning. Recently, Fiddick, Spampinato, and Grafman (2005) found that reasoning about social contracts and precautions activates a different constellation of neurological structures, although, in that study, the rules and demands of the task were matched in terms of their logical structure (Fiddick et al., 2005). However, the cognitive and neural processes in reasoning might depend on the nature of the problem. Reasoning with visually presented spatial relations may elicit mental models, whereas reasoning with other problems may elicit other representations and processes (Fangmeier et al., 2006). Thus, our results support the view that human reasoning is not a unified phenomenon but is content-sensitive (Fiddick et al., 2005).

In addition, the present results found 'early' (at 680 ms) activity in the left ACC and 'late' (at 1730 ms) activity in the right ACC during different stages of reasoning processing. These findings are not consistent with some previous work (Goel & Dolan, 2003; Noveck et al., 2004) which found different brain activity, through fMRI, for different task types (MP vs. MT) in fronto-parietal areas. The different results may be due to two reasons. First, in the present study, participants were required to draw a logical conclusion immediately after the onset of the minor premise in order to analyze primarily the

functional neuroanatomy of the reasoning process according to the temporal information provided by ERP recordings. However, experiments that produced different results used fMRI and employed an inference-verification paradigm requiring the participants to evaluate the correctness of a conclusion presented after major and minor premises (Goel et al., 1998, 2000; Goel & Dolan, 2003; Knauff et al., 2002; Noveck et al., 2004). Second, materials of conditional reasoning that consist of abstract conditional propositions can be mastered well by practice. This may explain why the target conditions (MP, DA, AC, MT) in the current study produced very similar EEG correlates. Although ERP source localization has low resolution, the ACC seems the most likely area activated by the conditional reasoning tasks. Experiments using other techniques with more precise localization, such as fMRI, are needed in order to determine the role of the ACC in higher cognitive functioning. Moreover, studies should determine whether other brain areas are involved in deductive reasoning, such as syllogistic reasoning or three-term relational reasoning, and should analyze the ERP components in different reasoning processes in order to explain the cognitive neuroscience mechanisms of reasoning.

5. Conclusion

This study used ERP to investigate the neurophysiological correlates of conditional reasoning. The results suggest that the ERP components elicited by the BS task were different from the conditional reasoning tasks. However, there was no difference in the spatiotemporal course of brain processes corresponding to inferential processing in solving the different conditional reasoning tasks (MP, DA, AC, MT). The ERP results implicate the involvement of left frontal–central areas, especially the dorsal ACC, in inferential processing.

Acknowledgements

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