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UNIFORMITY AND NONUNIFORMITY OF NEURAL ACTIVITIES CORRELATED TO DIFFERENT INSIGHT PROBLEM SOLVING

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Abstract—Previous studies on the neural basis of insight reflected weak consistency except for the anterior cingulate cortex. The present work adopted the semantic and homophonic punny riddle to explore the uniformity and nonuniformity of neural activities correlated to different insight problem solving. Results showed that in the early period of insight solving, the semantic and homophonic punny riddles induced a common N350-500 over the central scalp. However, during −400 to 0 ms before the riddles were solved, the semantic punny riddles induced a positive event-related potential (ERP) deflection over the temporal cortex for retrieving the extensive semantic information, while the homophonic punny riddles induced a positive ERP deflection over the temporal cortex and a negative one in the left frontal cortex which might reflect the semantic and phonological information processing respectively. Our study indicated that different insight problem solving should have the same cognitive process of detecting cognitive conflicts, but have different ways to solve the conflicts.

Key words: insight, problem solving, event-related potential, cognitive conflict, right hemisphere.

INTRODUCTION

Insight means to resolve problems suddenly rather than by an approach of trial and error (Köhler, 1925), in which one would fall into an impasse at first, and the impasse would be broken by a new idea that suddenly came to mind (Qiu et al., 2008a). As a typical creative activity, the processing of insight has attracted the attention of many researchers (Kounios and Smith, 1995; Knoblich et al., 2001; MacGregor et al., 2001; Ormerod et al., 2002; Foerder et al., 2011). Especially from 1990s onward, the investigations on the neural correlates of insight flourished with the development of neuroimaging techniques (Dietrich and Kanso, 2010).

To explore the insight effect, a variety of tasks and experimental paradigms have been applied. Roughly, these insight problems can be classified into visual and verbal ones. For the former, the visual reconstruction plays a crucial role in problem solving; while for the latter, the semantic information integration should be the key process. Although the nine-dot problem and six-match-stick problem are the typical visual insight problems, they are not suitable for the study on neural basis of insight, because a number of homogenous mental events which can be repeatedly observed are required for the neuroimaging approach (Luo, 2004). Therefore, some researchers introduced the task of Chinese character chunk decomposition to investigate insight (Luo et al., 2006; Wu et al., 2012). It was found that the chunk composition was associated with the tendency of negative activation in the early visual cortex and the tendency of positive activation in the higher visual cortex (Luo et al., 2006).

The verbal problems were used by the majority of studies to explore the neural basis of insight, including compound remote associate (CRA) problems, riddles, logogriphs and anagrams. In the studies using the CRA problems, both functional magnetic resonance imaging (fMRI) and electroencephalogram showed increased activities at the anterior cingulate cortex (ACC) during the preparation before the insight problem solving and at the right anterior superior temporal gyrus during the insight (Jung-Beeman et al., 2004; Kounios et al., 2006). The right anterior superior temporal gyrus was thought to be associated with making connections across distantly related information during comprehension.

Different from those by the CRA, in studies using riddles, a trigger was provided to catalyze insightful solving processes, because riddles were hardly solved. The fMRI studies found that the ACC, the left prefrontal cortex and the right hippocampus were associated with the insight riddle solving (Luo and Niki, 2003; Luo et al., 2004). The corresponding event-related potential (ERP) studies found that the N380 or the N320 over the central

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Abbreviations: ACC, anterior cingulate cortex; ANOVA, analysis of variance; CRA, compound remote associates; ERP, event-related potential; fMRI, functional magnetic resonance imaging.

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sites localized in the ACC might reflect the insight effect (Mai et al., 2004; Qiu et al., 2006b). Additionally, using a paradigm of answer selection, researchers found that insight riddle solving was associated with a dynamic neural network comprising the ACC, the middle temporal gyrus, the hippocampus and the amygdala (Zhao et al., 2013).

Chinese logogriphs were also introduced to investigate insight (Qiu et al., 2008a). Using a learning-testing paradigm, researchers found that successful guessed logogriphs elicited a larger P200-600 localized in the left superior temporal gyrus and the parietotemporo-occipital cortex areas, a larger N1500-2000 localized in the ACC and a larger N2000-N2500 localized in the posterior cingulate cortex than did unsuccessful guessed logogriphs (Qiu et al., 2008b). The corresponding fMRI results showed that the insight activated more in the precuneus, the left inferior/middle frontal gyrus, the inferior occipital gyrus and the cerebellum (Qiu et al., 2010).

As reviewed above, the majority of studies reported a common brain region in insight problem solving: the ACC which may be responsible for detecting cognitive conflicts and initiating processes that lead to the breaking of mental mindset that keeps one stuck in the wrong solution space (Dietrich and Kanso, 2010). Meanwhile, different studies also found some different brain regions associated with their experimental materials respectively. For example, Chinese character chunk decomposition relies on the visual reconstruction, and then activates the occipital areas (Luo et al., 2006; Wu et al., 2012); the key cognitive process of solving the CRA problems and riddles is to retrieve the extensive semantic information to form novel associations, and therefore the temporal areas are reported to be activated in insight (Luo and Niki, 2003; Jung-Beeman et al., 2004; Zhao et al., 2013); while the solution of Chinese logogriphs is dependent on the integration of visual and semantic information, and then both the temporal and occipital areas are activated (Qiu et al., 2008b, 2010).

Thus, we think that different insight problem solving should have the same cognitive process of detecting cognitive conflicts, but have different ways to solve the conflicts. Because there are multiple distinctions between the visual and verbal insight problems, the direct comparison between them is complicated to interpret. Therefore, the present study adopted two different types of riddles which originated from Chinese two-part allegorical sayings to test and verify our hypothesis. They are the same in form, but have different crucial processes to solve. Therefore, they are suitable for the study on the uniformity and nonuniformity of neural activities correlated to different insight problem solving.

Additionally, both the stimulus-locked and response-locked analyses were adopted in this work to catch the neural activities of detecting and solving the cognitive conflicts respectively. The cognitive conflicts usually emerge at the early stage of insight problem solving, and then the stimulus-locked analysis is suitable. According to the previous studies (Mai et al., 2004; Qiu et al., 2006b), the detection of the cognitive conflicts could be indicated by a negative ERP compound over the central scalp sites during 300–400 ms after the riddles were presented. After that, a late positive component localized in temporal cortex might be elicited (Zhang et al., 2011), which may reflect the retrieval of the novel semantic information. However, this component is not so meaningful in the present study, because the solution of the cognitive conflicts usually occurs at the end of the insight problem solving. Due to the different reaction times of different trials, the response-locked analysis rather than the stimulus-locked analysis can accurately catch this mental event. It is speculated that a positive component localized in temporal cortex prior to the solution might be elicited to integrate the semantic information for both types of the riddles. Additionally, the homophonic punny riddle might elicit a negative ERP prior to the solution to process the phonological information (Rugg, 1984; Liu et al., 2011), which might be over the left frontal cortex (Tan et al., 2005).

EXPERIMENTAL PROCEDURES

Participants

As paid volunteers, 21 undergraduates as well as postgraduates (nine men and twelve women) of Central China Normal University, aged from 20 to 28 (average age, 23.3 years old), participated in this experiment and signed informed consent according to the requirements of the Institutional Review Board of Central China Normal University. Data of four participants were eliminated from the analysis because of their low accuracy rate ($\leqslant$40%). All participants are right-handed with no physical or mental diseases, have normal or corrected-to-normal visions, and have not taken part in any similar experiment before.

Materials and experimental paradigm

The present experimental materials are two types of riddles, semantic punny and homophonic punny, which are developed from Chinese two-part allegorical sayings. A Chinese two-part allegorical saying is a special kind of language form, which can be divided into two segments, namely, a descriptive part and an explanatory part. The former consists of a short phrase, portraying an image of an object, an event, or a situation, and foreshadowing the whole saying like the riddle, while the latter is often made up of a few words, carrying a message derived from the first part and presenting the essence like the key to the riddle. Both the types of riddles are short phrases consisting of about two to seven characters, and their answers are two-character Chinese words. Two special types of Chinese two-part allegorical sayings are developed into riddles, one is semantic punny and the other is homophonic punny. For the semantic punny riddle, the metaphorical meaning of the answer is its prominent meaning, and its literal meaning is hardly used at ordinary times. This produces a mental set, which prevents a successful riddle solving because riddles aim at the unconstrained meanings of individual characters