Neuroscience 256 (2014) 334–341

NEURAL PATHWAY IN THE RIGHT HEMISPHERE UNDERLIES VERBAL INSIGHT PROBLEM SOLVING

Q. ZHAO,[a,b] Z. ZHOU,[a,b*] H. XU,[c*] W. FAN[c] AND L. HAN[d]

[a] Key Laboratory of Adolescent CyberPsychology and Behavior (CCNU), Ministry of Education, Central China Normal University, Wuhan 430079, China

[b] Key Laboratory of Human Development and Mental Health of Hubei Province, School of Psychology, Central China Normal University, Wuhan 430079, China

[c] MRI Center of Union Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan 430022, China

[d] School of Psychology, Shandong Normal University, Jinan 250014, China

Abstract—Verbal insight problem solving means to break mental sets, to select the novel semantic information and to form novel, task-related associations. Although previous studies have identified the brain regions associated with these key processes, the interaction among these regions during insight is still unclear. In the present study, we explored the functional connectivity between the key regions during solving Chinese 'chengyu' riddles by using event-related functional magnetic resonance imaging. Results showed that both insight and noninsight solutions activated the bilateral inferior frontal gyri, middle temporal gyri and hippocampi, and these regions constituted a frontal to temporal to hippocampal neural pathway. Compared with noninsight solution, insight solution had a stronger functional connectivity between the inferior frontal gyrus and middle temporal gyrus in the right hemisphere. Our study reveals the neural pathway of information processing during verbal insight problem solving, and supports the right-hemisphere advantage theory of insight.

Key words: insight, fMRI, functional connectivity, Chinese 'chengyu' riddle, right hemisphere.

INTRODUCTION

Since Köhler (1925) observed that chimpanzees could resolve problems suddenly rather than by an approach of trial and error, the processing of insight has attracted the attention of many researchers. Since unsuitable representations of problem would lead to the failure of effective problem solving in many situations, some cognitive psychologists proposed that the representation change such as constraint relaxation and chunk decomposition should be the crucial process of insight (Kaplan and Simon, 1990; Knoblich et al., 2001; Ormerod et al., 2002). Using some visual-representation-based problems such as the nine-dot problem and the Chinese chunk decomposition problem, researchers found that there were multiple sources of difficulty of particular insight problems, and that early perceptual processes could crucially affect thinking and problem solving (MacGregor et al., 2001; Kershaw and Ohlsson, 2004; Luo et al., 2006; Wu et al., 2013).

With the development of neuroimaging techniques, especially from 1990s onward, the investigations on the neural correlates of insight flourished (Dietrich and Kanso, 2010). However, since a number of homogenous mental events which can be repeatedly observed are required for the neuroimaging approach, the classic insightful paradigms such as nine-dot problem and six-matchstick problem are no longer suitable (Luo, 2004). Thus, a variety of verbal problems have been applied in the studies of insight, such as riddles, logogriphs and compound remote associates problems (Luo and Niki, 2003; Jung-Beeman et al., 2004; Qiu et al., 2010; Zhao et al., 2013). In these studies, researchers focused on two key components of insight processing, that is to break the mental sets and to form novel, task-related associations among the old nodes of concepts or cognitive skills (Luo and Niki, 2003; Bowden and Jung-Beeman, 2007).

Studies indicated that the frontal cortex played a key role in breaking mental sets. Therein, the anterior cingulate cortex was highlighted and proposed to monitor the cognitive conflicts resulting from mental sets (Luo et al., 2004; Mai et al., 2004; Qiu et al., 2008; Aziz-Zadeh et al., 2009). After detecting the cognitive conflicts, one should break its mental sets to solve the conflicts in insight. It was found that the lateral prefrontal cortex, including the inferior and middle frontal gyri, was activated in chunk decomposition of Chinese characters (Luo et al., 2006), set-shift problems (Goel and Vartanian, 2005) and insightful riddle solving

*Corresponding authors. Address: Key Laboratory of Adolescent CyberPsychology and Behavior (CCNU), Ministry of Education, Central China Normal University, Wuhan 430079, China. Tel: +86-02767865767 (Z. Zhou).

E-mail addresses: zhouzj@mail.ccnu.edu.cn (Z. Zhou), xuhaibo1120@hotmail.com (H. Xu).

Abbreviations: BOLD, blood oxygenation level dependent; EPI, echo planar imaging; fMRI, functional magnetic resonance imaging; LHIPP, left hippocampus; LIFG, left inferior frontal gyrus; LMTG, left middle temporal gyrus; ROI, region of interest; RIFG, right inferior frontal gyrus; RHIPP, right hippocampus; RTMD, right middle temporal gyrus; SPM, statistical parametric mapping.

0306-4522/13 $36.00 © 2013 IBRO. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.neuroscience.2013.10.019

(Luo and Niki, 2003; Luo et al., 2004; Qiu et al., 2010). Due to its role in establishing and shifting the attentional sets (MacDonald et al., 2000; Luks et al., 2002), the lateral prefrontal cortex was thought to be associated with conflict resolution.

The breaking of mental sets would result in the retrieval of new information pieces. Then, the selection of novel information pieces and forming novel, task-related associations were the keys of insight problem solving (Bink and Marsh, 2000). According to the coarse semantic coding theory, the right-hemisphere engages in coarse semantic coding, weakly and diffusely activating alternative meanings and more distant associates (Faust and Chiarello, 1998; Beeman and Bowden, 2000; Bowden and Jung-Beeman, 2003). Therefore, some researchers highlighted the role of the right hemisphere (especially the right anterior superior temporal gyrus) in making connections across distantly related information during insight (Bowden and Jung-Beeman, 2003; Jung-Beeman et al., 2004). In fact, the right temporal cortex might be mainly in charge of processing novel semantic information (Faust and Mashal, 2007; Mashal et al., 2008; Pobric et al., 2008), while the hippocampus should be the key brain region in forming the novel associations (Luo and Niki, 2003; Zhao et al., 2013), due to its function in path reorientation (Redish, 2001), relational memory (Cohen et al., 1999; Luo and Niki, 2002) and response to novel stimuli (Knight, 1996; Johnson et al., 2008).

Obviously, verbal insight problem solving activates a distributed neural network including the anterior cingulate cortex, lateral prefrontal cortex, right temporal areas and hippocampus. Although previous studies have identified the roles of these brain regions, the information integrations among them are still unclear. The electroencephalograph study showed that good performance in the divergent thinking task was related to increased functional connectivity of central–parietal areas of both hemispheres and greater ipsilateral connections between the cortex regions of the right hemisphere in the beta2 band (Razoumnikova, 2000). And the study using diffusion tensor imaging reported significant positive relationships between individual creativity as measured by the divergent thinking test and fractional anisotropy in the white matter in or adjacent to the bilateral prefrontal cortices, the body of the corpus callosum, the bilateral basal ganglia, the bilateral temporal-parietal junction and the right inferior parietal lobule (Takeuchi et al., 2010). These studies indicated the importance of the information integration of different brain regions in creativity.

In verbal insight problem solving, the forming of novel associations is dependent on the selection of novel semantic information. Since the lateral prefrontal cortex, temporal areas and hippocampus are respectively associated with conflict resolution, semantic processing and relational memory, it is speculated that the functional connectivity between the lateral prefrontal cortex and temporal areas might reflect the information selection process in insight and that between right temporal areas and hippocampus might underlie the forming of novel association. The current work aims to reveal the functional connectivity among the key brain regions which underlies the cognitive processing in insight.

Additionally, according to the coarse semantic coding theory, the right temporal cortex should play a crucial role in verbal insight problem solving, and this is supported by several studies (Bowden and Jung-Beeman, 2003; Jung-Beeman et al., 2004; Zhang et al., 2011; Zhou et al., 2011). However, there are also some studies revealing bilateral activation patterns associated with insight events (Luo and Niki, 2003; Aziz-Zadeh et al., 2009; Zhao et al., 2013). There might be several reasons why the latter studies do not find the right hemisphere advantage. First, verbal insight problems cannot be solved by the conventional semantic information processing, and then the process of retrieving the novel semantic information is the key of insight solving. However, some of the latter studies adopted the paradigm of providing triggers to catalyze the insight processes. This would simplify the retrieval of the novel meanings and distant associates, and then weaken the activation of the right temporal cortex. Second, since insight solution comes to mind suddenly, the right temporal cortex should show greater activation at the time just prior to the solution (Jung-Beeman et al., 2004). However, most of the latter studies focused on the activation throughout the solving period, not exactly catching the key period of the activation in right temporal cortex. It is noticed that all these findings, no matter supporting the right hemisphere theory or not, are from the location analysis of brain functions. Thus, as one of the two patterns of brain functional organization (Tononi et al., 1994), the functional integration analysis may provide something new for the discussions on hemisphere difference in insight.

EXPERIMENTAL PROCEDURES

Participants

As paid volunteers, 20 undergraduates or graduates (13 women, 7 men), aged 21–35 years (mean age, 23.6 years) from the Central China Normal University, participated in the experiment, and gave their informed consent according to the requirements of Institutional Review Board of the Central China Normal University. All participants were healthy, right-handed, and had normal or corrected to normal vision. Two participants were excluded from analysis due to their experiencing of less than 15% normal associations during the experiment. Another participant was excluded due to the excessive head motion during functional magnetic resonance imaging (fMRI) scanning.

Stimuli and task

In the present study, we adopted the Chinese 'chengyu' (in Chinese pinyin) riddles to explore the underlying neural mechanism of insight. A Chinese 'chengyu' riddle may be a phrase, or a saying, and its answer is a