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Research Report

How perceptual processes help to generate new meaning: An EEG study of chunk decomposition in Chinese characters

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ABSTRACT

Chunk decomposition has been regarded as an important process in problem solving that helps problem solvers to generate new solution paths through changing inappropriate problem representations. We studied the neural bases of chunk decomposition in Chinese characters using the electroencephalogram (EEG). Participants decomposed Chinese characters either at the level of radicals or at the level of strokes to generate new target characters with a different meaning. We hypothesized that decomposition at the stroke level would require a more fundamental change in the problem representation that should involve differences in basic visual processing. To test this hypothesis, we compared the alpha rhythm (8–13 Hz) over parietal–occipital regions between the two different conditions. The regrouping of tight chunks (stroke level) exhibited a stronger alpha activation than the regrouping of loose chunks approximately 500 ms prior to response. Thus visual areas were less active during the decomposition of tight chunks. Together with a previous fMRI study the results provide convincing evidence that attenuation of early visual information is required to generate new meaning.

1. Introduction

Problems can be difficult for different reasons. Some problems are difficult because one needs to find the correct solution in a large space of possible solutions. However, problems can also be difficult because problem solvers have a perception or conception of the problem situation that does not allow them to solve the problem or because they conceive of the goal in a way that does not lead to the solution (Ohlsson, 1992; Schooler et al., 1993). Problems of the latter kind have been called insight problems (e.g., Metcalfe, 1986), because the solution appears suddenly in the problem solver's mind, leading to an AHA experience. In fact, in such problems solvers can often not predict whether they will solve a problem even if they are already very close to the solution (Metcalfe, 1986).

Recently, researchers have started to unravel the neural processes underlying the AHA experience (see Bowden et al. (2005) and Luo and Knoblich (2007), for two recent overviews). The results of these studies suggest that it is unlikely that there is a unitary brain process or a unitary brain area that triggers insight in problem solving. Rather, insights (defined as sudden solutions to a problem) seem to occur when unconscious perceptual (Luo et al., 2006) and semantic (Jung-Beeman et al., 2004; Mai et al., 2004) processes lead to a reconfiguration

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or new integration (Luo et al., 2004; Wagner et al., 2004) in the problem solver's representation of the problem that opens up a new solution path (Knoblich et al., 2001).

The aim of the present study was to investigate the neural processes that occur when perceptual processes are involved in reinterpreting a problem and changing its meaning. Previous studies on the role of semantic processes in restructuring found that the 'Aha' feeling response involved the activation of the right hemisphere (Bowden and Jung-Beeman, 2003). Brain imaging result indicated that when problem solvers reported to have had an insight, areas in the parietal–occipital cortex showed stronger alpha activity than when they reported no insight. The increased alpha activity was interpreted as idling or inhibition of cortical areas that serves to protect easily perturbed central processes from bottom-up stimulation (Jung-Beeman et al., 2004). In the present study we asked whether a similar neural process occurs when the problem requires a perceptual regrouping of problem elements in order to be solved.

This can be investigated with tasks that require chunk decomposition (Knoblich et al., 1999; Knoblich et al., 2001). Previous behavioral research demonstrated that some problems are difficult because they require the solver to decompose familiar chunks into their components and to regroup them in a different manner. The "tightness" of such familiar chunks varies depending on what the components of a chunk are. To illustrate the tightness of chunks consider the following two matchstick problems:

a) IV = III + III
b) XI = III + III

The task in these problems is to move only one stick to generate a correct arithmetic statement and the solution to the two above problems is the same: VI = III + III. Knoblich et al. (1999) found that it was more difficult to decompose the tight chunk 'X' into its perceptual components '/' and '\' than to decompose the loose chunk 'IV' into its meaningful components 'I' and 'V'. In contrast to loose chunks where meaningful components are regrouped, the regrouping of a tight chunk requires a decomposition of the chunk into meaningless components before a new meaningful component can be created. Unfortunately, the task domain for the above tasks is not flexible enough to provide a sufficient number of trials required by brain studies (Luo and Knoblich, 2007).

However, Luo et al. (2006) have recently developed a new chunk decomposition task using Chinese characters. Chinese characters are ideal examples for perceptual chunks that implement particular meanings through groupings on different levels (Tan et al., 2001; Tan et al., 2005a,b; Fu et al., 2002). The decomposition of Chinese characters can occur at different levels. Chinese characters are formed by radicals, which in turn, are formed by strokes (Fig. 1). The radicals always carry some phonetic or semantic meaning, and they have independent visual patterns so they can be regarded as chunks themselves. In contrast, strokes are basic perceptual components that do not carry meaning and tightly embedded in the character. Therefore, a Chinese character can be separated into its radicals and the radicals can be separated into strokes. Because radicals are meaningful and strokes are not meaningful it should be easier to decompose a character at the radical level than at the stroke level according to the chunk decomposition hypothesis. As is shown in Fig. 2, the character "旧" is a loose chunk because it is composed of two independent visual components "丨" and "日", just like "I" and "V" in the Roman numeral "IV". This should make chunk decomposition easy. In contrast, the strokes in the character "四" form a holistic visual pattern, or a tight chunk. Accordingly, it should be difficult to decompose "四" into "一" and "匹", just like it was hard to decompose the Roman numeral "X" into "\" and "/".

Luo et al. (2006) performed an event-related fMRI study that compared brain activation for character decomposition at the radical level and at the stroke level. This study showed that the activation in parts of the visual cortex was reduced as chunk decomposition became harder. This result suggests the following mechanism for chunk decomposition: individual features of a chunk are processed in early visual cortex (Uchida et al., 1999). During problem encoding these individual features are automatically grouped together to form a holistic chunk. If the need to decompose a tight chunk arises these individual chunk components need to be rearranged into a different chunk. Accordingly, the representation of these features is suppressed and altered and this explains the inhibition of visual information about chunk's features in occipital brain areas, including the primary visual cortex (Luo et al., 2006).

However, there are also some problems that Luo et al.'s (2006) chunk decomposition study could not answer. First, the chunk decomposition process was induced by an external hint. This highlighted the parts to be moved out (radicals or strokes) from the character chunk in red color. Providing an external hint aimed at catalyzing the participants' solution process after they had failed to solve a puzzle on their own. Although this hint-catalyzing method allowed the accurate recording of neural activity correlated with cognitive insight to a problem that participants had previously regarded as unsolvable within a particular time window, this comes at a cost. It is not certain that the external hints trigger similar processes as internally generated solution attempts. The present study investigated internal restructuring processes relative to the point in time at which participants indicated that they had found the solution.

A second issue with Luo et al.'s (2006) previous study is that the negative BOLD signals in visual cortex may have been caused by a blood stealing effect (Smith et al., 2004). There may have been less blood flow in early visual cortex because more blood was shunted to other areas. Accordingly, it is not fully clear whether the deactivation in visual cortex observed in Luo et al.'s study was really related to changes in the firing patterns and synaptic activity of neurons or not. Therefore, a direct observation of the activity in parietal occipital would benefit to clarify whether the previously observed deactivation in the visual cortex is caused by cognitive processes or a blood stealing effect. Finally, Luo et al.'s (2006) experiment, like all fMRI studies, had low temporal resolution. Although the results suggest that the deactivation of visual cortex makes special contribution to the perceptual restructuring, the exact time course of chunk decomposition remains unclear.