Neural Correlates of Insight Phenomena

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1 Introduction

Difficult problems are sometimes solved in a sudden flash of illumination, a phenomenon referred to as "insight." Recent neuroimaging studies have begun to reveal the neural correlates of the cognitive processes underlying such insight phenomena (Luo and Niki 2003; Jung-Beeman et al. 2004; Luo et al. 2004a, 2006; Mai et al. 2004; Lang et al. 2006). However, researchers have encountered a number of difficulties in applying neuroimaging methods to investigate insight. We will outline these difficulties, define general criteria brain-imaging studies of insight should meet, and then discuss in detail to what extent these criteria have been met in recent attempts to unravel the brain bases of insight.

One main difficulty that is well known from behavioral research is to produce insight phenomena in the laboratory. Even in purely behavioral studies it is hard to be certain whether participants in laboratory settings actually have insights or whether they solve problems in a more stepwise manner. A related problem is the small numbers of problems that are available to study insight (Bowden et al. 2005). In addition, the well-known classical insight problems, such as the nine-dot problem (Scheerer 1963), the two string problem (Maier 1930), and the candle problem (Duncker 1945), greatly vary in their sources of difficulty (Kershaw and Ohlsson 2004). This raises the question whether the data obtained in laboratory research can be generalized. Furthermore, studying how people solve single problems normally does not produce very reliable data. For this reason, recent experimental paradigms addressing the brain bases of insight have adopted so-called mini-insight problems (Bowden et al. 2005). These problems can normally be solved in a short period with or without external help and many exemplars can be created (Luo and Niki 2003; Jung-Beeman et al. 2004).

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However, in addition to picking the right tasks, brain-imaging studies of insight pose a number of other (related) problems. This led us to suggest a number of criteria that would characterize the ideal experimental paradigm for studying the neural correlates of insight with functional MRI (fMRI) or EEG (Luo and Knoblich 2007). We will discuss each of these five criteria in turn:

(1) *Use of problems that elicit restructuring*: Although there is debate about how insight is best characterized, most modern researchers agree with the Gestalt psychologists' point of view that insight involves a restructuring of the problem situation (Duncker 1945; Köhler 1921; Wertheimer 1925, 1959). In order to solve insight problems one needs to detach oneself from one's prior experience with similar problems and to treat the problem in a novel and efficient way (Davidson 2003; Knoblich et al. 1999; Ohlsson 1992; Weisberg 1995). For this reason, any study that claims to investigate the neural correlates of insight should create mental events that essentially contain the feature of restructuring.

(2) *Multiple insight events and accurate onset time*: The neuroimaging study of insight requires that multiple insight events can be elicited within a limited time period. Most event-related fMRI or event-related-potential (ERP) studies require at least ten to 50 trials in each condition. Although it is possible that efficient single trial analysis methods will be reliably established in the future, for now, multiple insight events are a must. A related requirement is that one needs to be able to precisely time-lock the insight events. In event-related fMRI or ERP studies, the researcher needs to know exactly the temporal onset of the critical mental events. One may wonder whether one can avoid this problem using fMRI studies adopting a block design. However, we believe that these designs are not well suited for the study of insight. The reason is that restructurings are usually short-lived moments of exceptional thinking that would only make up a tiny fraction of all mental processes occurring within a block. Thus, it is likely that brain activations reflecting insight will get lost in myriads of other activations when using block designs.

(3) *Hypothesis testing*: The ideal experimental paradigm to study insight should allow one to perform flexible manipulations to test various kinds of research hypotheses. This includes general hypotheses derived from theories as well as hypotheses about the precise function of particular brain areas. For example, during the moment of insight, an old inefficient way of thinking is likely to be replaced by a new and more efficient way of thinking and this replacement implies cognitive conflict. Thus, one could predict that brain areas that mediate the processing of cognitive conflict (e.g., the anterior cingulate cortex, ACC; Botvinick et al. 2001; Carter et al. 2000; MacDonald et al. 2000) should participate in the restructuring. This hypothesis is based on cognitive models of insight and should hold across different studies of insight, regardless of the particular problem used. However, in addition to testing general hypotheses, it is also important to know the exact function of a given region in restructuring. To determine this function is not as simple as it might seem, because insight is a holistic process in which people achieve multiple breakthroughs in one single thought (Kershaw and Ohlsson 2004). A good experimental paradigm for the

study of insight would be flexible enough to enable a number of manipulations to test more specific hypotheses. In the abovementioned example, ACC activation could be related to different functions, such as conflict monitoring (realizing the contradictions between different ways of thinking), error detection (realizing that one's initial thinking was inappropriate), problem success (realizing the crucial step towards the solution), or general attentive control. The above examples illustrate that the ideal experimental paradigm for the study of insight would enable one to conduct precise tests of multiple alternative hypotheses.

(4) *Defining reference states*: An ideal insight paradigm should enable researchers to define suitable reference states. Brain-imaging analysis relies heavily on the contrast between a target state and a reference state (i.e., the baseline). An ideal reference state should be comparable with the target state in every aspect except the one to be examined. Compared with other domains of brain-imaging research, it is relatively difficult to come up with good reference states in studies of insight problem solving, because insight includes a set of highly integrated processes that are released in one moment. This makes insight somewhat incomparable with other analytical modes of thinking.

(5) *Triggers for insight*: Finally, the ideal insight paradigm should allow one to study internally and externally triggered insights. This refers to the fact that problem solvers can achieve restructurings on their own (internal trigger). Alternatively, restructuring can be triggered by solution hints (external trigger). Although many behavioral and neuroimaging experiments addressing insight problem solving are based on the assumption that solution hints trigger similar processes as internally generated solution attempts (Kershaw and Ohlsson 2004; Ormerod et al. 2002; Weisberg and Alba 1981; Luo and Niki 2003), one cannot be sure whether this assumption really holds. Without doubt, the phenomenon of interest is internally generated insight. Triggering insights externally is just a way of creating paradigms that make scientific research on insight tractable. However, there is a conflict between the requirement of ecological validity that dictates one to investigate internally generated insights and the methodological requirement of accurate onset times for target events in event-related fMRI and ERP studies (see point 2). Accurate onset times are more easily obtained for externally triggered insights than for the internally generated ones. Although we can ask participants to indicate the time of their insight (e.g., with a button press), participants' reports may be delayed. Thus, researchers may have to come up with some estimate that allows them to go back several hundred milliseconds to anchor the onset time of the internally generated insight and they can never be sure whether the event timing is correct.

The above list of criteria illustrates that coming up with an adequate experimental setting to study insight is highly challenging. In fact, we are not aware of any single brain study of insight that would meet all of these criteria. However, we think the five criteria are useful as a benchmark against which brain studies of insight can be tested. However, each single study will likely have to make compromises. There is no general rule as where to cut back. This will depend on the particular question addressed by a study and the particular methods employed (Luo and Knoblich 2007).

Before we discuss how recent studies addressing the brain processes underlying insight meet the abovementioned criterion, we would like to emphasize our belief that insight can only be understood if we conceptualize it as a cluster of different processes working together. In our view, insight is not a single process. Rather, it is a collection of different mental processes. Some of these processes may occur in many different insight tasks (e.g., detecting that there is a conflict). Others may be less general and may only be needed for particular types of insight tasks. For instance, perceptual processes may only be involved in tasks where the solution crucially depends on a spatial restructuring of problem elements.

Thus, studying insight is different from studying basic cognitive processes. Take episodic memory as an example for such a basic process. We know that a particular set of brain mechanisms, including the key function of associating or binding different mental events, subserve the formation and retrieval of episodic memory, regardless of whether the contents of the memory are words, pictures, voices, or emotional responses. However, for higher cognitive processes such as thinking and reasoning, the situation is more complicated. Recent neuroimaging studies reveal that in seemingly identical syllogistic reasoning tasks, the content-based (concrete) reasoning and the abstract reasoning (which lacked semantic content) activated distinct neural networks (Goel et al. 2000).

The diversity of brain processes involved is even larger for insight. Although restructuring is believed to be the main component of insight, previous research suggests that there are different types of restructuring. Restructuring can involve a perceptual reinterpretation of the problem (Ohlsson 1992), directing attention to the critical problem elements (Knoblich et al. 2001, 2005; Grant and Spivey 2003), a recombination of elements that gives the problem a new meaning (Bowden et al. 2005; Davidson et al. 1995), or a change in the goal of problem solving (Ohlsson 1992). Therefore, when looking at different paradigms for insight study, we may not ask if these studies investigate the identical cognitive process or which study is the only correct one that truly addressed the target topic. Rather, we may keep in mind that different paradigms may be related to different types of restructuring and all of them belong to the category of insight, and the correct question we should ask is which type of restructuring is examined in a given study. In this chapter, we will discuss four different experimental paradigms that have been used to address the brain processes underlying insight: The first paradigm (Luo and Niki 2003; Mai et al. 2004; Luo et al. 2004a) used ambiguous riddles and puzzles to study insights that result from a reinterpretation of meaning. The second paradigm used items from the Remote Associates Test (RAT) to address how one can create meaningful links between seemingly unrelated items (Jung-Beeman et al. 2004; Kounios et al. 2006). The third paradigm addressed perceptual contributions to insight, in particular, the decomposition of perceptual chunks (Luo et al. 2006). Finally, a fourth paradigm addressed the question of whether insight occurs in repetitive tasks that provide opportunities for effective changes in strategy (Haider and Rose 2007; Lang et al. 2006).

2 Reinterpretation of Meaning in Riddles and Puzzles

One attempt to study the brain bases of insight used riddles and puzzles that can reliably produce insight-like experiences within a relatively short time. One important factor in this approach is to select riddles for which participants understand the exposition of the problem well but for which they cannot produce a solution. During scanning, an external trigger (the solution) is provided to catalyze the riddle-solving process. This allows one to produce insight-like experiences at particular points in time and to record neural activity correlated with these experiences in particular time windows. Of course, this implies the troubling assumption that an external solution hint triggers similar processes as an internally generated insight.

Three types of riddles or puzzles have been used in brain studies on insight so far. The first type were riddles such as "The thing that can move heavy logs, but cannot move a small nail" (the answer is "river"; Luo and Niki 2003) that require a solution word in order to resolve a seeming contradiction. The second type were ambiguous sentences that require a reinterpretation of dominant word meaning in order to be understood, such as "The haystack was important because the cloth ripped" that referred to the situation of "parachute jumping" (Mai et al. 2004; Luo et al. 2004a). The third type were the so-called cerebral gymnastics puzzles such as "Unfortunately, Smith and his son met a traffic accident; Smith died on the spot and the boy was badly hurt. They brought the boy to the hospital for he needed an immediate operation. However, the surgeon saw the son and said: 'Sorry, I cannot perform an operation to my own son.' How could this occur?" (The answer is "The surgeon is boy's mother.") (Luo et al. 2004b).

Solving these riddles or puzzles crucially involved the process of restructuring because the solutions almost certainly differ from the solver's initial way of conceptualizing the problem. For instance, in the "river" riddle, to come up with the correct answer "river" one has to ignore object weight that is the focus of the problem description, and restructure the question in a way that allows a reformulation of the problem in terms of density of objects. Similarly, in the "parachute jumping" riddle and the "mother surgeon" puzzle, one has to change one's initial understanding that "cloth" refers to something wearable and a "surgeon" must be a man.

There are huge number of such kinds of riddles and puzzles, so it is not difficult to get sufficient items that are suitable with regard to cognitive components, complexity, length, and other features. However, the riddles and puzzles that create a need for restructuring are usually difficult. People cannot solve many of these on their own without external help in a short period. Some items will take the thinker several seconds to solve, whereas others will take minutes, hours, or even days. So, it is impossible in a neuroimaging study to simply provide participants with the puzzles and to wait for the moment of insight. In order to obtain a sufficient number of events of insight problem solving in a limited time period one needs to provide solution hints to trigger successful problem solving. The fact that insight phenomena investigated by the riddle-solving approach are externally triggered is a disadvantage, but the advantage of this approach it that it produces multiple insight events with a very accurate onset time. Moreover, using different kinds of reference states, we can flexibly use this approach to test various hypotheses on insight.

For example, Weisberg (1995) proposed differentiating between superficial and structural changes in a problem representation. A structural change allows new types of solution to be proposed or in some ways constrains the solution that can be proposed, whereas a superficial change has neither of those effects. To examine the neural network involved in the superficial and structural changes, we asked participants to work on a list of "cerebral gymnastics" puzzles (e.g., the abovementioned mother surgeon puzzle; Luo et al., unpublished results). For each participant a set of puzzles was selected so that he/she understood the puzzles very well but could not solve them. Then, during fMRI scanning, we showed each participant the selected puzzles, followed by three kinds of hints: restructuring hints that should result in a deep structural change of problem representation (for the mother surgeon example, the hint presented is "the surgeon has long hair"); unrelated hints that should induce superficial changes in the problem representation but should not lead to restructuring (e.g., "the surgeon has blue eyes"); and repetition hints that restated the original problem description (e.g., "the surgeon was unable to do the operation").

Participants are likely to obtain the correct solution with the help of repetition hints, but the unrelated hints and restructuring hints usually do not trigger a correct solution. In the experimental session, participants were shown three to five hints after attempting to solve each puzzle on their own. The hints were presented one by one in a randomized sequence, and participants were not given any information in advance on which hint was the real efficient one. This ensured that participants paid equal attention to each hint. The event-related fMRI results showed that the different types of hints led to activation of different neural networks. Most importantly, in the restructuring hints condition we observed activation in bilateral superior frontal gyrus (BA 8/6), medial frontal gyrus (BA 8) extending to cingulate cortex, and bilateral posterior middle temporal gyrus, suggesting that this network is involved in restructuring. In contrast, the more superficial change in the problem representation induced in the unrelated hints condition was associated with activation in anterior parts of bilateral superior and middle temporal gyrus (BA 22/21), together with frontal activation in superior/medial superior frontal gyrus (BA 8) and in left middle frontal gyrus (BA 9).

Another example for how the riddle-solving approach can be used to test specific hypotheses is the investigation on the role of ACC in insight. Although activation of ACC and of medial prefrontal cortex were consistently observed in brain studies of insight (Luo and Niki 2003; Mai et al. 2004; Luo et al. 2004a,b, 2006), its exact function was unclear. Two observations further revealed the dynamic feature of ACC activation during insight. First, ERP study indicated that ACC activation was present as early as 380 ms after the onset of a restructuring cue (Mai et al. 2004). Given that it takes around 2,000 ms for the participants to fully understand the meaning of a solution cue, the problems were still not completely solved when ACC became active. Second, we examined how ACC activation changed across a long session of solving riddles and found ACC activity decreased as the session progressed (Luo et al. 2004a). This suggests that ACC becomes functionally less important when problem solvers start to develop general strategies to deal with a particular type of task, even when most tasks require restructuring.

On the basis of these observations, together with the prevalent theory that suggested ACC implements an early warning system (Botvinick et al. 2001) and is engaged when top-down control fails to block the automatic processing of information out of the central processing mechanism, we predicted (1) that the activation of ACC was insensitive to the difficulty of solution/hint understanding and (2) that the activation of ACC was sensitive to the variation of implicit regularity underlying the structure of puzzles.

To check whether or not ACC was responsive to the difficulty of solution/hint understanding, we compared the solution cues that were judged by the problem solver as "understandable, but fairly hard" and those judged as "obvious to understand" (Luo et al. 2004a). The results showed that ACC was equally involved in both types of cues. In contrast to ACC, lateral prefrontal cortex was observed to be responsive to the difficulty of processing of the solution cue; this area showed higher activation when the solution cue was difficult to process. A further ERP study by Qiu et al. (2006, 2007) compared three kinds of solutions: hints that confirmed participants' initial correct thinking; hints that led to a successful restructuring that allowed participants to solve insight problems they could not solve on their own; and hints that did not lead to a successful solution of insight problems. The results showed that, relative to the confirming hint, the other two hints both elicited more negative ERP deflections between 250 and 400 ms. The dipole analysis localized the generator of the difference waves within ACC. This observation implies that the activation of ACC is unrelated to the finding of the correct solution. As long as the hint suggests a new solution path the solvers had not thought about so far, ACC activation increases.

In a further recent study (Luo et al., unpublished results), we compared four types of solution cues: correct solutions to comprehensible questions (type 1, e.g., "air-conditioned" to "The office was cool because the windows were closed."); correct solutions to ambiguous questions (type 2, e.g., "parachute" to "The haystack was important because the cloth ripped."), fake solutions to comprehensible questions (type 3, e.g., "knife" to "The dirty clothes were cleaned, because the rotation had been done." – the solution is washing machine); and fake solutions to fake questions (type 4, e.g., "raining" to "The teacher changed a classroom, because the surface is round."). The results of 16 participants showed that, relative to correct solutions to comprehensible questions (type 1), not only the true solutions to ambiguous questions (type 2), but also the fake solutions to comprehensible questions or fake questions (type 3 or type 4) evoked lateral and medial prefrontal cortex activation (the territory of activation extended into ACC). This result implied that these areas participated in the processing of an unexpected solution, regardless of whether the solution finally turned out to be reasonable or not.

To examine whether or not the activation of ACC was sensitive to the variation of regularity underlying the structure of puzzles, we compared the neural correlates of solving two kinds of puzzles (Luo et al. 2004b). In condition A, the subjects solved a list of puzzles that were constructed by different principles; whereas in condition B, all of the puzzles were constructed by the same principle. Thus, it was possible for the solvers to allocate some task-general strategy to solve the puzzles in condition B. For condition A, this was relatively difficult to achieve. The results showed that, relative to the resting baseline, both conditions evoked comparable activities in the left lateral prefrontal cortex, but that condition A evoked more ACC activity than condition B. This confirms that ACC is sensitive to the deep structure of problems, showing stronger activation when this structure is variable, and does not permit one to develop a top-down strategy.

3 Integrating Meaning in the Remote Associates Test

The RAT approach to investigate the brain basis of insight was developed by Jung-Beeman et al. (2004) and Kounios et al. (2006, 2008). In most studies, participants were presented with three words such as *french, car, shoe* or *boot, summer, ground* and were required to generate a solution word that can form a compound word or two-word phrase with each of the three words (the solution words are *horn* and *camp* in the abovementioned two examples).

According to Bowden et al. (2005), although RAT items are not as complex as classic insight problems, they exhibit three properties of insight problems:

(1) Solvers are often misdirected in their solution efforts. For example, in the problem *pine, crab, sauce* the word *pine* might direct the initial search of memory toward items such as *pine tree* or *pine cone* rather than *pineapple*.
(2) Solvers often cannot report how they overcame an impasse ("It just popped into my head.").
(3) Solvers sometimes have an "Aha!" experience when they achieve solutions.

Bowden et al. (2005) used the subjective Aha! experience as the defining criterion for whether an insight had occurred. If an item was solved with the Aha! experience ("You may not be sure how you came up with the answer, but are relatively confident that it is correct without having to check it."), then this item was classified as an insight item; all other items were classified as noninsight items.

The items were successfully preselected so that the ratio of trials for successful insight solving and noninsight solving was comparable in most of the participants (56 vs. 41%), and so were the response times (10.25 vs. 11.28 s) (Jung-Beeman et al. 2004). An advantage of the RAT approach is that problems can be solved in a short time without any external help, and that, therefore, it can be used to investigate internally generated insight. As mentioned earlier, however, it is relatively difficult to determine the onset time of an internally generated insight because participants' reports are usually delayed ones and the researcher has to go back several hundreds milliseconds to anchor the onset time of the internally generated insight. Jung-Beeman et al. (2004) in their fMRI study chose a point about 2 s prior to each button press with which participants indicated they had found the solution as the onset of insight or noninsight events. Their parallel EEG study showed there was a burst of gamma-band activity associated with the insight solutions (but not noninsight solutions) beginning approximately 0.3 s before the button-press solution response at the anterior right temporal electrodes.

The RAT approach has been used to test the neurological model of insight of Bowden et al. (2005). This model proposes that insight problem solving originates from the integration of problem elements that are nondominant for the individual. The core assumption is that weak semantic activation in the right hemisphere that is not consciously available is crucial for this integration and for obtaining insights in general. Using visual-hemifield presentation and subliminal priming, Bowden and Jung-Beeman (1998) found that participants showed greater priming effects (i.e., faster responses to solution target words than to unrelated target words) for solution words presented to the right hemisphere through the left visual field than to the left hemisphere through the right visual field. Consistent with these results, an fMRI study revealed increased activation in the right anterior superior temporal gyrus for insight relative to noninsight solving of RAT, and scalp EEG recordings revealed a sudden burst of high-frequency (gamma-band) neural activity in the same region just before insight (Jung-Beeman et al. 2004).

4 Altering Meaning Through Perceptual Reorganization: Chunk Decomposition

Chunk decomposition refers to the decomposition of familiar patterns into their component elements so that they can be regrouped in another meaningful manner. Such a regrouping is required in some insight problems because during problem encoding problem elements become automatically grouped into familiar chunks. For instance, it is easy to decompose the loose perceptual chunk that forms the word "BIT" into its component letters and remove one letter (i.e., the "B") away to form the word "IT," whereas it is much more difficult to transform "BIT" to form the word "PIT" by removing the lower part of the letter "B." Knoblich et al. (1999) proposed that the need to decompose perceptual chunks is an important difficulty source characterizing many insight problems.

In their study, problem solvers were given a false matchsticks arithmetic statement, written using roman numerals (e.g., I, II, and IV), operations (+ and −) and an equal sign (=) and were required to transform the statement into a true equation by moving only one stick from one position to another. It was easy for the participants to transform the equation VI = VII + I to VII = VI + I, whereas it was difficult for them to transform the equation XI = III + III to VI = III + III, because the chunk tightness of "X" is much more higher than that of "VII." Unfortunately, the matchsticks arithmetic task is not appropriate for neuroimaging studies, because the task domain does not provide a large enough variety of problems.

To overcome this problem, we developed a new chunk decomposition task using Chinese characters as materials (Luo et al. 2006). As a logographic language system, Chinese characters are ideal examples of perceptual chunks (Perfetti et al. 2005; Tan et al. 2001, 2005a,b; Fu et al. 2002; Siok et al. 2004). Chinese characters

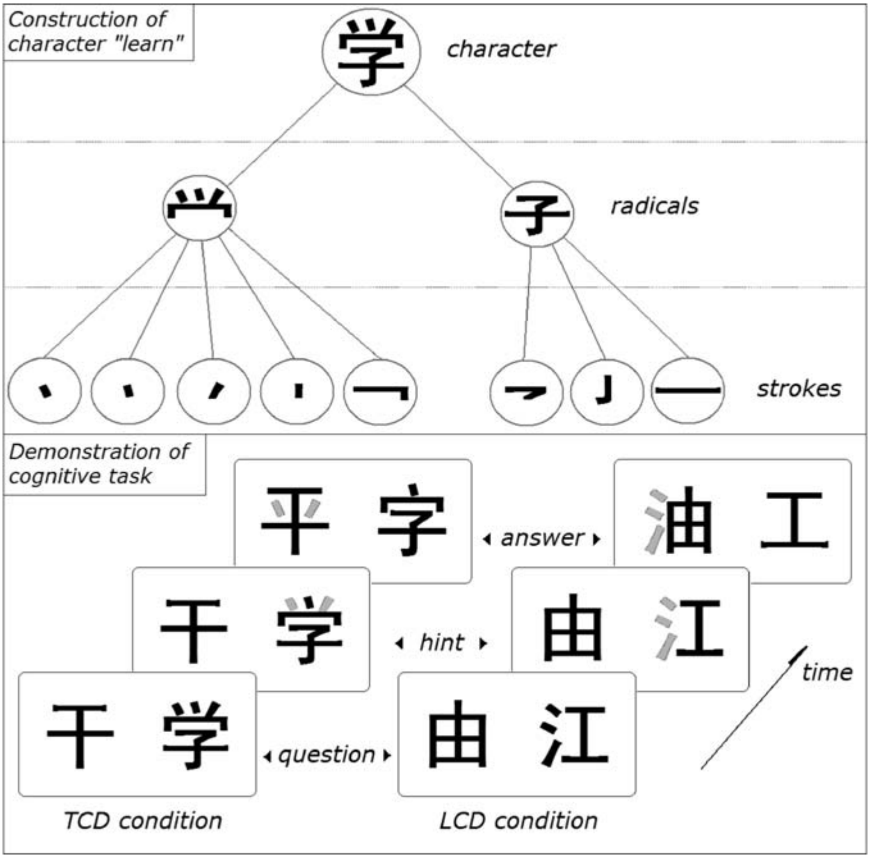

Fig. 1 Illustration of construction of Chinese character and chunk decomposition task using Chinese characters. *TCD* tight chunk decomposition, *LCD* loose chunk decomposition

are composed of radicals, which in turn are composed of strokes (Fig. 1). Strokes are the simplest and most basic components of a Chinese character. Usually, strokes do not carry meaning in themselves. In contrast, radicals convey information about the meaning and pronunciation of the character. The radicals usually consist of several strokes and can be thought of as subchunks of a character. Thus, radicals are meaningful chunks, whereas strokes are not meaningful in isolation. According to the chunk decomposition hypothesis it should be much easier to separate a character by its radicals than to separate a character by its strokes, because particular strokes are tightly embedded in a perceptual chunk. In other words, the decomposition of characters into strokes should require a specific process that breaks the tight bond among strokes created by the perceptual chunk.

Participants were given tasks that always involved two valid characters, one on the left side of the display and the other on the right. They were asked remove a part of the right character and add it to the left character so that two new valid characters resulted after the move (Fig. 1). There were two conditions. In the tight chunk decomposition (TCD) condition, the problem could be solved only if participants decomposed the character into separate strokes and moved some of the resulting strokes from the right to the left character. In the loose chunk decomposition (LCD) condition, it was sufficient to decompose the character into separate radicals and to move one of the resulting radicals to the left character. Pilot studies showed that problems requiring the decomposition of a tight chunk were much more difficult than problems requiring the decomposition of a loose chunk. The former were often not solved or took several minutes to solve (frequently accompanying "Aha!" reaction), whereas the latter were usually solved within 2–4 s.

The large differences in problem difficulty make it generally difficult to address the brain processes related to problem solving. Therefore, we provided a hint to catalyze the puzzle-solving process, after the problem solvers had failed to solve the puzzle by themselves and had got into an impasse state. During the hint stage, the to-be-moved part of the right-side character was highlighted in red (Fig. 1). This method enabled us to produce a large enough number of chunk decomposition trials in the TCD condition. Contrasting the processing of the hint between the TCD condition and the LCD condition (where participants had already solved the problem on their own and the presentation of the hint just confirmed their previous solution), we were able to identify the brain areas contributing to chunk decomposition.

Our results showed that the early visual cortex was less active in the TCD condition than in the LCD condition, whereas the higher visual cortex was more active in the TCD condition. These results suggest the following interpretation. The individual features/components contained in a chunk are processed in the early visual cortex (Uchida et al. 1999). During normal chunk perception, the processing of these individual features/components will be automatically grouped to form a holistic chunk. However, chunk decomposition requires that these individual chunk features be rearranged into a different perceptual chunk. Thus, processing of individual features is suppressed as reflected by the inhibition in early visual cortex, while the grouping is rearranged as reflected by the higher activation in higher visual cortex. A more general implication of these results is that perceptual processes seem to be involved in at least some forms of restructuring. In this sense the results seem to support the Gestalt psychologists' original claim that restructuring shares similarities with perceptual reinterpretation.

5 Insight and Strategy Change

Research by Haider and Rose (2007) suggests that insight cannot only occur when people try to solve a particular difficult problem. They claim that restructuring can also occur when people find new strategies to deal with routine problems. In order to address this hypothesis they use standard implicit learning tasks, such as the serial reaction time task (Nissen and Bullemer 1987) or the number reduction task (NRT; Haider and Frensch 2005). Haider and Rose (2007) start with the observation that

10–70% of the participants are able to verbally describe the deterministic regularity built into the task when asked to do so in a postexperimental interview. Although researchers in the field of implicit learning are not interested in these participants and exclude them from further data analyses, Haider and colleagues point out that the process of spontaneously arising explicit knowledge during an incidental learning situation strongly resembles the process of finding the solution for an insight problem. Accordingly, they used modified implicit learning tasks as a paradigm to study insight (Wagner et al. 2004; Lang et al. 2006).

In the standard version of the NRT, participants receive a string of six digits one by one on a computer screen. The string always consists of the same three digits, "1," "4," and "9" arranged in a different order for each trial (e.g., "9 9 9 1 4 1"). The participants' task is to compute the final response for the entire string. To do so they are instructed to process the digit string pairwise from left to right by applying one of two rules (Fig. 2). The first rule states that two identical digits in a pair yield the same digit (same-rule). The second rule states that the result for two nonidentical digits is the remaining third digit (different-rule). Participants are explicitly told these two rules. In the example "9 9 9 1 4 1," participants first receive the first two digits of the digit string "9 9." These two digits are identical, and therefore comply with the same-rule, resulting in "9." After the response "9" has been entered, the third digit "9" occurs on the screen. Participants compare their response with the new digit "9." Again the same-rule generates "9." Then the fourth digit "1" is presented. Participants compare their last response "9" with the fourth digit. According to the different-rule, this comparison yields "4." The fifth digit "4" again yields "4" (same-rule) and the sixth digit "1" yields "9" (different-rule). In sum, the stimulus string "9 9 9 1 4 1" yields the response string "9 9 4 4 9" according to the two rules. Participants are especially instructed to confirm the last result "9" as the final result of the entire string by pressing the "Enter" key.

Presented digit	Participants' response	Applied rules
9		
9	9	Same-rule
9	9	Same-rule
1	4	Different-rule
4	4	Same-rule
1	9	Different-rule

Fig. 2 Demonstration of the number reduction task

In the experiments of Haider and colleagues people calculate the solutions for a large number of such digit strings and, of course, get faster as they go. In this respect the task is like any other implicit learning task. However, there is one crucial difference. The response string has a regular structure so that for any given stimulus sequence, the fourth response is always identical to the third response, and the fifth response is always identical to the second response. Put differently, participants' responses 4 and 5 are a mirror image of responses 2 and 3. However, this regularity within response strings is neither communicated to participants, nor are they asked to search for regularity hidden in the task. The results show that participants who have discovered the task regularity are able to speed up substantially. This big improvement results in discontinuities in the learning curve that cannot be explained by the principle of gradual learning. Some participants start to enter responses 4 and 5 in very quick succession because these can be directly derived from responses 3 and 2, ignoring the stimulus. Others skip responses 3, 4, and 5 altogether because responses 2 and 5 are always identical.

The sudden change in strategy in this incidental learning situation that goes hand in hand with explicit knowledge about the regularity in the response structure meets the condition of restructuring very well. The reason is the strategy change, which enables the participants to deal with this (tedious) task in an unexpectedly simple way, brought about when the participants' initial understanding of the nature of the cognitive task is fundamentally changed. In addition, participants achieve the strategy change on their own without any external trigger. Thus, this approach is appropriate for investigating internally generated restructurings. In contrast to the previously discussed paradigms that focus on the moment of insight, the implicit learning approach allows one to more closely look at the genesis of a single "insight" (strategy change). As a consequence this approach is not appropriate to study which areas of the brain are active at the moment of insight. However, it enables one to dynamically track brain activations that prepare a strategy change, that is, the transition from getting more effective without knowing why to explicitly using more effective strategies.

6 Conclusion

Although the cognitive processes underlying insight have been studied for many years (Sternberg and Davidson 1995), the study of the brain basis of insight and restructuring has only recently begun. In this chapter, we reviewed four types of experimental approaches that have been used so far. Although the validity of these experimental designs seems not good enough (yet) to fully demystify the well-known legends of important discoveries (like Archimedes's solving of the golden crown problem or Kekulé's discovery of the ring structure of benzene), these paradigms do address different important aspects of insight. Thus, we are confident that future brain research will help us to understand why some of our best ideas seem not to result from hard work but seem to come to us out of the blue.

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