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Abstract

This study aims to develop a Japanese version of the remote associates test required to decompose semantic chunks for use not only in behavioral studies but also in brain researches. Further, this study attempted to reveal the relationship between the process of solving insight problems and brain activities. Results of the behavioral data show that the solution time was significantly longer in the chunked than in the non-chunked condition. The imaging data identified the following brain activities. First, the right and left cingulate gyri, related to conflict monitoring, were more activated during the process of searching for a target in the chunked than in the non-chunked condition. Second, the left posterior cingulate gyrus was more activated when the participants could find a target by overcoming constraints as semantic chunks related to emotional process.

Keywords: fMRI; insight; remote associates test; chunk decomposition.

Introduction

Reproductive thinking is the application of previously acquired knowledge and efficiently solves typical problems. However, in insight problems, such reproductive thinking forms mental sets, preventing solution and leading problem solvers to an impasse (Dominowski & Dallob, 1995; Ohlsson, 1992; Smith, 1995). Thus, problem solving is accomplished by overcoming such reproductive thinking. Problem solvers often have an "aha!" experience when solving insight problems (Davidson, 1995; Metcalfe, 1986a,b; Metcalfe & Wiebe, 1987). Such characteristics of insight process, including an impasse and sudden attainment with the emotional experience, have been studied through psychological experiments. Moreover, in recent years, many studies revealed the mechanisms between characteristic insight processes and brain functions (Dietrich & Kanso, 2010).

Insight problems generally used for related researches (e.g., nine dots problem, candle problem, triangle of coins) require at least several minutes to solve them. Further, once they are solved, they cannot be reused as problem solving tasks among the same participants. In contrast, when employing brain imaging studies, verbal problems including anagram tasks, riddles, and the remote associates test (RAT) have been used. This is owing to the fact that these studies require not only the use of problems that can be solved within several tens of seconds but also can be used repeatedly for the same participants. However, almost all tasks used in brain imaging studies are premised on using English speaking participants. Therefore, insight tasks based on a wide variety of languages are required to promote the development of research in this field.

Thus, our research purpose is to develop a Japanese version of the RAT for use in brain research using examples from the standard RAT task widely used in current neuroscience studies. In addition to developing the task, we tried to reveal the relationship between brain activities and the process of insight problem solving, including both processes of an impasse and evoking an emotional experience when solutions are found.

Japanese RAT Required to Decompose Semantic Chunks

Insight problem solving characterized by an impasse and the suddenness of solution with emotional experience represents a radical representation change. Problem solvers have to reconstruct their erroneous mental representations constructed at an early stage of insight problem solving, whereas they can take step-by-step analytic approaches in non-insight problems. Such representation change in the insight process has been interpreted based on the theories such as the transition of problem spaces and the chunk decomposition by conducting psychological experiments (Kaplan & Simon, 1990; Knoblich et al., 1999; Ohlsson, 1992). Familiarity with a class of objects and events leads to the creation of patterns as chunks that capture recurring constellations of features or components. Preserving the mental efforts by using chunked knowledge contributes to efficient problem solving. However, if the available chunk does not work in a way that is helpful vis-à-vis finding a solution, it might work to prevent solving the problem. Moreover, once it is constructed, it is difficult to decimate and an impasse might result (Knoblich et al., 1999; Ohlsson, 1992).

RAT consists of sets of three words drawn from a mutually remote associate cluster. Problem solvers are required to find a fourth word which could serve as a specific kind of associative connective link between these disparate words (Mednick, 1962). One example might be a set of three problem words: "arm," "coal," "peach." The answer to the example is the word "pit." The answer word generate three words or phrases, "armpit," "coalpit," and "peach pit," being connected with each problem word. However, constraints have not been controlled in the RAT used in cognitive neuroscience research (e.g., Bowden & Jung-Beeman, 2003). Thus, in previous studies using RAT-like problems, the definition of obtaining insight was based on finding a solution, solution time, and/or self-reported sudden, unforeseen flash of illumination. Alternatively, this study developed a Japanese RAT with controllable constraints based on chunk decomposition. The existence of chunks, which prevents finding association between problem words, would lead problem solvers to search for a target within incorrect problem spaces and arrive at an impasse. They might also get an "aha!" experience when an impasse based on chunks is resolved, and subsequently the problems are solved.

Hypotheses

As demonstrated in previous neuroscience studies, conflicts attributed to constraints preventing problem solving were associated with activity in the anterior cingulate cortex (ACC) (Aziz-Zadeh et al., 2009; Kounios & Jung-Beeman, 2009; Luo et al., 2004; Qiu et al., 2008). Moreover, in the process of insight problem solving, a solution seems to arise suddenly, accompanied by an emotional experience generally known as an "aha!" experience (Csikszentmihalyi & Sawyer, 1995; Davidson, 1995; Metcalfe, 1986a,b; Metcalfe & Wiebe, 1987). It is known that such emotional experiences in insight problem solving are associated with activity in the posterior cingulated cortex (PCC) (Qiu et al., 2008).

In this study, which involves the use of an fMRI while conducting psychological experiments, we propose the following two hypotheses regarding brain activities both when struggling with an insight problem and then solving it.

Hypothesis 1 When problem solvers fail to find a solution, the existence of chunks are associated with activity in the ACC because in preventing solutions conflicts arise.

Hypothesis 2 When problem solvers find a solution, the solutions are associated with activity in the PCC related to emotional experience, in addition to activation in the ACC.

Task

Figure 1 illustrates the structure of a Japanese RAT that requires decomposition of semantic chunk. Stimuli of the task are presented on a computer screen containing six kanji characters. The purpose of the task was to find a common kanji character (target) with which each of the three kanji characters presented on the upper row (problem characters) could form a meaningful word. However, distracters presented below the problem characters prevent the finding of the target because the distracters could form meaningful words with each of the problem characters. Therefore, participants are required to decompose the semantic chunks between the problem characters and distracters to find the target through remote association. Moreover, the task can control the existence of the semantic chunks between problem characters and

Figure 1: An Example of a Japanese RAT (required semantic chunk decomposition)

distracters by changing distracters that cannot be connected with the problem words. The kanji characters used in this experiment were known to the participants, who were native Japanese speakers.

Neuroactivity

Methods

Participants Eighteen healthy, right-handed undergraduate students (aged 19 to 36 years) participated in this experiment. The participants were native Japanese speakers and their handedness was assessed by a modified Oldfield questionnaire (Oldfield, 2004). The participants provided written informed consent in accordance with the research ethics committee guidelines of Nagoya University's Research Institute of Environmental Medicine.

Design Participants were given a practice session using two examples outside of the MRI scanner. Following the practice session, they engaged in 60 problems while in the scanner. The problems consisted of 30 chunked and 30 non-chunked problems. The chunked and non-chunked problems were counter-balanced between participants (the chunked problems presented to the half of the participants were treated as non-chunked problem for the other half, and vice versa). The sequences of problems were also randomized throughout the experimental session.

Figure 2 illustrates the experimental sequence. Each problem was presented for 30 seconds to the participants. The resting interval between trials was 12 seconds. They were required to press the left button assigned to the index finger of their right hand when finding a target immediately. After pressing the left button, the target, the answer to the problem was presented. Participants were required to press the left button when their answer corresponded to the target, whereas they were required to press the right button assigned to their middle finger when their answers were incorrect. Taking a 10 minute break outside of the scanner, this sequence was repeated 60 times. The experiment consisted of two fMRI runs.

Imaging Data Acquisition All scanning whole-brain images were acquired by using a gradient echo planar image acquisition on a 3T MRI Scanner (Siemens Verio, Siemens Healthcare, Erlangen, Germany). The functional imaging pa-

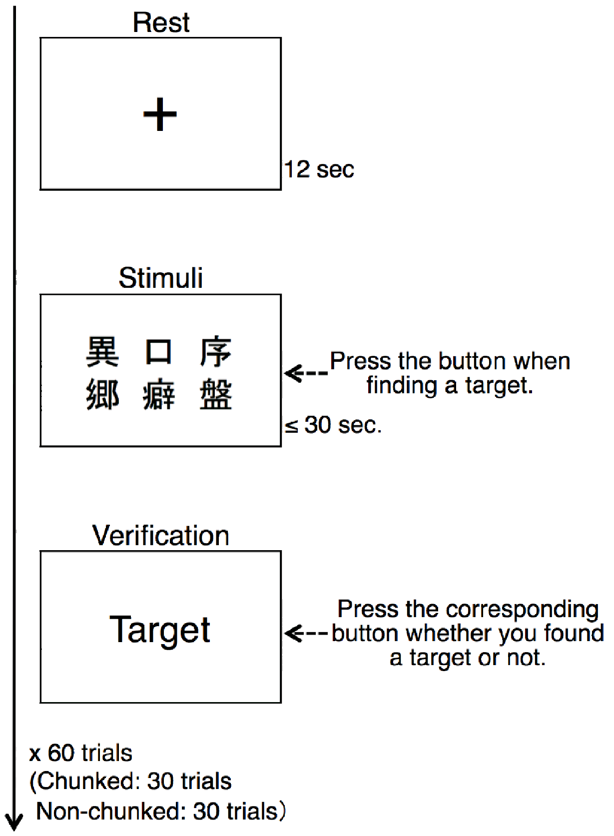

Figure 2: Experimental sequence

rameters were TR = 2.5s, TE = 30ms, FA = 70°, VoF = 20cm × 20cm, and 39 slices. To avoid head movement, the participants wore a neck brace and were asked not to talk or move during MRI scanning. High-resolution anatomical images (T1) were also acquired by using gradient echo planar image acquisition. We acquired T1 images (TR = 2.5s, TE = 2.48ms, FA = 8°) with 192 sagittal slices, each being 1mm in thickness. Motion correction was also performed in a standard realign process in SPM8.

Imaging Data Analysis The image data were analyzed using SPM8. Each participants's imaging data was individually preprocessed (realignment, slice time adjustment, coregistration, normalization, smoothing) and the spatially preprocessed data was then estimated to establish a random effects model. Statistical threshold was set at $p < .001$, uncorrelated with an extended threshold of 10 contiguous voxels.

Results

Behavioral Results Results of the solution rates within both 15 and 30 seconds, as shown in Figure 3 (the error bars indicate the standard error). A *t*-test showed a significant difference between the two conditions within 15 seconds ($t(17) = 2.95,\ \ p < .01$), whereas within 30 seconds no significant difference was observed ($t(17) = 1.90$, n.s.).

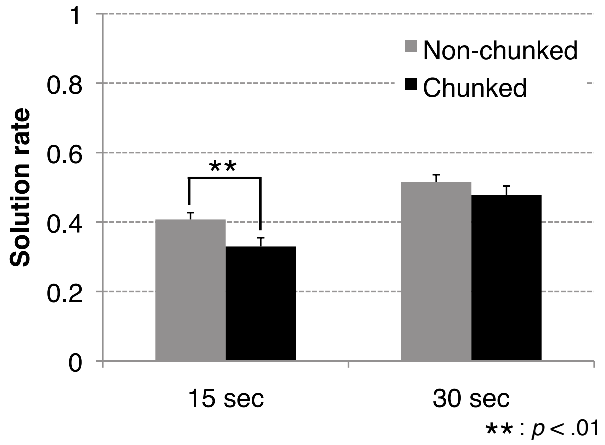

Figure 3: Solution rate within both 15 and 30 seconds

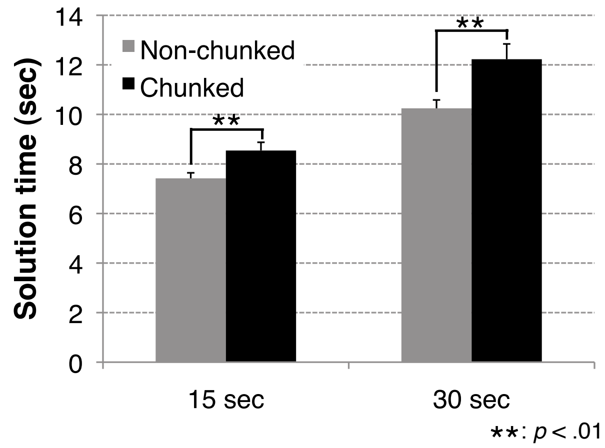

Figure 4: Solution time within both 15 and 30 seconds

Next, we compared the average solution time when the participants could find a target between two conditions (Figure 4). The *t*-tests within both 15 and 30 seconds showed significant differences between the two conditions (15 sec: $t(17) = -3.67,\ \ p < .01$; 30 sec: $t(17) = -3.39,\ \ p < .01$).

These results demonstrate that the search for the targets was prevented more in the chunked than in the non-chunked condition owing to the existence of the semantic chunks.

Imaging Results Next, we compared the brain activations in both the chunked and non-chunked conditions. In the following analyses, we focused on two different trials: participants failed to find a target (failed trials) and participants could find a target (correct trials). In the correct trials, imaging data were analyzed for the entire 30 seconds while the

Table 1: Brain areas that were more activated during searching for a target in the chunked condition when compared with those in the non-chunked condition in the failed trials

Cluster	Voxel			MNI coordinates			Region	BA
k_E	T	Z	p_{uncorr}	x	y	z		
166	5.42	4.02	0.000	-3	5	46	Left cingulate gyrus	32
	5.26	3.95	0.000	0	2	49	Left medial frontal gyrus	32
	5.17	3.91	0.000	0	-13	55	Left medial frontal gyrus	6
	4.52	3.58	0.000	15	-7	46	Right cingulate gyrus	24
	4.41	3.51	0.000	-6	-19	49	Left paracentral lobule	31
	4.37	3.49	0.000	6	-7	49	Right cingulate gyrus	24
	4.01	3.29	0.001	-12	-7	49	Left cingulate gyrus	24
	3.88	3.21	0.001	6	5	37	Right cingulate gyrus	24
13	5.19	3.92	0.000	15	-10	-2	Right medial globus pallidus	
	4.48	3.56	0.000	-6	38	-14	Left medial frontal gyrus	11

$N = 17$; $p < .001$ (uncorrected w/ extended threshold of 10 contiguous voxels)

Table 2: Brain area that was more activated until a target was found in the chunked condition when compared with that in the non-chunked condition in the correct trials

Voxel			MNI coordinates			Region	BA
T	Z	p_{uncorr}	x	y	z		
4.23	3.41	0.000	-15	-58	10	Left posterior cingulate	30

$N = 17$; $p < .001$ (uncorrected w/ extended threshold of 10 contiguous voxels)

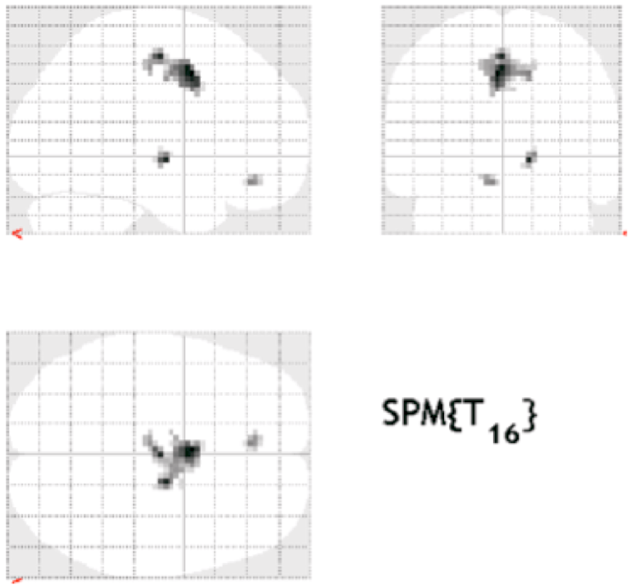

Figure 5: Brain areas that were more activated during searching for a target in the chunked condition when compared with those in the non-chunked condition in the failed trials

stimuli were presented. In the failed trials, imaging data were analyzed until finding a target.

Chunked > Non-chunked (failed trials)

In the failed trials, this contrast examined the brain areas that were more activated during searching for a target in the chunked condition when compared with those in the non-chunked condition. Several peaks of activation were found, including the right and left cingulate gyri (right BA 24, left BA 24, left BA 32), the left medial frontal gyrus (left BA 32, left BA 11, left BA 6), and the left paracentral lobule (left BA 31) (Table 1). Figure 5 depicts these areas of activation.

Chunked > Non-chunked (correct trials)

In the correct trials, this contrast examined the brain areas that were more activated until a target was found in the chunked condition when compared with those in the non-chunked condition. It was confirmed that the left posterior cingulate (left BA 30) was activated (Table 2). Figure 6 depicts this area of activation.

Non-chunked > Chunked (failed trials)

This contrast revealed no voxels that were significantly more active in the non-chunked than in the chunked condition when the participants could not find targets.

Non-chunked > Chunked (correct trials)

Same as when the participants could not find a target, this contrast revealed no voxels that were significantly more activated in the non-chunked than in the chunked condition when participants found a target.

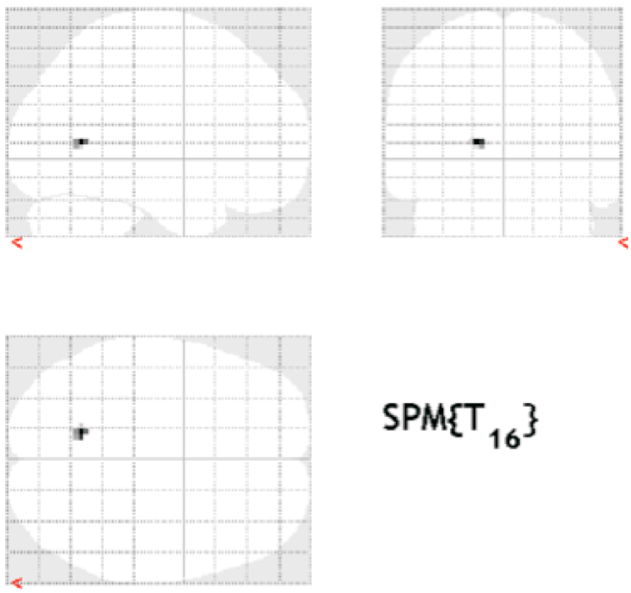

Figure 6: Brain area that was more activated until a target was found in the chunked condition when compared with that in the non-chunked condition in the correct trials

Discussion

Results of the behavioral data show that the solution time was significantly longer in the chunked than in the non-chunked condition. Knoblich et al. (1999) constructed an insight task with chunks having different tightness, and displayed that the problem solving performance while solving problems with a tight chunk declined from those with a loose chunk. Our behavioral results suggest that the semantic chunks, introduced by the Japanese RAT, prevent finding solutions, which is consistent with the related work.

In the following, we will discuss in detail more activated brain areas in the chunked than in the non-chunked condition, both when the participants could find a target and when they could not.

Failed Trials The right and left cingulate gyri (right BA 24, left BA 24, left BA 32) were more activated during the process of searching for a target in the chunked than in the non-chunked condition. The cingulate gyrus has been widely believed to be related to insight problem solving (Aziz-Zadeh et al., 2009; Kounios & Jung-Beeman, 2009; Luo et al., 2004; Qiu et al., 2008). For example, Aziz-Zadeh et al. (2009) reported that the ACC is more activated in insight solutions when compared with the search solution while solving anagram tasks. Luo et al. (2004) also showed that relative to the non-"aha" event, the "aha" event was associated with activities in ACC. Botvinick et al. (1999) revealed that the ACC might also be linked with conflict monitoring.

Previous results indicated that the ACC is related to preliminary process to evade impasse in which problem solvers get fixated with incorrect problem spaces as conflict monitoring (Dietrich & Kanso, 2010). The activation on the cingulate gyrus in our research appears to monitor the process among the competing, an option aroused by semantic chunks and alternatives. This result supposes hypothesis 1.

Correct trials In addition, when the participants could find a target, the left posterior cingulate gyrus (left BA 30) was more activated until they found a target in the chunked than in the non-chunked condition. Some researches indicated that the retrosplenial cortex, in particular BA 30 and the neighboring posterior cingulate cortex including BA 23 and BA 31 might be associated with the cognitive processing of emotions (Cato et al., 2004; Maddock, 1999; Maddock & Buonocore, 1997). For example, Cato et al. (2004) showed that activation uniquely associated with word generation to categories with positive or negative versus neutral emotional connotation occurred in the retrosplenial cortex.

One of the essential characteristics of insight problem solving is an impressive and surprising emotional experience upon sudden and discontinuous solution. For example, Csikszentmihalyi & Sawyer (1995) conducted detailed interviews with creative individuals who have made a creative contribution to the natural sciences, social sciences, arts and humanities, or business/politics, and were generally older than 60 years. The interviewees reported their exciting experiences when receiving insight. Such emotional experience in insight problem solving is known as the "aha!" experience (Davidson, 1995; Metcalfe, 1986a,b; Metcalfe & Wiebe, 1987). (Qiu et al., 2008) also discussed in their ERP study that the "aha!" feeling might increasingly activate the PCC when Chinese logogriphs were completed than when they were not solved. In our experiment, the activation of the left posterior cingulate (left BA 30) when the participants found a target suggests that when finding a target, overcoming constraints correlates more with emotional process than without such a constraint.

However, the activation of the cingulate cortex when the participants could not find a target was not confirmed when they could. This result was likely to be caused by the semantic chunks as constraints preventing to solve problems might be decomposed in the early stage of the insight problem solving process when they found a target. Therefore, the activation of the cingulate cortex was not confirmed. These results are partially supported by our hypothesis 2.

Conclusion

This study aims to develop a Japanese version of the RAT required to decompose semantic chunks for use not only in behavioral studies but also in brain researches. Moreover, we tried to reveal the relationship between the brain activity and both process of an impasse and evoking an emotional experience when solutions are found.

Results of the behavioral analysis showed that the Japanese RAT constructed in our research worked well as expected. The imaging data identified the following brain activities. First, the right and left cingulate gyri related to conflict monitoring were increasingly activated during the process of searching for a target in the chunked than in the non-chunked condition. Second, the left posterior cingulate gyrus was more activated when the participants could find a target by overcoming constraints as semantic chunks related to emotional process. These are important initial steps to be taken in the study of the relationship between insight problem solving process and brain activities using the Japanese version of the RAT.

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