Thinking Patterns, Brain Activity and Strategy Choice

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Abstract: In this study we analyzed the relationship between thinking patterns, behavior and associated brain activity. Subjects completed a self-report assessing whether they could voluntarily stop thinking or not, and were then divided into two groups: those with the ability to stop thinking and those without. We measured subjects’ brain activity using magnetoencephalography while giving them a series of tasks intended to encourage or discourage spontaneous thinking. Our findings revealed differences between the two groups in terms of which portions of the brain were active during the two types of task. A second questionnaire confirmed a relationship between the ability to stop thinking and strategy choices in a dilemma game. We found that subjects without the ability to stop thinking had a tendency to choose cooperative behavior.

1. Introduction
Economics has attached importance to studies focusing on the allocation of resources in societies made up of heterogeneous agents [1]. It is also a common practice in economics to group these agents into risk lover and risk averter categories according to their attitudes toward risks [2]. Game theory has studied the interdependent relationships among heterogeneous agents, for instance with regard to conflict of interest and cooperation, as well as these agents’ decision-making strategies [3],[4],[5].

Neuroeconomics has recently received growing attention and has been the subject of an increasing number of articles in scientific journals. This field explores the relationship between economic behavior and associated brain activity and aims to elucidate the ways in which people make decisions. In this sense, it may be described as the synthesis of brain science research and experimental and behavioral economics. More precisely, experiments in this field of study involve performing brain activity scans using fMRI, PET, MEG, etc. These functional neuroimaging devices and measurements of the time courses of different brain events provide us with records of the activities of neurons and neurotransmitters as people engage in economic decision making such as choosing between risks and rewards and interacting with other people. Meta-analyses of functional imaging studies have shown that the prefrontal cortex of the brain operates on choices to be faced in the distant future, while the limbic system works on choices to be encountered in the near future [6]. Thus, these types of study may be regarded as an effective approach to understanding individuals’ attitudes and behaviors.

Despite the fact that researchers have recognized the importance of focusing expressly on individual differences, the scope of studies on economic behaviors of heterogeneous agents has been limited. Indeed, there has been almost no research on how differences in individual thinking patterns affect decision making. We therefore aim to study how the way in which one thinks affects his or her behavior.

Accordingly, this study focuses on the reasons for differences in decision making among heterogeneous agents as well as differences in brain activity involved in the decision-making process. Few studies of this sort have been performed thus far, but we believe that this approach to investigating thinking traits and decision making will lay the foundation for elucidating the way in
which consumers and investors decide on economic issues and future choices. In our study, we divided our subjects into two types based on their thinking patterns: Group A consisted of individuals who claimed they could stop themselves from thinking, whereas Group B consisted of individuals who reported that they could not. Section 2 examines the survey results in light of recent findings concerning the relationship between the ability to stop thinking and brain activity.

Section 3 reports the results of a questionnaire that was administered to examine the relationship between thinking patterns and decision making in a dilemma game. In this game, subjects were asked to choose between cooperative and non-cooperative behavior. The survey results showed that subjects without the ability to stop thinking had a tendency to choose cooperative behavior.

2. Thinking patterns – can one stop thinking or not?

2.1. Materials and methods

Data from 14 healthy subjects (age: 17–34) were analyzed. We recruited participants from among our colleagues and their families.

2.1.1. Experimental paradigm. We previously conducted studies to measure the brain activity underlying human thought [7], [8], [9]. To do this, we prepared tasks that would direct subjects to “think” or “stop thinking,” and then measured these subjects’ brain activities using magnetoencephalography (MEG).

In these experiments, subjects lay down in a neuroimaging device and were assigned tasks designed to encourage or discourage thinking. For instance, subjects were asked to recall images or engage in linguistic activity, and were also requested to stop thinking for 20 sec. In order to verify our previous results, we used the same tasks in this study.

Our test protocol asked subjects to picture images of (1) Kiyomizu Temple and (2) the Diet Building, (3) to recall the Chinese zodiac, (4) to recall a conversation they had earlier in the day, and (5) and (6) to not think at all (Table 1). We asked subjects to go through this series of tasks twice.

Tasks 1 and 2 stimulated subjects’ thinking by encouraging their recall of a familiar place, while Tasks 3 and 4 tested their ability to recall words. The final tasks (5 and 6) were intended to examine subjects’ capability to suspend their thinking. Our goal was to determine whether we could detect differences in brain activity between Tasks 1−4 and Tasks 5−6.

We used a 100-msec beep tone as the signal for the subjects to advance to the next task. During the tests, brain activity was monitored as changes in the spontaneous brain magnetic field.

Data acquisition began at the first beep, though the data we actually used began 500 msec afterward. Thus, we sampled only the brain’s thinking activity, not the auditory-evoked response elicited by the beep. Measurements were taken every 50 msec.

Table 1. “Thinking” Tasks during MEG

| Task | What to do: |
|------|-------------|
| 1    | Picture Kiyomizu Temple |
| 2    | Picture the Diet Building |
| 3    | Think of the name of each animal in the Chinese Zodiac |
| 4    | Recall a conversation you had earlier today |
Sit still, relax, and try not to think at all.

5 Rest (eyes open) and do not think at all

6 Rest (eyes open) and do not think at all

2.1.2. Data acquisition. Assessing higher cognitive functions such as thought in terms of brain activity can only be accomplished using methods that measure intracerebral bloodstream or cranial nerve currents. When frequency discrimination is required, as in this experiment, measurement of cranial nerve currents is more suitable, as it allows for accurate detection of time series signals.

In order to assess higher functions such as cognition, we employed MEG, which can detect ultra-low intensity cerebral magnetic fields at the femto-Tesla (fT) level [10]. Actual cerebral measurements are fairly unstable and are liable to include various artifacts. In particular, the measurement of spontaneous cerebral activity such as thought is extremely difficult. To confirm that the electric current dipoles were measured accurately as brain activity, we analyzed the relatively large waveform (an alpha wave) that appeared in the occipital region and then superimposed the electric current dipoles that had been obtained. As a result, we could confirm that the electric current dipoles corresponded to the pattern of the sulci in the brain, which seems to represent brain activity.

2.1.3. Data analysis. Our experiment used a 64-channel whole head-type superconducting quantum interference device (SQUID) made by CTF System Inc., an axial type of neuromagnetometer.

Let $B=(B_x, B_y, B_z)$ be the magnetic field vector. $B_z$ is the element of $B$ along the z-axis that is perpendicular to the head surface. The 64-sensor neuromagnetometer can measure the first derivative of $B_z$ (an element in the z-axis of the magnetic field) through individual SQUID sensors installed on the helmet, or it can calculate $\left(\frac{\partial B_z}{\partial z}\right)_i$ based on the data from SQUID sensor $i$. Its dimension is $fT/cm(Hz)^{1/2}$, and relative to the 64 parts of the head surface, $i$ varies from 1 to 64. A total of 64 pieces of magnetic field data is recorded at a particular interval and $\left(\frac{\partial B_z}{\partial z}\right)_i(i=1, 2, \cdots, 64)$ are calculated.

**Single dipole method**

Based on Biot–Savart’s law, the Single Dipole Method is a common technique used to estimate a signal source of magnetic field distribution that emerges on the surface of the head. This technique was based on the hypothesis that the brain magnetic field does not distort. We therefore surmised that the first-order approximation of reading values would not be affected because the influence of the distribution current, the so-called “volume current,” could be balanced out by the spatial symmetry. The equivalent current dipole, displayed using three-dimensional vectors, should subsequently emerge from the brain [11].

Current dipoles can be estimated by solving the inverse problem of the magnetic field distribution as projected on the head surface. For the estimation procedures, we first drew a contour map from a magnetic field in reference to the measured values of $\left(\frac{\partial B_z}{\partial z}\right)_i$. This contour map allowed us to estimate the signal source by following the least-squares estimation method. Using this method, the signal source could be defined as in the middle position of the extreme and the sink identified on the magnetic field. The estimated signal source should therefore have been closer to the actual value. We applied the Single Dipole Method only when goodness of fit was sufficiently high to guarantee accuracy in the least-squares estimation.

2.2 Results

We examined the differences in brain activity between subjects who were able to stop thinking and those who were not. The frontal region was activated during thinking tasks whereas occipital activity was noticeable during tasks that required cessation of thinking, though individual differences were also observed (see Fig. 1). In Subject A, frontal region activity diminished slightly but was nonetheless present after transitioning to the stop-thinking tasks. This suggests the possibility that the subject continued thinking when presented with the stop-thinking tasks. On the other hand, Subject O demonstrated a clear concentration of activity in the occipital region during the stop-thinking task, suggesting that the subject did actually stop thinking when asked to do so.
These results indicate that individual differences in thinking methods correspond to the degree with which localized functions are activated in different brain regions. The same pattern of function localization is generally observed among individuals, but the specific way these functions are activated is considered to underlie individual differences in thinking methods.

3. Game theory – decision making

3.1. Material and method

In an attempt to analyze the relationship between thinking patterns and decision making, a questionnaire (Table 2) was administered to 51 undergraduate and graduate students at the Faculty of Economics, Hitotsubashi University.

We prepared a dichotomous-choice, single-answer questionnaire for each task. The students were asked to perform various tasks and were classified into groups accordingly. We requested that participants try not to think, and afterwards asked them if they were able to avoid doing so. Thirty-two participants (62.7%) replied that they were able to stop thinking, while 19 (37.3%) responded that they were not.

We evaluated whether there were any behavioral differences between these two groups by assessing strategy choices in a dilemma game as described in the next section.

Table 2. Self-report on thinking.

|                          | stopped | not certain | could not stop |
|--------------------------|---------|-------------|----------------|
| Please close your eyes and try not to think at all. Use the scale below to evaluate whether or not you were able to stop thinking. | 1       | 0            | -1             |

3.2. Experiment – Dilemma game

A dilemma game requires two individuals to choose between two behaviors without consulting each other. An individual’s profit (or benefit) depends not only on his or her behavior but also on the other person’s behavior, as shown in the following profit matrix.

In Table 3, the two strategy combinations, (A, B) and (B, A), represent the Nash equilibria. If both subjects opt for Strategy A, they both gain a profit of 100. If only one of them opts for Strategy B, the individual who chooses Strategy B gains the game’s maximum profit of 200, while the individual who continues with Strategy A receives a profit of only 80. If both individuals opt for Strategy B with the
aim of gaining the maximum profit of 200, both are awarded the game’s minimum profit of 50. In view of this relationship between behavior and profit, Strategy A can be interpreted as representing “cooperative behavior,” and Strategy B as representing “non-cooperative behavior.” This dilemma game has two Nash equilibria, so players cannot easily decide which strategy to opt for. The dilemma is whether to cooperate with the other player or not. These features of the exercise allowed us to evaluate how each player’s strategy choice was related to his or her thinking traits, especially his or her ability or inability to stop thinking. The game also required each player to assess the other player’s strategy in making decisions, and we included an item in our questionnaire to examine the accuracy with which each individual was able to do so.

**Table 3. Dilemma game.**

|       | Other player |       |
|-------|--------------|-------|
|       | A            | B     |
| You   | 100, 100     | 80, 200 |
|       | 200, 80      | 50, 50 |

3.3. Results and discussion

We administered the questionnaire shown in Table 3 regarding the strategies employed in the dilemma game in order to verify the relationship between the ability to stop thinking and decision making in a social environment where decision making is required. The subjects of this questionnaire were the same Hitotsubashi University students who had studied game theory and had participated in Experiment 1. However, two participants were removed from the sample because they did not answer this experiment’s questionnaire.

The results are shown in Figs. 2 and 3. Figure 2 demonstrates that in the group with the ability to stop thinking, 16 players, or 51.6%, estimated that their opponent would opt for Strategy A, while 15, or 48.4%, predicted that the other player would choose Strategy B. In the group without the ability to stop thinking, nine players anticipated that their opponent would choose Strategy A, while nine predicted a choice of Strategy B, thus also yielding a ratio of 50%. Figure 3 shows that each player’s own strategy also differed depending on his or her ability to stop thinking. Sixteen (51.6%) members of the group with the ability to stop thinking chose the non-cooperative Strategy B, whereas only four individuals (22.2%) without the ability to stop thinking did so.

We compared the ratio differences between groups and found no significant difference between the groups with and without the ability to stop thinking in terms of the ability to predict the opposing player’s behavior ($z = -0.10888$, $q = 1.644854$, $P = 0.5433512$, $p < .05$). On the contrary, there was a significant difference between groups in players’ own strategy choices ($z = 2.107952$, $q = 1.644854$, $P = 0.021798$, $p < .05$). These results demonstrated that those who were unable to stop thinking were more likely to choose cooperative behavior.
4. Conclusion

Why is behavior influenced by an individual's ability to stop thinking?

Those who are unable to stop thinking are apt to devote a significant amount of thought to anticipating future events; they are circumspect and are indecisive worriers. An individual who thinks all the time might have difficulty in letting his or her worries go. In contrast, those who are able to stop thinking do not suffer from the same degree of anticipatory worry or persist in their worries. They are decisive and able to concentrate well.

We measured brain activity using a full head-type MEG device with 64 sensors. Active sites were concentrated more heavily in the central frontal region than in the occipital region while thinking was carried out, while the reverse was true while thinking was stopped.

We administered a questionnaire designed to compare subjects who were able to stop thinking with those who were not in terms of strategy choices in a dilemma game. Those without the ability to stop thinking had a tendency to opt for cooperative behavior. A dilemma game requires quick and determined decision making. It is also possible that the degree of one's ability to stop thinking is related to decisiveness.

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