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Our Choice of Cognitive Frames is Affected by the Frames of Others in Financial Economy: A Neuroeconomic Study Using Brain Decoding Methods

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Abstract

Earlier studies have investigated how cognitive frames distort decision making in experiments where various types of cognitive frames are given to subjects in controlled experimental tasks. There is, however, no economic study that has intensively analyzed the free and voluntary choice of cognitive frames. We present a brain decoding study to investigate how subjects are affected in their free choice of cognitive frames by the frames of others in experimental financial markets. Examining the neural data obtained from the experiment, the neuroeconomic method enabled us to directly investigate the subjects' mental states to judge what type of cognitive frame was used. The results of our experiment were more complicated and context-sensitive than we hypothesized before our experiment. In the complicated results, however, we found new empirical evidence that showed a strong effect on the choice of cognitive frame that arose from a warning of reason telling the subjects that obstinate and biased frames could make them unaware and could completely deprive them of alternative understandings of the world. Brain decoding studies can be used to develop new research possibilities for the framing effects of free choice of cognitive frames in interpersonal relationships in financial markets.

1. Introduction

In criticizing the mainstream microeconomic theory, which is based on the hypothesis of rational economic agents, behavioral economics has studied framing effects on the decision making process that result from different types of cognitive frames held by bounded rational agents. Tversky - Kahneman (1981) developed the fictitious problem of Asian disease which has been widely tested as a famous example of the framing effect. In this example, the same basic message was explained using two different frames, the gain frame and the loss frame. Subjects were told that the Asian disease was expected to kill 600 people, and they were shown two options for combatting the disease. In the gain frame, the first option was explained as a risk-free option that would save 200 people and the second option was explained as a risk-seeking (or gamble) option that had a 1/3 probability of saving 600 people but a 2/3 probability of saving nobody. In the loss frame, the same options were explained differently. In first option, the subjects were told that 400 people would die, and the second option was explained as a 1/3 probability that nobody would die and a 2/3 probability that 600 people would die. Subjects were apt to inconsistently choose different options in different frames. In the gain frame, many subjects chose the risk-free option, while in the loss frame they chose the risk-seeking option.

As reviewed by Kuhberger (1998) and Levin et al. (1998), the results obtained in the Asian disease case have been confirmed by many studies, but framing effects in other types of problems have not always been obtained. Therefore, as Kuhberger (1998), Levin et al. (1998), and Stanovich-West (1998, 2000) claimed, an essential question is to investigate under what conditions framing effects are likely to be obtained.

Using the neuroeconomic method of brain decoding, our study advances the previous studies. Earlier studies have investigated the problem of how strong framing effects are observed on decision-making when a certain type of cognitive frame is given to subjects in experimental tasks. In everyday life, however, we freely choose cognitive frames to understand our world. Why hasn't a new type of experiment been created to investigate the unsolved problem of how agents freely choose a cognitive frame in our economy? A more exciting and open question is one of what circumstances affect our free choice of cognitive frames. In this study, we focused on analysis of how the choice of cognitive frames is affected by the cognitive frames of others. This is a first step in the study of the interrelationships among different cognitive frames and in the study of cognitive frame convergence or divergence in our dynamic economy.

Brain decoding is a brain-reading method used to interpret data regarding neural activities. It enables us to directly judge which cognitive frame has been used by the subject to understand the world. In our study, we used functional near-infrared spectroscopy (fNIRS) to obtain neural data and a statistical algorithm to interpret those data. We classified the neural activity data into several groups, representing different mental states, to predict which cognitive frames were used by the subjects to understand the world. The introduction of this method extends the analytical possibilities of framing effects to include the analysis of realistic cases in which people can freely choose their cognitive frames but are affected by the cognitive frames of others as in our complicated world.

We predicted the results of the experiment before executing our experiment. We hypothesized that convergence between the cognitive frames would come from the interpersonal relationships between agents having different types of frames. For example, talking with others who had positive frames would make the subject more likely to choose positive frames, and the adverse case of loss frames would also be affected in the same manner. However, through the experiment, we found more complicated and context-sensitive implications of how the choices of cognitive frames are affected by the frames of others. In this manuscript, we explain the methods and the results of the experiment to show the effectiveness of using the new neuroeconomic approach of brain decoding to innovatively extend the analysis of framing effects.

2. Methods

Brain decoding is a brain-reading method used to interpret data regarding neural activity. In this study, we used a statistical algorithm for the interpretation of fNIRS data to classify the neural activity into two groups with different mental states to predict which cognitive frames were used to understand the world of the laboratory market. Our experimental method is explained by the following paragraphs. First, we explain the subjects and the tools used in our brain decoding experiment. Then, we illustrate the experimental tasks executed by the subjects.

2.1 Subjects and Tools for Brain Decoding

Experimental games were played by six healthy right-handed subjects (three males; three females) who were 19 -21 years of age. All of the subjects were sophomores or juniors at our university. While each subject was playing the games, we obtained the necessary brain decoding data 20 different times, giving us enough data to execute brain decoding 120 times. The subjects were not allowed to eat for two hours before playing to provide clear neural reactions to the experimental tasks at hand. Before beginning the experiment, we explained the experimental procedures, the experimental safety, information on data security, and instructions on how to get paid for participation to the subjects. Then, we obtained informed consent from the subjects. Our experimental plans and procedures were endorsed by the Research Ethical Committee of Aoyama-gakuin University, Tokyo, Japan.

As illustrated in Figure 1, we used fNIRS, a simpler and more convenient tool for examining brain activation than the more widely used method of functional magnetic resonance imaging (fMRI). As the use of fNIRS results in only minimal stress to the subjects, we were able to ask the subjects to execute lengthy and complex tasks. We used the Spectratech OEG-SpO2 model (updated from the OEG-16 model, sampling rate 6.10Hz) of fNIRS, based on the modified Beer-

Lambert law, to scan the frontal cortex of the brain.[1] fNIRS uses small, lightweight, 16-channel digital sensors on a headband to obtain event-related fNIRS data through a dynamically changing, high-sensitivity optical signal which reflects how the in vivo hemoglobin combines with oxygen in blood vessels with high or low cortical activation. Our fNIRS method provided three types of event-related neural data: changes in oxyhemoglobin (ΔCoxyHb), changes in de-oxyhemoglobin (ΔCdeoxyHb), and aggregate changes in the two types of hemoglobin (ΔCoxyHb + ΔCdeoxyHb). We selected the changes in oxyhemoglobin to use for brain decoding. Strangman et al. (2002) found a strong correlation between fMRI variables and fNIRS measures, with oxyhemoglobin data providing the strongest correlation. Therefore, using the oxyhemoglobin data, our results of fNIRS brain decoding will correspond to those of fMRI studies. We claim that this method enables us to perform efficient and low-stress experiments in brain decoding.

Figure 1 fNIRS Multi-channel Digital Sensors on a Headband

The locations of the 16-channel digital sensors were fixed by the headband during the experiment. After each subject completed the experiment, the locations of the sensors were measured using a 3D position measuring method with a digital camera (Nikon D5100) and NIRS-SPM software to allow statistical analysis of the fNIRS signals and to confirm that the channels were properly located on the frontal cortex of the brain.[2] For example, Figure 2 illustrates the locations of the sensors in the first subject, as registered to a compatible canonical brain optimized for NIRS analysis. We obtained event-related, high-sensitivity optical signals from these channels.

Figure 2 Locations of the 16 fNIRS Channels in the First Subject, Registered to a Canonical Brain

2.2 Experimental Tasks

We presented the subjects with the tasks to be executed via a computer monitor. We obtained neural data when the subjects chose the cognitive frames they would used to execute the tasks. As Figure 3 illustrates, our experiment was composed of five parts, Games A, B, C1, C2 and C3. Games A and B were preliminary games used to learn the subjects' typical patterns of neural activity in gain and loss cognitive frames. In Game A, the subjects were asked to adopt the gain frame, while in B the subjects were asked to adopt the loss frame. In these preliminary games, the subjects would acclimate to playing the games in the gain and loss cognitive frames. The Neural Network Tool Box, run on MATLAB, enabled us to learn the typical patterns of neural activity for each subject. Games C1, C2 and C3 were the parts of the experiment in which we obtained the neural data that was used to execute brain decoding. In these games, the subjects could freely choose either the gain frame or the loss frame. After obtaining the neural data of the free choices, we used brain decoding to judge which cognitive frames were chosen by the subjects. In the brain decoding method that used the Neural Network Tool Box, the data obtained from Games C1, C2 and C3 were matched to the two typical neural patterns previously identified in Games A and B.

Figure 3 Games Performed by Each Subject in Our Brain Decoding Experiment

As illustrated in Figure 3, there were Intervals T1 (between C1 and C2) and T2 (between C2 and C3) between the games. During these intervals the subjects had conversations with two other agents who had either the same or different cognitive frames as the subjects. These other agents

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[1] This model has previously been employed in scientific studies (Kita et al. (2011).

[2] There were, of course, slight differences in the channel locations among the different subjects. However, the differences in the locations were not large, and we ensured that the channels were properly located on the frontal cortex using the 3D position measuring method. The neural data obtained from the fixed channel locations in each individual experiment suggest that the data can be successfully decoded without inconsistencies.

were employed by our experimental team to talk to the subjects about employment issues after graduation. The first agent used the gain frame during Interval T1, and the second agent used the loss frame during Interval T2. All of the subjects in this experiment were sophomores or juniors. Therefore, they showed keen interest in employment issues for students, regardless of the cognitive frame that the agents were using. Figure 4 shows the instructions presented to the two agents that guided and regulated the contents of their conversation with the subjects. The subjects talked with these agents in both the gain frame and the loss frame, and the subjects' choices of cognitive frames were fully expected to be affected. Our goal was to examine the effects of talking with the agents on the subject's free choice of cognitive frame.

Figure 4 Instructions Presented to the Agents Who Talked to the Subjects Using Either the Gain or the Loss Frames

Games A, B, C1, C2 and C3 were each composed of short tasks. The short tasks were repeated 4 times in each game. The short tasks in C1, C2 and C3 were the parts of the experiment when we obtained the neural data needed to perform brain decoding. During these tasks, the subjects could freely choose either the gain frame or the loss frame when playing the games. In contrast, in Games A and B, the preliminary experiments, the subjects were restricted to using the assigned cognitive frames. This experimental procedure was used to learn the subjects' typical patterns of neural activity in the gain and loss frames.

Figures 5(a) and 5(b) illustrate the short tasks in Games A and B. The screen was switched every 4 seconds. The tasks asked the subjects whether they would buy one unit of a risky stock or a risk-free bond. For simplicity, the problem stated that buying the risky stock would cause the subjects to either gain \$10 or lose \$5, with a 50% probability of either result, while buying the bond would cause no financial gain. The results of the decision were added to (or deducted from) the starting paycheck of \$40. The most lucrative paycheck was \$50 and the least lucrative was \$35. The subjects were informed that the amount of their paycheck for participating in the experiment would be changed by the gains or losses. After each subject finished all of the games, we randomly selected one result to determine the amount of the final paycheck. This provided the subjects with an incentive for playing the games.

As illustrated in Figures 5(a) and 5(b), the first screen of the computer monitor displayed the message "Let's Start." After 4 seconds, the second screen, shown in Figure 5(a), asked the subjects to consider the following problem using the gain frame, while, as shown in Figure 5(b), the subjects were required to consider the problem using the loss frame. The third screen displayed the problems of choosing to buy either the risky stock or the risk-free bond. The displayed problems included guidelines indicating whether the problems should be considered using either the gain frame or the loss frame. The guidelines were presented based on a reference level (or an aspiration level) of the subject's paychecks. Using prospect theory, Kahneman - Tversky (1979, 2000) described how people make decisions using reference-dependent value functions. Our experimental tasks followed the basic idea of Kahneman - Tversky's studies. In our experiment, as shown in the third screen in Figures 5(a) and 5(b), when the reference point level of the paycheck was \$35, the subjects would consider the problem using the gain frame, whereas when the reference level was \$50, the subjects would consider the problem using the loss frame. The next screen, which appeared after 4 seconds, asked "Stock or Bond? Push One of Two Buttons." The subjects were required to push either the first button to buy the risky stock or the second button to buy the risk-free bond. When the subjects pushed a button, the result was immediately shown. The result of buying the stock was uncertain, whereas the result of buying the bond was certain.

Figure 5(a) Short Task Repeatedly Executed in Game A
Figure 5(b) Short Task Repeatedly Executed in Game B

Next, we will explain the short tasks in Games C1, C2 and C3. All of the short tasks in C1, C2 and C3 were identical and were each repeated 4 times. Figure 6 illustrates the content of the tasks. These tasks represent the part of the experiment during which the subjects could freely choose either the gain frame or the loss frame while playing the games.

Figure 6 Short Task Repeatedly Executed in Games C1, C2 and C3

As shown in Figure 6, the first screen displayed the message "Let's Start." Then, the second screen instructed the subjects to use freely either the gain frame or the loss frame while playing the games. The third screen displayed the choice of either buying the risky stock or buying the risk-free bond. The risky stock and the risk-free bond were assumed to have the same probability of gain and loss as previously assumed in games A and B. The problem involved two sets of guidelines, one set for the gain frame and one for the loss frame, which were designed to help the subjects to consider the problem. A reference paycheck level of $35 triggered the guidelines for considering the problem in the gain frame, whereas a reference paycheck level of $50 triggered the guidelines for considering the problem in the loss frame. The fourth screen displayed "Stock or Bond? Push One of Two Buttons," and after the subjects pushed a button, the result was immediately shown.

By comparing the neural data obtained from the experimental tasks in C1, C2 and C3, we examined how the subjects' choices of cognitive frame were affected by talking with other agents who used either the same frames or different frames.

2.3 Random Sampling of Neural Data for Brain Decoding

Using the brain decoding method, we empirically investigated how the subjects actually chose the cognitive frames they used to execute the experimental tasks. For brain decoding, we randomly sampled necessary data from all of the experimental data obtained by fNIRS.

First, to identify the typical neural patterns of the cognitive frames, we randomly sampled 40 pieces of neural data from then 4 repeated tasks in Game A and in Game B. We conducted this random sampling from within a specific period of time within the experimental data: 8 seconds $< t < 12$ seconds from the beginning of each task, i.e., the period after the third screen but before the fourth screen in Figures 5(a) and 5(b). Thus, all of the data used to identify the typical neural patterns were obtained from this specific time period, during which the subjects had considered the choice between the stock and the bond in the gain frame or loss frame but while they were still waiting for the screen to allow them to select their choice. The data obtained during this time period were expected to show the patterns of neural activity used by each subject to play the games.

A second round of random sampling was conducted to obtain the necessary neural data for brain decoding from the tasks in Games C1, C2 and C3. In these games, the subjects freely chose either the gain frame or the loss frame when executing the tasks. We randomly sampled 20 pieces of data from each of Games C1, C2 and C3 for each subject. Six subjects participated in the study, providing neural data for 120 instances of brain decoding for each game. The time period for random sampling was the time after the subjects had been presented the choice between the stock and the bond but before they were allowed to push a button to indicate their decision, i.e., the period after the third screen but before the fourth screen in Figure 6.

2.4 Incentives for Subjects to Play the Experimental Games

To make our experiment effective, we presented an incentive plan to the subjects. The subjects were informed that their paycheck for participating in the experiment would be changed depending on the results of their decisions in Games C1, C2 and C3. After each subject finished all of the games, we randomly selected one result to determine the amount of the final paycheck. As illustrated in Figure 6, the largest paycheck was \$50, and the smallest paycheck was \$35.

The incentive plan was explained before the start of the experiment. We explained the possibility that the two types of cognitive frames, the gain frame and the loss frame, would sometimes cause inconsistent understanding and decision making, for example, one of the frames might encourage the subject to buy the risky asset but the other might not. However, we also told the subjects to freely use either the gain frame or the loss frame to maximize their profits. This explanation made the incentive plan more effective. The subjects became more concerned with the contents of the experimental game and they intensely considered which cognitive frames, the gain frame or the loss frame, would increase chances to maximize their paycheck.

3. Results

Figure 7 illustrates neural images generated by fNIRS that show the typical changes in neural activity at the 16 channels located on the frontal cortex. The images were obtained by calculating the cumulative means of data in the preliminary games A and B. The changes were measured using the standard unit of mMmm. The neural images illustrate three types of event-related neural data: the upper images illustrate changes in oxyhemoglobin (ΔCoxyHb), the middle images illustrate changes in de-oxyhemoglobin (ΔCdeoxyHb), and the lower images illustrate aggregate changes in the two types of hemoglobin (ΔCoxyHb + ΔCdeoxyHb). The left-sides of the three images show the typical changes in neural activity observed in Game A, and the right-sides of the three images show the typical changes in neural activity observed in Game B. As previously explained, following the procedures described by Strangman et al. (2002) to retain the strong correlations between fMRI variables and fNIRS measures, we selected changes in oxyhemoglobin (ΔCoxyHb) for use in brain decoding. By using the Neural Network Tool Box, the event-related data obtained from Games C1, C2 and C3 were matched to the typical neural activity patterns seen in Games A and B, as illustrated in Figure 7, to determine which cognitive frame was used by the subjects.

Figure 7 fNIRS Images of Typical Neural Activity in the Frontal Cortex in Games A and B

Figures 8, 9 and 10 illustrate the results provided by our 120 rounds of brain decoding of games C1, C2 and C3. In these scatter diagrams, each point of neural activity has two types of plausibility, gain and loss. The horizontal axis represents the plausibility of using the gain frame. The vertical axis represents the plausibility of using the loss frame. The plausibility of using each type of cognitive frame is represented by the values of the sigmoid function calculated using the Neural Network Tool Box in MATLAB and imply how the data generated in C1, C2, and C3 successfully match the typical neural patterns previously identified in Games A and B. The points located in the lower right of the diagrams have larger values on the horizontal axis than on the vertical axis and they can be categorized as cases in which the subjects used the gain frame. Conversely, the points located in the upper left of the diagrams can be categorized as cases in which the subjects used the loss frame.

Before our experiment, we hypothesized that the probability of the subject choosing to use the gain frame would increase after conversing with other agents who were using the gain frame, and vice versa. However, the scatter diagrams in Figures 8, 9 and 10 illustrate that the results of the brain decoding were markedly different from our expectation, as illustrated in the following two points.

Figure 8 Scatter Diagram Obtained by Brain Decoding in Game C1
Figure 9 Scatter Diagram Obtained by Brain Decoding in Game C2
Figure 10 Scatter Diagram Obtained by Brain Decoding in Game C3

(1) After talking with an agent using the gain frame, in contrast to our expectations, the changes in the average of the values of the sigmoid function implied that the plausibility of the subject using the gain frame decreased from 0.491849 to 0.401451, whereas the plausibility of using the loss frame increased from 0.288666 to 0.601795. These changes in the average values were statistically significant ($p < 0.1$).
(2) After talking with an agent using the loss frame, the changes in the average of the values of the sigmoid function implied that the plausibility of the subject using the loss frame increased from 0.288666 to 0.525994, whereas the plausibility of using the gain frame decreased from 0.491849 to 0.364318. Theses changes were not different from our prior expectations. However, the changes in the average values were not statistically significant ($p > 0.1$).

Why were the results of the brain decoding different than expected? To investigate these anomalies, we examined the individual subject data in detail. Figures 11 to 16 illustrate the results of our findings. Figures 11, 12 and 13 show scatter diagrams obtained by 40 repetitions of brain decoding in the subjects who always used the gain frame before talking to the other agents, and Figures 14, 15 and 16 show the scatter diagrams obtained by 20 repetitions of brain decoding in the subjects who always used the loss frame before talking to the other agents. The results illustrated in Figures 11 to 16 show statistically significant changes ($p < 0.05$ or $p < 0.1$) in our examination of the individual data. However, the results from the subjects with mixed choices of gain and loss frames before talking to other agents do not show statistically significant changes in the use of cognitive frames ($p > 0.1$). Therefore focusing on Figures 11 to 16, we consider the reasons for the anomalies (1) and (2).

As Figures 11, 12 and 13 illustrate, brain decoding in subjects with a strong tendency to choose the gain frame showed that after talking to an agent who also used the same frame, the plausibility of the subject using the gain frame sharply decreased from 0.982025 to 0.277483, while the plausibility of the subject using the loss frame increased from 0.022598 to 0.894900. The changes were in contrast to our expectations but were statistically significant ($p < 0.05$). These changes were larger than the changes caused after talking to an agent using the loss frame, i.e., a decrease from 0.982025 to 0.411423 in the plausibility of using the gain frame and an increase from 0.022598 to 0.580718 in the plausibility of using the loss frame. When the subjects had a strong tendency to choose the gain frame, talking to an agent using the same type of frame caused large changes in the opposite direction, i.e., decreases in using the gain frame and increases in using the loss frame. These results help to explain anomalies (1) and (2).

Figure 11 Scatter Diagram of Subjects With a Strong Tendency to Use the Gain Frame, Obtained by Brain Decoding, in Game C1
Figure 12 Scatter Diagram of Subjects With a Strong Tendency to Use the Gain Frame, Obtained by Brain Decoding, in Game C2
Figure 13 Scatter Diagram of Subjects With a Strong Tendency to Use the Gain Frame, Obtained by Brain Decoding, in Game C3

Another explanation for the anomalies is obtained from Figures 14 to 16. These figures are scatter diagrams that illustrate the results of brain decoding in the subject that always used the loss frame before talking to other agents. The brain decoding of the subjects with a strong tendency to use the loss frame showed that after talking to other agents using the loss frame, the plausibility of using the loss frame sharply decreased from 0.999850 to 0.249875, while the plausibility of using the gain frame increased from 0.000010 to 0.326115. These changes were also in contrast to our expectations but were statistically significant ($p < 0.05$ and $p < 0.1$). The decrease in the plausibility of using the loss frame (from 0.999850 to 0.249875) was larger than the decrease caused after talking to an agent using the gain frame (from 0.999850 to 0.445005). When the subjects had a strong tendency to choose the loss frame, talking to an agent using the loss frame caused large changes in the opposite direction, i.e., decreased the use of the loss frame. These results also help to explain anomalies (1) and (2).

Figure 14 Scatter Diagram of Subjects With a Strong Tendency to Use the Loss Frame, Obtained by Brain Decoding, in Game C1
Figure 15 Scatter Diagram of Subjects With a Strong Tendency to Use the Loss Frame, Obtained by Brain Decoding, in Game C2
Figure 16 Scatter Diagram of Subjects With a Strong Tendency to Use the Loss Frame, Obtained by Brain Decoding, in Game C3

The above explanations for the anomalies require further analysis as to why the subjects showed non-expected choices of cognitive frames after talking to agents who were using the same type of frames as the subjects. We discuss this question in the following sections.

4. Discussion

Before starting our discussion, we will summarize the main results of our brain decoding experiments.
(A) When choosing cognitive frames, the subjects were affected by talking to agents who were using either the same or a different type of frame. After talking to an agent using the gain frame, the subjects did not always increase their use of the gain frame. They sometimes used the opposite choice of cognitive frame to what was expected, resulting in decreased usage of the gain frame and increased usage of the loss frame. When the subjects talked to an agent using the loss frame, the changes were not statistically significant.
(B) In examining these complicated results, we found strong and statistically significant changes in the use of cognitive frames. First, when subjects had a strong tendency to choose the gain frame, talking to an agent using an identical frame caused large changes in the opposite direction, i.e., decreased usage of the gain frame and increased usage of the loss frame. Second, when subjects had a strong tendency to choose the loss frame, talking to an agent using the loss frame caused large changes in the opposite direction, i.e., decreased use of the loss frame and increased use of the gain frame.

The statistically significant changes explained by (B) are anomalies and major factors that complicate the result of our brain decoding (A). Therefore, in this section, focusing on the result (B), we explore the problem of why talking to an agent using an identical type of cognitive frame caused large changes in the choice of frames in the opposite direction to our expectations.

As explained in the Introduction, economic studies have not yet explored the problem of free and voluntary choice of cognitive frames. Therefore, we have to take instruction from other research fields. In psychology, especially in studies of cognitive therapy, the choice of cognitive frames has been intensively discussed and is known as "reframing." Neuro-Linguistic Programming, as studied by Bandler-Grinder (1982) and Bandler (1985), is a typical example that of a method used to consciously change cognitive frames to understand the world and to make adoptive decisions. The authors showed that humans consciously select frames that will improve our daily lives. However, the necessity of this paradigm comes from the fact that humans fail to choose appropriate cognitive frames, as they are affected by various irrational emotions and feelings. Humans choose cognitive frames not only voluntarily and consciously using reason, but also involuntarily using irrational emotions and feelings.

Considering that there are two ways of choosing cognitive frames, we discuss the reasons for the statistically significant changes explained by (B). First, we consider the case where the subject consciously chose to switch cognitive frames after talking to an agent using the same frame. We can interpret this switch in choice of cognitive frame to be the result of a warning that an obstinate and biased view and frame could make the subject unaware and could completely prevent alternative understandings of the world. The lack of awareness would sharply decrease the opportunity to profit. The subject would notice the warning after talking to the agent and would consciously choose the other type of cognitive frame to avoid the lack of awareness and to restore the possibility of an alternative world view. Therefore, the first interpretation of our results is that the subjects showed strong movements toward balance and equilibration among the different types of cognitive frames. We denote this consideration by Discussion (I). Following Discussion (I), we can justify the result that when subjects had a strong tendency to choose the gain frame, talking to an agent using the gain frame decreased subject's usage of the frame. We can also justify the opposite scenario, where subjects decreased their usage of the loss frame after talking to an agent using the loss frame.

There is, however, another way of considering the switch in cognitive frames. If the subject wanted to examine whether their choice of cognitive frame was appropriate or not, then talking to others using the identical frames would satisfy their desire to justify their belief in the chosen frame. However, talking to others using different types of frames would decrease their belief and would require the subject to reexamine the choice of a different type of frame. In the former case, the subject would increase usage of the previous cognitive frame, while in the latter case the subject would decrease usage of the previous frame. We denote this consideration by Discussion (II). Discussion (II) can be used to illustrate different directions of switches in cognitive frames from those discussed by Discussion (I). If these different directions of change occur simultaneously, they will cancel each other out. Following Discussion (II), we expect that the subject will increase usage of the gain frame after talking to an agent using the same type of gain frame, but, following Discussion (I), we expect that the subject will decrease their use of the gain frame. When we consider cases where the subjects talked to others using the same type of loss frame, the story is the same. Following Discussion (II), we expect that the subject will choose the opposite direction of change from Discussion (I). The mutual cancelation of these opposite changes generally makes the realized results uncertain. As previously explained in the Results section, our results of brain decoding in subjects who did not show any extreme biases in the choice between gain and loss cognitive frames before talking to an agent showed that changes in the choice of cognitive frames were not statistically significant ($p > 0.1$).

The uncertain results expected from Discussions (I) and (II) were absent when the subjects showed a strong bias in their choice of frames. When subjects had always being using only a specific cognitive frame before talking to others using the same type of frame, the marginal effect of Discussion (II) was negligible, and only the effects expected from Discussion (I) influenced the final results. The above-mentioned cancelation between the opposite changes did not exist. These realized results were neither small nor uncertain. As showed in Figures 11 and12, brain decoding of subjects with extreme tendencies to use the gain frame showed that after talking to an agent using the gain frame, the plausibility of the subject using the gain frame sharply decreased from 0.982025 to 0.277483, while the plausibility of the subject using the loss frame increased from 0.022598 to 0.8949. The results of our brain decoding can be justified because of the warning of reason explained by Discussion (I). The justification will also be valid in the cases of subjects who had an extreme tendency to use the loss frame. As shown in Figures 14 and 15, the plausibility of using the loss frame sharply decreased from 0.99985 to 0.249875, while the plausibility of using the gain frame increased from 0 to 0.326115. These results are also explained and justified by Discussion (I).

Next, we discuss the effects of emotion on choice of cognitive frames. Bandler-Grinder (1982) and Bandler (1985) claimed that the ”rapport” (the reliable interpersonal relation) between a patient and a therapist is an essential and necessary condition for successful “reframing”, where the therapist helps the patient to reorganize his or her cognitive frames to more positively feel and understand the world and to achieve goals. If there is not rapport, however, the therapist's advice will not have any effects on patient reframing and, moreover, in some cases, the advice may induce the patient to choose more pessimistic and confused frames. A relationship between a patient and a therapist is built on empathy and mutual understanding of the mind and emotions. As Damasio (1994, 1999, 2003) , Loewenstein et al. (2001) and Slovic et al. (2004) claimed, emotions are not only noises that disturb the function of reason, but they can play a guiding role in our ability to choose an appropriate cognitive frame to enable us to rationally understand our world.

From the point of view of emotion, switching cognitive frames after talking to others may be interpreted to be the results of a lack of fundamental emotional condition in the establishment of rapport between the individuals talking to each other. Generally speaking, we cannot deny the possibility of a lack of rapport between our subjects and the others with whom they conversed. However, in our experiment, there was no room of the possibility of a lack of rapport. All of the subjects participating in the experiment were sophomores or juniors who showed interest in employment issues for university students, and the agents talking to the subjects were seniors at the same university who had already succeeded in obtaining informal offers of employment. The seniors were required by our experimental team to give the subjects valuable comments on employment issues using either the gain frame or the loss frame. We observed that the seniors and the subjects were invested in their conversation. There was little room for a lack of rapport.

Examining two possible mechanisms for switching cognitive frames, the conscious mechanism and the emotional mechanism, we can conclude that the former was the dominant mechanism for switching cognitive frames in our experiment as there was rapport between the subjects and the seniors. In particular, as we explained in Discussion (I), we can interpret the switch in cognitive frame as a result of a warning of reason telling the subject that obstinate and biased frames could make them unaware and completely deprive them of possible and alternative understandings of the world. The subjects seemed to be consciously risk-averse, being afraid of losing chances to earn profits because of their obstinate and biased view and frames.

5. Concluding Remarks

Using an experimental financial game, we demonstrated that the choice of cognitive frame was affected in complicated and context-sensitive ways by others using either identical or different frames. Our hypothesis was that usage of the gain frame (or loss frame) would increase after talking to others using the gain frame (or the loss frame) in the financial game, but our hypothesis was rejected. In the complicated results, however, we found new empirical evidence that showed a strong effect on the choice of cognitive frame that arose from a warning of reason telling the subjects that obstinate and biased frames could make them unaware and could completely deprive them of alternative understandings of the world. For example, when the subjects had a strong tendency to use the gain frame, they sharply decreased their usage of the gain frame and, in contrast, increased their use of the loss frame after talking to others using the gain frame. This result was valid in the opposite scenario. When the subjects had a strong prior tendency to use the loss frame, they decreased their usage of the loss frame after talking to others using the loss frame. The subjects seemed to be risk-averse: being afraid of losing chances to earn profits could arise from their obstinate and biased view and frames.

There is no economic study that has intensively analyzed the free and voluntary choice of cognitive frames. Earlier studies investigated the problem of how strong framing effects were implicated when a certain type of cognitive frame was given to subjects in controlled experimental tasks. In those experiments, the subjects were not permitted to voluntarily choose their cognitive frames. We believe that the existence of the unexplored problem is due to a lack of sufficient analytical tools. Using the neuroeconomic method of brain decoding, we advanced the previous studies. We designed an experiment where subjects were permitted to freely choose their cognitive frames, and we investigated the problem of how the subjects were affected by others in their free choice of frames. Our brain decoding method enabled us to directly investigate the mental states of the subjects by analyzing the patterns of neural activity during the time when they were freely choosing their cognitive frames. We expect further applications of the brain decoding method to open new fields of research on framing effects in economics.

Figure 1 fNIRS Multi-channel Digital Sensors on a Headband

Figure 2 Locations of the 16 fNIRS Channels in the First Subject, Registered to a Canonical Brain

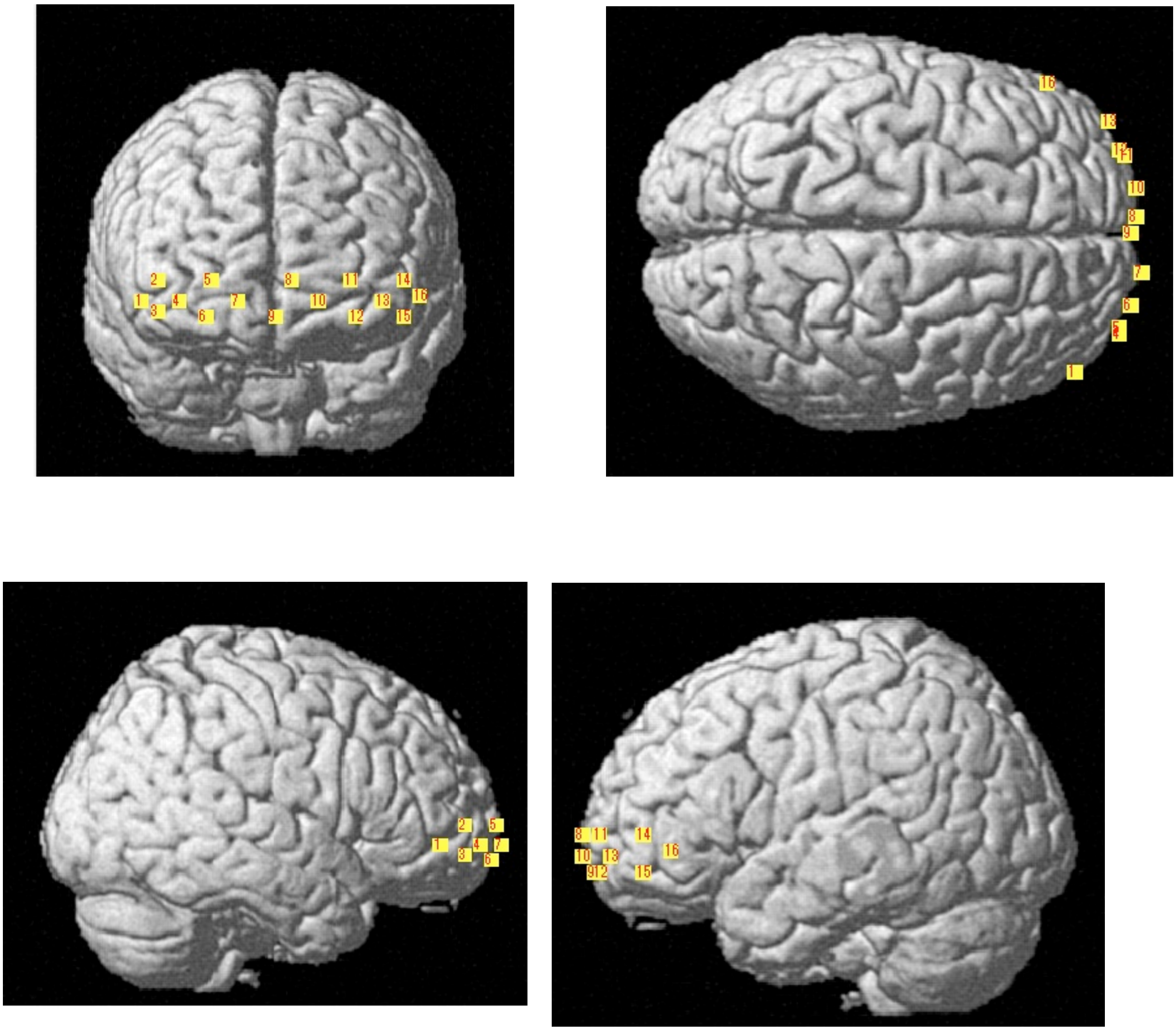


Figure 3 Games Performed by Each Subject in Our Brain Decoding Experiment

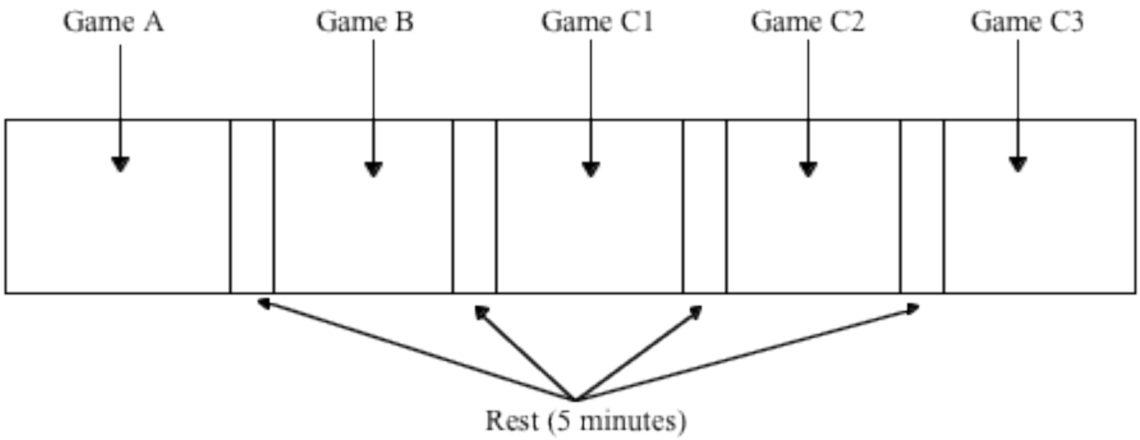


Figure 4 Instructions Presented to the Agents Who Talked to the Subjects Using Either the Gain or the Loss Frames

Instructions for Talking to the Subjects

(In the case of gain frames)

(1) Please talk with the subjects friendly and naturally. The subjects are sophomores or juniors at your university. They are younger than you.

(2) Please give the subjects some valuable comments about how to succeed in searching for and getting a job after graduation. The subjects are interested in your advice.

(3) Your comments are more interesting when they include actual stories of successes achieved by your peers.

(4) The reasons for successes in getting jobs should be clearly told to the subjects. Your advice to the subjects should be based on the reasons for success.

(5) Your talk with the subjects is five minutes long.

(In the case of loss frames)

(1)' Please talk with the subjects friendly and naturally. The subjects are sophomores or juniors at your university. They are younger than you.

(2)' Please give the subjects some valuable comments regarding how to avoid failure in searching for and getting jobs after graduation. The subjects are interested in how to avoid failures in getting jobs.

(3)' Your comments are more interesting when they include actual stories of failures by your peers.

(4)' The reasons for the failures should be clearly told to the subjects. Your advice to the subjects should be based on the reasons for the failures.

(5)' Your talk with the subjects is five minutes long.

Figure 5(a) Short Task Repeatedly Executed in Game A

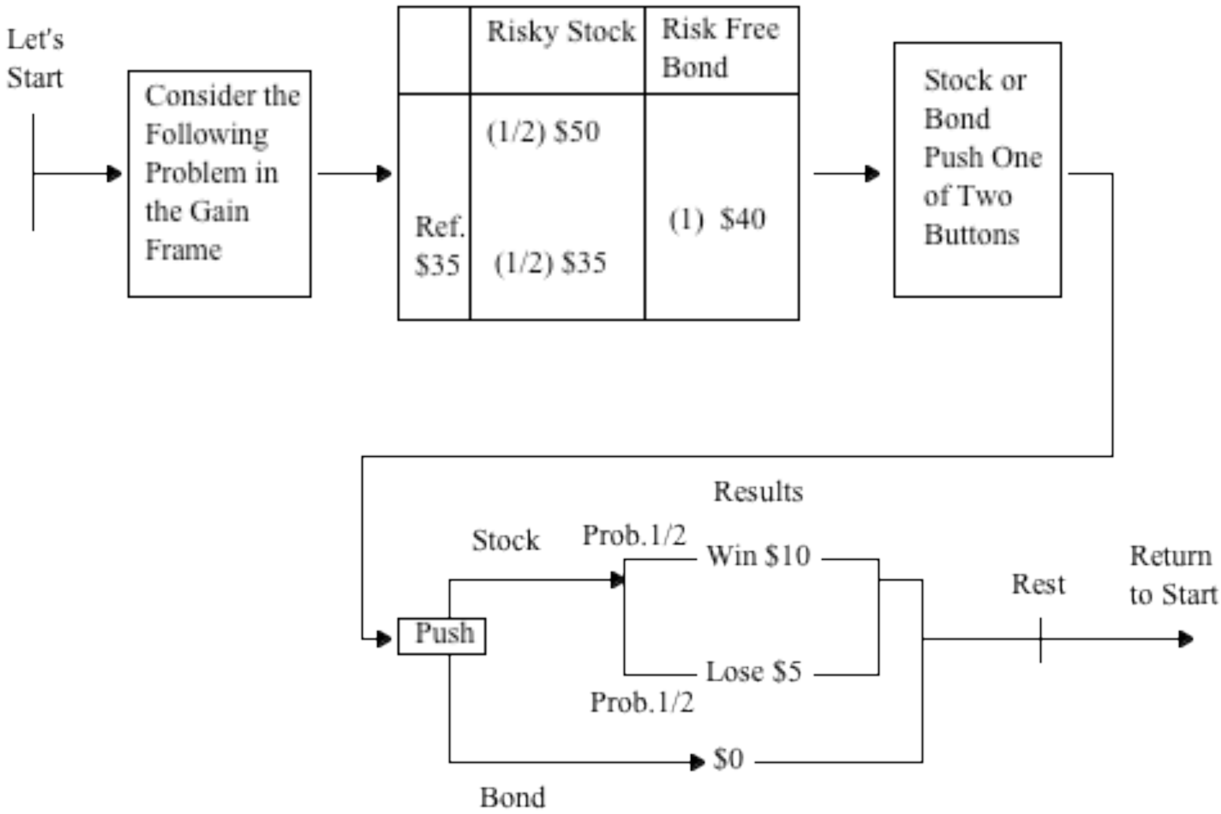


Figure 5(b) Short Task Repeatedly Executed in Game B

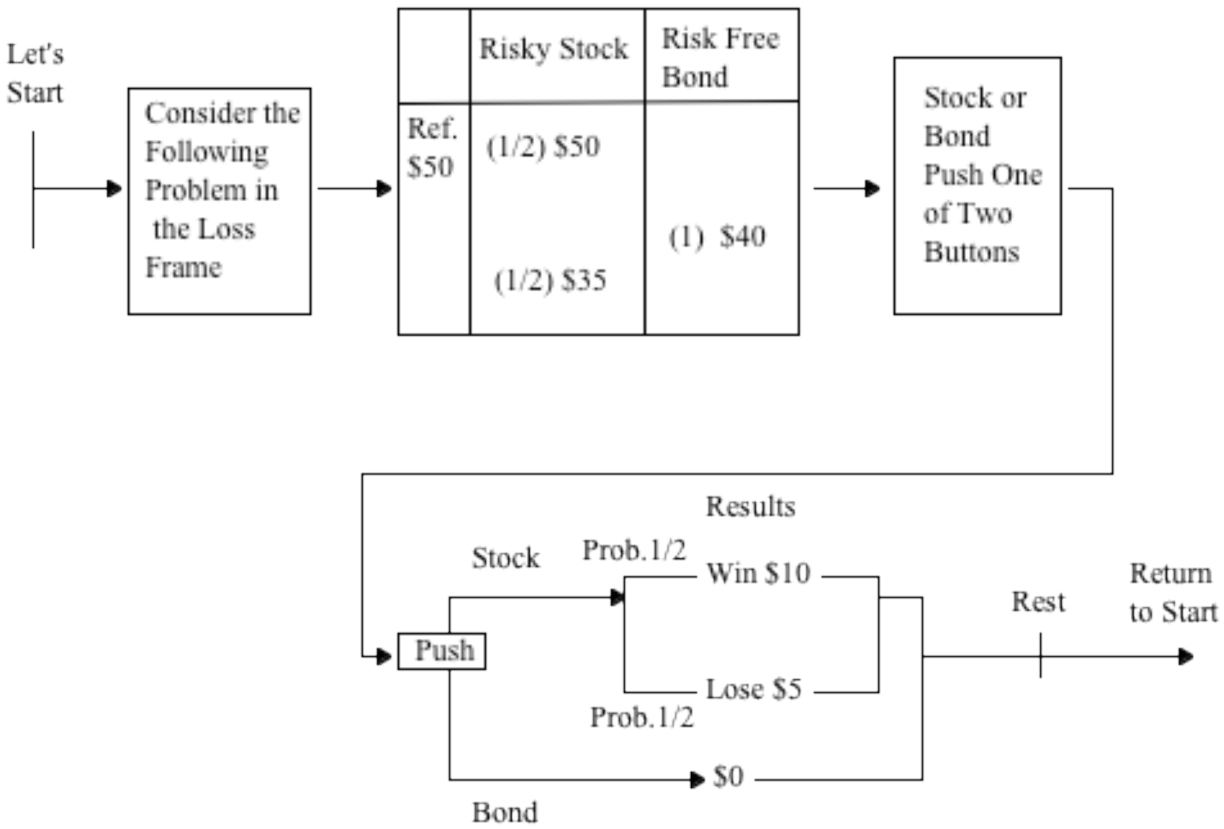


Figure 6 Short Task Repeatedly Executed in Games C1, C2 and C3

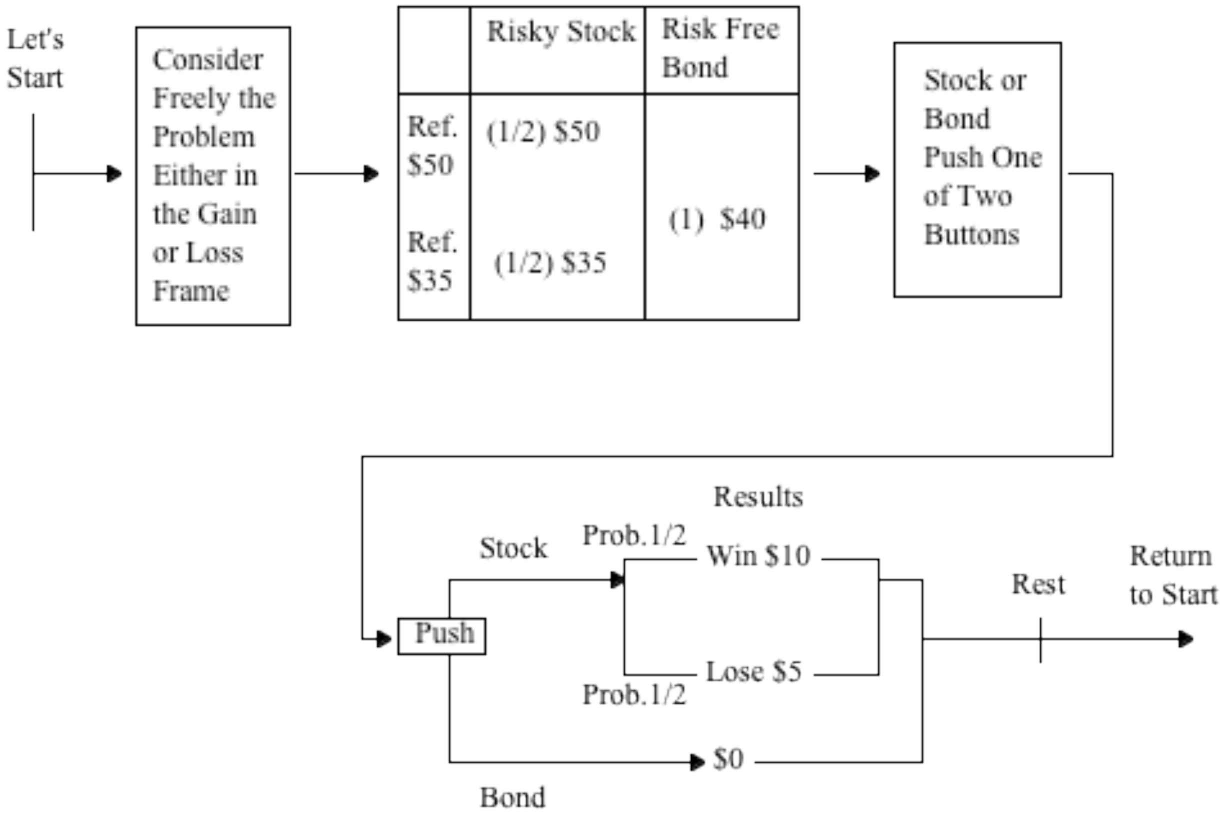
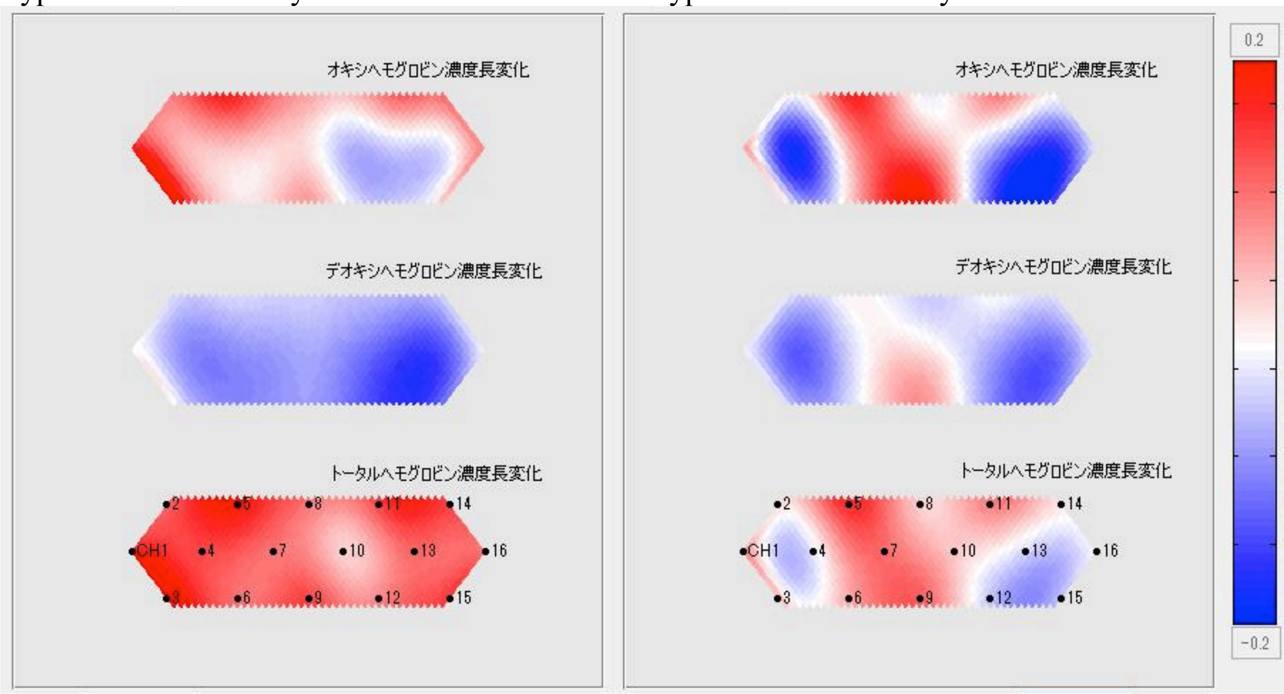


Figure 7 fNIRS Images of Typical Neural Activity in the Frontal Cortex in Games A and B*

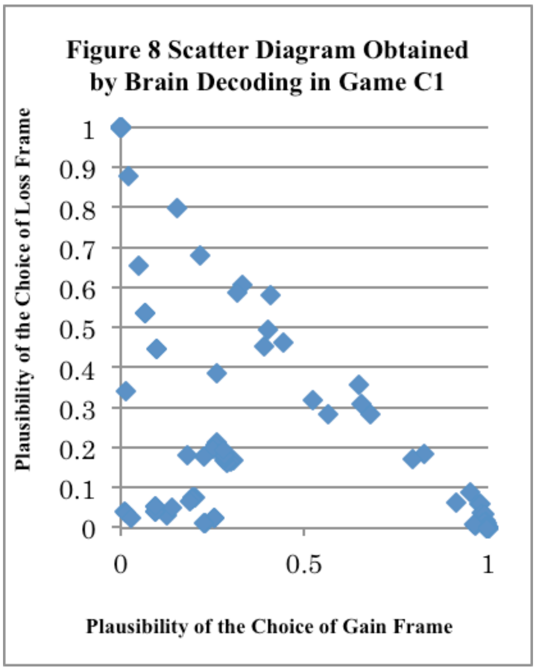
Typical Neural Activity Observed in Game A Typical Neural Activity Observed in Game B

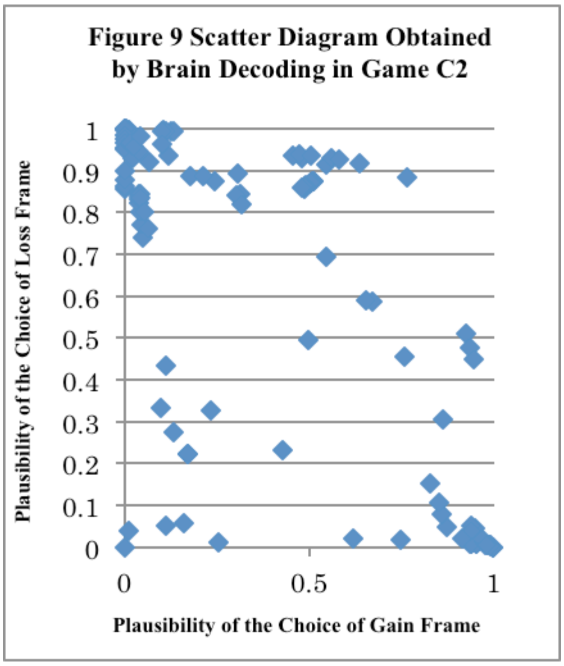


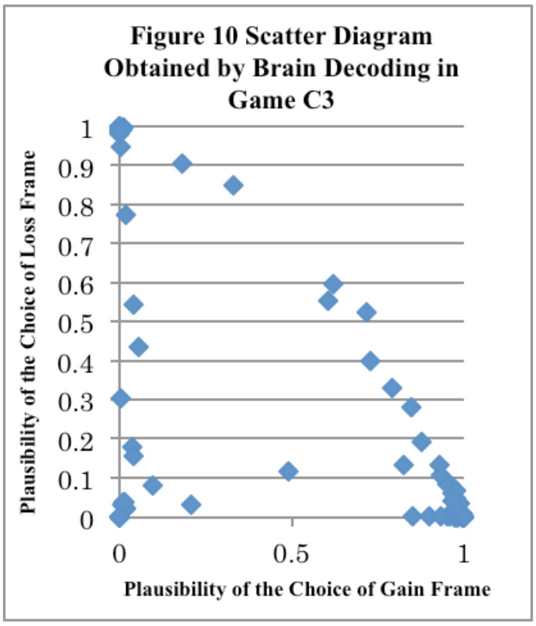
*

The neural images illustrate three types of hemoglobin changes at the 16 channels located on the frontal cortex of the brain that were obtained using the cumulative means of preliminary games A and B. These changes are measured using the standard unit of mMmm. The upper images illustrate changes in oxyhemoglobin (ΔCoxyHb), the middle images illustrate changes in de-oxyhemoglobin (ΔCdeoxyHb), and the lower images illustrate aggregate changes in the two types of hemoglobin (ΔCoxyHb + ΔCdeoxyHb). We selected the changes in oxyhemoglobin (ΔCoxyHb) to use for brain decoding, following Strangman et al. (2002), to retain the strong correlation between fMRI variables and fNIRS measures.

Figures 8 to 10
(The horizontal axis represents the plausibility of using the gain frame expressed by the sigmoid function. The vertical axis represents the plausibility of using the loss frame expressed by the sigmoid function.)

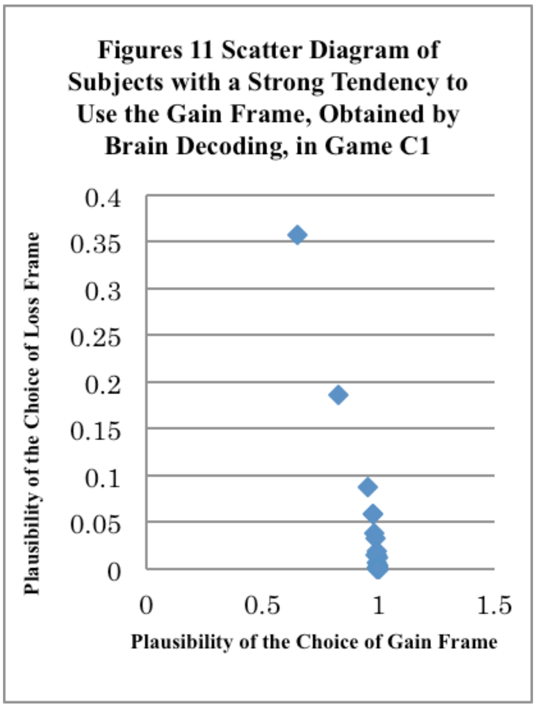


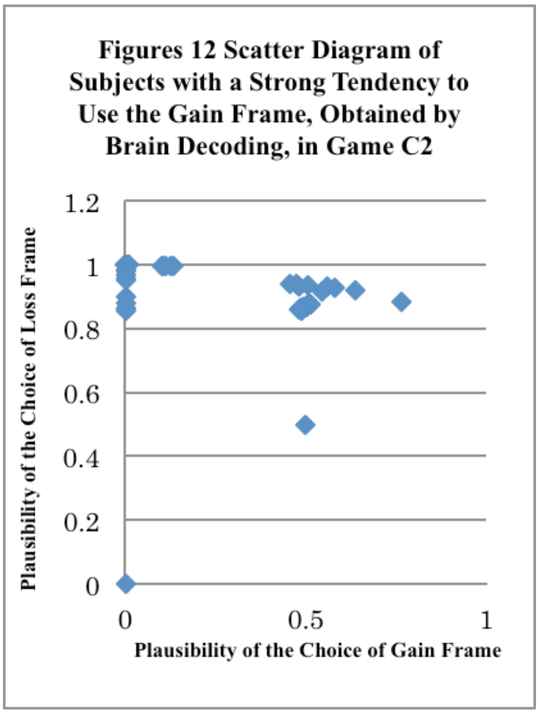


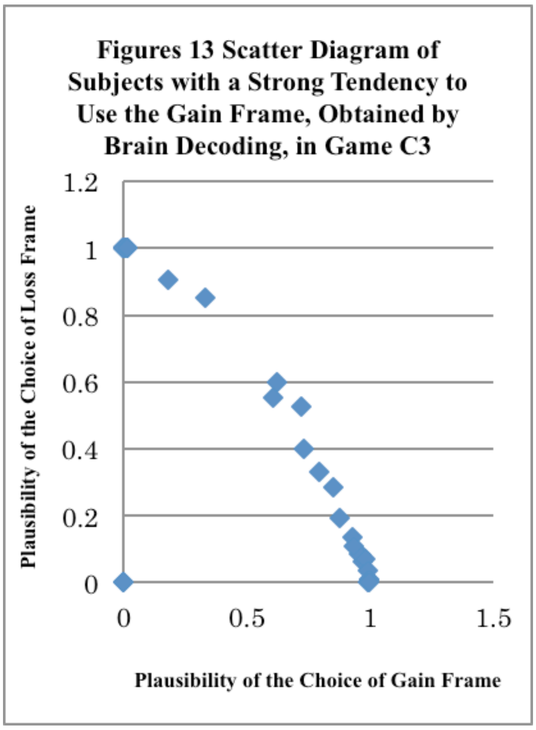


Average and Variance		
	Plausibility of the Choice of Gain Frame	Plausibility of the Choice of Loss Frame
Figure 8	0.491849 (0.175337)	0.288666 (0.136278)
Figure 9	0.401451 (0.140195)	0.601795 (0.158070)
Figure 10	0.364318 (0.201913)	0.525994 (0.213114)

Figures 11 to 13
(The horizontal axis represents the plausibility of using the gain frame expressed by the sigmoid function. The vertical axis represents the plausibility of using the loss frame expressed by the sigmoid function.)







Average and Variance		
	Plausibility of the Choice of Gain Frame	Plausibility of the Choice of Loss Frame
Figure 11	0.982025 (0.00362)	0.022598 (0.003993)
Figure 12	0.277483 (0.064248)	0.894900 (0.027737)
Figure 13	0.411423 (0.192067)	0.580718 (0.185614)

Figures 14 to 16
(The horizontal axis represents the plausibility of using the gain frame expressed by the sigmoid function. The vertical axis represents the plausibility of using the loss frame expressed by the sigmoid function.)

Figure 14 Scatter Diagram of Subjects with a Strong Tendency to Use the Loss Frame, Obtained by Brain Decoding, in Game C1

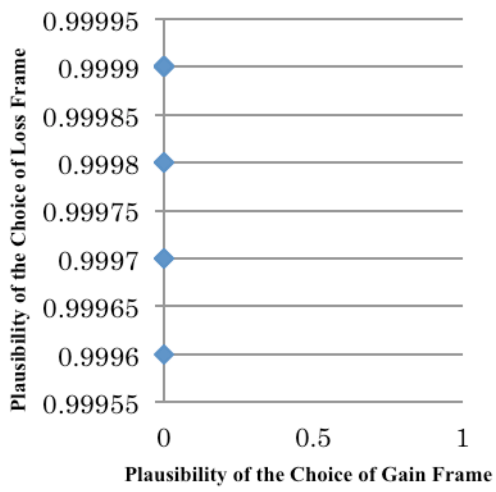


Figure 15 Scatter Diagram of Subjects with a Strong Tendency to Use the Loss Frame, Obtained by Brain Decoding, in Game C2

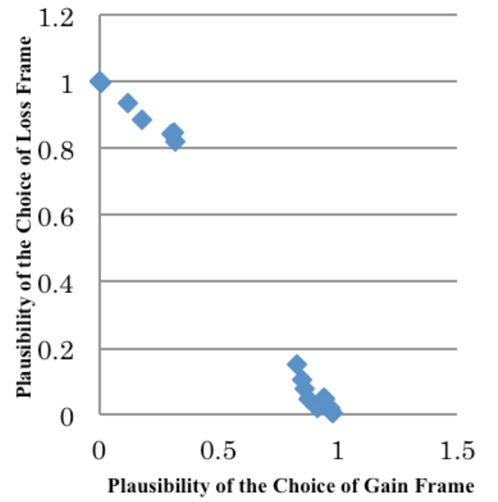
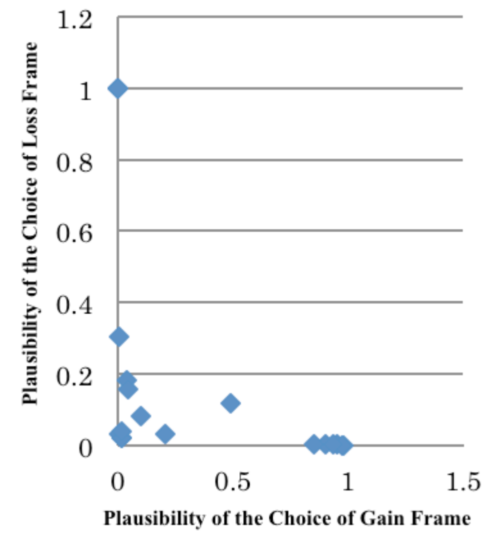


Figure 16 Scatter Diagram of Subjects with a Strong Tendency to Use the Loss Frame, Obtained by Brain Decoding, in Game C3



Average and Variance		
	Plausibility of the Choice of Gain Frame	Plausibility of the Choice of Loss Frame
Figure 14	0.000010 (0.000013)	0.999850 (0.000012)
Figure 15	0.565605 (0.158842)	0.445005 (0.191155)
Figure 16	0.326115 (0.169088)	0.249875 (0.146261)

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