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The Generation of Perception Gap and Ambiguity Aversion Under Uncertainty:
An Electroencephalographic Study of Contingent Negative Variation (CNV)

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Abstract

Investigating the pattern of contingent negative variation by using the digital electroencephalography, we explain perception gap generation and ambiguity aversion in executing risky games. The perception of risk is considered to be transformed to ambiguity, when subjects perceive the difficulty level to increase in risky games. Combining our result with the implications of recent neuroeconomic studies, this paper suggests that the interconversion between risk and ambiguity is possible in human agents' perception and cognition. To obtain a conclusion, three kinds of experimental games Z, A and B are presented to the subjects. After playing the games, an interview survey is conducted to confirm that games Z, A and B are perceived by the subjects to be simple, slightly complicated, and highly complicated respectively. Examining the results of the interview survey and the changes in the pattern of contingent negative variation (CNV), we find that the perception gap and ambiguity aversion appear with reduced motivation and pessimistic expectations in decreasing the perceived challenges of winning the game. Our study extends neuroeconomics to a new field with reciprocal transformation between two different kinds of uncertainty, i.e., risk and ambiguity.

Keywords: neuroeconomics, risk, ambiguity, reciprocal transformation,
electroencephalography (EEG), contingent negative variation (CNV)

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Abstract

Investigating the pattern of contingent negative variation by using the digital electroencephalography, we explain perception gap generation and ambiguity aversion in executing risky games. The perception of risk is considered to be transformed to ambiguity, when subjects perceive the difficulty level to increase in risky games. Combining our result with the implications of recent neuroeconomic studies, this paper suggests that the interconversion between risk and ambiguity is possible in human agents' perception and cognition. To obtain a conclusion, three kinds of experimental games Z, A and B are presented to the subjects. After playing the games, an interview survey is conducted to confirm that games Z, A and B are perceived by the subjects to be simple, slightly complicated, and highly complicated respectively. Examining the results of the interview survey and the changes in the pattern of contingent negative variation (CNV), we find that the perception gap and ambiguity aversion appear with reduced motivation and pessimistic expectations in decreasing the perceived challenges of winning the game. Our study extends neuroeconomics to a new field with reciprocal transformation between two different kinds of uncertainty, i.e., risk and ambiguity.

1.Introduction

When human subjects perceive that the difficulty of experimental risky games have increased beyond a certain limit, they exhibit a perception gap that represents the difference between the game's actual difficulty and subjects' perception. The remarkable characteristic of this perception gap is that it occurs with ambiguity aversion. Our study interprets this psychological and neurological change as the transformation from the perception of risk to that of ambiguity. The primary purpose of our study is to investigate the transformation mechanism using electroencephalography (EEG) and the Brain Electrical Source Analysis (BESA) software in order to analyze the changes in the pattern of Contingent Negative Variation (CNV).[1]

CNV is one of the typical event-related potential (ERP) components which has a long history of investigation beginning with Walter (1964). CNV brainwave is generated as consistent patterns of the amplitude of electric responses resulting from a subject's cognitive activities during the warning stimulus S1 and the imperative stimulus S2 in an experimental task. The analysis of the CNV time interval during the two stimuli is suitable for economic studies where subjects' "deliberation" (not only the reaction) is examined, while other types of neurological analyses, for example the study of P300, deal solely with the instantaneous reaction to a stimulus. Our unique study examines the disappearance (or destruction) of CNV as the first study to investigate the characteristics of risk perception variability. CNV is considered "a backdrop for the portrait," an element that accentuates the original figure of the main character by its own disappearance. We study the changes of the "backdrop" to discern the characteristics of the primary figure. This is an indirect method , whereas most previous studies have used direct methods to examine the "portrait" (target). Looking at the same images from different directions enables us to discover unique insights with valuable implications not previously examined.

Comparing the CNV pattern with the result of the interview survey, we find not only a partial correlation but also an interesting difference between them. When subjects perceive that executing games is complex and difficult with new imperfect knowledge, CNV is destroyed. It is, however, noteworthy that CNV partially recovers from its complete destruction, when subjects' perception of the risky games' difficulty increases beyond a certain limit. The reversal of CNV implies that the increase in risky games' difficulty begins to be perceived and understood in a different manner from that in less complex risky games. We interpret this different perception as the ambiguity aversion is perceived by the subjects who exhibit reduced motivation and pessimistic expectations. The generation of ambiguity aversion implies the generation of a new kind of uncertainty ("ambiguity") in executing risky games. The transition from risk to ambiguity occurs, when the complexity of risky games is perceived to increase beyond a certain limit.

The generation of ambiguity aversion is accompanied by a perception gap, and the gap stimulates ambiguity aversion. Our experimental study confirms the generation of a perception gap between the actual difficulty of games and the perceived one. When the result in the interview survey is compared with the actual theoretical difficulty in the calculation of the games' optimal strategy, there is a remarkable difference between them. We present an experimental game (game B) where the subjects perceive great difficulty in executing the game, although as the appendix shows, the game does not

[1] Our EEG system is composed of EEG-1200 (Nihon Kohden), Multi-trigger system (Medical-Try Systems) and BESA software (BESA GmbH) to analyze the changes in the pattern of Contingent Negative Variation (CNV).

theoretically require any complex calculations for determining the optimal strategies. The implications of the perception gap are explained from the viewpoint of behavioral economics. Considering from the viewpoint of the availability heuristic as well as the anchoring and categorization effects, we admit the validity of Kahneman-Tversky approach in explaining the gap between the perception results of the interview and the games' actual theoretical difficulty.[2]

In addition, the perception gap is accompanied by an ambiguity aversion. Although the perception gap provides an opportunity to confirm the validity of the earlier behavioral economics by Kahneman and Tversky, the ambiguity aversion provides an opportunity for us to extend the theoretical framework of neuroeconomic studies to a new field with a reciprocal relationship between risk and ambiguity. Our primary purpose is to analyze the ambiguity generation mechanism for further development of neuroeconomics. To understand the implications of ambiguity generation, we examine the theoretical relationships between our study and the seminal studies conducted by Hsu et al.(2005), Huettel et al.(2006), Bach et al. (2009) and others which use the functional magnetic resonance imaging (fMRI) system to produce the neurological evidence for the fact that risk and ambiguity are perceived differently in the human brain.[3] In contrast to the myth of assumptions adopted by the subjectivist school, these neuroeconomic studies demonstrate that vagueness plays an essential role in decision making under uncertainty. Moreover these studies demonstrate that neurological responses to ambiguity, particularly the higher activation of the posterior inferior frontal sulcus (pIFS), come from the anticipation that hidden information under ambiguity is searched for to reduce to risk (uncertainty with known probabilities). The

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[2] The studies on availability heuristic include that of Tversky-Kahneman (1973, 1974), Chapman-Chapman (1969), Ross-Sicoly (1979), Taylor (1982), Kahneman-Tversky (1982), Folkes (1988), Macleod-Campbell (1992) and so on. For the anchoring effect, see Slovic-Lichtenstein (1971), Cohen-Chesnick-Haran (1971 1972), Bar-Hillel (1973), Gettys-Kelly-Peterson (1973), Tversky-Kahneman (1974) and Trope (1978). The research on categorization effects has a long history with the development of cognitive psychology. See for example Bower (1972), Rosch (1975) and Rosch-Lloyd (1978). On the application of cognitive categorization to behavioral economics, see Thaler (1980,1999), Benartzi-Thaler (1995), Camerer-Babcook-Loewenstein-Thaler (1997) ans so on.

[3] Hsu et al.(2005) as well as McCabe et al. (2001) and Rustichini et al. (2002) are the first studies to investigate the neural mechanism in processing of risk and ambiguity. Huettel et al.(2006) finds that with careful experiments a higher neural activation for ambiguous gambles than that for risky gambles in the posterior inferior frontal sulcus (pIFS), the anterior insula cortex (aINS) and the posterior parietal cortex (pPAR). Bach et al. (2009) extends this result and concludes that these responses to ambiguity, particularly the higher activation of the pIFS, result from anticipation after which the hidden information with ambiguity will be searched to reduce ambiguity to risk (uncertainty with known probabilities). The neural activation of pIFS mediates the transition mechanism from ambiguity to risk with the learning process of ambiguous probability distribution by sampling data repeatedly. The survey articles on the development of neuroeconomics are Glimcher (2003), Rustichini (2005), Camerer-Loewenstein-Prelec (2004, 2005) and so on.

neural activation of the pIFS mediates the transition mechanism from ambiguity to risk in the learning process of an ambiguous probability distribution.

Two open issues remain to be examined in neuroeconomics. Will a reverse transition occur? What psychological and neurological mechanism may trigger and stimulate the reverse transition process where the perception of risk reverts back to the perception of ambiguity? In our study, we use the digital EEG to examine the reverse transition in the CNV pattern which implies the emergence of a different perception called "ambiguity aversion."

Our study is the first to investigate the in depth relationship between risk and ambiguity which may interconvert in human perception and cognition. The interconversion problem is certainly an interesting question for neuroeconomics. Moreover it provides the possibility of a new theoretical foundation for macroeconomics by explaining how the volatility of macroeconomic investment and business fluctuations increase. Consider a case, for example, where ambiguity aversion has a greater negative effect on investment decision than does risk aversion. Then, the transition from risk to ambiguity will lead to economic recession with a low level of investment, while the reverse transition will cause a recovery in investment decisions to improve the business climate. This case holds, when reduced motivation and pessimistic expectations accompanying widespread ambiguity aversion dominate aims, activity and rationality to strongly restrict investors' active behavior. Our experimental study presents a new paradigm in economics which provides a more close relationship between economics, psychology and neuroscience beyond the previous studies.

2. Methods

The experimental games are played by eight healthy right-handed subjects, four males and four females aged 20 to 29.[4] To play the experimental games, each subject enters a shielded tent located in a quiet room protected from electro magnetic interference (EMI) and noises.

Before the experiment, the subjects are required to wash their head and hair to decrease the bioelectrical impedance resistance and facilitate measuring their brainwaves with the electroencephalography (EEG). They are prohibited from eating within two hours before executing the games. The brain waves are measured by the electro-cap containing the international 10-20 positioning system.

[4] The number of subjects might seem small. However, as Fig.4 shows, the subjects' data provide us a typical and complete CNV pattern that can serve as a reference point to analyze the changes in CNV in complicated experimental games.Thus the eight subjects' data in our study are sufficient and effective to investigate the destruction and recovery of CNV with the generation of a perception gap and ambiguity aversion.

Three kinds of games, game Z, game A and game B are presented to the subjects. Each game consists of a short task (10 seconds) which is repeated 30 times in order to obtain the event-related potential (ERP) components by calculating the arithmetic mean. First, game Z is a simple and stress-free game where the complete pattern of CNV is expected to be obtained. Therefore before explaining the results of our experimental games A and B, we examine the result of the simple preliminary game as a reference point. Obtaining the complete pattern of CNV in our results implies that our experimental method with the eight healthy subjects has an effective and reliable scientific basis for economic analysis. The content of the short task in game Z is illustrated by Fig.1. In the game Z task, the subject notices only the 1kHz tone as the stimulus S1 and presses any button after hearing the 3kHz long tone as the stimulus S2.

Fig.1. Short Task Repeated 30 Times in Simple Game Z

The content of the short task in game A is illustrated in Fig.2. The first screen of the computer monitor displays a magician (disguised by an undergraduate at Aoyama-Gakuin University) showing his spade card. After two seconds, the next screen displays a choice for the subject between two alternative cards which are laid face down on a table. One is a spade and the other is a heart, but their suit marks are not visible to the subject. He is not informed about which is the spade (heart) and what rule will change the placement of the two cards for each task. In our experiment, we randomly change the placement of the two cards with a prior probability of 50%. If the subject chooses the spade that is identical to the magician's card, he wins \$1 per task, but if he chooses the heart which is different from the magician's card, he loses \$1. Playing the tasks repeatedly, profit maximization requires the subject to learn what rule will change the placement of the two cards that lie face down on the table.

Fig.2. Short Task Repeated 30 Times in Game A

Finally, observe the content of the short task in game B which is illustrated in Fig.3. The difference between game B and game A is only the card revealed by the magician on the first screen. While a spade is shown in game A, an "unknown card" is shown in game B. The subject does not know whether this unknown card is a spade or a heart and is only informed that the unknown card changes randomly to be a spade or a heart with a prior probability of 50%. If the unknown card is a spade (a heart), the subject wins when he chooses the same suit card from the alternative choice. In game B, the short task is also repeated 30 times, and the subject is required to determine his/her optimal behavior in choosing one of the alternative cards.

Fig.3. Short Task Repeated 30 Times in Game B

After the three games are completed, an interview survey is conducted. The subjects are asked to answer the following two questions. (1) Rank the order of difficulty of games Z, A and B. (2) Explain your perceptions about playing these experimental games. What is the strength of your psychological stress while playing the games?

3.Results

In this study, we consider the generation of a perception gap and ambiguity aversion in playing three risky games. A perception gap is observed as the difference between the result of the interview survey and the theoretical difficulty of calculating the games' optimal strategy. The generation of ambiguity aversion is proposed based on the "reverse change" of CNV in spite of the increase in the games' perceived difficulty as shown by the interview survey.

Table 1 illustrates the summary of our experimental results. The result of the survey is shown by the ranking order of the games' difficulty, Z < A < B. Game B is perceived to be the most difficult of the three, and game Z is the simplest as well as the easiest. Although perceived as the most difficult in the survey result, game B is actually the easiest in the theoretical difficulty ranking. As the appendix shows, we prove that game B's optimal strategy is never difficult to calculate. We address the question of why the subjects perceive difficulty in playing game B and explain the reason for this perception gap from the viewpoint of behavioral economics in the following sections.

Table 1. The Results of Our Experiment

Next, we consider ambiguity aversion generation. The survey's ranking order of difficulty Z < A < B is not completely consistent with the ranking of the magnitude of CNV destruction Z < B < A, i.e., the complete CNV pattern observed in game Z disappear partially and totally in games B and A. If the perception of difficulty correlated perfectly with the strength of mental stress, the destruction of CNV would monotonically increase with the strength of subjects' perception of difficulty, i.e., the ranking order of the magnitude of CNV destruction would be Z < A < B, the same order as that in the interview survey. As found by Tecce (1972), Van Veen et al (1973) and Nakamura et al (1979), the reason for this is that the CNV pattern directly correlates to changes in emotions and feelings involving psychological stress and anxiety. However, our actual result of the CNV changes is Z < B < A which diverges from the above discussion. Reconsidering the validity of this discussion, we will again explain the actual CNV data.

Here we examine in detail the changes in CNV obtained by EEG. CNV is one of the typical event-related potential components. It is generated as a pattern of the amplitude of electrical responses by the subject during the warning stimulus S1 and the imperative stimulus S2. In our experiment, stimulus S1 is the appearance of the screen with a 1kHz tone displaying a choice for the subject between the two cards laid face down on a table.

Stimulus S2 is the appearance of the screen with a 3kHz long tone which permits the subjects to indicate their choices by pressing one of the buttons.

Fig.4 shows the CNV pattern which is the first principal component obtained by calculating the arithmetic mean and the principal component analysis of game Z with simple and stress-free tasks. CNV is the negative brainwave consisting of the orienting wave (the first wave) following stimulus S1 and the expectancy wave (the second wave) following stimulus S2.[5] While the first wave is usually generated at approximately 400-700 ms after stimulus S1, the second wave usually occurs approximately 1000 ms after stimulus S1 and before stimulus S2. The CNV brainwave is primarily observed around the channels at the top of the head. In our observation, the summit potential of the first principal component has a latency of 1467 ms, and the CNV maximum amplitude is -1.17 μV which is recorded from the Pz site around the top of the head in the international 10-20 system. Following the detailed investigation by Tecce (1972), Van Veen et al (1973) and Nakamura et al (1979), as mentioned above, the CNV pattern directly correlates to changes in emotions and feelings with psychological stress and anxiety, because emotions and feelings change the subject's level of attention to as well as consciousness of stimuli S1 and S2. From the studies conducted by Knott-Irwin (1968), McCallum (1969), Tecce (1972), Howard et al (1984) and others, the lower level of attention to the stimuli decreases the generation of CNV.

Fig.4. The First Principal Component of CNV of Game Z

While the simple and stress-free game Z produces the complete pattern of CNV, we demonstrate the different results of games A and B in Fig.5 and Fig.6 respectively. The original pattern of CNV disappears in game A. Fig.5 shows the pattern of brainwave as the first principal component of game A. The negative CNV brainwave is not generated. In contrast, the result of game B is illustrated in Fig.6 showing the CNV pattern of the first principal component partially recovers from the complete destruction. The summit potential of the first CNV wave has a latency of 606 ms, and the CNV's maximum amplitude is -1.99 μV which is recorded from the Pz site around the top of the head in the international 10-20 system. This result implies that the execution of game B does not require larger areas of neurological resources in the brain to work than does the execution of game A. Therefore the subjects pay a higher level of attention to the stimuli in game B than in game A to partially recover the negative CNV wave. In addition, it is noteworthy that the first CNV wave in game B is generated to recover, while the second wave is not. The first wave can more sharply indicate the effects of variable attention to the stimuli on CNV than does the second wave. The subjects do not have a heavier psychological and neurological burden in executing game

[5] See Loveless-Sanford (1975) and Weerts-Lang (1973).

B than game A, although they feel it is more difficult to play game B than game A. This is the anomaly to be analyzed in our study.

Fig.5. The First Principal Component of CNV of Game A

Fig.6. The First Principal Component of CNV of Game B

4.Discussion

The pattern of CNV is either partially or completely destroyed by psychological stress. We observe that CNV disappears in game A, but partially recovers in game B. Our theory is that a new kind of perception "ambiguity aversion" is generated, when the subjects perceive more difficulty in executing game B because of the additional imperfect knowledge about the card shown by the magician. It is noteworthy that the new perception generation is accompanied by an increase in the subjects' perceived difficulty which may be greater than the game's actual difficulty. Ambiguity aversion results from the feeling of difficulty combined with a perception gap.

In order to understand the characteristics of the perception gap in depth, we examine how theoretically difficult it is to mathematically calculate the optimal behavior of the subjects in game B. Does the additional imperfect knowledge about the magician's card increase the theoretical difficulty of game B? Before executing game B, the subjects are informed that the magician's unknown card randomly changes to be either a spade or a heart with a prior probability of 50%. This imperfect information provided to the subjects seems to increase the complexity of the experimental game. However, the subjects are also informed that the winning pattern of the game increases to include a new pair of heart cards. Therefore, we can easily understand that each choice of the subjects between the two cards has the same prior subjective probability of wining the game.[6] All the choices would be judged optimal, if the subjects were fictitious and rational subjectivists. There would be no need to calculate the optimal strategy. However, being different from the fictitious assumption by neoclassical economics, real human agents are not rational subjectivists, and the subjects respond to the interview survey that the game B is the most difficult. They do not find game B simple and easy with every strategy having the same probability of wining. This perception gap is not a random error of human agents that occurs as a mistake based on their limited rationality. The anomaly of the perception gap is certainly discordant with the results expected by standard economics, but it shows a strong tendency to have certain predictable characteristics that are explained by availability, heuristics as well as the anchoring and

[6] See the appendix of this paper.

categorization effects claimed by behavioral economics. We confirm the validity of Kahneman-Tversky's approach to understand the perception gap.[7]

Now let us investigate in detail the characteristics of the perception gap, using the viewpoint of the availability heuristic as well as the anchoring effects and categorization effects to explain the problem. First, the availability heuristic claimed by Tversky-Kahneman (1973, 1974) strongly supports our approach. In game A, the subjects obtain perfect knowledge of the magician's card. Using this knowledge, the subjects easily and clearly image the winning pattern of the card game that requires a pair of spade cards for wining. When the availability heuristic is in play, human agents will likely judge that events with a clear pattern can be more easily and less stressfully achieved than is objectively possible. Thus the subjects have hope and motivation to make efforts to win the game. In game B, however, the subjects do not obtain information about the magician's card, and they do not know which of the cards, a spade or a heart, is presented to them. It is not possible for them to image directly the wining pattern of the card game. The proposition of the availability heuristic suggests that agents are likely to judge the possibility of wining such a game to be less than its actual possibility, when they can only indirectly image the wining pattern. The subjects may feel discouraged and lose motivation even before playing the game. These negative emotions and perceptions have strong anchoring effects on their subsequent decision making under risk and uncertainty making their behavior pessimistic and aversive. We propose that game B may be categorized by subjects with pessimism and low motivation into the group categorized as "ambiguous games" or "heterogeneous uncertain games" which is distinct from game A's "risky games" group. After categorizing games into different groups, it is not easy for the subjects to exclude the first prejudice which results from the availability heuristic. The categorization effect prevents the subjects from realizing that game B is only a simple game without any need of calculation. Behavioral economics can explain the perception gap between the actual difficulty and the perceived difficulty of the games.

Then, we observe the changes in the CNV pattern, when the subjects feel the difficulty of the games to increase with the perception gap. In game B, the CNV pattern partially recovers from complete destruction. Why does CNV partly recover despite an increase in difficulty felt by the subjects? If the feeling of difficulty monotonically increased the subjects' psychological stress, CNV would not recover in game B, because, as Tecce (1972), Van Veen et al (1973) and Nakamura et al (1979) claim, the CNV pattern is directly disturbed by an increase in psychological stress and anxiety. However, the results obtained in our experiment is quite different from the expectation derived from the assumption that the feeling of the difficulty monotonically increases psychological stress. We analyze the aforementioned assumption. Psychological stress

[7] See Kahneman-Tversky (2000) and Camerer- Loewenstein (2004).

does not always increase with an increase in the feeling of difficulty. The partial recovery of CNV as an anomaly in game B requires other explanation factors based on a new economics paradigm. Thus generating ambiguity aversion and discussing further the transformation from risk to ambiguity becomes the focus of our analysis.

We present a new theoretical explanation that the perception of risk is transformed to that of ambiguity, when the perception of the games' difficulty increases beyond a certain limit. The perception of ambiguity is accompanied by ambiguity aversion with reduced motivation and pessimistic expectations. When the subjects lose their motivation and optimistic expectations to win the game, they decrease both their mental stress and heavy psychological burden to execute the game. The partial recovery of CNV can be explained by the theoretical understanding that the perception of ambiguity with ambiguity aversion is generated when executing riskier games.

5.Significance and Implications

Considering the implication of the changes in CNV, we present the theoretical explanation that the perception of ambiguity is generated together with reduced motivation and pessimistic expectations in executing risky games. It implies that the perception of risk is transformed to that of ambiguity, when the subjects perceive the difficulty of games to increase with the perception gap. Combining our analysis with the results of earlier studies, we propose the possibility of interconversion between risk and ambiguity in the perception and cognition of human agents. This problem is not only of great interest in neuroeconomics, but in also macroeconomics in which it provides a new theoretical foundation to explain how the volatility of investments causes large business fluctuations. In the framework, the Knightian and Keynesian paradigms regain importance.[8]

Our study is, however, the first attempt to explore the close reciprocal relationship between risk and ambiguity. Further analyses are needed to examine in detail what psychological and neurological factors may trigger (or accelerate) the interconversion between risk and ambiguity in social contexts. The behavioral as well as neuroeconomic analyses need to be extended to the "risk society" described by Ulrich Beck (1986) where the perceptions of risk and ambiguity amplify one another with the interrelationships between multiple human agents.

[8] See Knight (1921), Keynes (1921) and Ellsberg (1961). The recent works on the subject are for example Bateman (1987, 1996), Davis(1994), Runde (1994), Fontana-Gerrard (2004), Feduzi (2007) and so on.

Appendix

First, consider the subjective probability of winning game A. The second screen of game A displays a choice for the subject between two alternative cards laid face down on a table. One is a spade and the other is a heart, but their suit marks are not shown to the subject. He is not informed about which is the spade (heart) and is unaware of what rule will change the placement of the two cards in each task. Assume that the subject is a rational subjectivist. Denote by x his subjective probability of the uncertain state where a spade is placed on the left side. Then x (or 1 - x) implies the probability of winning, when he selects the card placed on the left side (or the right side). The optimal behavior of the subject is simple. If $x > 1-x$, the left side is selected. If not, the right side is selected. It is worth noting that the simple decision rule is the long-run optimal strategy of the repeated game. Because the choice of the left side is equivalent to the choice of the right side as the learning behavior to obtain new information for revising his present subjective probability by the Bayesian method. In this game, when one of the two cards is revealed, the other is automatically known. Therefore the subject does not apply the learning behavior to acquire future profit by reconciling himself to the present loss. The short-run optimal strategy is identical to the long-run optimal strategy.

Next consider the subjective probability of winning game B. In this game, as is already explained, the magician shows an unknown card which is changed randomly with a probability of 50%. Then, when the subject selects the card placed on the left side, his subjective probability of winning is $(1/2)x + (1/2)(1-x)$, i.e., the probability of winning is always expected to be 1/2. Following the same mathematical procedure, when the right side is selected, the probability of winning is also expected to be 1/2. This model implies that every strategy for selecting cards is optimal for profit maximization. Being different from the difficulty perceived by the actual human subject, it does not theoretically require any stressful calculations to decide optimal strategies. There is a perception gap between the subject's perception and the theoretical requirement for calculation to execute game B.

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Fig.1. Short Task Repeated 30 Times in Simple Game Z
(10×15)

Task Z is a simple and stress-free game where the complete pattern of CNV is expected to be obtained. Obtaining the complete pattern of CNV in our results implies that our experimental method has an effective and reliable scientific basis for economic analysis. In the game Z task, the subject notices only the 1kHz tone as the stimulus S1 and presses any button after hearing the 3kHz long tone as the stimulus S2.

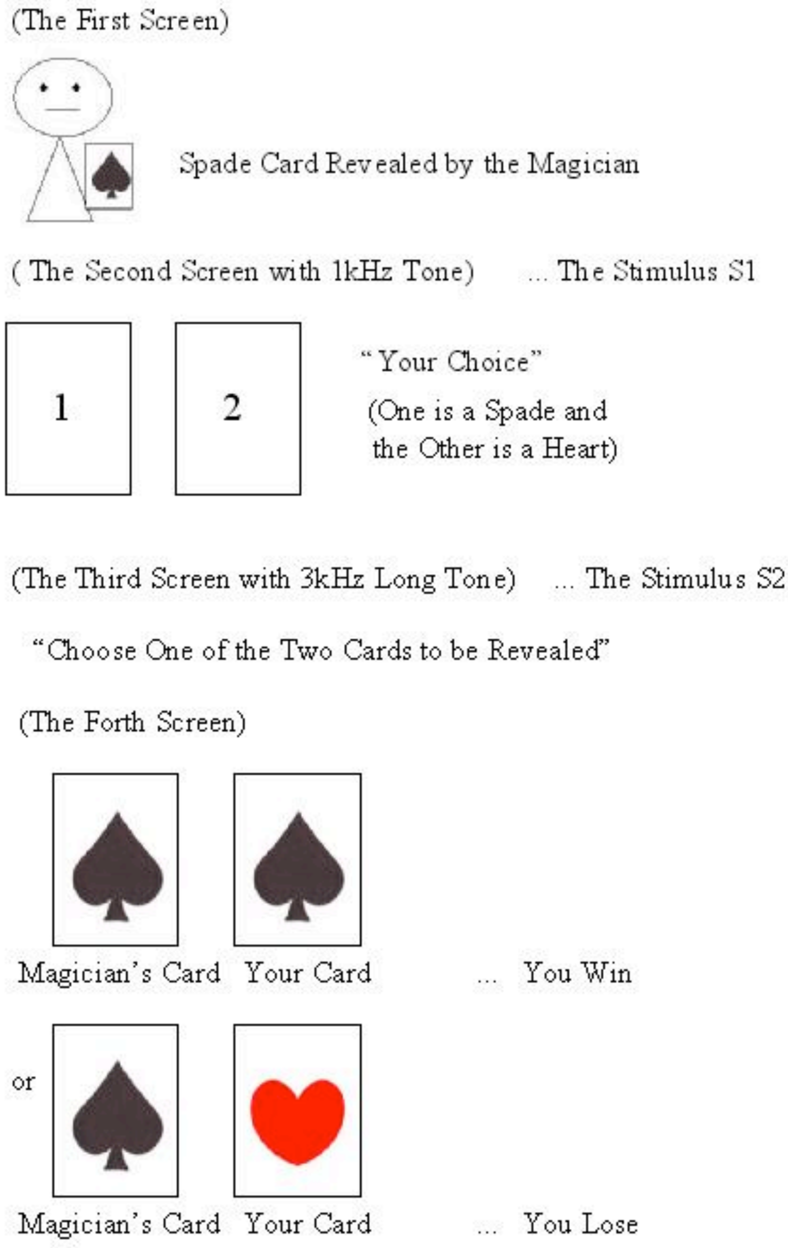

Fig.2. Short Task Repeated 30 Times in Game A
(17×14)

Task A is a risky game. The screen displays a choice for the subject between two alternative cards which are laid face down on a table. If the subject chooses the spade that is identical to the magician's card, he wins \$1 per task, but if he chooses the heart which is different from the magician's card, he loses \$1. Playing the tasks repeatedly, profit maximization requires the subject to learn what rule will change the placement of the two alternative cards that lie face down on the table.

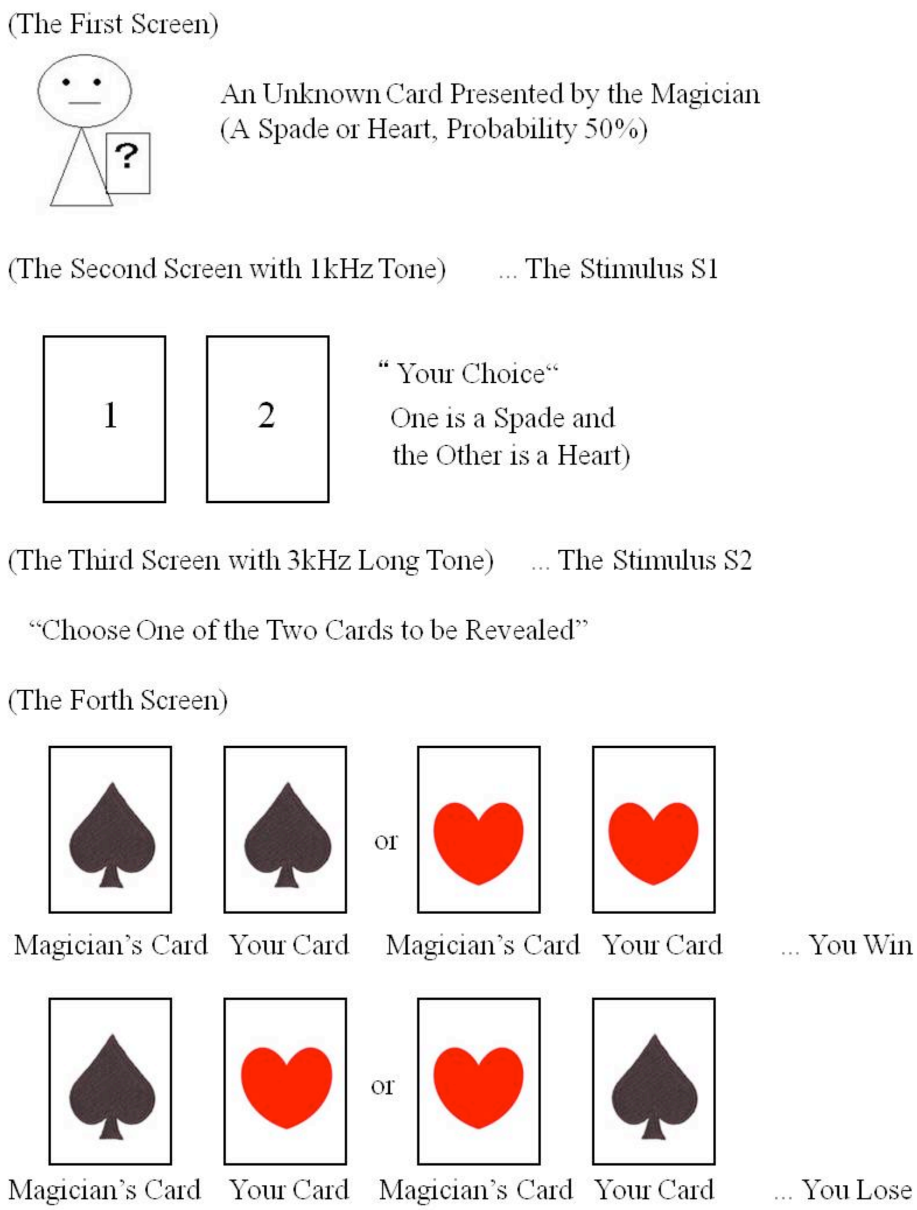

Fig.3. Short Task Repeated 30 Times in Game B

(18×15)

The difference between game B and game A is only the card revealed by the magician on the first screen. While a spade is shown in game A, an "unknown card" is shown in game B. Shown by the interview survey after the experiment, game B is perceived by the subjects to be the most difficult of the three, Z, A and B.

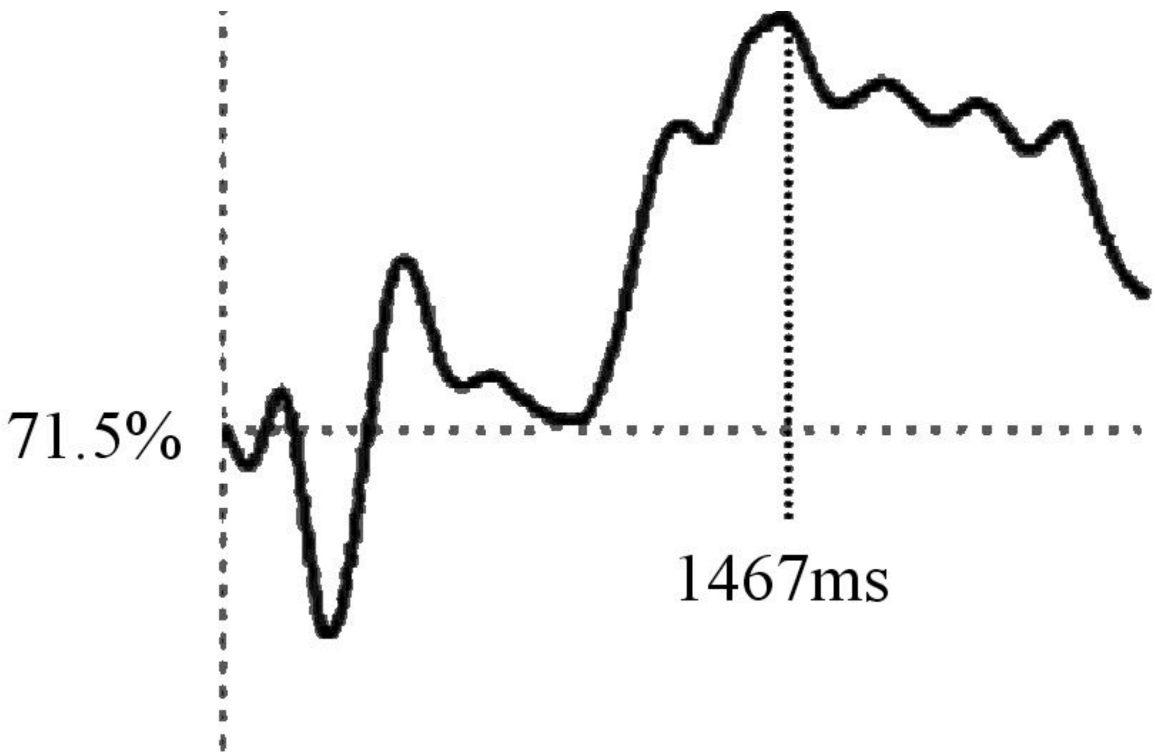

Fig.4. The First Principal Component of CNV of Game Z

(10×15)

Fig.4. shows the CNV pattern which is the first principal component obtained by calculating the arithmetic mean and the principal component analysis of game Z with simple and stress-free tasks. CNV is the negative brainwave consisting of the orienting wave (the first wave) following stimulus S1 and the expectancy wave (the second wave) following stimulus S2.

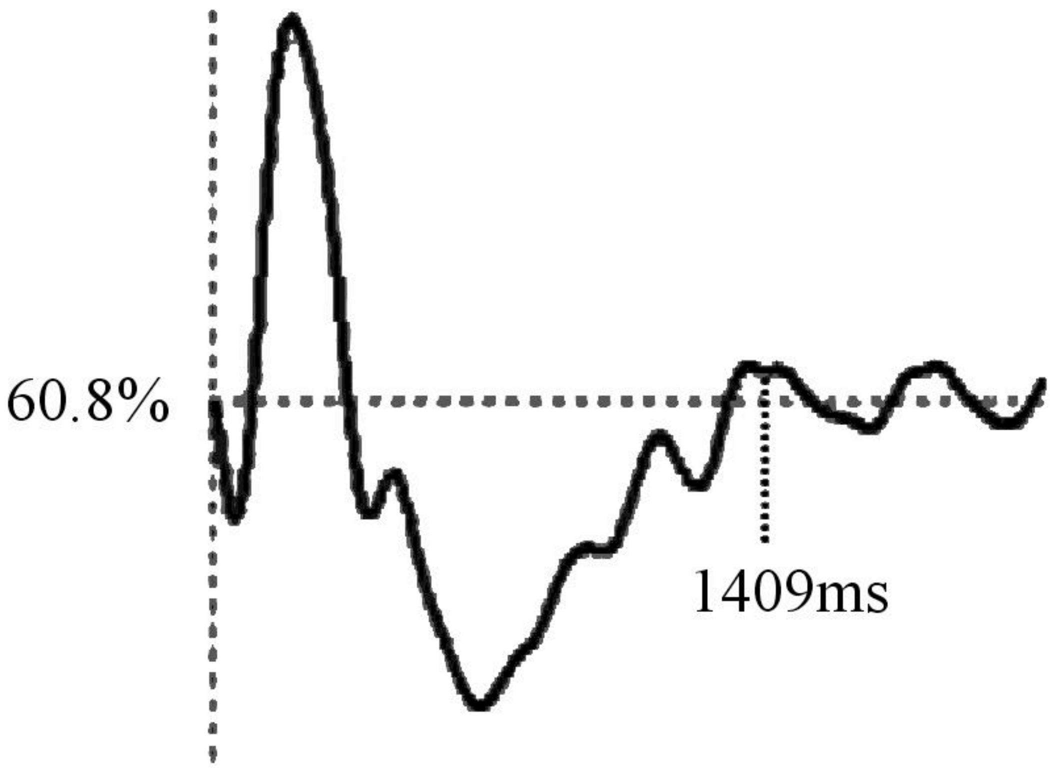

Fig.5. The First Principal Component of CNV of Game A
(10×15)

Fig.5. shows the pattern of brainwave as the first principal component of game A. The negative CNV brainwave is not generated.

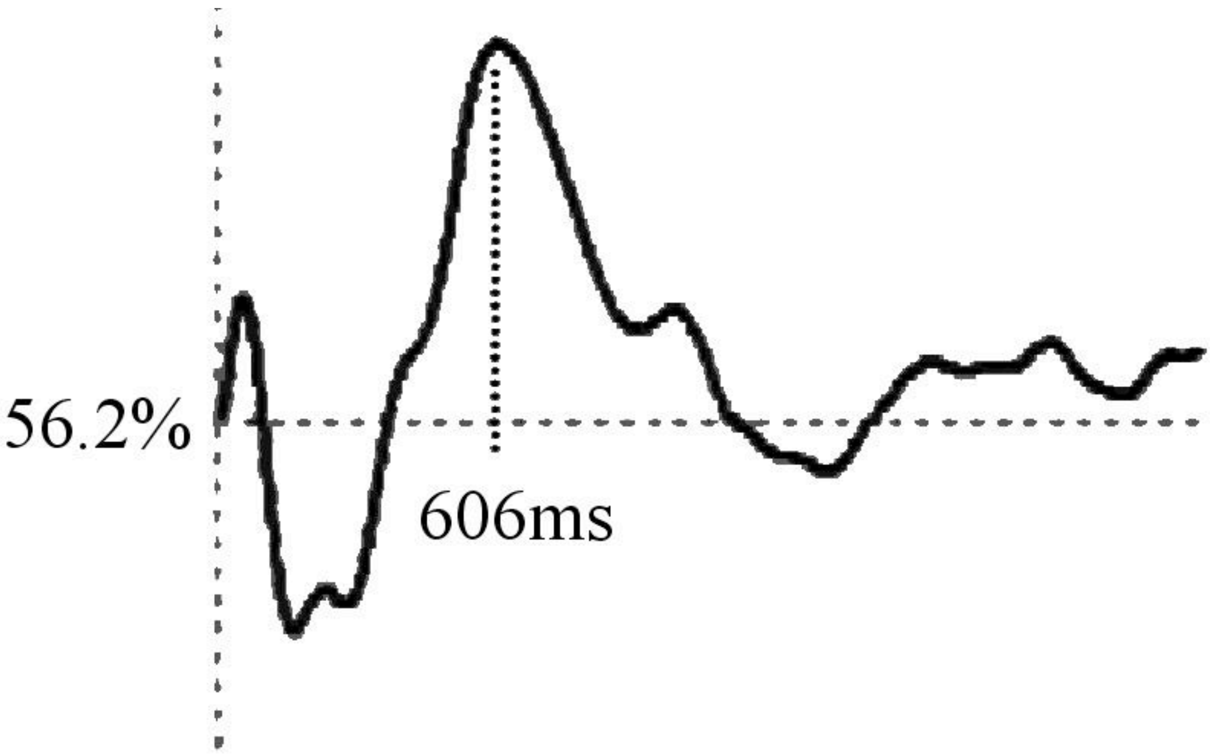

Fig.6. The First Principal Component of CNV of Game B
(10×15)

Fig.6. shows the pattern of brainwave as the first principal component of game B. The CNV pattern of the first principal component partially recovers from the complete disappearance (or destruction) in Fig.4. The first CNV wave in game B is generated to recover, while the second wave is not. The summit potential of the first CNV wave has a latency of 606 ms, and the CNV's maximum amplitude is -1.99 μV which is recorded from the Pz site around the top of the head in the international 10-20 system.

Table 1. The Results of Our Experiment
(12×15)

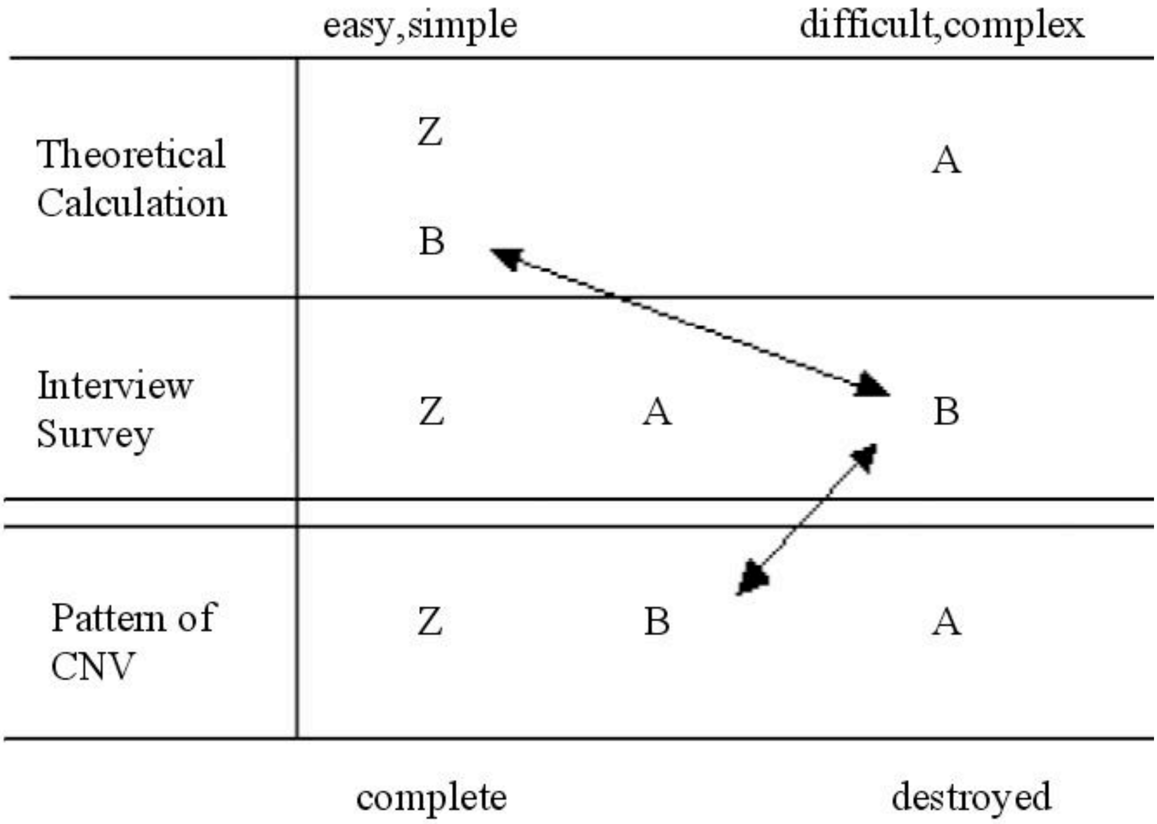

Table 1. illustrates the summary of our experimental results. The result of the interview survey is shown by the ranking order of the games' difficulty, Z < A < B. Game B is perceived to be the most difficult of the three, and game Z is the simplest as well as the easiest. As the appendix shows, however, we prove that game B's optimal strategy is never difficult to calculate. The theoretical difficulty is different from the result of the survey. Moreover, we examine the changes in the CNV pattern. The survey's ranking order of difficulty Z < A < B is not completely consistent with the ranking of the magnitude of CNV destruction Z < B < A, i.e., the complete CNV pattern observed in game Z disappear partially and totally in games B and A.