Decision-Making Mechanism under Economic Management Risk Based on Event-related Potential Neuroimaging Technique

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ABSTRACT

This paper aims to gain more insights into risk-based decision-making of the brain. For this purpose, the author decided to adopt such methods as electroencephalography (EEG) experiment, literature review and hypothesis testing. Based on the neuroscience for decision-making, the mechanism of management risk-based decision-making was investigated under different economic risks. Then, the "economic management risk-based decision-making" hypothesis was presented in light of the mathematical model for risk-based decision-making and the neuroscience for decision-making. After that, the author prepared the detailed design of an experiment and conducted pre-experiments. The high-time resolution event-related potential (ERP) technique was adopted to capture the signal processing procedure and neural action pattern in the brain in different risk scenarios. Through the analysis of the experimental data, it is discovered that the brain's decision-making under economic management risk demonstrates the decision-maker's adaptive choice. The research findings provide valuable reference for the decision-making of enterprise managers.

Key Words: Risk-Based Decision Making, Electroencephalography (EEG) Experiment, Event-related Potential (ERP), Neuroscience for Decision-making

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Introduction

Depending on the specific conditions, decision-making is either deterministic or indeterministic (i.e. risk-based or fuzzy-based). The risk-based decision-making has been the focal point in the research of economic management, psychology and neuroscience (Krain *et al*., 2006). In recent years, neuroscience has been increasingly integrated with other disciplines, creating new disciplines like neuromanagement, neuroeconomics and the neuroscience for decision-making. This gives researchers the chance to open the black box of the brain, and lays the basis for studying the behavior of decision-makers.

Among the new disciplines, the neuroscience for decision-making is an organic integration between neuroscience and decision-making science. The novel discipline came into being at the beginning of the 21st century. Based on the theories on behavioral decision-making, the neuroscience for decision-making aims to disclose the actual procedure of decision-making and to create the behavioral decision-making model (Huettel, 2010). The relevant research suggests that the brain makes decisions automatically under risk, and the risk-based decision-making process can be observed through imaging. Through the above analysis, this paper attempts to gain more insights into

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risk-based decision-making of the brain. For this purpose, a risk-value model was introduced for decision-making under economic management risk based on the neuroscience for decision-making, revealing the behavioral and neurological principles of mean-variance. Meanwhile, the brain regions and event-related potential (ERP) components involved in economic management risk-based decision-making were discussed in details. On this basis, the author put forward the "economic management risk-based decision-making" hypothesis, and conducted the detailed design of the experimental method, process and paradigm (Miyapuram and Pammi, 2013). To verify the hypothesis, the ERP neuroimaging was adopted to obtain the decision-making process and neural mechanism in the brain under economic management risk in different scenarios. The research findings provide theoretical and empirical references for risk-based decision-making of enterprises, governments and individuals.

Relevant Theories

Risk-value model for decision-making under economic management risk

(1) Behavioral explanation of mean-variance

Risk is usually defined as the probability distribution in uncertain situations. By this definition, it can be expressed by variance or standard deviation. For example, Markowitz, the founder of modern finance, argues that the preference of risk options can be illustrated by the mean-variance model (Drnec *et al*., 2016), and that the decision-maker becomes more risk-averse as the mean-variance indifference curve approaches the upper left quadrant (the inverse is also true).

(2) Neurological evidence of mean-variance

Much research has been done on mean-variance from the perspective of neuroscience (Venkatraman, 2013). Through a gambling experiment, Critchley and Mathias *et al*., (2004) are the first to neurologically verify that the ventral striatum and insula of the brain will be activated with the increase in probability, and that the two brain regions respectively characterize the amount of reward and the degree of risk perception. Similar experiments were performed by Tobler and Christopoulos as well as Christopoulos and Toler. From the angle of neuroscience, all three experiments verified the separability between the brain's characterization of risk and that of value, laying a neurological basis for mean-variance model.

Basic concepts of neuroscience research on economic management risk-based decision-making

(1) Brain regions involved in economic management risk-based decision-making

This section briefly introduces the brain regions related to the decision-making under economic management risk.

1) *Prefrontal cortex*: Located at the forefront of human brain, the prefrontal cortex acts as the supreme commander in decision-making under economic management risk. Previous studies (Cohen and Aston-Jones, 2005) have shown that the medial prefrontal cortex provides the feedback to the expected reward, and the orbitofrontal cortex participates in the characterization of the target value in the decision selection phase; besides, the orbitofrontal cortex is more likely to be activated by fuzzy-based decision-making than risk-based decision-making.

2) *Subcortical structure*: As shown in Figure 1, there are three dopaminergic pathways in the brain (Majer *et al*., 2016), namely the nigrostriatal pathway, the mesolimbic pathway, and the mesocortical pathway. The latter two are closely related to the reward and punishment in economic management risk-based decision-making.

a. Positive motive reward system

Relevant studies have shown that the dopamine system plays a critical role in the adjustment of the decision-making strategy.

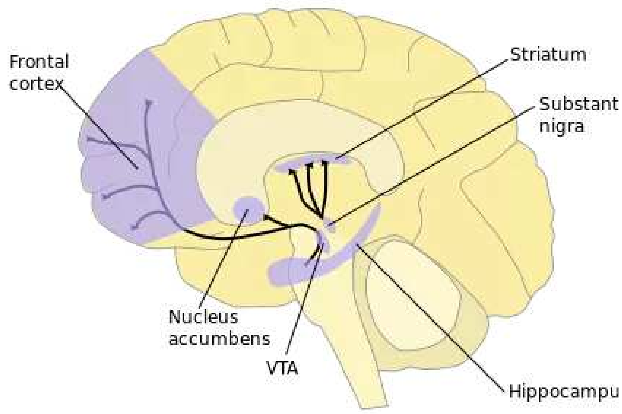

Figure 1. Dopamine reward system

b. Loss avoidance system
The brain regions of the loss avoidance system are presented in Figure 2. Due to space limitations, this section only introduces the insular lobes and cingulate cortexes related to economic management risk-related decision-making. The insular lobes are located deep in the lateral sulcus. Once activated, this brain region can predict the risk avoidance behaviors in the risk-based investment decision-making. The anterior cingulate cortex (Van Duijvenvoorde and Crone, 2013) lies on the inner surface of the frontal lobe. It is the junction center top-down and bottom-up processing of the brain, and the source of the error-related negativity (ERN) and feedback-related negativity (FRN).

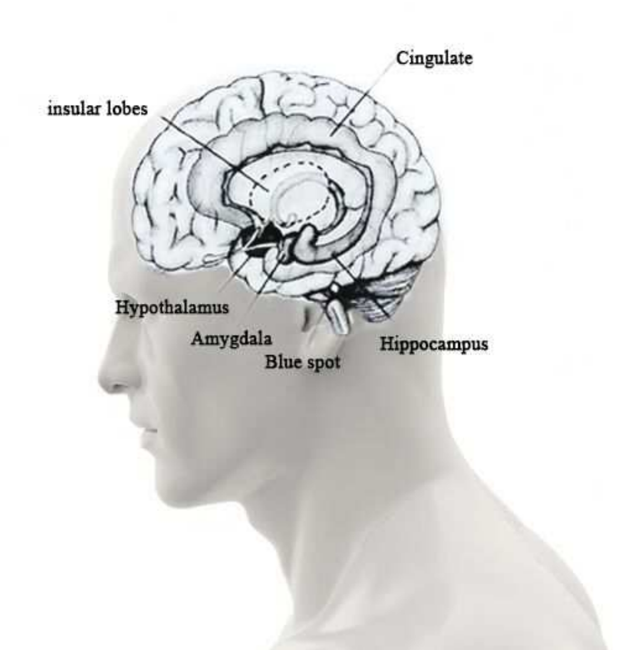

Figure 2. Loss avoidance system

(2) ERP related to economic management risk-based decision-making
During economic management risk-based decision-making, the various psychological and cognitive processes are illustrated by different ERP components (Van *et al.*, 2014). These components can be observed by recording the surface potential of the scalp, and traced to the source regions in the brain. The ERP is featured by high-time resolution.

1) *ERN*
The ERN refers to the ERP component deflected to the negative direction. This component usually appears within 50~100ms after quick or impulsive wrong decision-making. Among the various explanations of the ERN, the most widely accepted theory holds that the ERN is the result of the mismatch between the expected behavior and the actual behavior (Yechiam and Aharon, 2012). In the event of the ERN, the subject should make immediate adjustment to reduce or prevent errors in subsequent tasks.

2) *Error positivity (Pe)*
The Pe stands for the ERP component deflected to the positive direction. This component occurs after the ERN, at about 200~600ms after the wrong response. It can be traced back to the rostrum of the anterior cingulate gyrus or posterior cingulate gyrus. Figure 3 displays the waveform and scalp distribution of the ERN and the Pe (Summerfield and Tsetsos, 2012). Despite the various explanations of the Pe, it is generally agreed, through amplitude research and source tracing, that the Pe and the ERN reflect two distinct phases of the same processing system, and help to understand the overall processing of errors.

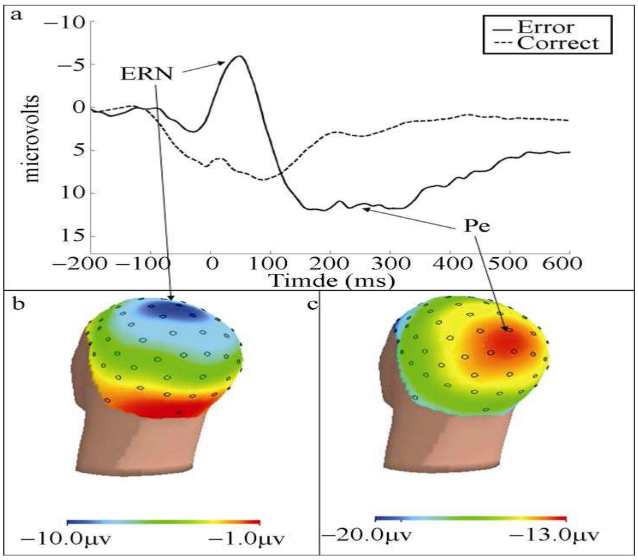

Figure 3. Waveform and scalp distribution of the ERN and the Pe

Research on Decision-Making Mechanism under Economic Management Risk Based on ERP Neuroimaging Technique

Research hypothesis
During the economic risk-based decision-making, the risk selection is related to the ERP components of the ERN and the Pe. Considering the effect of risk selection on the decision-making process, the following hypothesis was put forward:

Hypothesis: During the economic risk-based decision-making, the decision-making mechanism changes with the risk scenario (risk-advantage, risk-neutral and risk-disadvantage) and the decision on investment (investment or non-investment), leading to variation in the ERN and Pe components of the ERP in the brain.

Experimental method and process

19 healthy university students (10 males and 9 females) were recruited for our experiment. The subjects selected between the definite value 1 and the probable result 2, 3 or 4. Table 1 lists the risk-advantage, risk-neutral and risk-disadvantage probabilities for 2, 3 and 4. 20 pre-experiments were conducted before the formal experiments, so that the subjects could fully understand the experimental process. The formal experiments were divided into 6 rounds, each of which contains 90 experiments. The experiments were separated by an interval of 1s, giving the subjects a break. Meanwhile, the electroencephalography (EEG) data were tested on a computer. The experimental process is presented in Figure 4 (Grossberg and Gutowski, 1987). After each round of experiments, each of the subjects received a reward. The amount of the reward was determined by his/her performance score (15 points for 1 yuan).

Table 1. Experimental design

Risk situation	Value 4	Value 3	Value 2
Risk advantage	4×1/3	3×1/2	2×2/3
Risk-neutral	4×1/4	3×1/3	3×1/2
Risk disadvantage	4×1/5	3×1/4	3×1/3

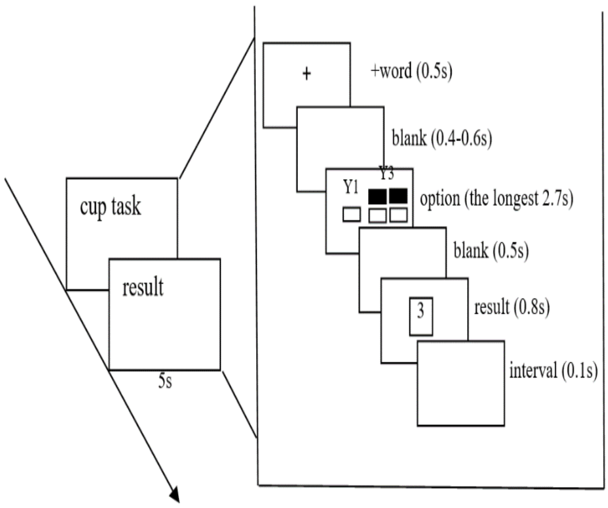

Figure 4. Experimental process

After the experiments, the EEG signals were analyzed by Neuroscan commercial analysis software, and the EEG data were tracked back to the source regions in the brain. The specific steps are shown in Figure 5.

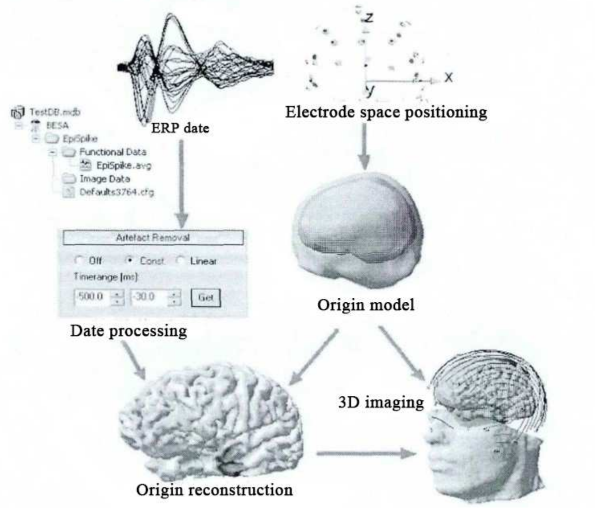

Figure 5. Source tracing

Experimental results and analysis

(1) Computer analysis of option presentation

Taking the decision-making point as point 0, the 400ms and 400ms before and after this point were considered as the study period. With -400ms~200ms as the baseline, the computer waveforms before and after point 0 were observed after the signals under the three risk scenarios were superposed (Moser *et al.,* 2014).

Two ERP components, i.e. the ERN and the PE, were discovered in different scenarios. The former appeared at about 20ms and concentrated in the center of the prefrontal lobe, while the latter appeared at 100ms and concentrated near the center of the prefrontal lobe.

Next, the author will discuss the ERN and Pe waveform curves of economic management risk-based decision-making under investment or non-investment scenarios.

(2) Economic management risk-based decision-making under investment scenario

1) *ERN*

The tracing results show that the ERN concentrated in the prefrontal lobe under the investment scenario. 10 electrode points were selected from both sides of the central part of the prefrontal lobe as the typical statistical points. Then, the 3×10 repeated measures ANOVA was performed under three different risk scenarios.

After removing the invalid data, the remaining 16 subjects received data analysis. Figure 7 compares the ERN under investment in different risk scenarios. The mean amplitude of the ERN under investment in different risk scenarios was subject to Bonferoni correction, and recorded in Figure 8.

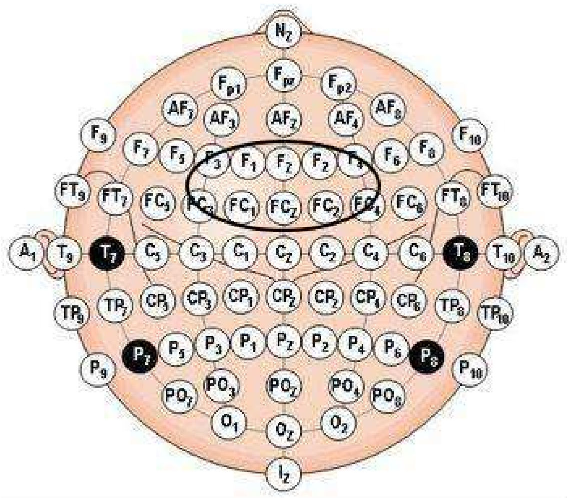

Figure 6. Distribution of electrode points and the ERN components of these points

Judging by the waveform under investment, the ERN in the risk-neutral scenario is smaller than that in the risk-disadvantage scenario. According to the ERN amplitude, the ERN induced by the risk-advantage scenario is lower than that induced by the risk-neutral scenario. Thus, the risk-advantage scenario induces the lowest ENR. To sum up, the ERN amplitude is correlated with the risk scenarios of the decision-making (Lăzăroiu *et al.*, 2017).

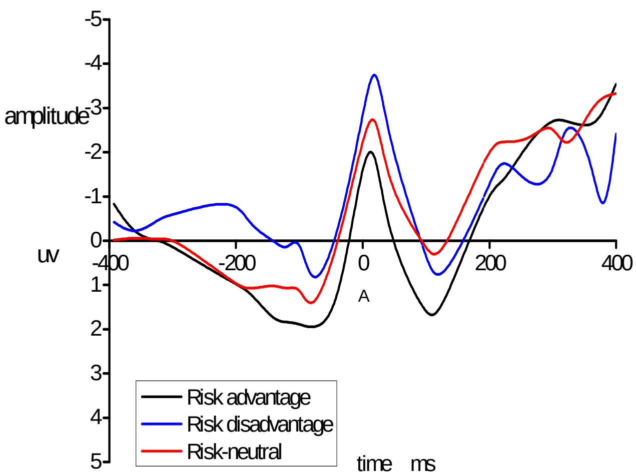

Figure 7. ERN under investment in different risk scenarios

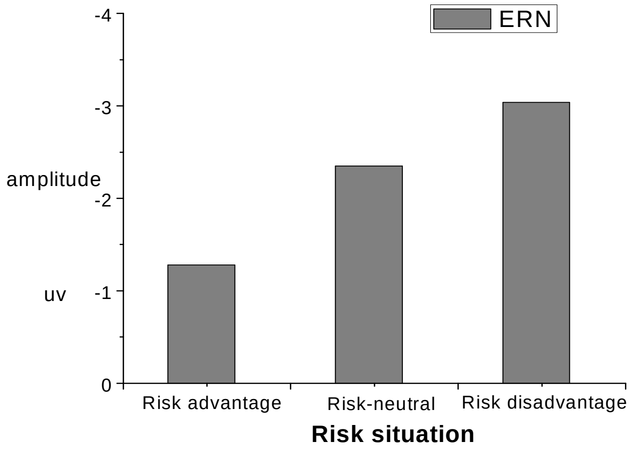

Figure 8. Mean ERN under investment in different risk scenarios

2) *Pe*

According to source-tracing, the Pe is mainly distributed in the prefrontal lobe and the parietal region. Considering the distribution pattern, the 10 electrode points were selected from the center of the prefrontal lobe as the typical statistical points (Figure 9). Similar to the ERN data processing, the 3×10 repeated measures ANOVA was performed under three different risk scenarios. After removing the invalid data, the remaining 16 subjects received data analysis. Figure 10 compares the Pe under investment in different risk scenarios. The mean amplitude of the Pe under investment in different risk scenarios was subject to Bonferoni correction, and recorded in Figure 11.

Judging by the waveform under investment, the Pe in the risk-disadvantage scenario is smaller than that in the risk-neutral scenario. According to the amplitude image, the risk-advantage scenario induces the greatest Pe. This means the Pe amplitude depends on the specific risk scenario of the decision-making.

(3) Economic management risk-based decision-making under non-investment scenario

The ENR and Pe data under non-investment were processed in a similar way as those under investment. Figures 12~15 show the ENR and Pe results under non-investment in three different risk scenarios.

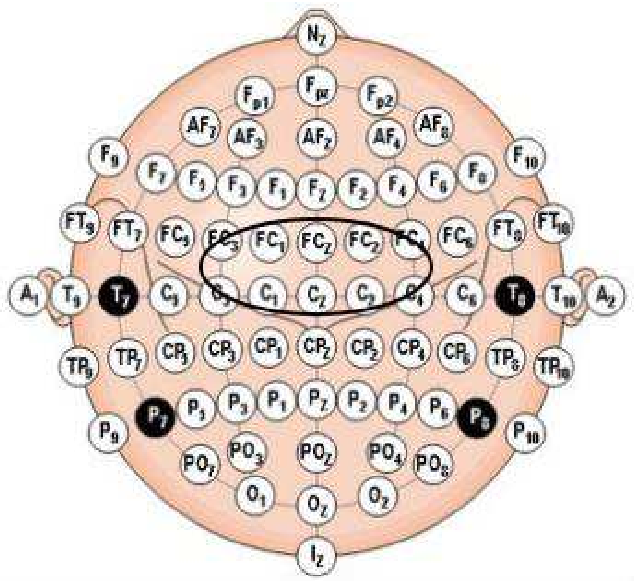

Figure 9. Distribution of electrode points and the Pe components of these points

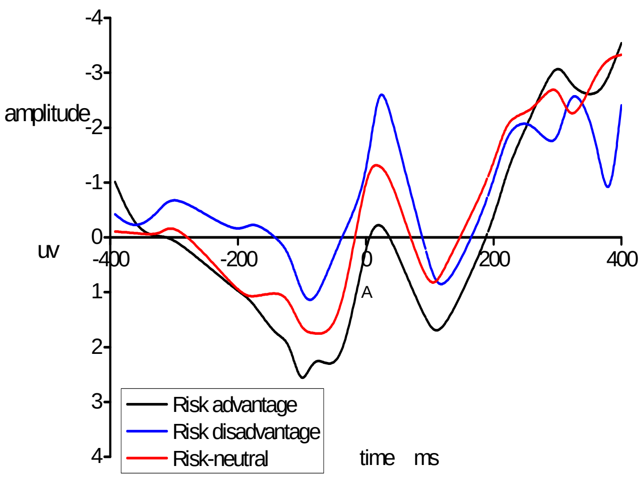

Figure 10. Pe under investment in different risk scenarios

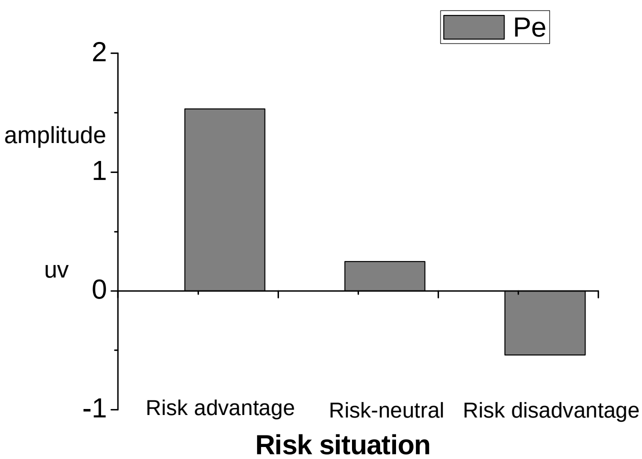

Figure 11. Mean Pe under investment in different risk scenarios

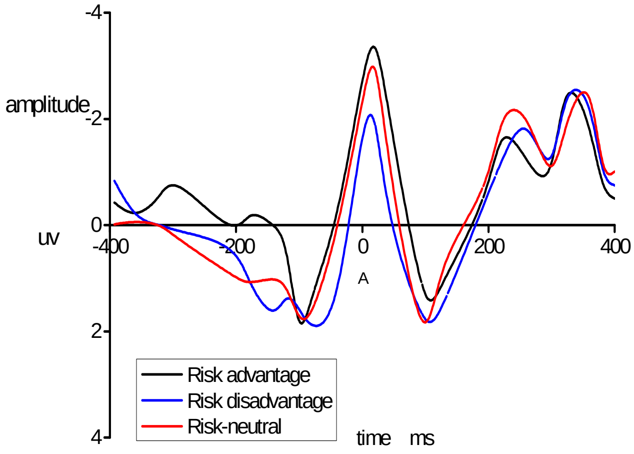

Figure 12. ERN under non-investment in different risk scenarios

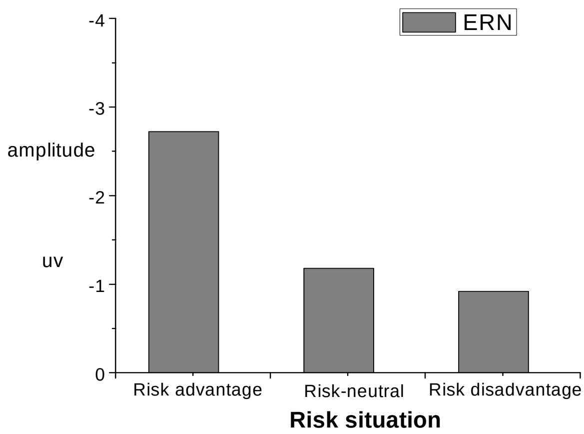

Figure 13. Mean ERN amplitude under non-investment in different risk scenarios

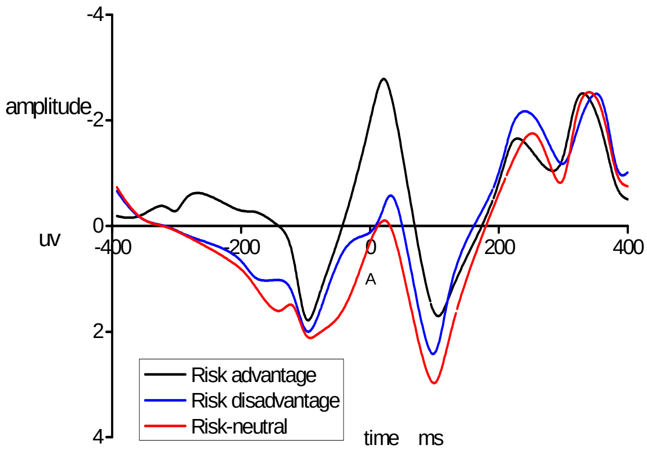

Figure 14. Pe under non-investment in different risk scenarios

(4) Results analysis

The above results reveal that all three risk scenarios can induce obvious ERN and Pe during economic management risk-based decision-making. Below is an analysis of the difference in the ERN and Pe induced by investment and non-investment.

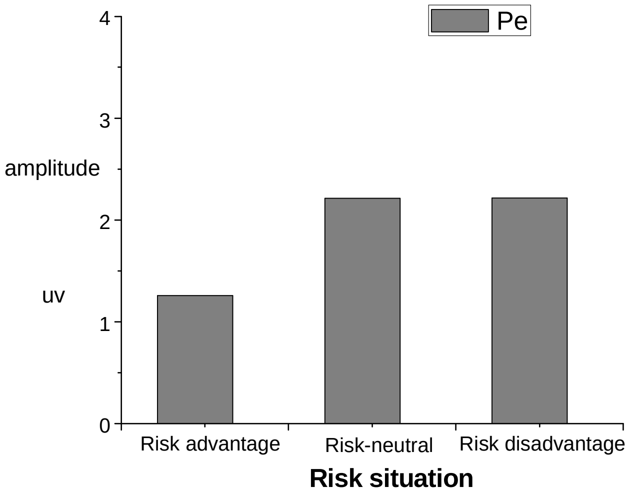

Figure 15. Mean Pe amplitude under non-investment in different risk scenarios

1) ERN

a. Under investment, the three risk scenarios are ranked as risk-advantage<risk-neutral<risk disadvantage in descending order of ERN (Figure7). Statistically speaking, the smallest ERN occurs the risk-advantage scenario, and there is no difference in the ERN between the risk-neutral and the risk-disadvantage scenarios.

b. Under non-investment, the three risk scenarios are ranked as risk-disadvantage<risk-neutral<risk advantage in descending order of ERN (Figure 12). Statistically speaking, the biggest ERN occurs in the risk-advantage scenario, and there is no difference in the ERN between the risk-neutral and the risk-disadvantage scenarios.

2) Pe

Under both investment and non-investment, there is an obvious Pe 100ms after the emergence of the ERN.

a. Under investment, the three risk scenarios are ranked as risk-disadvantage<risk-neutral<risk advantage in descending order of Pe (Figure 10). Statistically speaking, the biggest Pe occurs in the risk-advantage scenario, and there is no difference in the Pe between the risk-neutral and the risk-disadvantage scenarios.

b. Under non-investment, the Pe in risk-neutral and risk-disadvantage scenarios is greater than that in risk-advantage scenario, but the amplitude is similar across the three scenarios (Figure 14). The same results can be obtained through statistical analysis.

Conclusion

To disclose the mechanism of decision-making under economic management risk, this paper draws merits from neuroscience, and explores the mechanism through an ERP neuroimaging experiment. Three risk scenarios (risk-advantage, risk-neutral, and risk-disadvantage) and two options (investment and non-investment) were taken into account. The main conclusions are as follows:

First, the three risk scenarios induce the ERN under both investment and non-investment. This proves the “economic management risk-based decision-making” hypothesis. Moreover, the ERN reflects the adaptive choice for the potential risk and reward in the decision-making under economic management risk.

Second, obvious Pe can be induced by the ERN of any amplitude. The Pe is negatively correlated with the ERN. Through the analysis on the Pe under investment and non-investment in the three risk scenarios, the decision-maker was proved to be risk-averse by the Pe results. This demonstrates the mental level assessment of the subjects.

Overall, this research reveals the mechanism of economic management risk-based decision-making in different risk scenarios. The research findings provide theoretical and empirical references for risk-based decision-making of enterprises, governments and individuals.

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