Psychological and Physiological Mechanisms in the Workplace: An ERP Study on Risky Decision-Making of Safety Behaviors Among Industrial Employees

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Abstract: Even with highly automated modern human-machine systems, safety accidents persist, largely stemming from operators' unsafe behaviors. Heavy cognitive loads from multi-sensory information processing on human-machine interfaces impair workers' judgment. From psychological and cognitive perspectives, employees can be divided into high-, moderate- and low-proactivity groups, whose safety performance varies markedly. It is practically valuable to develop targeted interventions to reduce unsafe behaviors based on proactivity traits. This research explores cognitive neural disparities in safety risk decision-making among workers with different proactivity levels. The study adapted the Iowa Gambling Task to simulate industrial safety decision scenarios and recorded participants' event-related potential (ERP) signals throughout experiments. Feedback-related negativity (FRN) and P300, two core neural indicators for outcome evaluation and risk processing, served as electrophysiological markers. Drawing on existing theories of proactivity and safety cognition, testable hypotheses were proposed to uncover neural patterns behind safety risk judgments. ERP analyses confirmed all hypotheses. Under rewarding feedback, high-proactivity individuals produced larger P300 amplitudes. When facing loss-related negative feedback, low-proactivity participants showed the strongest FRN responses, with gaps widening under high-risk settings; all differences were statistically significant. In conclusion, proactivity drives notable cognitive neural divergences in safety risk decision-making and shapes neural reactions during risk evaluation. These results support enterprises in safeguarding staff wellbeing, improving person-job fit, refining incentive systems, and comprehensively boosting workplace safety management.

Keywords: Safety Management; ERP Experiment; Safety Behavior; Risky Decision-Making; Human-Machine Interaction

1. Introduction

Human response to signals is essentially a process of information processing, in which attention, as a form of mental effort, runs through the entire procedure. The human brain receives a constant stream of diverse dynamic external information, yet it selectively focuses on part of such information — a characteristic known as the selectivity of attention. Individuals differ in the level of information processing when confronted with near-miss scenarios[1]. This indicates that people learn unevenly from near-miss events, which ultimately leads to disparate outcomes in subsequent risky decision-making.

Event-related potentials (ERPs) as specific electroencephalographic signals generated by the brain in response to external stimuli such as auditory, visual and tactile inputs, which are time-locked to the triggering stimuli[2]. ERPs serve as a vital approach to investigating higher brain functions including cognition, memory, comprehension, learning, judgment, reasoning and intelligence, and have been widely adopted in human cognitive research and clinical medical assessment[3].

In the field of work safety, individual safety behavior is complex and dynamic, featuring diversity, purposiveness, planning and plasticity. It is regulated by personal safety awareness, governed by mental activities such as thinking, volition and emotion, and also influenced by social psychology and external environments. Psychological studies have demonstrated a close correlation among individual attitudes, emotions, cognition and behaviors. Proactive individuals are less constrained by environmental factors, capable of identifying favorable opportunities and taking a series of proactive actions. In contrast, inactive individuals exhibit the opposite traits[4]. Specifically, personal attitudes, awareness, knowledge and cognitive ability determine the level of safety performance, resulting in individual differences in safety behaviors.

In this study, participants are categorized into three groups: high-proactivity, moderate-proactivity and low-proactivity individuals. We explore how factors affecting work safety behavior vary across these groups, and further analyze the discrepancies in their safety behaviors. The analytical results are presented in Table 1.

Risky decision-making was initially explained by the expected utility theory proposed by Neumann and Morgenstern in 1947[5]. Later, Kahneman and Tversky put forward the prospect theory in 1979, arguing that human cognitive factors exert a crucial influence on decision-making[6]. Levin, Gaeth, and Schreiber et al.examined the relationship between personality traits and risky decision-making under different gain-loss conditions and framing effect types[7]. Their findings revealed that individuals with high neuroticism are more susceptible to framing effects, while those with high openness and boldness tend to prefer high-risk options[7].Nicholson demonstrated that an individual's overall risk-taking tendency across various life domains is positively correlated with extraversion and openness, and negatively correlated with neuroticism, agreeableness, and conscientiousness[8]. Cavanagh, James E. et al. investigated the effects of age on the underlying cognitive processes and risky decision-making using the Balloon Analog Risk Task (BART)[9].

Table 1. Differences in Individual Safety Behaviors

Factors of Safety Behavior Differences	High Proactivity	Low Proactivity	Moderate Proactivity
Safety Awareness	Strong	Weak	Moderate
Emotion	Positive, volatile	Prone to negativity	Stable
Self-Consciousness	Autonomous	Dependent	Disciplined
Environment	Actively adaptive	Highly environment-sensitive	Environmentally adaptive

2. Materials and Methods

2.1 Research Hypotheses

When making decisions under safety-related risks, individuals selectively process information during the information-gathering stage. Different individuals prioritize different information while ignoring other details, assigning higher weights to information they deem important, which influences their judgment and final decisions. Regarding risk targets, different individuals may perceive the same risky decision-making task as having different subjective values. After evaluating the subjective utility of the risk target against environmental information, varying risk preferences among individuals lead to the selection of different alternatives.

In risky situations, factors influencing decision-making stem from two aspects: environmental conditions such as task characteristics and framing effects, and individual traits including personality and cognitive ability. An individual's tendency toward risk events or outcomes is a relatively stable personality trait. Pratt first proposed classifying risk preferences into three categories: risk aversion, risk neutrality, and risk-seeking[10]. Nicholson et al. found that individuals' risk-taking levels across different decision-making contexts are positively correlated with openness and extraversion[8]. Significant differences exist in cognitive processes such as stimulus discrimination, cognitive evaluation, memory updating, and final decision-making among individuals with different levels of proactivity[11]. Highly proactive individuals tend to seek to change their environment and hold an actively engaged decision-making attitude, while low-proactivity individuals tend to compromise with difficulties and adopt a passive, reactive decision-making attitude. Previous experimental studies have shown that decision outcomes differ significantly between participants with different proactive personality types under different emotional states. Based on the classification and characteristics of individuals with varying proactivity levels, the following hypotheses are proposed:

Hypothesis1: Highly proactive individuals are more inclined toward risk-seeking in safety behavior-related decisions.

Hypothesis2: Low-proactivity individuals are more inclined toward risk aversion in safety behavior-related decisions.

Hypothesis3: Moderately proactive individuals tend toward risk neutrality in safety behavior-related decisions.

Electrophysiological characteristics of ERPs are analyzed by first collecting electroencephalogram (EEG) signals from the scalp using a 64-channel electrode cap following the international 10-20 system. The collected signals are then amplified, converted into digital signals, and recorded by a computer. After noise reduction, the corresponding ERP components are obtained. Analysis of ERP components focuses on four key aspects: scalp distribution, polarity, latency, and amplitude. The components most closely related to psychological factors include N1, P1, N2, P2, P3, and slow waves (>500 ms, with significant sustained deviation from baseline). Among these, N1, P1, and P2 are exogenous (physiolofgical) components influenced by the physical properties of stimuli; N2 and P3 are endogenous (psychological) components unrelated to stimulus physical properties, but associated with participants' mental state and attention. The P3 component is the most typical and widely used in ERP research, closely linked to cognitive processes and commonly used to measure cognitive functions during decision-making (e.g., responses to stimulus evaluation and classification).

P300, named for its typical occurrence around 300 ms after stimulus onset, was first identified as a single wave by Sutton et al. in 1965 using the oddball paradigm[12]. Classified by latency, P300 is a late positive component, recorded at the scalp when participants attend to and identify target stimuli, with the highest amplitude near the Pz electrode[13]. Recent research has shown that P300 is not a single component but can be divided into P3a and P3b. P3a reflects attentional processes related to signal evaluation, serving as an initial response to stimuli, while P3b reflects attentional and memory processes during signal processing[13]. Two main interpretations exist regarding the cognitive processes reflected by P300: one view suggests it merely marks the end of a perceptual task, while Donchin proposed that P300 latency reflects the time required to evaluate or classify stimuli, indicating its role in studying higher-order cognitive processes in the brain[14]. Due to its relatively large amplitude and ease of elicitation, P300 is widely used in cognitive science research. Numerous studies have shown that P3 is associated with factors such as task difficulty in risky decision-making, subjective probability, stimulus salience, evaluative attitudes toward decision outcomes, decision confidence, attention, memory, and emotion[15-17]. Regarding P300, if it reflects the evaluation of relative magnitude based on a wager as a reference point, feedback with a larger relative magnitude elicits a larger P300 than feedback with a smaller relative magnitude, demonstrating sensitivity to relative quantities.

FRN peaks approximately 250–300 ms after stimulus presentation, appearing as a negative ERP component in the prefrontal region when participants observe errors or negative feedback during the outcome feedback stage. Research indicates that positive feedback increases dopamine levels, inhibiting activity in the anterior cingulate cortex (ACC) and resulting in smaller FRN amplitudes[18-19]. Conversely, negative feedback does not increase the activity of midbrain dopamine neurons, leading to stronger ACC activity and larger FRN amplitudes. There is growing interest in exploring the cognitive processes reflected by FRN, with two main theoretical explanations: reinforcement learning theory and the emotional/motivational hypothesis. The brain system thus provides advance warnings for correct and incorrect responses, adjusting expectations based on feedback to reflect dynamic learning processes underlying decision-making behavior, which in turn modulates decisions in subsequent trials. In gambling tasks, both large and small monetary losses elicit large FRN amplitudes, while correct/incorrect responses alone elicit little to no negative deflection, indicating that FRN is sensitive to gains and losses but not to response correctness. The relevant hypotheses are presented in Figure 1.

Hypothesis H1: Individuals with different levels of proactivity differ in their P300 waveforms in response to positive feedback incentives in risky scenarios, and such differences are more pronounced under low-risk conditions.

H1-1: The P300 waveform is more prominent in high-proactivity individuals.

H1-2: The P300 waveform amplitude is smaller in low-proactivity individuals.

H1-3: The P300 waveform of

moderate-proactivity individuals falls between the above two groups.

Hypothesis H2: Individuals with different levels of proactivity differ in their P300 waveforms elicited by negative feedback related to losses in risky scenarios, and such differences are more pronounced under low-risk conditions.

H2-1: The P300 waveform is more prominent in high-proactivity individuals.

H2-2: The P300 waveform amplitude is smaller in low-proactivity individuals.

H2-3: The P300 waveform of moderate-proactivity individuals falls between the above two groups.

Hypothesis H3: Individuals with different levels of proactivity differ in their FRN waveforms elicited by negative feedback related to losses in risky scenarios, and such differences are more pronounced under high-risk conditions.

H3-1: The FRN waveform amplitude is smaller in high-proactivity individuals.

H3-2: The FRN waveform amplitude is the most prominent in low-proactivity individuals.

H3-3: The FRN waveform differences of moderate-proactivity individuals fall between the above two groups.

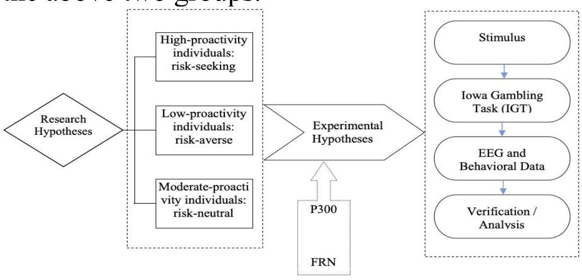

Figure 1. Theoretical Hypotheses and Experimental Hypotheses

2.2 Experimental Paradigm and Procedure

To investigate risky decision-making using ERPs, participants complete a simple game-like task, during which their behavioral responses and electroencephalographic (EEG) activity are recorded to analyze their responses to different feedback stimuli. Gambling paradigms are frequently employed in classic psychological experiments. In neuroscience, the Iowa Gambling Task (IGT) is a widely used experimental paradigm for examining affective decision-making mechanisms. Recent research has accumulated substantial data on the IGT, including whether it measures ambiguous or risky decision-making, its relationship with emotion and cognition, its links to working memory and declarative memory, and its underlying neural networks and molecular genetic mechanisms[20]. Studies have shown that individuals with different risk orientations perform and behave very differently in the IGT[21]. Typically, risk-seeking individuals tend to choose disadvantageous decks more frequently, resulting in significantly poorer task performance compared to risk-averse individuals.

The Iowa Gambling Task was designed by Damasio and his collaborator Bechara et al[22]. To simulate real-life decision-making scenarios, characterized by uncertain rewards and penalties. The task involves four decks of cards: two "advantageous decks" with small immediate rewards but positive long-term net outcomes, and two "disadvantageous decks" with large immediate rewards but negative long-term net outcomes. During the experiment, four card piles (1, 2, 3, and 4) are displayed on the screen. Participants are asked to select one card from any of the four piles. The selected card reveals either a gain or a loss. Participants start with 2000 virtual coins; all gains and losses are automatically added to or subtracted from their total balance. The goal is to win as many coins as possible and maximize their profit.

2.2.1 Participants are not informed of the following rules

Deck 1 (Disadvantageous, negative expected value): Every selection yields an immediate gain of 100 coins. However, once every 10 trials (probability = 1/10), a card will show a gain of 100 coins along with a large loss of 1250 coins.

Deck 2 (Disadvantageous, negative expected value): Every selection yields an immediate gain of 100 coins. However, five out of every 10 trials (probability = 1/2) will result in a gain of 100 coins along with a loss of 250 coins.

Deck 3 (Advantageous, positive expected value): Every selection yields an immediate gain of 50 coins. However, five out of every 10 trials (probability = 1/2) will result in a gain of 50 coins along with a loss of 50 coins.

Deck 4 (Advantageous, positive expected value): Every selection yields an immediate gain of 50 coins. However, once every 10 trials (probability = 1/10), a card will show a gain of 50 coins along with a loss of 250 coins.

Notably, Deck 1 has a higher magnitude of losses, while Deck 3 has a higher frequency of losses compared to Deck 4. Participants' decision-making behaviors are assessed using metrics such as net gain, the proportion of strategy shifts following positive/negative feedback, and the number of selections under different reward magnitudes and punishment frequencies. Concurrently, EEG data are recorded throughout the experiment to examine the decision-making-related ERP components, P300 and FRN. As shown in the Figure 2.

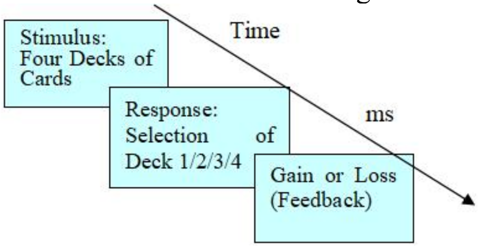

Figure 2. Experimental Procedure Diagram

2.2.2 Participants

Fifty-one safety-related personnel from industrial enterprises were recruited as participants, aged between 17 and 35 years, including 32 males and 19 females. All participants were right-handed, with no history of psychiatric disorders or brain trauma, and had normal or corrected-to-normal vision. All participants volunteered to take part in the study, read the experimental instructions prior to the experiment, signed an informed consent form, and received corresponding remuneration upon completion of the experiment.

2.2.3 Experimental Preparation

First, participants completed the BIS-BAS Scale questionnaire to be classified into high-proactivity, low-proactivity, or moderate-proactivity groups[23]. Before the experiment, participants washed their hair in the laboratory washroom using a special conditioner-free shampoo and dried their hair thoroughly. They were then led into an electromagnetically shielded experimental room, seated in a comfortable chair, and prepared for EEG recording: an electrode cap was fitted, electrodes were attached, and conductive gel was injected (a process that took 15–30 minutes). During this period, the experimenter chatted with participants to help them relax and maintain a calm, non-anxious state before the experiment began. While waiting, participants were provided with a printed explanation of the experimental procedure to read, and any questions were addressed by the experimenter. The viewing distance was adjusted to approximately 1 meter, and the lighting was set to a comfortable level for each participant.

2.2.4 Experimental Procedure

2.2.4.1 Instructions

"You are an employee in the production workshop of an enterprise. Rewards and punishments will be given based on your identification of and preference for safety-related behavioral risks, corresponding to gains and losses during the card-flipping task. Press the 'Enter' key when you are ready to begin."

2.2.4.2 Practice Session

Before the formal experiment, participants completed 5 practice card flips to familiarize themselves with the operation. They could restart the practice interface by pressing the '5' key on the keyboard. The formal experiment began after pressing the 'Enter' key.

2.2.4.3 Formal Experiment

The participant's total score was displayed at the top of the screen, starting with an initial amount of 2000 virtual coins. Below the score, four decks of cards with identical backs were displayed side by side, labeled with the numbers "1, 2, 3, and 4". Participants selected a deck by pressing the corresponding number key (1, 2, 3, or 4), which automatically turned the card over. The outcome (gain or loss) was displayed, and the cumulative total was updated at the top of the screen. The feedback screen remained visible for 600 ms before automatically proceeding to the next trial. After 50 card selections, a rest prompt appeared on the screen; participants could continue the experiment by pressing any key.

2.2.4.4 Post-Experiment

EEG data were saved, the electrode cap was removed from the participant, and the participant was thanked for their participation.

2.3 Experimental Implementation

EEG signals were recorded using a 32-channel electrode cap arranged in accordance with the extended International 10–20 Electrode System. Horizontal and vertical electrooculography (EOG) were recorded simultaneously, with the nose tip serving as the reference electrode. The band-pass filter was set at 0.05–70 Hz and the sampling rate at 500 Hz. Electrode-scalp impedance was kept below 5 kΩ throughout the experiment.

Offline processing and amplification of raw EEG data were performed via Scan 4.5 software. The analysis epoch was set to 500 ms, covering 100 ms pre-stimulus to 400 ms post-stimulus. The processing procedures in Scan 4.5 included artifact segment rejection, EOG correction, epoch extraction (100 ms before stimulus onset to 400 ms after stimulus onset), baseline correction, artifact removal, low-pass filtering at 20 Hz, and classified averaging [24].

Referring to existing literature on risky decision-making, electrodes FZ, FCZ and CZ were selected to analyze FRN and P300 components. Located along the midline of the frontal and centro-parietal regions, these three electrodes primarily captured P300 and FRN signals originating from the anterior cingulate cortex and medial prefrontal cortex (see Figure 3). FRN was defined as the maximum negative deflection occurring 200–300 ms after feedback onset; if no negative deflection was observed within this time window or only positive waveforms appeared, the FRN amplitude was recorded as zero. P300 was defined as the maximum positive deflection within 300–400 ms post-stimulus. The electrode topography as shown in the Figure 3.

SPSS 20.0 was adopted for significance testing, and repeated-measures analysis of variance (ANOVA) was used to process and analyze behavioral data.

This study adopted the classic Iowa Gambling Task (IGT) paradigm to explore differences in safety-related risky decision-making among individuals with varying proactivity levels. Most previous studies using this paradigm adopted 100 trials; the present experiment increased the total number to 400 trials. The adjustment was made because participants tended to make ambiguous judgments and engage in ambiguous decision-making in the early stage. Behavioral data revealed that choices were irregular within the first 40 trials, representing typical ambiguous decision-making.

In card selection tasks involving risky decisions, highly proactive participants preferred options with higher risks and greater potential gains. Low-proactivity participants tended to make conservative choices with smaller gains and generally avoided consecutive selections of loss-related cards. Moderately proactive participants exhibited mixed behavioral patterns and made choices after rational deliberation.

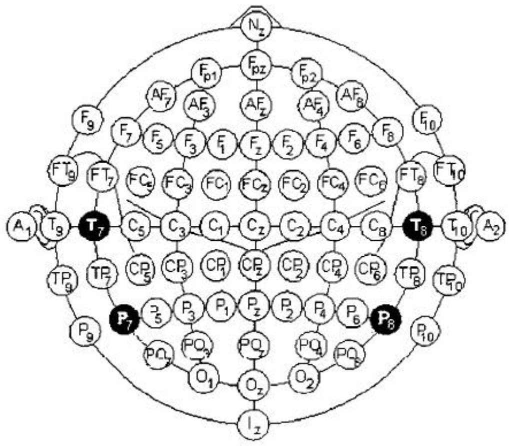

Figure 3. Electrode Topography

3. Results

3.1 Experimental Data

The ERP waveforms of participants with different proactivity levels under loss conditions are presented in the corresponding figure. Thin lines denote waveforms elicited by negative feedback, and thick lines represent waveforms evoked by positive feedback. The negative deflection at 200–300 ms post-stimulus corresponds to FRN, while the positive deflection at 300–400 ms post-stimulus corresponds toP300. As shown in Figure 4.

The ERP waveforms of individuals with different proactivity levels under the gain condition are shown in the figure. Thin lines represent the EEG waveforms elicited by negative feedback stimuli, while thick lines represent those elicited by positive feedback stimuli. The negative deflection occurring 200–300 ms after stimulus onset corresponds to the FRN, and the positive deflection occurring 300–400 ms after stimulus onset corresponds to the P300. As shown in Figure 5.

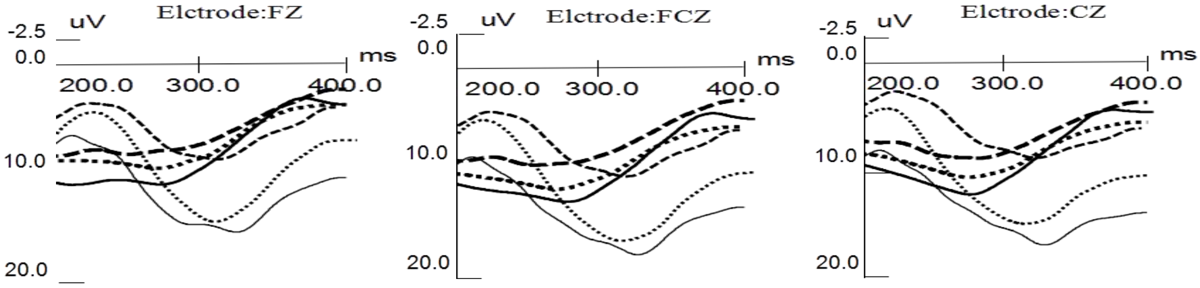

Figure 4. Comparison of Risk Differences Among Individuals with Different Proactivity Levels Under Gain Conditions

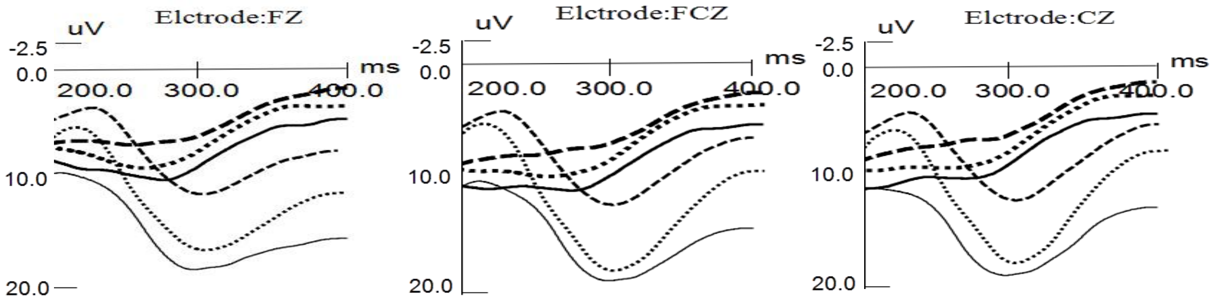

Figure 5. Comparison of Risk Differences Among Individuals with Different Proactivity Levels Under Loss Conditions

The ERP waveforms of individuals with different proactivity levels during high-risk choices are shown in the figure. Thin lines represent the EEG waveforms elicited by negative feedback stimuli, while thick lines represent those elicited by positive feedback stimuli. The negative deflection occurring 200–300 ms after stimulus onset corresponds to the FRN, and the positive deflection occurring 300–400 ms after stimulus onset corresponds to the P300. As shown in Figure 6.

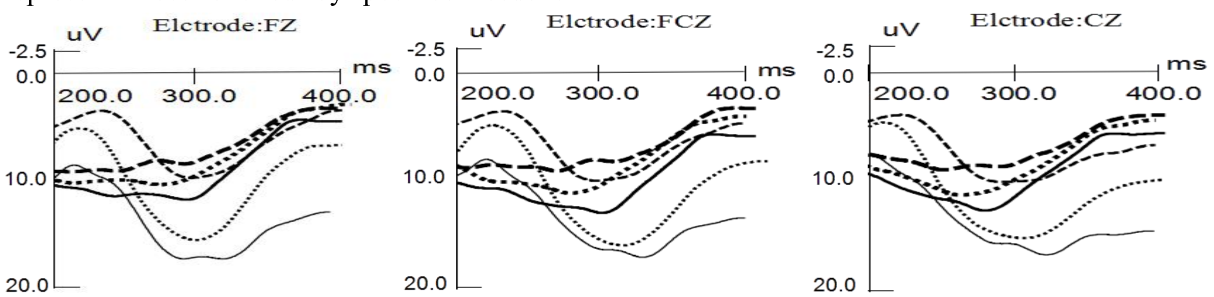

Figure 6. Comparison of Risk Differences Among Individuals with Different Proactivity Levels Under High-Risk Conditions

The ERP waveforms of individuals with different proactivity levels during low-risk choices are shown in the figure. Thin lines represent the EEG waveforms elicited by negative feedback stimuli, while thick lines represent those elicited by positive feedback stimuli. The negative deflection occurring 200–300 ms after stimulus onset corresponds to the FRN, and the positive deflection occurring 300–400 ms after stimulus onset corresponds to the P300. As shown in Figure 7.

The schematic As shown in Figure 8.

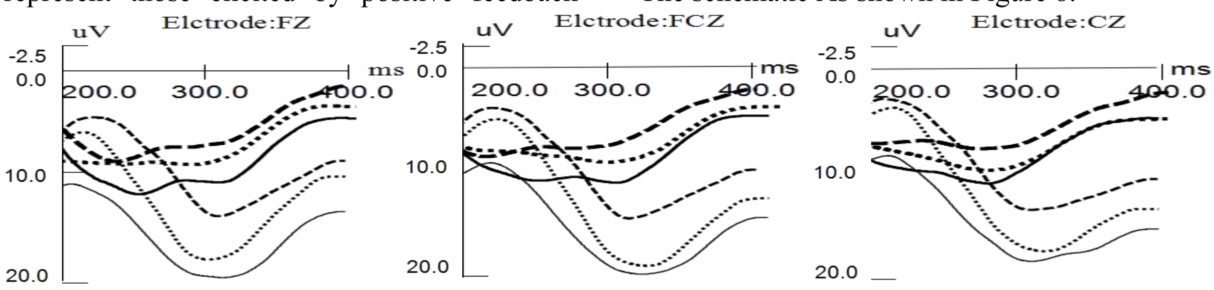

Figure 7. Comparison of Risk Differences Among Individuals with Different Proactivity Levels Under Low-Risk Conditions

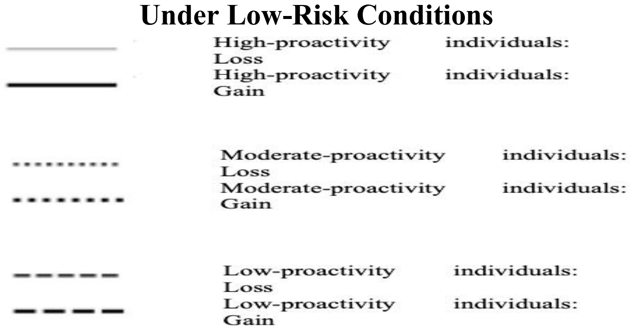

Figure 8. Schematic

3.2 Hypothesis Testing

A three-way repeated-measures analysis of variance (ANOVA) was conducted on P300 amplitude, with three participant groups (high-proactivity, low-proactivity, moderate-proactivity) × four stimulus types (positive gain, negative gain, high-risk gain, low-risk gain) × three electrode sites (FZ, FCZ, CZ). The results indicated a significant main effect of stimulus type ($F(1,16) = 7.437$, $P = 0.003 < 0.05$). Among participants with different proactivity levels, high-proactivity individuals elicited larger P300 amplitudes in response to positive feedback stimuli, which was consistent with Hypothesis H-1. The detailed results are presented in Table 2.

Table 2. Within-Subjects Effects of Repeated-Measures ANOVA for P300 Amplitude under Positive Feedback

Effect		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Stimulus Type	Sphericity Assume	2876.104	2	1438.052	7.437	.003	.403
	Greenhouse-Geisser	2876.104	1.928	1491.965	7.437	.004	.403
	Huynh-Feldt	2876.104	2.000	1438.052	7.437	.003	.403
	Lower-bound	2876.104	1.000	2876.104	7.437	.020	.403

A three-way repeated-measures analysis of variance (ANOVA) was conducted on P300 amplitude, with three participant groups (high-proactivity, low-proactivity, moderate-proactivity) × four stimulus types (positive loss feedback, negative loss feedback, high-risk loss feedback, low-risk loss feedback) × three electrode sites (FZ, FCZ, CZ). The results revealed a significant main effect of stimulus type ($F(1,16) = 42.139$, $P = 0.000 < 0.05$). Compared with participants of other proactivity levels, high-proactivity individuals exhibited larger P300 amplitudes in response to negative feedback stimuli, which was consistent with Hypothesis H-2. The detailed results are presented in Table 3.

Table 3. Within-Subjects Effects of Repeated-Measures ANOVA for P300 Amplitude under Negative Feedback

Effect		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Stimulus Type	Sphericity Assume	18107.701	2	9053.850	42.139	.000	.793
	Greenhouse-Geisser	18107.701	1.762	10277.597	42.139	.000	.793
	Huynh-Feldt	18107.701	2.000	9053.850	42.139	.000	.793
	Lower-bound	18107.701	1.000	18107.701	42.139	.000	.793

A three-way repeated-measures analysis of variance (ANOVA) was conducted on FRN amplitude, with three participant groups (high-proactivity, low-proactivity, moderate-proactivity) × four stimulus types (positive gain, negative gain, high-risk gain, low-risk gain) × three electrode sites (FZ, FCZ, CZ). The results revealed a significant main effect of stimulus type ($F(1,16) = 10.339$, $P = 0.001 < 0.05$). Among participants with different proactivity levels, low-proactivity individuals exhibited larger FRN amplitudes in response to negative feedback stimuli, which was consistent with Hypothesis H-3. The detailed results are presented in Table 4.

Table 4. Within-Subjects Effects of Repeated-Measures ANOVA for FRN Amplitude under Negative Feedback

Effect		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Stimulus Type	Sphericity Assume	3891.175	2	1945.587	10.339	.001	.485
	Greenhouse-Geisser	3891.175	1.708	2278.653	10.339	.001	.485
	Huynh-Feldt	3891.175	1.990	1955.341	10.339	.001	.485
	Lower-bound	3891.175	1.000	3891.175	10.339	.008	.485

4. Conclusions

As an endogenous ERP component, P300 is closely associated with attention, cognitive processing capacity, motivation, and task difficulty. It is highly correlated with individual cognitive activities and participates in core cognitive processes including stimulus evaluation, decision-making, and memory updating. Therefore, the P3 component can effectively reflect the characteristics and differences of cognitive processing underlying risky decision-making behaviors across various situational conditions. The EEG data demonstrated that both positive gain feedback and negative loss feedback in risky scenarios elicited robust P300 amplitudes within the time window of 300–400 ms, with no significant difference observed between the two feedback types. This finding indicates that individuals are insensitive to reward valence during risky decision-making.

A three-way repeated-measures ANOVA was performed on the peak-to-peak P300 amplitudes under positive feedback, with participant type (high-proactivity, moderate-proactivity, low-proactivity individuals), stimulus outcome (positive gain, negative gain, high-risk gain, low-risk gain), and electrode site (Fz, FCz, Cz) as within-subject factors. The results showed a significant main effect of participant type, and consistent findings were obtained for P300 amplitudes under negative feedback. Previous studies have verified that P300 amplitudes are significantly larger in risk-seeking decisions than in risk-averse decisions. This phenomenon occurs because risk-seeking behaviors involve intensified attention, enhanced motivation, and higher cognitive effort, accompanied by strong cognitive perception of potential gains and losses. In line with the above analysis, high-proactivity individuals exhibited larger P300 amplitudes compared with moderate- and low-proactivity individuals, suggesting a stronger tendency toward risk seeking.

In terms of FRN responses under risky conditions, positive gain feedback failed to induce prominent FRN waveforms, whereas negative loss feedback elicited significant FRN activity within 250–350 ms after stimulus onset, especially in high-risk scenarios. Existing literature confirms that the Fz, FCz, and Cz electrode sites are sensitive to FRN amplitude changes. A three-way repeated-measures ANOVA was conducted on FRN peak-to-peak amplitudes with participant type, stimulus outcome (positive loss, negative loss, high-risk loss, low-risk loss), and electrode site as variables. A significant main effect of participant type was identified, revealing that low-proactivity individuals showed larger FRN amplitudes than high- and moderate-proactivity individuals.

FRN is highly sensitive to negative outcome valence. Negative feedback inhibits the electrical activity of midbrain dopaminergic neurons and enhances the activation of the anterior cingulate cortex (ACC). Generally, negative feedback stimuli can evoke FRN components in most individuals. Specifically, risk-averse individuals are more sensitive to negative feedback during risky decision-making. The enlarged FRN amplitudes observed in low-proactivity individuals further validate that low-proactivity individuals are inclined toward risk aversion.

The findings of this study provide practical implications for enterprise employee recruitment and safety management. High-proactivity individuals are active, enthusiastic at work, and equipped with strong safety awareness, while they also have inherent drawbacks such as overconfidence and emotional instability. Therefore, such individuals are more suitable for positions where operational safety is less affected by emotional fluctuations. In contrast, low-proactivity individuals tend to behave passively and hesitate in decision-making, lacking initiative in exploring opportunities and coping with challenges. However, their low tendency to take risks avoids impulsive behaviors and potential safety accidents, making them suitable for meticulous, standardized, and rule-based jobs with low safety behavior risks. Moderate-proactivity individuals usually abide by rules and regulations, perform stable and reliable operational behaviors, and maintain steady work efficiency, yet they show poor adaptability to environmental changes. Individual proactivity traits significantly affect workplace safety behaviors, and different personality traits correspond to different adaptabilities to safety production work. Accordingly, employee scheduling and team construction should be reasonably arranged based on job demands and individual characteristics.

Work safety training is a professional training activity designed to improve the efficiency of enterprise safety production, aiming to enrich employees' safety risk knowledge, strengthen risk prevention awareness and professional skills, and prevent workplace accidents. As a core link of enterprise safety management, safety training guarantees the smooth implementation of safety production work.

Nevertheless, most enterprises adopt a single and unified training model, ignoring the diversity of employee characteristics and job attributes.

Targeted training strategies should be formulated according to employees' proactivity levels. In addition to screening individual proactivity in the recruitment stage, differentiated training schemes should be implemented for high-, moderate-, and low-proactivity employees. For high-proactivity individuals, targeted guidance training can help them exert subjective initiative and improve their ability to resist unsafe behaviors consciously. For low-proactivity individuals, training should focus on the punishment mechanism for unsafe behaviors to restrain their passive working attitudes. Diversified training methods including case analysis, on-site observation, accident discussion, and experience sharing are recommended to fully present the adverse consequences and corresponding penalties of safety violations.

Moderate-proactivity individuals are most restricted by institutional and normative constraints. Thus, their safety instinct and internal safety demands should be strengthened in targeted training. Meanwhile, systematic education on responsibility, sense of honor, and enterprise identity should be carried out to foster positive social and moral awareness throughout their safety production practices. Furthermore, training content can be optimized to strengthen guiding motivational factors, so as to gradually improve the initiative of low- and moderate-proactivity employees and promote their positive development toward high-proactivity traits. This can effectively enhance the overall safety risk awareness of employees and improve enterprise safety management efficiency.

Pure institutional management relying solely on rules and regulations can only solve partial safety problems in production practices. Motivation is an essential management method that stimulates employees' enthusiasm, initiative, and creativity based on human behavioral laws, and appropriate motivation strategies are decisive to employees' work performance and the achievement of enterprise safety management goals. Given that individuals with different proactivity levels have distinct sensitivity to rewards and punishments, differentiated motivation strategies can achieve better management effects.

High-proactivity individuals are more responsive to positive and flexible incentives, so timely and variable positive motivation should be adopted to mobilize their work enthusiasm. For low-proactivity individuals, negative incentives that clarify strict penalties for violations can effectively constrain and correct unsafe behaviors, converting passive working attitudes into active compliance. For moderate-proactivity individuals, sustained positive incentives including material rewards and honor recognition should be applied to reinforce their standardized safety behaviors. In conclusion, differentiated motivation strategies tailored to individual proactivity traits can effectively reduce safety accidents caused by risky workplace behaviors and improve the overall efficiency of enterprise safety production.

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