Evaluation of Visualization of Game Advantage/Disadvantage in Abstract Games Using Physiological Data

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Abstract: - Abstract games such as chess, Go, shogi, and Reversi are widely enjoyed as leisure activities. In recent years, technologies have been developed that not only evaluate the position on the board but also instantly predict and visualize the relative strength of each player's moves, providing this predictive information to players as a reference. Therefore, in this study, we used physiological data to analyze the impact of visualizing the relative strength of the board state on psychological states in these abstract games. The results showed that in matches against AI, psychological load tended to increase when there was no visual representation of advantage, whereas in face-to-face matches, psychological load tended to increase when external stimuli were present. Furthermore, it was thought that the visualization of the advantage has a dual nature. Specifically, while it reduces cognitive load for the winner, it amplifies stress and increases cognitive burden for the loser.

Key-Words: - abstract games, dominance score, physiological data, electroencephalogram (EEG), electrocardiogram (ECG), R-R interval (RRI), Poincaré plot, visualization of advantage.

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1 Introduction

Abstract games are a genre of board games that allow players to enjoy abstract thinking, with chess, Go, shogi, and Reversi being some of the most well-known examples. Their most distinctive feature is that they contain almost no thematic elements or luck-based components. There are no specific stories, settings, or character backgrounds, nor are there elements influenced by chance, such as dice or cards. As a result, players must aim for victory using purely logical thinking and strategic planning. All information is open; it is fundamentally impossible to conceal one's pieces or hand—or, in other words, to cheat. Furthermore, these games are typically played by two people taking turns, with the game progressing as players attempt to read each other's thoughts. Abstract games are widely enjoyed as a common leisure activity. Their uniqueness lies not only in logical thinking but also in the importance of psychological warfare. As the game progresses, the visual representation of the board's state constantly reminds players of their relative advantage or disadvantage. This visualized situation triggers emotions such as complacency when in a favorable position or impatience when in a disadvantageous one. Therefore, victory or defeat in abstract games is thought to depend not only on logical thinking—such as assessing the board's position—but also on the ability to read the opponent's psychology and control one's own emotions. This is a game in which pure intellectual ability and psychological maneuvering interact in a complex manner. Previous research reports have measured physiological signals to analyze in detail the states associated with optimal performance, [1], [2]. Additionally, there are research reports that measured the physiological signals of players during chess matches—a type of abstract game—and analyzed psychological changes and conditions for victory or defeat, [3], [4], [5]. Furthermore, in recent years, technology has been developed that not only assesses the board's formation but also allows a computer to instantly predict and visualize the advantage or disadvantage of each player's move, enabling players to use this predictive information as a reference.

2 Objective

The objective of this study is to use Reversi—the most simplified of the abstract games typically played for relaxation or recreation—to evaluate, using physiological data, the impact of instantaneous prediction information on psychological state and the relationship between psychological state and game performance in an environment where the advantage on the board is visualized.

3 Methods

In this study, using Reversi—the most simplified of abstract games—we evaluate the impact of visualizing the advantage on the board and providing instant predictions on psychological state, as well as the relationship between psychological state and game performance. Six men and women (two women and four men) in their 20s participate as subjects. We will collect and analyze four types of physiological data (electroencephalogram (EEG) and electrocardiogram (ECG)) during: in standard computer (AI) matches, AI matches where the advantage on the board is visualized, AI matches where the advantage is not visualized, and in human-vs-human matches, standard face-to-face matches and matches where an external stimulus (a bell) sounds upon making a bad move. For EEG measurement, we use the MindWave Mobile 2 [6], a non-invasive, headset-type EEG measurement device manufactured by NeuroSky. The data obtained from these measurements includes ATTENTION (a β-wave-emphasized index) and MEDITATION (an α-wave-emphasized index). As an indicator of stress levels, Professor Emeritus Taguchi of Mie University devised a stress level metric (β-wave intensity/α-wave intensity), [7]. In NeuroSky's EEG chip (eSense algorithm), "ATTENTION" and "MEDITATION" do not simply output the raw intensities of β or α waves; however, since this study aims to compare general stress tendencies, we use the ratio of the two as an approximate (β/α) parameter representing a simple ratio of concentration to relaxation. For heart rate measurement, we use Hamon [8], a wearable heart rate monitor developed by Mitsufuji. We create a Poincaré plot from the R-R interval (RRI) derived from the ECG waveform to evaluate the state of mental load, [9], [10], [11]. Furthermore, to instantly predict and visualize the advantage or disadvantage of each player's move, we adopt the application "Egaroucid for Web" [12] developed by Mr. Yamana of the University of Tsukuba. We use the "Dominance score" (+64 to -64, where positive values indicate the subject's advantage)—a dynamic indicator of advantage that changes moment by moment—as a benchmark to assess the board situation. Six men and women in their early 20s with no specific strengths or weaknesses in Abstract games served as subjects. The four types of experiments described below were conducted in stages, but each was carried out on a different day to prevent adaptation.

Experiment 1: Matches Against AI
(1) Playing against AI while viewing the dominance score
The subject plays a match against AI using Egaroucid for Web. The AI's strength is set to Level 1 (beginner level), and the subject can only view the board, the current number of stones, and the dominance score.

(2) Playing against AI without viewing the dominance score
The subject plays a match against AI using Egaroucid for Web. The AI's strength is set to Level 1, and the participant can only view the board layout and the current number of stones.

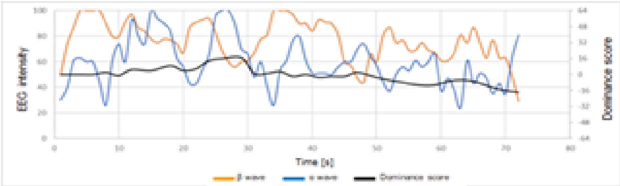
Experiment 2: Human-vs-Human Games
(1) Standard Face-to-Face Game

(2) Face-to-Face Game with Added Impatience (Sense of Urgency)

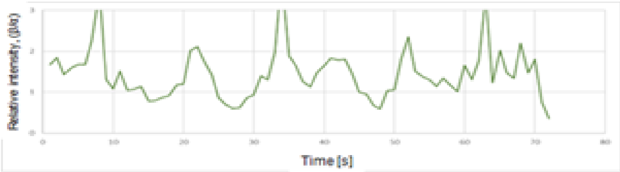
To investigate how the emotion of impatience affects the game, a bell is manually rung whenever a bad move is made. The procedure involves entering information on each move in real time into Egaroucid for Web. Starting from the 30th move, the bell is rung whenever a stone is placed in a position where the dominance score is ranked third-worst or lower among the available options. Additionally, a questionnaire using a Likert scale is administered to account for the subjects' psychological and personality traits in the analysis of the measurement data.

4 Results and Discussion

Figure 1 shows typical EEG data from preliminary experiment participants during AI matches, with (a) EEG and dominance scores, and (b) stress levels (β-wave intensity/α-wave intensity).



(a) EEG and dominance scores



(b) Stress levels (β-wave intensity/α-wave intensity)

Fig. 1: Typical EEG measurement data and dominance scores from participants in the preliminary experiment when playing against AI.
Source: created by the authors

Figure 1 (a) shows that α waves are high in advantageous situations, while β waves are high in disadvantageous or complex situations due to increased mental activity. In particular, around the 30-second mark, β-wave activity peaks just before the dominance score begins to decline. As shown in Figure 1 (b), while the (β/α) ratio remains consistently high from the start, it reaches its peak approximately 8 seconds after the dominance score drops. These characteristics of the EEG data directly reflect the subjects' psychological state at that moment.

4.1.1 Experiment 1 (1)

Figure 2 (a)-(f) shows the EEG data and dominance scores for subjects A–F, respectively, while they played against the AI while monitoring the dominance score. Since the match duration varied for each subject until a winner was determined, the duration differed for each subject. It is believed that EEG patterns reflecting the subject's perception of each move appear in reference to the dominance score.

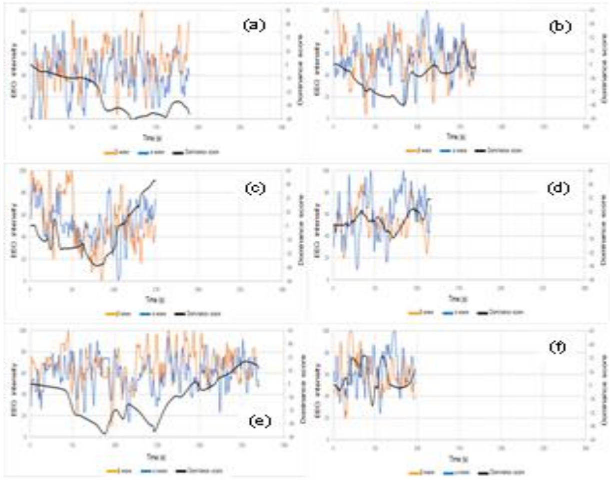


Fig. 2: EEG data and dominance scores for Subjects A–F while playing against the AI while viewing the lead score: (a) Subject A's data, (b) Subject B's data, (c) Subject C's data, (d) Subject D's data, (e) Subject E's data, (f) Subject F's data.
Source: created by the authors

The stress levels (β-wave intensity/α-wave intensity) of each subject during these games are shown in Figure 3 (a) – (f).

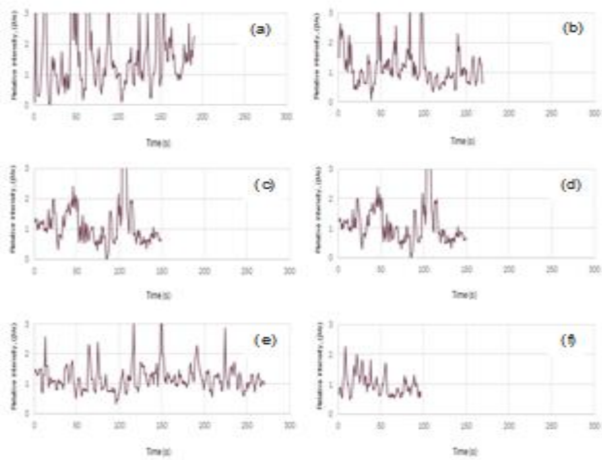


Fig. 3: Stress levels (β/α) of Subjects A–F while playing against the AI while viewing the dominance evaluation score: (a) Subject A's data, (b) Subject B's data, (c) Subject C's data, (d) Subject D's data, (e) Subject E's data, (f) Subject F's data.
Source: created by the authors

Figure 4 (a)–(f) shows the Poincaré plots representing the mental load derived from the subjects' ECG waveforms during these games. A Poincaré plot is a scatter plot (graph) used to visually assess the "fluctuations (heart rate variability)" in heart rate intervals (R-R intervals (RRI)) derived from ECG waveforms. This plot illustrates the changes in the nth and (n+1)th RRI, which fluctuate instantaneously. It is a common method for evaluating stress and relaxation, where a short, dense cluster of RRIs indicates a tendency toward stress, while a long, dispersed pattern indicates a tendency toward relaxation.

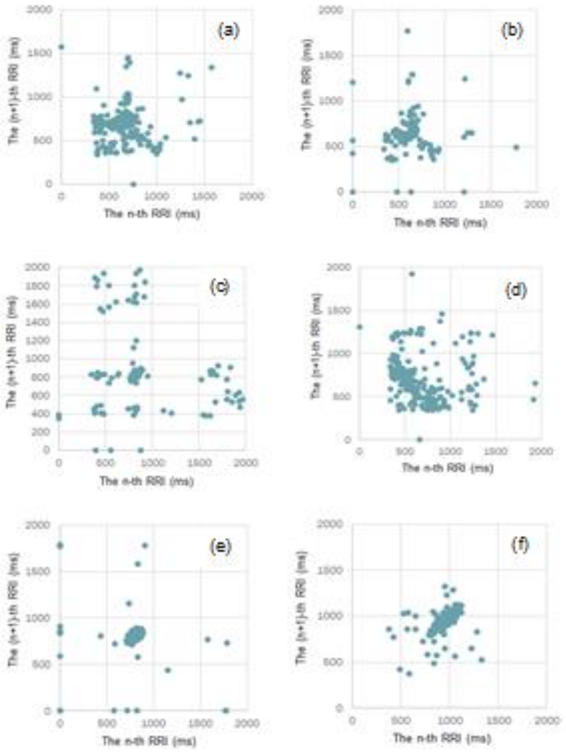


Fig. 4: Poincaré plots representing the mental load status derived from each subject's ECG waveforms: (a) Subject A's data, (b) Subject B's data, (c) Subject C's data, (d) Subject D's data, (e) Subject E's data, (f) Subject F's data.
Source: created by the authors

4.1.2 Experiment 1 (2)

Next, Figure 5 (a)–(f) shows the EEG data and dominance scores for subjects A–F when they played against the AI without viewing the dominance score. Since the duration of these matches varied for each subject until a winner was determined, the time spent playing differed for each subject. Because they could not refer to the dominance score, it is believed that EEG patterns indicative of careful deliberation and foresight appeared at each move.

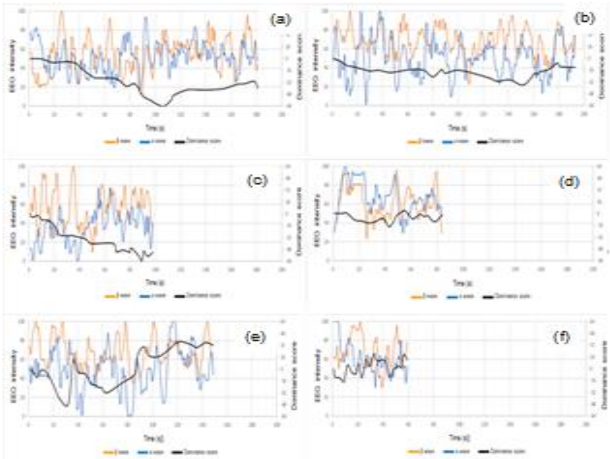


Fig. 5: EEG data and dominance scores for Subjects A–F during games against the AI without viewing the advantage scores: (a) Subject A's data, (b) Subject B's data, (c) Subject C's data, (d) Subject D's data, (e) Subject E's data, (f) Subject F's data.
Source: created by the authors

The stress levels (β-wave intensity/α-wave intensity) of each subject during these games are shown in Figure 6 (a)–(f).

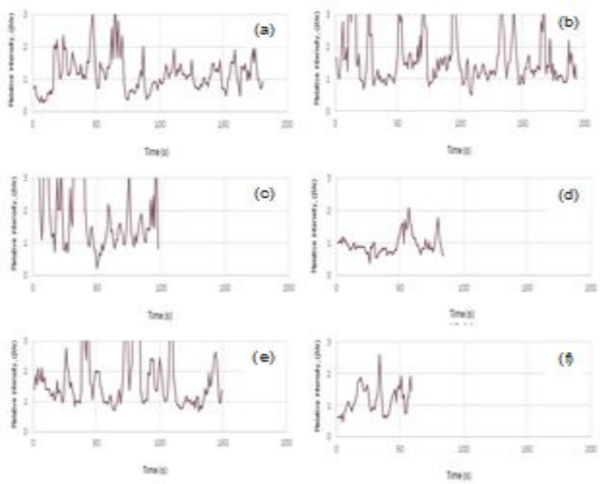


Fig. 6: Stress levels (β/α) of subjects A–F during games against the AI without viewing the advantage score: (a) Subject A's data, (b) Subject B's data, (c) Subject C's data, (d) Subject D's data, (e) Subject E's data, (f) Subject F's data.
Source: created by the authors

Figure 7 (a)–(f) shows the Poincaré plots representing the mental load derived from the subjects' ECG waveforms during these games.

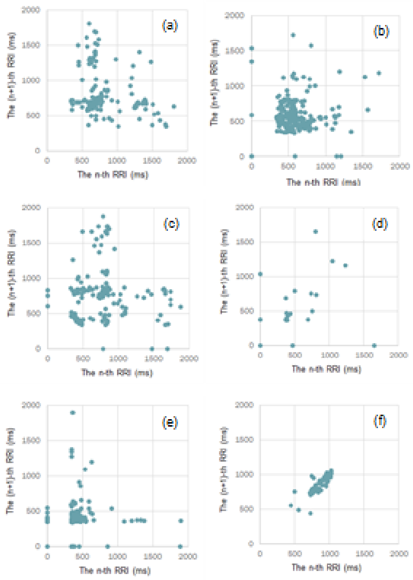


Fig. 7: Poincaré plots representing the mental load status derived from each subject's ECG waveforms: (a) Subject A's data, (b) Subject B's data, (c) Subject C's data, (d) Subject D's data, (e) Subject E's data, (f) Subject F's data.
Source: created by the authors

4.1.3 Experiment 2 (1)

Next, Figure 8 (a)-(f) shows the EEG measurement data and dominance scores for subjects A–F during standard face-to-face games. These include matches between experimental subjects, and in such cases, the dominance scores of the subjects show nearly opposite trends in each match. Since the subjects cannot see the dominance scores, it is believed that EEG activity indicating careful deliberation and foresight to predict the opponent's moves appears at each move.

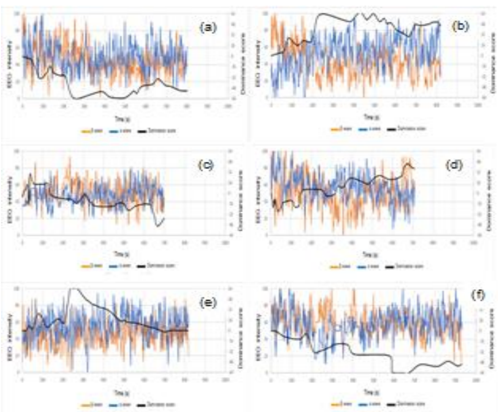


Fig. 8: EEG data and dominance scores for subjects A–F during face-to-face matches: (a) Subject A's data, (b) Subject B's data, (c) Subject C's data, (d) Subject D's data, (e) Subject E's data, (f) Subject F's data.
Source: created by the authors

The stress levels (β-wave intensity/α-wave intensity) of each subject during these games are shown in Figure 9 (a)-(f).

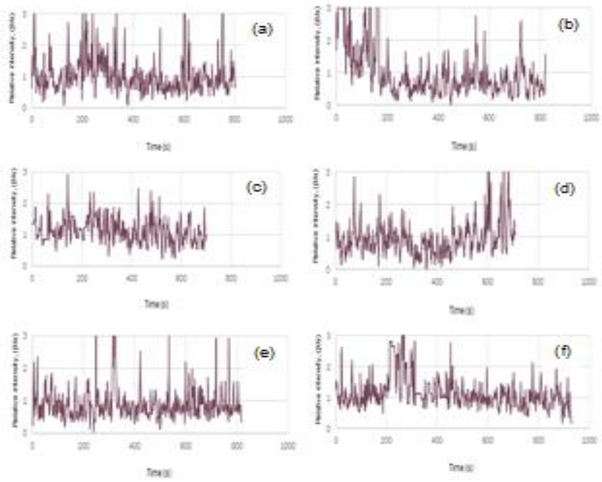


Fig. 9: Stress levels (β/α) of subjects A–F during face-to-face matches: (a) Subject A's data, (b) Subject B's data, (c) Subject C's data, (d) Subject D's data, (e) Subject E's data, (f) Subject F's data.
Source: created by the authors

Figure 10 (a)-(f) shows the Poincaré plots representing the mental load derived from the subjects' ECG waveforms during these games.

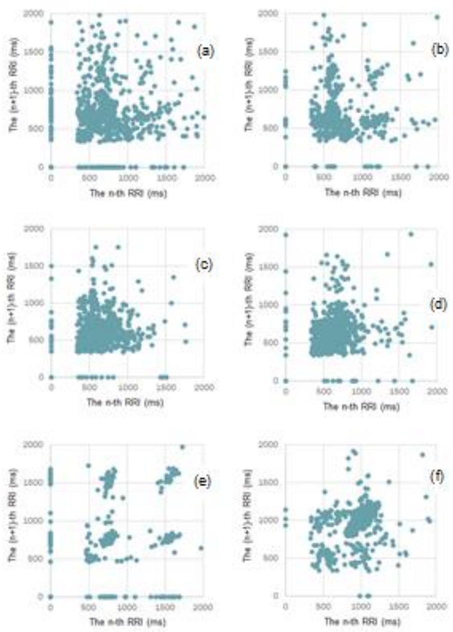


Fig. 10: Poincaré plots representing the mental load status derived from each subject's ECG waveforms: (a) Subject A's data, (b) Subject B's data, (c) Subject C's data, (d) Subject D's data, (e) Subject E's data, (f) Subject F's data.
Source: created by the authors

4.1.4 Experiment 2 (2)

Next, Figure 11 (a)-(f) shows the EEG data and dominance scores for Subjects A–F during face-to-face games with added impatience (a sense of urgency). As in Experiment 2 (1), these games included matches between experimental subjects; in such cases, the dominance scores for some subjects showed nearly opposite trends across the games. The subjects cannot view the dominance scores. Because they cannot see the dominance scores, they carefully consider each move and look ahead to anticipate their opponent's moves, which is reflected in the EEG. However, when a bell rings due to a bad move, it is believed that the sense of urgency causes a tendency for beta waves to rise.

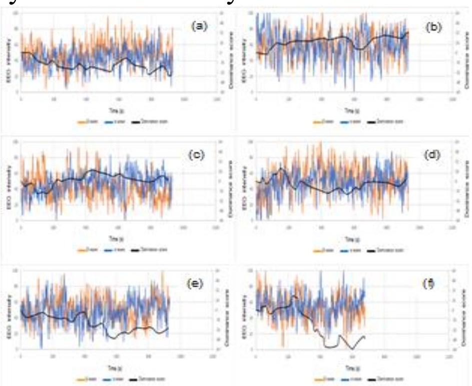


Fig. 11: EEG data and dominance scores for subjects A–F during face-to-face games with added impatience (a sense of urgency): (a) Subject A's data, (b) Subject B's data, (c) Subject C's data, (d) Subject D's data, (e) Subject E's data, (f) Subject F's data.
Source: created by the authors

The stress levels (β-wave intensity/α-wave intensity) of each subject during these games are shown in Figure 12 (a)-(f).

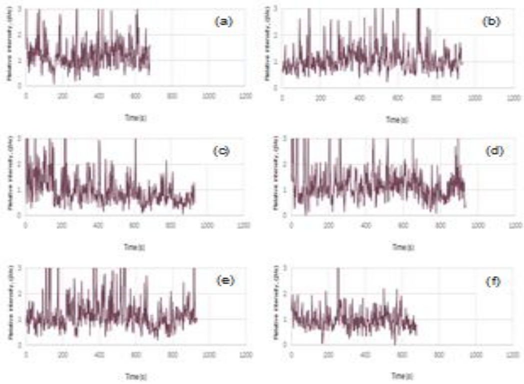


Fig. 12: Stress levels (β/α) of Subjects A–F during face-to-face games with added impatience (a sense of urgency): (a) Subject A's data, (b) Subject B's data, (c) Subject C's data, (d) Subject D's data, (e) Subject E's data, (f) Subject F's data.
Source: created by the authors

Figure 13 (a)-(f) shows the Poincaré plots representing the mental load derived from the subjects' ECG waveforms during these games.

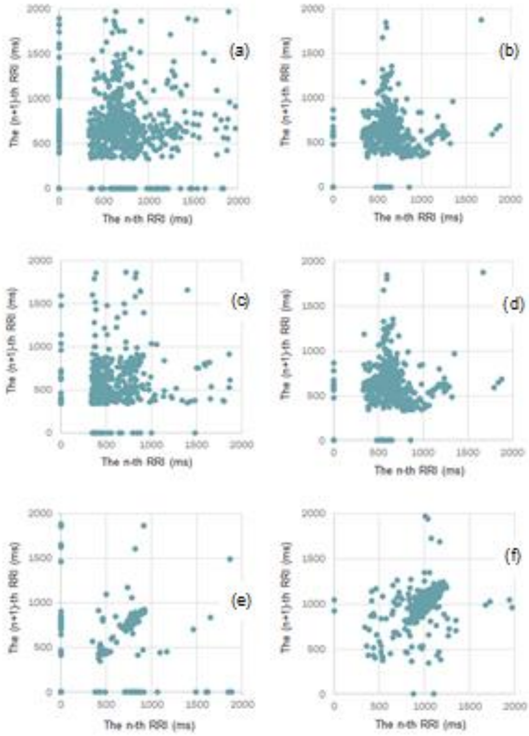


Fig. 13: Poincaré plots representing the mental load status derived from each subject's ECG waveforms: (a) Subject A's data, (b) Subject B's data, (c) Subject C's data, (d) Subject D's data, (e) Subject E's data, (f) Subject F's data.
Source: created by the authors

Table 1 shows the win-loss records for each subject in each experiment. Table 2 shows the average β/α values for subjects in AI matches and the differences between them, while Table 3 shows the average β/α values for subjects in face-to-face matches and the differences between them. Table 4 shows the results of the psychological personality questionnaire for subjects using a Likert scale.

Table 1. Win-Loss record by Subjects

	Subject A(M)	Subject B(M)	Subject C(M)	Subject D(M)	Subject E(F)	Subject F(F)
Experiment 1 (1) with Dominance score	L	W	W	W	W	W
Experiment 1 (1) without Dominance score	L	L	L	W	W	W
Experiment 2 (1) Standard	L	W	L	W	Draw	L
Experiment 2 (2) with Impatience	L	W	L	W	L	L

Source: created by the authors

Table 2. Average β/α values for subjects in AI matches and the difference between them

	Experiment 1 (1) (β/α) AI with Dominance Score	Experiment 1 (2) (β/α) AI without Dominance Score	Difference (1) –(2)
Subject A(M)	1.17	1.07	0.1
Subject B(M)	1.01	1.38	-0.37
Subject C(M)	1.03	1.57	-0.54
Subject D(M)	0.88	0.93	-0.05
Subject E(F)	1.12	1.39	-0.27
Subject F(F)	0.94	1.11	-0.17

Source: created by the authors

Table 3. Average β/α values for subjects in face-to-face matches and the difference between them

	Experiment 2 (1) (β/α) Standard matches	Experiment 2 (2) (β/α) Matches with Impatience	Difference (1) –(2)
Subject A(M)	0.91	1.15	-0.24
Subject B(M)	0.8	1.0	-0.2
Subject C(M)	1.07	0.85	0.22
Subject D(M)	0.87	1.06	-0.19
Subject E(F)	0.81	1.06	-0.25
Subject F(F)	1.02	0.93	0.09

Source: created by the authors

Table 4. Psychological Personality Questionnaire Results

	Subject A(M)	Subject B(M)	Subject C(M)	Subject D(M)	Subject E(F)	Subject F(F)
Preference for Abstract Games	3	4	3	3	3	4
Frequency of Playing Abstract Games	1	1	1	3	1	4
Obsession with Winning	4	4	4	4	3	2
Frequency of Watching Quiz Shows	3	5	2	2	1	3
Seriousness	4	1	4	4	5	4

Source: created by the authors

In Experiment 1 (1), when viewing the dominance scores, the relative strength of the position is directly communicated to the subject as a numerical prediction. At first glance, this situation appears to improve thinking efficiency by reducing the burden of analyzing the board position oneself. However, the numerical indication of relative strength exerts a strong psychological influence on the subject as an objective prediction of victory or defeat. In particular, subjects who were at a disadvantage experienced significant stress when their disadvantageous position was quantified as an objective fact, leading to a predominance of β wave activity; thus, the increase in the (β/α) ratio is thought to reflect an increase in psychological tension. As shown in Table 1, this effect was particularly pronounced in Subject A, who suffered many defeats, suggesting that viewing the dominance scores may have actually hindered concentration and flexible thinking. On the other hand, subjects who were shown to be in a dominant position in a given situation likely felt psychologically reassured and were able to proceed with the game while maintaining calm judgment. Therefore, it is thought that viewing the dominance scores tends to have two distinct effects depending on the outcome of the game: for winners, it serves as a favorable factor that reduces cognitive load, while for losers, it amplifies stress and increases cognitive burden.

In Experiment 1 (2), when participants did not view the dominance scores, they had to judge the relative strength of the position on their own, which undoubtedly increased cognitive load. Consequently, constantly analyzing the position required sustained high-level thinking and concentration. However, in this situation, the absence of external information, such as the dominance scores, may have relatively reduced psychological stress. Since participants are unaware of their disadvantageous position and can assess the game situation independently without being misled by external factors, the psychological burden may be milder than when they view the dominance scores. Based on Table 2, it appears that, generally, psychological load tends to be higher when the dominance scores are not viewed compared to when they are viewed, although there are exceptions, such as Subject A. Furthermore, this study can be compared with prior research [5] on chess, which is also an abstract game. In chess, as the opponent's strength increases, the difficulty of the task rises; in such cases, an increase in α and θ waves has been observed in subjects who win. In particular, an increase in θ waves is considered an indicator of divergent thinking, which involves exploring diverse possibilities. Although this study did not analyze θ waves, the changes in (β/α) ratio observed under conditions where dominance scores were not viewed are also likely to have contributed to divergent thinking and flexible strategy formulation. In other words, when dominance scores were not viewed, it is possible that this broadened the scope of thinking while increasing task difficulty, which may have worked to the advantage of participants who achieved victory.

Next, focusing on the results of the face-to-face matches in Experiment 2, it can be inferred that there were differences in playing style and focus among the subjects, which were reflected in their performance. In particular, Subject B and Subject D achieved consistent victories, suggesting that they are relatively skilled at strategic thinking and maintaining concentration. From the perspective of EEG data, an increase in (β/α) ratio is thought to reflect cognitive load and a high level of concentration during task performance. Specifically, in the bell-ringing condition of Experiment 2 (2), the additional psychological pressure of constantly having to avoid bad moves likely caused (β/α) ratio to rise in many subjects compared to the standard matches in Experiment 2 (1), and Table 3 illustrates this trend. However, because game skill is also a factor, EEG fluctuations do not necessarily correspond to the game's outcome. Although Subject E showed an increase in (β/α) ratio under the bell-ringing condition, the result was a loss. This suggests that excessive cognitive load may act as a stressor rather than enhancing concentration, thereby becoming a factor that impairs performance. On the other hand, subjects who consistently won, such as Subject B and Subject D, showed a strong tendency to be concerned about losing (both scoring 4 points) on the psychological personality questionnaire in Table 4, and possessed personality traits that led them to actively engage with intellectual tasks, such as frequently watching quiz shows (5 points for Subject B). These factors are thought to be one reason they were able to maintain their strategies calmly even under high-pressure situations. Conversely, among the losing participants, Subjects A, C, and F all scored a low 1 on the item regarding the frequency of abstract game play in Table 4, suggesting a possible lack of experience or familiarity. Additionally, Subject F scored a low 2 on the item regarding concern about losing, and this weak awareness of winning or losing may have affected their ability to sustain concentration. In terms of personality, there were differences ranging from extremely high (5 points for Subject E) to extremely low (1 point for Subject B) on the “seriousness” item, and it is thought that these personality traits influence the way psychological stress is experienced and emotional control during the game. Furthermore, this may also be related to the relationship with the opponent and to awareness of winning or losing.

5 Conclusion

We analyzed the impact of visualizing the advantage or disadvantage on the board and receiving instantaneous predictive information on psychological state, as well as the relationship between psychological state and game performance, in abstract games typically played for relaxation or recreation. Viewing the dominance score appears to reduce cognitive load and make it easier to win; however, when at a disadvantage, it increases psychological stress and is thought to have contributed to the rise in the (β/α) ratio among participants who lost. When players did not view the dominance scores, the difficulty of continuously assessing the game situation on their own was a contributing factor to the difference in outcomes; this is thought to have been reflected in brain activity as an increase in task difficulty. Therefore, in experiments where matches were played against an AI with and without the dominance scores, (β/α) ratio is considered not merely an indicator of stress, but a composite indicator resulting from the interaction between task difficulty and divergent thinking. Brainwave changes during face-to-face games are not unidirectional—with (β/α) ratio increasing simply as psychological load rises—but may involve the complex interplay of individual personality traits, awareness of winning or losing, and gaming experience. The bell, as an external stimulus, is thought to induce fluctuations in EEG intensity—an indicator of mental load—by constantly applying psychological pressure to avoid making incorrect moves. However, this effect may vary significantly from person to person and is likely not uniform across all individuals. EEG fluctuations are closely related to individual personality traits and attitudes toward winning and losing. In particular, subjects with conscientious personality traits tend to exhibit polarized reactions to pressure, and this reaction pattern is considered a key factor influencing game performance. Additionally, the relationship with the opponent may also play a role. These results suggest that reactions to mental load caused by external stimuli are significantly influenced by an individual’s internal characteristics.

If the commercial market for abstract games such as chess, shogi, and Go expands further in the near future, it may become possible to apply these findings in innovative ways—even accounting for the influence of personality traits—by utilizing systems that objectively track physiological data such as brainwaves and heart rate, as well as the game’s current state. This could lead to applications in training programs or the entertainment industry that employ a form of biofeedback to objectively visualize the situation and thereby enhance the sense of victory.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

The authors wrote, reviewed and edited the content as needed and verifies that none utilized artificial intelligence (AI) tools were used. The authors take full responsibility for the content of the publication.

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Conflict of Interest

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