Amplitude of neural oscillations in the parietal area is associated with the results of esports competitions

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Abstract*—The neural efficiency hypothesis predicts the contribution of neural synchronization to sports performance. Professionally-trained athletes exhibit changes in low-frequency neural synchronization in task-relevant cortical regions during the processing of tasks related to the competition. Of note, the increase in alpha/beta oscillations reduces the allocation of brain resources to task-irrelated processing, resulting in enhanced efficiency. Previous studies have only dealt with single-action sports competitions as experimental tasks. The optimization of single-action processing can also improve outcomes in match format games, which are more complex and prolonged. To test the contribution of low-frequency oscillations of task-relevant cortical regions towards the outcome of match format gaming, this study focused on esports athletes engaging in a fighting video game (FVG). We examined the association between EEG results during round-intervals of FVGs and the consequences of the rounds. The beta power of the parietal area increased just before a winning round. The findings suggest that the neural efficiency hypothesis can be extended beyond the performance of single actions to affect the outcomes of a match.

Keywords*—beta oscillation, gamma oscillation, amplitude, esports

I. Introduction

Neural oscillations and sports performance are correlated [1–3]. For example, theta oscillations in the frontal cortex increases during the preparation period prior to successful free throws by skilled basketball players [2]. In the waiting period just before air-pistol experts achieved high shooting scores, 12–15 Hz oscillations in the sensorimotor cortex increased [3]. The neural efficiency hypothesis posits that in well-trained individuals, fronto-parietal cortex showed low-frequency neural synchronization associated with better performance [4, 5]. Of note, alpha/beta synchronization is thought to suppress task-irrelated neural activities, resulting in more efficient sensorimotor processing [4–6].

Single-action sports refer to basic sports movements performed by an individual over a short period, such as free throws in basketball. Although previous studies have only dealt with single-action sports performance as an experimental task, the outcome of a match may also be affected by the optimization of single-action processing. Due to the nature of the task, the match format and the single-action format of competitions are different in two major aspects. The first is uncertainty. In the case of a single action in a competition, the players know in advance what action they will perform, and the series of motions is completed by one person. Nonetheless, in the match format, two or more players interfere with each other's actions. Since a player's actions can completely change depending on the opponents' actions, it is impossible to completely predict what actions to take beforehand. The second is the difference in time scale. In single-action tasks, the action time fits into the order of seconds [1–3]. Nonetheless, in the match format of a competition, tens of seconds to tens of minutes of playtime are generally assumed.

This study utilized a fighting game, a type of esports competition, to investigate the relationship between the neural oscillations and the outcome of more complex and prolonged match formats. Match format games allow capture of various outcomes of interest in the athlete subjects. A match of fighting video game consists of rounds, which are the smallest units of the win/loss, and round-intervals, which are the preparation periods just before the round. In particular, in the round-interval, the positional relationship of the controlled characters is reset after the screen darkens, and the player's operations are not accepted during this period. Therefore, it is relatively easy to control the experimental conditions during this period. In addition, players maintain a high heart rate (HR) throughout the match for enhanced performance [7].

In previous findings, the inhibitory effect of low-frequency neural synchronization eliminates irrelevant neural activities in the cortical areas for single-action processing, which enhances performance [4–6]. We hypothesized that this effect would also influence the outcome of a match. Here, we tested whether neural oscillations in the low-frequency band during the round-interval are associated with the win or loss of a match. Since fighting video game has aspects of a visuo-motor task [9], EEG measurements were performed in motor and visual areas in addition to the parietal area. ECG was also recorded based on a previous study that suggested an association between HR and match performance [7]. EMG was measured to confirm that there was no effect of arm movement on physiological changes during the round-interval.

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II. Materials and Methods

A. Participants

We recruited 15 expert fighting video game (FVG) players (all men; mean age=30.6; range=18–43) and excluded 3 participants because we failed to obtain sufficient rounds. All participants had league points higher than 4,000 in Street Fighter V Arcade Edition (CAPCOM, Osaka, Japan), which indicated that they were proficient enough in that game. Athletes provided written informed consent for participation. Our study was approved by the Ethics and Safety Committees of NTT Communication Science Laboratories (protocol number- H30–002). We followed the tenets of the Declaration of Helsinki.

B. Procedure

The competition consisted of a repetition of the round period (from the disappearance of the word "Fight" until "KO" or "Perfect" appeared on the screen) and round-interval period (from the appearance of "KO" or "Perfect" until "Fight" disappeared on the screen). The pre-round period was defined as the 8-s period before the appearance of the "Fight" prompt. We assumed that the result of each round was the outcome of an independent competition. There were 59–78 rounds in total.

C. EEG/ECG/EMG data acquisition

We simultaneously measured electroencephalography (EEG), electrocardiography (ECG), and electromyography (EMG) using a BIOPAC MP150 (BIOPAC Systems, Goleta, CA). The sampling frequency was 5,000 Hz. Furthermore, we used Ag/AgCl disc electrodes for bipolar induction during EEG. Eleven electrodes were placed at the left and right motor areas (ch1: F3-C3, ch2: F4-C4), parietal areas (ch3: CP1-CP2), the left and right visual areas (ch4: P7-O1, ch5: P8-O2), and the ground (Fp2), as per the 10-10 system. ECG measured the interbeat intervals (R-R intervals; [RRIs]). EMG measured the electrical activities produced by the skeletal muscles of the right arm corresponding to the button press during the attack command.

D. EEG/ECG/EMG data analysis

We analyzed the measurements using Fieldtrip toolbox [9] on MATLAB. Pre-round data with large head and body movements were removed using a fixed-point camera. Data with large noise in the raw waveform caused by eye blinking in the round/pre-round were manually removed. Zero-padding on 8-s pre-round data to make it 10 s (5000×10 time points) and zero-padding for 100 s (5000×100 time points) were done (attributed to the round data being <100 s). We applied a Fourier transform to the dataset and computed the averaged amplitude values in delta (1–4), theta (4–7), alpha (7–13), beta (13–30), low-gamma (30–45), and high-gamma (60–95) bands.

We detected peak signals in ECG. The RRIs were resampled at 10 Hz by cubic spline interpolation. Additionally, we converted the RRIs into the average HR as bpm.

Hum noises at 50 Hz in the EMG were noted. Thus, a bandstop filter was applied to 47.5–52.5 Hz. We shifted a 2-s time window (5000×2 time points) by 0.1 s and calculated the root mean square (RMS). The RMS was averaged for all periods.

We calculated the *z*-score from all the pre-round/round datasets of each participant after confirming the absence of an outlier value by Smirnov-Grubbs test. We eventually calculated an average *z*-score for all conditions.

E. Statistical comparisons

We conducted a two-tailed paired *t*-test to examine the difference in each physiological index. All *p*-values were Bonferroni corrected; all *p*-values were multiplied by the number of combinations (32.0) of the frequency band channels (6.0×5.0) and HR/RMS (2.0). Significance was set at α=0.05.

We computed the absolute value of the temporal gradient of the residual percentage of the hit points (HP) bar that directly reflects the damage received from the opponent. This facilitated us investigating the time of performance depending on the conditions. Furthermore, we performed a cluster-based permutation test [10] to determine the significance of the difference between the conditions.

III. Results

We compared the averaged amplitude across the frequency spectrum of EEG, HR, and RMS of EMG of the right arm immediately before the round between the win and loss round results. The neural oscillation in the beta and low-gamma bands of the parietal area significantly increased in the win condition (beta band: $t(11)=4.41$, $p=0.007$, $d=1.80$, Fig. 1A; low-gamma band: $t(11)=4.37$, $p=0.008$, $d=1.78$, Fig. 1B). Additionally, HR significantly decreased in the win condition ($t(11)=-4.45$, $p=0.007$, $d=1.82$, Fig. 1C). There was no significant difference in RMS of EMG between the conditions ($t(11)=0.027$, $p=1.00$, $d=0.011$, Fig. 1D).

Within the 44.0±13.3-s round (mean±SD), the high-gamma power in the right visual area and the alpha power in the left visual area significantly increased on winning (right high-gamma band: $t(11)=4.72$, $p=0.003$, $d=1.93$, Fig. 1E; left alpha band: $t(11)=3.74$, $p=0.035$, $d=1.53$, Fig. 1F). Although the difference in HR was not significant ($t(11)=1.39$, $p=1.00$, $d=0.57$, Fig. 1G), the RMS of EMG increased on winning ($t(11)=6.82$, $p<0.001$, $d=2.79$, Fig. 1H).

During the pre-round/round, there was no significant difference in the other EEG amplitudes between the conditions (Table 1).

We computed the gradient of the time-series of hit points (HP) that directly reflected the performance of playing. This facilitated evaluation of the within-round period performances. The damage received from the opponent per second during the early stage did not significantly change according to the outcomes (Fig. 1I).

IV. Discussion

The present results indicate that neural oscillations were associated with the result of a competition.

Previous studies have found a correlation between athletes' performance and their EEG amplitude [1-3]. Theta-beta oscillations in the fronto-parietal areas, including the motor cortex, increase before successful sports performance. In the neural efficiency hypothesis, low-frequency fluctuations increase the efficiency of task-related sensorimotor processing

[4-6]. Due to the consistent selectivity of the bandwidth and brain regions, this hypothesis implies that neural oscillations during exercise preparation affect performance in esports competition. In single-action gaming, which does not require an opponent, players anticipate possible scenarios and subsequent actions. We found that neural oscillations are related to the outcome of a competition where behavioral patterns are not fully anticipated. In our study, the effect of neural activation on performance seemed to follow a longer time-scale system. The effect was supported by the stability of the opponent damage incurred over the 8-s period following the start of the round. The round period in this study was much longer than the corresponding task periods in previous studies; we extended the contribution of neural oscillations on task performance to more long-term and complex tasks. The increases in parietal synchronization also did not persist throughout the round. Thus, the extent of the effect of neural oscillations on round performance is elusive.

Regarding the alpha and gamma bands in the visual areas within the round (Fig. 1E and F), the neural oscillations in the lower visual cortex are associated with the regulation of attended visual information processing [11]. Action video game players perform better in visual discrimination tasks with prominent activation/deactivation of the visual areas [12]. Thus, FVG players might have an advantage during a competition because of their far superior visual attention systems.

Additionally, expert athletes have decreased HR associated with positive psychological states [13]. The decreased HR observed immediately before the winning round hints at this psychophysiological state as a meta-factor affecting the outcome.

Considering the absence of immediate change in the RMS of EMG before the winning round, the increases in beta and low-gamma neural oscillations in the pre-round were not induced by the button-pressing exercise or exercise-related artifacts. However, the increase in the RMS of EMG in the winning round may reflect the number of button presses. The number of button presses is likely to increase in FVGs because of the winner's longer attack time.

In summary, we found an association between the beta/gamma oscillations of the parietal area and outcomes of FVG competitions, suggesting a new function of neural oscillations from the parietal areas in the competition. The mechanism underlying this relationship remains obscure. Future studies should clarify how these neural oscillations impact competition performance.

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TABLE I. P-VALUES FOR ALL COMBINATIONS OF EEG DATA BETWEEN 5 CHANNELS AND 6 FREQUENCY BANDS

Brain area	**Pre-round**					
	Delta	***Theta***	***Alpha***	***Beta***	***Low-gamma***	***High-gamma***
Right motor	1	1	1	1	1	1
Left motor	0.92	1	1	1	1	1
Parietal	1	1	1	**0.007**	**0.008**	1
Right visual	1	1	1	0.18	1	1
Left visual	0.33	1	1	1	1	1
Brain area	**Round**					
	Delta	***Theta***	***Alpha***	***Beta***	***Low-gamma***	***High-gamma***
Right motor	1	1	1	1	1	1
Left motor	1	0.19	0.15	1	0.35	0.59
Parietal	1	1	1	1	0.17	0.42
Right visual	0.73	1	0.4	0.54	1	**0.003**
Left visual	1	1	**0.035**	1	0.87	0.47

a. Significant values are shown in bold text.

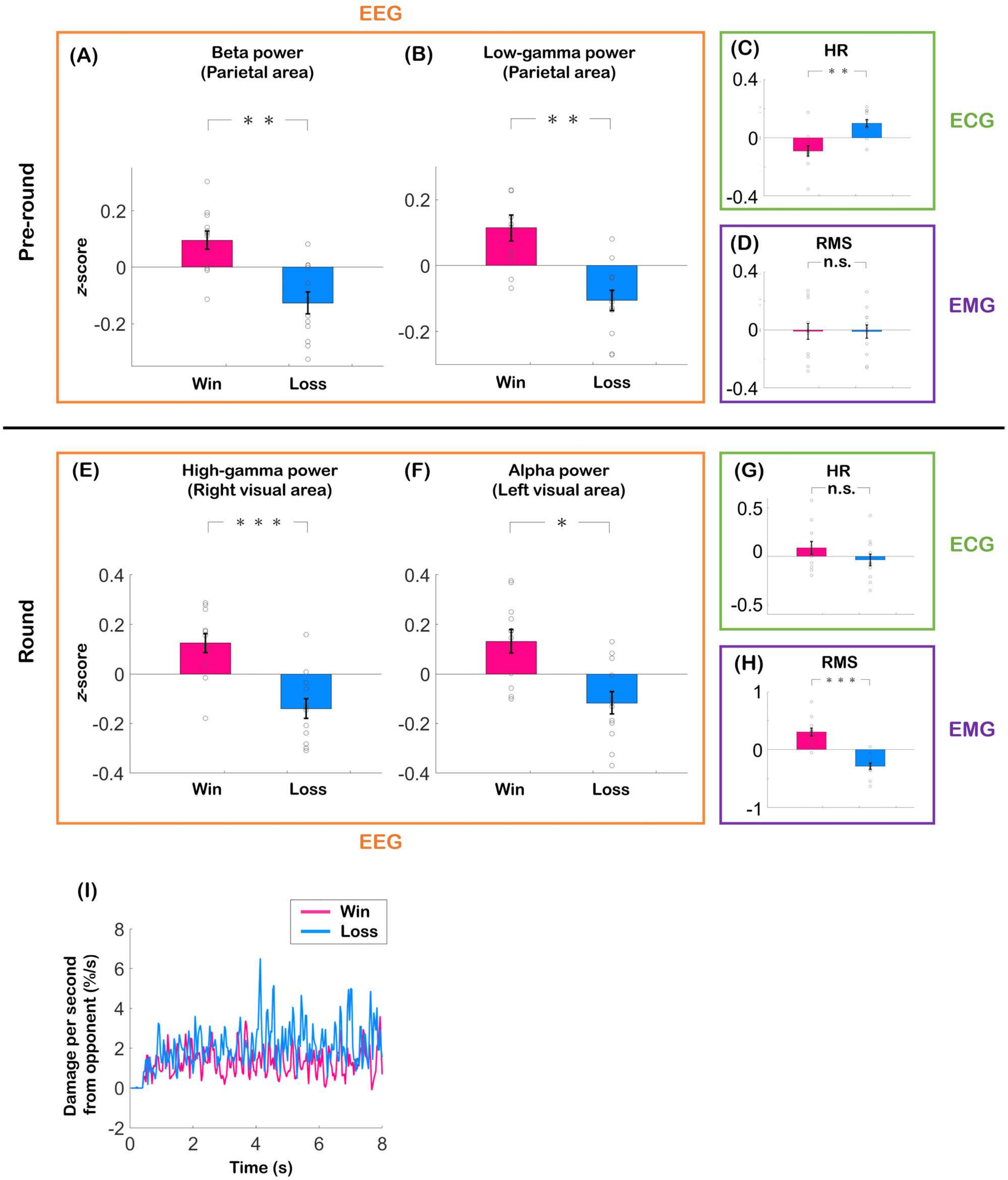

Fig. 1. The changes in neural oscillations and physiological state before and during the round indicated by the average z-scores of neural oscillations, heart rate (HR), and root mean square (RMS) of electromyography (EMG) in response to the button press. (A-D) Parameters during the pre-round: beta (A) and low-gamma (B) powers of the parietal area, average HR (C), and average RMS of EMG (D) between the win or loss condition. (E-H) Parameters during the round: high-gamma power in the right visual area (E), alpha power in the left visual area (F), average HR (G), and average RMS (H) between the win or loss conditions. (I) The absolute value of the temporal gradient of the residual percentage of hit points between the conditions during the 8-s period from the start of the round. Error bars represent the standard error of the mean. Statistical significance is indicated at $*p < 0.05$, $**p < 0.01$, $***p < 0.001$.