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Research article

The effects of competitive and interactive play on physiological state in professional esports players

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ABSTRACT

In esports competitions, both motor skills used to manipulate an avatar and psychological skills are important to achieve optimal performance. Previous studies have investigated the role of psychological skill on computer game performance by observing the modulation of physiological state. However, how physiological state is modulated in esports athletes during an esports match is unclear. In this study, we examined two hypotheses to clarify the effects of competitive and interactive play on the physiological state of esports professionals: (1) the sympathetic nervous system of esports players is activated by competitive play and modulated by the game situation, and (2) the autonomic nervous system activities of players in dyads are synchronized positively/negatively by interpersonal interaction.

We measured electrocardiograms (ECGs) in nine professional esports players while they played a fighting video game to investigate changes in physiological state. We compared ECGs collected in the resting state, while playing against a computer, and while playing against other players. We calculated the mean heart rate (HR), temporal pattern of HR, and correlation of temporal HR patterns of the pairs in the player-versus-player condition.

The results showed that mean HR was elevated by the presence of a human opponent compared with a computer opponent, and an increase in mean HR was also observed in specific game situations (beginning of the match, toward the end of a game or match). These results suggest that the sympathetic nervous system in esports players is activated by competitive play and is modulated by the game situation. In addition, the temporal HR patterns in the opponent pairs were synchronized, suggesting that autonomic nervous system activity is synchronized in player dyads via interpersonal interaction during competitive play. Our results provide insight regarding the relationship between physiological state and psychological skill in esports professionals during esports competitions.

1. Introduction

Esports are a category of competitive video games. The essential motivation of an esports athlete is to win against their opponent (Thiel and John, 2018; Banyai et al., 2019; Happonen and Minashkina, 2019). Although motor skills are needed to manipulate one's character, psychological skills (e.g. imagery, anxiety management, energy management, emotional regulation, motivation, attention control) are required to achieve optimal performance (Himmelstein et al., 2017; Martin-Niedecken and Schättin, 2020). Particularly for esports professionals, psychological skills can have an important impact on the game results (Himmelstein et al., 2017; Pedraza-Ramirez et al., 2020; Leis and Lautenbach, 2020).

Because a player's psychological state is mutually related to their physiological state (Kreibig, 2010; Hahn, 1973), the effect of psychological skill on performance can be estimated by investigating the modulation of physiological state during play. Indeed, changes in psychophysiological states during video game play have been previously investigated (Panee and Ballard, 2002; Anderson, 2004; Barlett et al., 2009; Hasan et al., 2013; Russoniello et al., 2009; Roy and Ferguson, 2016; Porter and Goolkasian, 2019). However, these studies did not focus on competitive and/or interactive situations. Therefore, how professional players modulate physiological states during esports competitions is unclear.

To clarify physiological modulation during esports competitions, we focused on fighting video games, which is one of the most famous esports

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genres. In fighting games, one player competes with another player by controlling his/her own character in a virtual world and interacting with the actions of the other player. As with many esports games, competitive and interactive elements make up a large portion of the time spent engaged in fighting video games, and these elements are affected by changes in the game situation.

Several studies have examined physiological changes in competitive or interactive situations. For instance, previous studies focusing on the effect of competition in competitive sports have shown that players exhibit increased stress, anxiety, salivary cortisol, and an increased low-frequency to high frequency ratio (LF/HF) of heart rate variability (HRV) prior to competition (Cervantes Blasquez et al., 2009; Mateo et al., 2012; Moreira et al., 2012; Mendes et al., 2018). This implies that competitive play elevates sympathetic nervous system activity during a match. Given the findings of previous investigations, we hypothesized that the sympathetic nervous system is activated by competitive play and modulated by the game situation in esports players.

In terms of the effect of interactions with one another, previous studies have reported that interpersonal interaction within cooperative dyads facilitates physiological synchrony which is defined as a change in physiological state in two or more individuals at a similar time (Feldman et al., 2011; Rodriguez-Zamora et al., 2012; McCraty and Zayas, 2014; Waters et al., 2014; Butler, 2015; Goldstein et al., 2017; Yoon et al., 2019). This implies that interpersonal interaction synchronizes the physiological states of players. Since players in esports competitions share some sensory information and interact with one another, we hypothesized that autonomic nervous system activity in dyads is synchronized positively/negatively by interpersonal interaction during esports play.

The main purpose of this study was to investigate the effects of competitive and interactive play on the physiological states of elite esports professionals during gameplay. To test the two hypotheses mentioned above, we measured electrocardiograms (ECGs) while two opponents played a fighting game. We first compared the heart rates (HRs) of the esports players in a player-versus-player (PvP) condition with those in a player-versus-computer (PvC) condition. Then, we explored how HRs were modulated temporally in the PvP competition. Finally, we investigated whether the temporal HR patterns of two opponents were synchronized.

2. Materials & methods

2.1. Participants

We recruited nine professional esports players (9 males, 30 $\pm$ 7 years old) who were highly skilled at manipulating their character and who had demonstrated very consistent gameplay performance. They were professional esports players of Street Fighter V Arcade Edition (CAPCOM Co., Ltd., Japan), and their CAPCOM Pro Tour 2019 rankings were in the top 128 out of one million global competitors.

The participants were given an information sheet that outlined the general purpose of the study, and were informed that they could withdraw from the study at any time without penalty. All participants gave their informed consent before participation. All of the methods employed in this study were approved by the Ethics and Safety Committees of NTT Communication Science Laboratories and were in accordance with the Declaration of Helsinki. The protocol number of the Ethics and Safety Committees of NTT Communication Science Laboratories is H30–002.

2.2. Physiological measurements

We used ECGs to measure interbeat intervals (R-R intervals) throughout the experiments. The electrodes were made of Ag–AgCl. The analog data were amplified and digitized using a BIOPAC MP160 (BIOPAC System, USA). The sampling rate was 1,000 Hz for all measurements.

2.3. Procedure

The participants were seated in front of a computer monitor (ProLite GE2788HS, Mouse Computer Co., Ltd., Japan) and played on PlayStation 4 (Sony Interactive Entertainment Inc., Japan) equipped with an arcade controller. They played Street Fighter V Arcade Edition, which is classified as a fighting video game. In fighting video games, a player controls a game character using an arcade controller and fights an opponent in a virtual world. Players move a joystick with their left hand to change the position of the game character and push buttons with their right hand to generate actions (e.g., attack, guard, avoid, counter). Players mainly use their fingers to control the character. A player wins a round when his/her opponent's life gauge decreases to zero.

The experimental procedure comprised three conditions: baseline, player-versus-computer (PvC), and player-versus-player (PvP). We measured ECGs from the participants during all conditions. In the baseline condition, the participants sat on a chair and ECGs were measured in a resting state for 3 min. In the PvC condition, they played against computer opponents for 5 min. In the PvP condition, two players competed with one another while sitting in the same room. The two players were positioned opposite one another, with a distance of over 2 m between them. Each player was unable to watch the other player's figure during play because there was a computer monitor in front of each player. The player who was the first to win two rounds was deemed the winner of a game, and the player who was the first to win five games was crowned the winner of a match. This reflected the system used in professional esports competitions, so as to produce a competitive situation. The participants competed with one another in pairs until one player achieved five game wins. Therefore, the durations of the rounds, games, and match were different between dyads. The average and SEM of the duration of one round was 49.863 $\pm$ 0.849 s. Each participant played against all of the others who participated on the same day. There were two experimental days, with three players on one day and six players on the other day.

Each participant repeated the PvC and PvP conditions two or five times each. In each PvP match, the opponent pairs were randomized. After the baseline condition, the PvC and PvP conditions were performed alternately, and the order was randomized for each participant. There were no rest periods during either condition, but the participants rested for more than 3 min between conditions. In addition, the players rested for 30 min after playing for 1.5 h. The total playing time was shorter than 3 h for each player.

Since it was necessary for the players to move their fingers while playing the game, we placed no restrictions on upper body movement during the PvC and PvP conditions. We confirmed that the differences in whole-body movement between the two conditions were sufficiently small by checking video recordings of the sessions. In addition, we objectively compared the motor activity in the PvP condition with that in the PvC condition by measuring electromyography (EMG) signals from the forearm muscles related to joystick control and button pressing in other participants who were not professionals but were expert esports players. We found no significant differences in the root mean square (RMS) of the EMG signals in the PvC vs. PvP condition (Figure 5B), indicating that the difference in motor activity levels between the two conditions was negligible.

2.4. Data analysis

The R-R intervals were obtained from the ECG measurements. We detected the peak ECG signals, and visually screened the data via R-wave detection to eliminate artifacts such as movement. The included R-R interval data were then resampled at 10 Hz using cubic spline interpolation. After that, the resampled R-R intervals were converted into second-by-second values and expressed as beats per minute (BPM) by dividing 60 by each value. The resampled and converted R-R intervals were defined as the HR. Examples of time-series HR data during one match are shown in Figure 1. Since the match durations were different among the dyads, as mentioned above, the time-series HR for the longest (Figure 1A) and shortest matches (Figure 1B) are shown as examples.

We first calculated the mean HR in each condition, and then obtained the mean HR for each participant to compare the changes in HR between the baseline, PvC, and PvP conditions. To determine the effect of the playing situation on the physiological indices, we performed a one-factor repeated-measures analysis of variance (ANOVA) followed by a post hoc paired *t*-test in which the significance level, α, was corrected using Ryan's method (Ryan, 1960). The α of the 1st comparison was 0.0167, and those of the 2nd and 3rd comparisons were each 0.0333.

We then normalized the HR time series in the PvP condition using the mean HR in the PvC condition to compare values across players. To evaluate the relationship between changes in HR and game flow for each player, we calculated the average of the normalized HR for each of the 1st and final rounds for the 1st, 2nd, middle (all games other than the 1st, 2nd, and final game), and final games. Since the number of games was different among the dyads in the PvP condition, the number of "middle" games ranged from 2–6. For example, in the longest match (Figure 1A), the middle games were the 3rd to 8th games, and the final game was the 9th game. In contrast, in the shortest match, the middle games consisted of the 3rd and 4th games, and the 5th game was the final game (Figure 1B). Since the participants played several matches, each obtained value in a match was averaged for each player. The difference between the normalized mean HR was analyzed using a two-way repeated-measures ANOVA with [game (4) x round (2)] as within-individual factors. The significance level was set at $p < 0.05$. This was followed by a simple main effects test and a post hoc paired *t*-test in which the significance level was corrected using Ryan's method. Then, the game or round factor was analyzed using a simple main effects test. We analyzed the difference between the normalized mean HR for each of the 1st and final rounds for the 1st, 2nd, middle, and final games using a paired *t*-test in which the significance level α was corrected using Ryan's method. The α of the first comparison was 0.00833, while those of the 2nd and 3rd comparisons were 0.0125 and those of the 4th, 5th, and 6th comparisons were 0.025.

Finally, to evaluate the similarity of temporal HR patterns among opponents, we calculated correlations between their normalized HR time-series data. Each correlation value was obtained using the time-series data from the two opponents in each match. In addition, we calculated correlations of mean HRs of two opponents in 1st and final rounds for all games. To examine whether the changes in HR among two opponents were significantly correlated, we performed a one sample *t*-test.

To confirm that the detection power of the ANOVA performed in our study was sufficient, we used the post-hoc G*Power analysis (Faul et al., 2009). The detection power (1-β) for all significant differences was more than 0.80 when the sample size was N = 9 and the effect size was more than 0.89. All significant differences had sufficient detection power.

2.5. Procedure and data analysis in additional experiments

Thirteen expert esports players participated in this additional experiments. ECGs of participants and Electromyography (EMG) of extensor digitorum of right and left forearms related to the joystick control and button press of participants were measured in PvC and PvP conditions. Since a Smirnov-Grubbs test showed that the mean HR of one participant was outlier, the sample size is N = 12 in all analysis ($t(12) = 2.653$, $p = 0.020$).

At first, we confirmed the increase in mean HRs during competitive play compared with solo play. We performed a one-factor repeated-measures ANOVA followed by a post hoc paired *t*-test in which the significance level, α, was corrected using Ryan's method. The α of the 1st comparison was 0.0167, and those of the 2nd and 3rd comparisons were each 0.0333.

In EMG analysis, a bandstop filter was applied to 45–55 Hz to remove hum noises at 50 Hz. We shifted a 2-second time window by 0.1 s and calculated the root mean square (RMS). The RMS of right and left forearms was averaged for all periods. We performed a one-factor repeated-measures ANOVA followed by a post hoc paired *t*-test in which the significance level, α, was corrected using Ryan's method. The α of the 1st comparison was 0.0167, and those of the 2nd and 3rd comparisons were each 0.0333.

3. Results

3.1. Effect of competitive play on player's physiological state

To examine the effect of competitive play on physiological states, we compared the mean HRs in the resting state (baseline) with those recorded during solo play (PvC) and competitive play (PvP). Figure 2 shows the mean HRs under these conditions. The average and SEM of HR was 79.240 ± 2.646 [BPM] for the baseline, 85.569 ± 2.517 [BPM] for PvC, and 97.828 ± 3.568 [BPM] for PvP (Figure 2). The mean HR was higher when the participants competed against an actual person compared with when they played the game against the computer or were resting. A one-way repeated-measures ANOVA indicated that the condition had a significant effect on the mean HR ($F(2, 16) = 40.583$, $p < 0.001$). A post hoc test revealed that the mean HR in the PvC condition was significantly larger than that in the baseline condition ($t(16) = 3.017$, $p = 0.012$). In addition, the mean HR in the PvP condition was

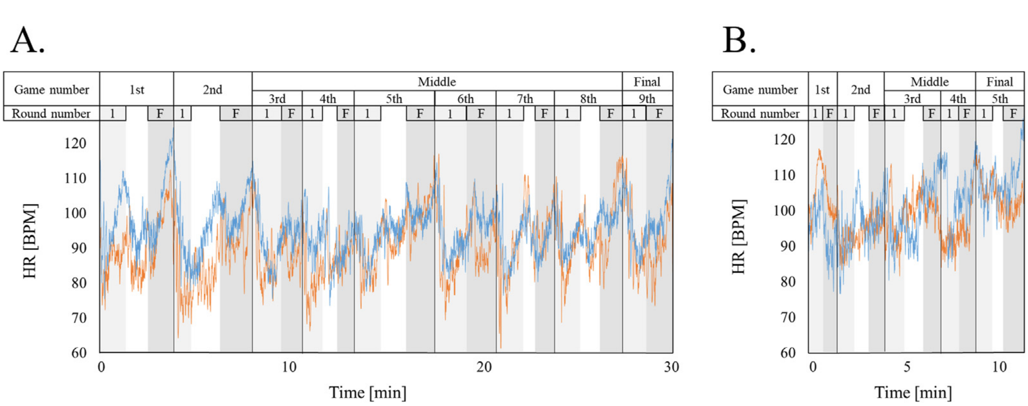

Figure 1. Examples of the time-series HR data during one match. A match consisted of 5–9 games and continued for 11–30 min. The longest match consisted of 9 games and continued for 30 min (A) and the shortest match consisted of 5 games and continued for 11 min (B). A game consisted of 2 or 3 rounds and continued for 3–5 min. The blue and orange lines show examples of normalized HR signals from two opponents. The vertical axis indicates the HR [BPM]. We calculated the normalized mean HR for each of the 1st and final rounds for the 1st, 2nd, middle, and final games. For example, the middle games consisted of the 3rd to 8th (A) and 3rd to 4th games (B). The final game was the 9th game (A) and the 5th game (B). Then, we calculated the correlation of the normalized HR.

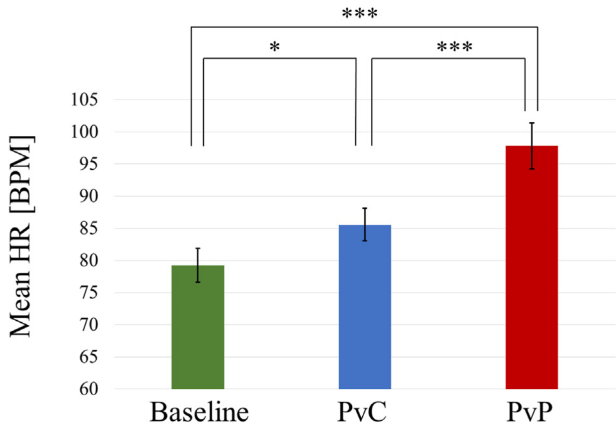

Figure 2. Mean HR at baseline, in the PvC condition, and in the PvP condition. The vertical axis indicates the mean HR [BPM]. Ryan's method was employed. The error bar shows the standard error. Statistical significance is indicated at $*p < 0.05$, $***p < 0.001$.

significantly larger than that in the baseline ($t(16) = 8.860$, $p < 0.001$) and PvC conditions ($t(16) = 5.843$, $p < 0.001$).

3.2. Temporal modulation of HR with changes in the game situation

To examine the effect of changes in the game situation on player HR, we obtained the normalized mean HR for the 1st and final rounds in each game phase and averaged it across participants (Figure 3). The normalized mean HR increased from the 1st to the final round except for in the 1st game. The HR in the 1st round was as high as that in the final round in the 1st game. Additionally, HR gradually increased from the 2nd to final game. The percentages and SEMs of the normalized mean HR were 114.279 ± 1.909 for the 1st round and 113.244 ± 1.365 for the final round in the 1st game, 107.490 ± 1.653 for the 1st round and 113.474 ± 1.800 for the final round in the 2nd game, 111.655 ± 2.503 for the 1st round and 115.910 ± 2.415 for the final round in the 3rd game, and 114.834 ± 2.561 for the 1st round and 119.460 ± 2.820 for the final round in the final game.

A two-way repeated-measures ANOVA yielded a significant game × round interaction ($F(3, 24) = 6.361$, $p = 0.003$), as well as significant main effects of game ($F(3, 24) = 6.618$, $p = 0.002$) and round ($F(1, 8) = 35.969$, $p < 0.001$).

A simple main effect test with regard to round revealed a significant difference between the normalized mean HRs in the 1st and final round in some games. The normalized mean HR in the final round was significantly larger than that in the 1st round of the 2nd game ($F(1, 32) = 24.614$, $p < 0.001$), the middle games ($F(1, 32) = 12.446$, $p = 0.001$), and the final game ($F(1, 32) = 14.709$, $p < 0.001$).

A post hoc test showed significant differences in the normalized mean HRs between the games in the 1st and final rounds. The normalized mean HR in the 1st round in the 1st game was significantly larger than that in the 1st round in the 2nd game ($t(48) = 3.929$, $p = 0.001$). The normalized mean HR in the 1st round in the middle game was significantly larger than that in the 1st round in the 2nd game ($t(48) = 2.410$, $p = 0.04$). The normalized mean HR in the 1st round in the final game was significantly larger than that in the 1st round of the 2nd game ($t(48) = 4.250$, $p < 0.001$). The normalized mean HR in the final round of the final game was significantly larger than that in the final round of the 1st ($t(48) = 3.597$, $p = 0.005$) and 2nd games ($t(48) = 3.464$, $p = 0.005$). The statistical results are indicated in Figure 3 by asterisks.

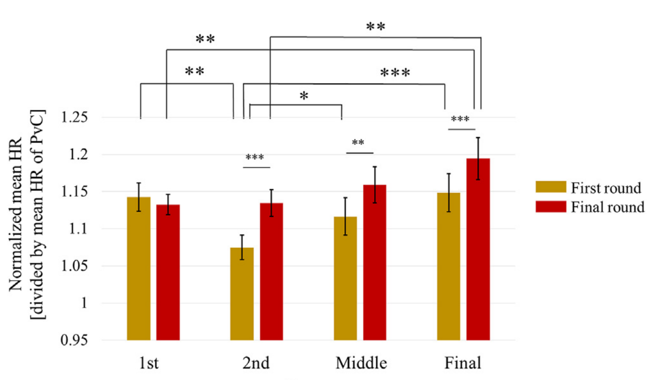

Figure 3. Normalized mean HR in the 1st and final rounds of each game. The dark yellow and red bars represent the normalized mean HR in the 1st round and final round for the 1st, 2nd, middle, and final games, respectively. Ryan's method was employed. The error bars show the standard error. Statistical significance is indicated at $*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

3.3. Synchronization of temporal HR patterns among two opponents

To evaluate the synchronization of temporal HR patterns among opponent pairs in the PvP condition, we calculated the correlation of the HR time-series data and mean HR in 1st and final rounds for all games for each player. Figure 4 shows Pearson's R for each combination of players. The label "XvY" on the horizontal axis represents combinations of players X and Y. The average and SEM of Pearson's R were 0.329 ± 0.028 (Figure 4A) and 0.455 ± 0.067 (Figure 4B) in the PvP condition. A t-test indicated that the average Pearson's R of the HR time-series data for all matches was significantly larger than zero ($t(17) = 11.769$, $p < 0.001$, Figure 4A). A t-test indicated that the average Pearson's R of mean HR in 1st and final rounds for all games for all matches was significantly larger than zero ($t(17) = 6.777$, $p < 0.001$, Figure 4B).

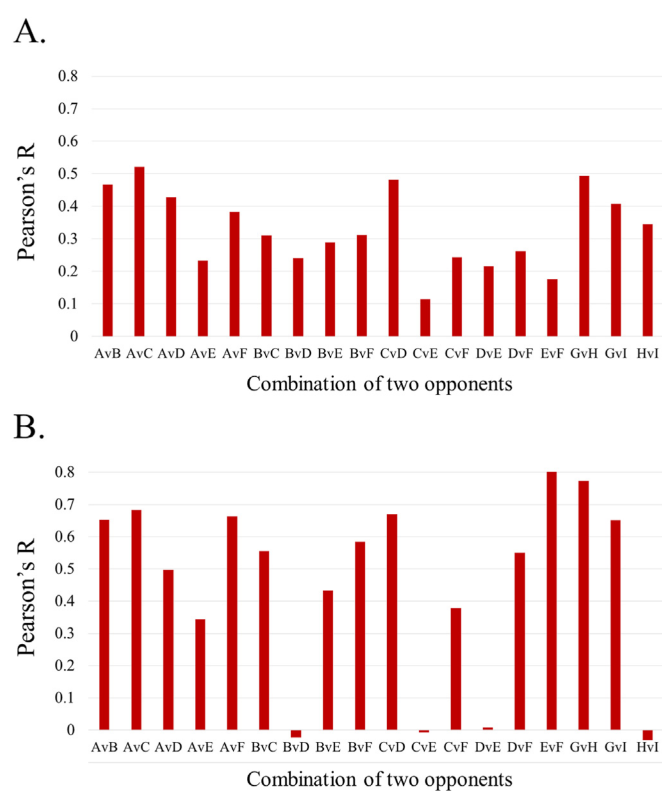

Figure 4. Correlation of normalized HR data with that of opponents in each pair (A) and correlation of mean HRs of two opponents in 1st and final rounds for all games (B). Each bar represents Pearson's R for each combination of opponents. The label "XvY" on the horizontal axis represents a combination of player X and player Y. A t-test showed that the average Pearson's R for all matches was significantly larger than zero ($p < 0.001$).

3.4. Motor activity levels during esports play

To compare the motor activity levels in the PvC and PvP conditions, we performed additional experiments and calculated the mean HR and RMS of EMG. Figure 5A shows the mean HRs under baseline, PvC and PvP conditions. The average and SEM of HR was 82.588 ± 2.722 [BPM] for the baseline, 87.768 ± 2.843 [BPM] for PvC, and 95.824 ± 3.874 [BPM] for PvP (Figure 5A). A one-way repeated-measures ANOVA indicated that the condition had a significant effect on the mean HR ($F(2, 22) = 20.572$, $p < 0.001$). A post hoc test revealed that the mean HR in the PvC condition was significantly larger than that in the baseline condition ($t(22) = 2.487$, $p = 0.031$). In addition, the mean HR in the PvP condition was significantly larger than that in the baseline ($t(22) = 3.877$, $p = 0.001$) and PvC conditions ($t(22) = 6.364$, $p < 0.001$).

Figure 5B shows the RMS of EMG under baseline, PvC and PvP conditions. The average and SEM of HR was 0.023 ± 0.004 [mV] for the baseline, 0.170 ± 0.015 [mV] for PvC, and 0.178 ± 0.015 [mV] for PvP (Figure 5B). A one-way repeated-measures ANOVA indicated that the condition had a significant effect on the mean HR ($F(2, 22) = 88.490$, $p < 0.001$). A post hoc test revealed that the RMS of EMG in the PvC condition was significantly larger than that in the baseline condition ($t(22) = 11.202$, $p < 0.001$). In addition, the RMS of EMG in the PvP condition was significantly larger than that in the baseline condition ($t(22) = 11.816$, $p < 0.001$). There were no significance difference between RMS of EMG in PvC and PvP conditions ($t(22) = 0.614$, $p = 0.818$).

4. Discussion

In this study, we examined the effects of competitive and interactive play on the physiological states of professional esports players during competitive matches. We found greater increases in HR during competitive play compared with solo play (Figure 2). Further, we found that HR changed as the game progressed (Figure 3) such that the mean HR was significantly higher toward the end of games or matches except for during the opening game, in which the mean HR in the 1st round was as high as that in the final round. We also found that the temporal pattern of HR during each match was highly correlated among the two opponents (Figure 4).

We interpreted the increase in HR in the PvC condition compared with that at baseline (Figure 2) to reflect the effect of "playing the game". However, we also observed an increase in HR in the PvP condition compared with that in the PvC condition. Because we expected the motor activity levels in the two conditions to be similar (Figure 5B), this observed increase might have been induced by the emotions elicited by the presence of a human opponent, which are quite different from those when playing against a computer. Indeed, a previous study on psychophysiological states reported increased anxiety levels, cortisol, and HR during a tournament compared with practice (McKay et al., 1997), suggesting that the sympathetic nervous system is activated in situations with higher levels of perceived pressure. Since the essential motivation of esports athletes is to win against their human opponent (Happonen and Minashkina, 2019), esports athletes might not play as seriously when their opponent is a computer, and may treat the situation more like practice. Therefore, the sympathetic nervous system was more likely to be activated in the PvP condition, which was highly competitive, relative to the PvC condition.

We observed temporal HR patterns that changed as the game progressed (Figure 3). The increase in HR closer to the end of the game or match could imply an emotional change (i.e. pressure, anticipation) associated with a situation that could determine the outcome of the match. When the end of a game or match is approaching, players may be more likely to consider the outcome of the competition, e.g., the winner gets a reward, and the loser does not. This situation is similar to the anticipation of reward and outcome in gambling. Previous studies have reported that anticipation of reward induces an increase in HR and sympathetic nerve activity (Rakover and Levita, 1973; Meyer et al., 2000; Schneider et al., 2018). Therefore, it is reasonable to expect that sympathetic nervous system activation would occur in situations close to the end of the game or match. In addition, we found that the mean HR at the beginning of the match was higher than that in the 1st round in the 2nd game. The increase in HR at the beginning of the match may have been induced by various factors such as anticipation and anxiety (Cervantes Blasquez et al., 2009; Mateo et al., 2012). However, the reason why this increase continued only for a few minutes is unclear. Further research is needed to clarify this phenomenon. Given the above, the results of our study (Figure 2, Figure 3) supported our first hypothesis: (1) the sympathetic nervous system of esports players was activated by competitive play and was modulated by the game situation (beginning of the match, end of game or match).

Physiological synchrony was observed under the PvP condition (Figure 4A). There were two possible reasons for this synchrony. The first possibility was that the HRs of the opponents were simultaneously affected by sensory stimuli (e.g. visual and sound effects) because they were watching the same scene at the same time. However, since a sensory stimulus induces an HR change within 10 sec (Holand et al., 1999; Bradley et al., 2001), any HR change caused by sensory stimuli should have occurred within a round. Even when HRs were averaged within a round, the correlations between dyads were still observed (Figure 4B). This indicates that the temporal changes in HR were not simply induced by a sensory stimulus. Therefore, the most plausible explanation is that interpersonal interaction synchronized the HRs of the two opponents. Given the above (shown in Figure 4), our data supported our second hypothesis: (2) the autonomic nervous system activity of players in dyads is synchronized by interpersonal interactions during competitive play.

If this hypothesis is supported, then what factor associated with interpersonal interaction induced synchronization of the autonomic nervous system? Many studies on interpersonal interaction have reported physiological synchrony among cooperative dyads via physical or

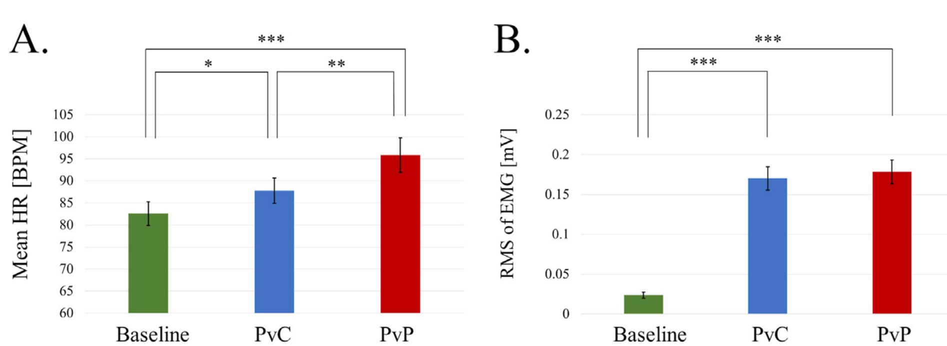

Figure 5. Mean HR (A) and RMS of EMG related to the joystick movement and button press (B) at baseline, in the PvC condition, and in the PvP condition. The vertical axis indicates the mean HR [BPM] (A) and the RMS of EMG of forearms [mV] (B). The error bar shows the standard error. Statistical significance is indicated at $^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

sensory contact (e.g. hand touch, conversation, eye contact) (Feldman et al., 2011; Rodriguez-Zamora et al., 2012; McCraty and Zayas, 2014; Waters et al., 2014; Butler, 2015; Goldstein et al., 2017; Yoon et al., 2019). In contrast, in this study, we found that physiological synchrony occurred in a competitive situation where players interacted with each other only via virtual avatars. In the context of virtual interaction, a previous study suggested that autonomic nerve activities of two opponents were weakly correlated during casual gameplay (Chanel et al., 2012). However, we found the autonomic nerve activities of esports players to be highly correlated during serious esports play. A shared perspective regarding the specific game situation may have induced this strong correlation. A player's action can interactively affect the game situation, and players can comprehend and predict such changes. In a highly competitive condition, specific game situations such as the end of a match might activate the sympathetic nervous system, as discussed above. Therefore, if the members of a dyad have a shared perspective regarding the game situation over a broad time range, then changes in autonomic nervous system activities in both players could occur with similar timing, leading to a strong HR correlation throughout the match.

In terms of potential implications, playing esports may have a negative impact on health. As mentioned above, the increase in HR in the PvP condition compared with that in the PvC condition might be mainly induced by the differing psychological factors. If the cardiovascular system of a player is activated by psychological stress for long periods of time, they may be at increased risk of cardiovascular disease (Porter and Goolkasian, 2019; Steptoe and Kivimäki, 2012). However, this increase in HR may have a positive short-term impact on esports athletes because activation of the sympathetic nervous system could temporarily boost cognitive abilities (Berridge and Spencer, 2016; Gellatly and Meyer, 1992). Considering that the essential motivation of an esports athlete is to win against their opponent, improved performance would be beneficial even if it were transient. Further studies are needed to clarify the short- and long-term effects of HR elevation on esports players.

There are some limitations to the present study. For example, the LF/HF of HRV is frequently used to estimate sympathetic nervous system activity. It is generally considered necessary to measure over 2 min of data for analysis of the LF/HF of HRV (Force, 1996). However, as we were investigating the physiological states of esports players in a real competitive situation, we were not able to collect data for a sufficient duration for analysis of HRV in each round. In addition, other measurements for estimating sympathetic nerve activity, such as electrodermal activity and pupil dilation, were not possible because esports players use all of their fingers and consistently watch a screen with a rapidly varying luminance. Therefore, we evaluated changes in the autonomic nervous system of esports player via changes in the HR temporal pattern and by referring to previous findings.

It is possible that the competitive effect in the current study occurred because the two opponents had comparable abilities. If the game outcome had been easily predictable, the stronger player would not have needed to make much of an effort to win, while the weaker player would not have expected to win regardless of effort. Therefore, the competitive effect might not occur when opponents have different ability levels. Furthermore, the competitive effect might arise only in professional players because they have a high skill level and enhanced foresight. To clarify these possibilities, further experiments should evaluate physiological synchronization between players with different skill-levels.

5. Conclusion

In this study, we found that competitive and interactive play affected the physiological state of professional esports players. HR was elevated in specific game situations (beginning of the match, end of a game or match) during competitive play, suggesting that the sympathetic nervous system of esports players was activated by the magnitude of competitiveness, depending on the game situation. In addition, the temporal HR patterns of pairs of players were synchronized, suggesting that the autonomic nerve activities of dyads are synchronized by interpersonal interaction. Our results provide insights regarding how physiological states are related to psychological ability in esports professionals during esports competitions.

Declarations

Author Contribution Statement

Ken Watanabe: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Naoki Saijo, Makio Kashino: Conceived and designed the experiments; Wrote the paper.

Sorato Minami: Performed the experiments; Wrote the paper.

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Data Availability Statement

The authors do not have permission to share data.

Declaration of interests statement

The authors declare no conflict of interest.

Additional Information

No additional information is available for this paper.

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