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Article

Effect of positive and negative ions in esports performance and arousal levels

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Abstract
The purpose of this study was to investigate the psychological effects of arousal levels in esports players during a racing-game under positive and negative ion environments. Participants (10 male) who belonged to the collegiate esports team were recruited. The influences of positive and negative ions were evaluated in a randomized, crossover, and placebo-controlled double-blind design. Each participant completed two experiments within a 4-week interval. Two experimental environments were used: positive and negative ions filled up the atmosphere (PNI), and a control (CON) condition. For the performance task, a car-racing game was adopted. Arousal state was measured by the Two-Dimensional Mood Scale (TDMS) and an electroencephalogram (EEG). Results indicated that the EEG level was significantly higher in PNI than CON condition. Also, the PNI had a significantly higher performance on the gaming task than the CON condition. The present study demonstrated the beneficial effects of positive and negative ion environments on esports players.

Keywords: electronic sports, athlete, game, car race, driving, EEG.

1. Introduction

Esports involves the enactment of video games as spectator-driven sport, carried out through promotional activities; broadcasting infrastructures; the socioeconomic organization of teams, tournaments, and leagues; and the embodied performances of players themselves (Taylor, 2016; Reitmen et al., 2020), and it is phenomenon that has grown dramatically over the past decade (Toth et al., 2019). Sport involves the display of elite athletes' physical and psychological skill in sports competition for entertainment aims in general (Campbell, et al., 2018). On the other hand, esports' athletes seem to rely more on psychological or emotional skills for success rather than motor skills that traditional sports athletes rely on (Himmelstein et al., 2017). Thus, training of psychological or emotional skills for esports is significant to promote its entertainment and it is necessary to pursue whether to improve psychological or emotional skills for esports athletes. Therefore, research on training method and environment to improve more psychological and emotional skills would be necessary in esports filed. However, currently, there is no esports training method that was established in the sports science filed, and further research would be needed. Furthermore, in the field of sports science, the training environment is also important in addition to the establishment of training methods. Hence, it is necessary to examine the training environment related to esports in the field of sports science.

Arousal is a human psychological state and defined as being "worked up" or energized (Perkins et al., 2001). High levels of arousal would benefit or be essential for maximal performance (Oxendine, 1970); thus, several studies investigated the relationships between arousal and sports performance (e.g., Gould & Krane, 1992; Hagiwara et al., 2019; Perkins et al., 2001). Athletes with higher arousal levels, assessed by a questionnaire, had a significantly higher

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success rates of shots in badminton (Yamazaki & Sugiyama, 2009). Subjective assessments (i.e., questionnaire) have been mostly used to understand the relationship between the arousal levels and performance (Nagao & Sugiyama, 2013; Perkins et al., 2001; Yamazaki & Sugiyama, 2009); however, a few studies have been conducted using EEG (Fronso et al., 2016; Hagiwara et al., 2019; Hagiwara et al., 2020). The higher EEG was associated with increased performance in Olympic athletes in air-pistol shooting (Fronso et al., 2016). Hagiwara et al. (2019) then examined the relationship between the arousal levels and swimming performance though both questionnaire and EEG before and after watching a motivational video. Hagiwara and colleagues demonstrated that athletes with higher arousal levels tended to perform better. However, it is important more work to understand the relationship between the two, especially by using EEG.

Various training environments have been used for facilitating sports performance, and an altitude environment has often been adapted (Berglund, 1992). Training in a hyperoxic or hypoxic environment found to enhance sports performance (Cardinale & Ekblom, 2018; Roels et al., 2007). Recently, training in an air-ionic environment has been considered to have positive impacts on athletes' emotional states, which might relate to their sport performance (Hagiwara et al., 2020; Nimmericher et al., 2014; Ryushi et al., 1998). Physical training under positive and negative ion environments among elite swimmers might enhance both (questionnaires, EEG) arousal levels and training performance (Hagiwara et al., 2020). However, research on the environmental contributions to sports performance was limited (Davids & Baker, 2007), and effective environments for esports performers are currently unknown. The current study examined this matter using positive and negative iron environments.

Air ions are small particles that exist in nature and are positively or negatively charged molecules or atoms in the air (Jiang & Ma, 2018). Positively charged ions are positive ions and vice-versa (Yamamoto et al., 2015). In addition, air ions containing positive and negative ions have certain abilities such as purification of the atmosphere and deodorization (Nishikawa, 2013). The relationship between air ion and emotions have been conducted (Flory et al., 2010; Perez et al., 2013). For instance, a high-density negative ion environment was found to reduce depression. In addition, other studies that examined the relationship between negative ions and depression (Goel & Etwaroo, 2006; Terman & Terman, 2006; Terman et al., 1998), lower stress (Malik et al., 2010), and increased well-being (Lips et al., 1987) have been conducted. Several studies also suggest that the relationships exist between positive ion environment and human emotions (Perez et al., 2013). For instance, Gianinni et al. (1986) examined the correlation between positive air ion and emotion. Results showed anxiety and excitement significantly increased under this condition. In addition, the relationship between positive ions and feelings of unpleasantness, irritation and anxiety has been verified (Giannini et al., 1986; Charry & Hawkinshire, 1981).

Although research findings have been mixed, environments that induce ions and emotions have been connected. To our knowledge, little research has been conducted to understand a better relationship among, environments, arousal states, and performance in esports. The purpose of the present study was to examine the arousal level and performance in esports under positive and negative ion environments.

2. Methods

2.1. Participants

Ten male participants who belonged to the collegiate esports team (age: M = 21.22 ± 1.59) were recruited. They were informed the purpose of the study and completed an informed consent form prior to participation. The Institutional review board approval was obtained from the research institute, National Institute of Fitness and Sports in Kanoya.

2.2. Experimental Protocol

The influence of plasmacluster ions was evaluated in a randomized, crossover, placebo-controlled double-blind trail. Each participant completed two experiments within a four-week interval. Two experimental conditions were prepared (Figure 1): positive and negative ions were filled up the atmosphere in the experimental tent (PNI) and ions were not generated (CON) condition. The PNI condition was delivered by a PlasmaclusterTM ionizer (Sharp Corporation, Japan) and exposed to positive and negative ions (147,000-164,000 PNI/cm3) with air wind from the ionizer. In the CON condition, air wind from the ionizer without ions at the same air wind velocity was adapted (wind velocity: 0.29 m/sec). This method to generate positive and negative ions was previous used (Yamamoto et al., 2015). First, molecules in the air were decomposed by applying positive and negative high voltages to each discharge brush electrode of the ion generation devices, and the devices generated positive ions and negative ions (Nishikawa & Nojima, 2001). The ion concentrations were determined by an ion counter (MY1210S, Asahi System Inc. Japan) by means of the double concentric circle tube method (Nishikawa & Nojima, 2001). The room temperature and humidity were 23.5 ℃±0.5 and 60% ± 2.0, respectively.

Figure 1 Bauhutte single-person gaming tent (be-s Co., Ltd., Japan)

The details of the experimental procedure were as follows (Figure 2). First, the participants were asked to put on an EEG device for 2 minutes for their baseline assessment of arousal level. The participants then completed a questionnaire to assess arousal level before performing a racing-type action game. They completed the 3 times as practice trials prior to performing in the experimental setting in the tent. They also performed 3 times as final trials. For the performance task, the participants completed MARIOKART Deluxe 8. The driving course was Mario Kart Stadium, and the race-mode setting was Time Attack, which involved driving 3 laps around the same course. The class of the vehicle was set to 150cc, and the participants choose the character of the driver. During the completion, EEG was assessed to measure their arousal level. After the task, participants completed the questionnaire

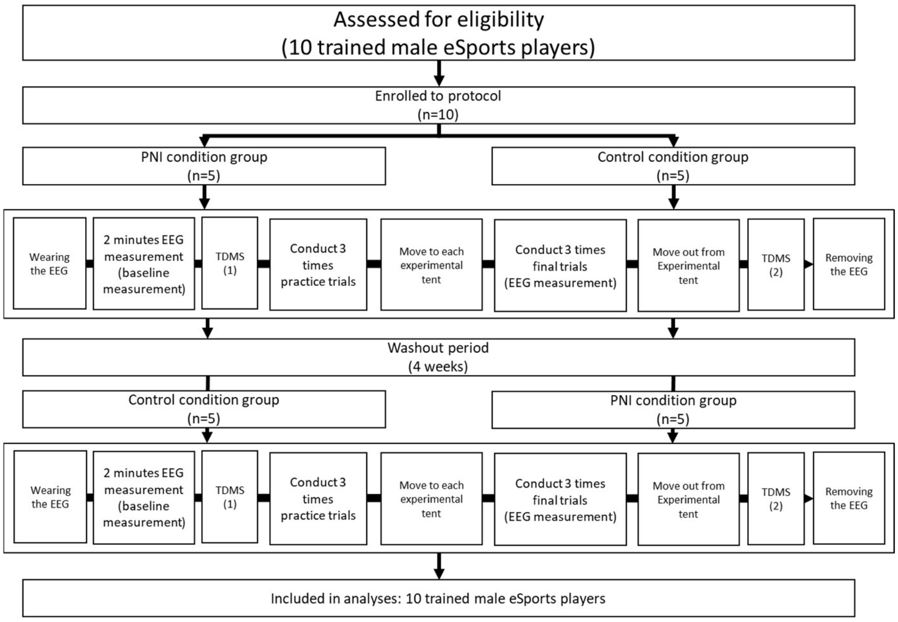

Figure 2 Flow diagram of the study design

2.3. Evaluation of Arousal

The arousal level was assessed by a questionnaire and EEG. A Two-Dimensional Mood Scale (TDMS) (Sakairi et al., 2013) was used to evaluate arousal level. The TDMS is composed of 8 items and 4 factors: activity, stability, comfort, and arousal. We adopted a simple band-type EEG device (NeuroSky Co., Ltd., Tokyo, Japan) that only measures the front polar area 1 (Fp1) lobe as defined by the international 10–20 system (Figure 3). The EEG obtained from Fp1 has been found to be suitable for obtaining data on psychological condition (Mitsukura, 2016; Hotta et al., 2017). Therefore, we used Fp1 to estimate the arousal level.

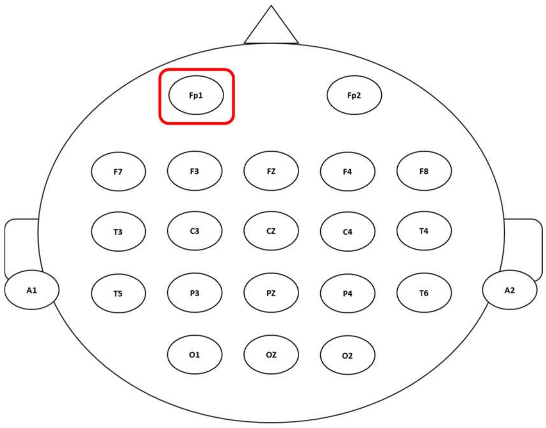

Figure 3 Measurement points of the international 10-20 system

Brainwaves were classified into 4 types according to their frequency range: 0.5–4 Hz: delta waves, 4–8 Hz: theta waves, 8–13 Hz: alpha waves, 13–40 Hz: beta waves. Psychological states were associated with each type (Okubo et al., 2018) (Table 1).

Table 1. Type of brain wave and psychological state

Type of brain wave	Frequency (Hz)	Psychological state
Delta wave	0.5 ~ 4 Hz	Non-REM sleep, unconscious
Theta wave	4 ~ 8 Hz	Sleep onset, illusion
Alpha wave	8 ~ 13 Hz	Relaxed mental state
Beta wave	13 ~ 40 Hz	Arousal

This present study examined the beta wave band. The EEG data were recorded on a smartphone in the Kansei Module Logger (Littlesoftware Inc., Japan). This produced the data output in the most sensitive manner. The occurrence ratio of the beta wave band was defined as the arousal level, and the value was displayed from 0 to 100. The arousal level by the Kansei Module Logger correlated with the subjective arousal level, measured by a questionnaire (Hagiwara et al., 2019). The basic concept of the Kansei Module Logger is that it calculates the power ratio between the beta wave bands. The potential difference obtained from the electrodes on the forehead and earlobe of the left Fp1 is amplified by the circuit inside the measuring instrument, digitized at 512 samples/sec, and subjected to the Hanning window processing. The power spectral analysis was then conducted using the fast Fourier transform. EEG data are analyzed every second, and the amplitude spectra can be obtained at 1-64 Hz. Thus, this study obtained delta, theta, alpha and beta waves. From the obtained power spectrum, the sum of each power in each frequency band was calculated after, and the ratio included in the total power is shown as a relative numerical value. However, the sum of the power of each frequency cannot be used because the amplitude of each frequency band is different. Therefore, the average value of the power of each frequency band was obtained. The calculation method used the following formula as a standard for analysis.

The average P_x of the x-wave power was calculated by formula (1), where V_f is the power of the EEG at the frequency f [Hz]. Since the beta wave band (13 Hz to 40 Hz) was handled, when $x = \beta$, it became (13, 40) [Hz], and the numerical value was applied to ($F_{xmax} - F_{xmin}$) in formula (1). Next, the sum of power averages (P_{sum}) in each frequency band was calculated by formula (2). The ratio (R_x) included in the total power of the beta wave band was calculated in formula (3). With these calculations below, the beta band were normalized to provide the value of 0-100.

$$P_x = \sum_{f=F_{min}^x}^{F_{max}^x} V_f / (F_{max}^x - F_{min}^x + 1) \quad (1)$$

$$P_{sum} = P_\delta + P_\theta + P_\alpha + P_\beta \quad (2)$$

$$R_x = P_x / P_{sum} \quad (3)$$

2.4. Analysis

The TDMS scores before and after completing the task and EEG during the task were averaged. A t-test was used to examine the difference between the PNI and CON conditions on the TDMS and EEG. For the task performance, the 3 trials prior between the PNI and CON conditions were averaged. A t-test was also performed to examine the difference between the two conditions. The IBM SPSS Statistics 25.0 software was used for the analysis, and p value was set at 0.05.

3. Results

3.1. TDMS

There was no significant difference between the PNI condition (*M* = 6.44, *SD* = 5.10) and CON condition (*M* = 4.78, *SD* = 4.63) on TDMS ($p > .05$) (Figure 4).

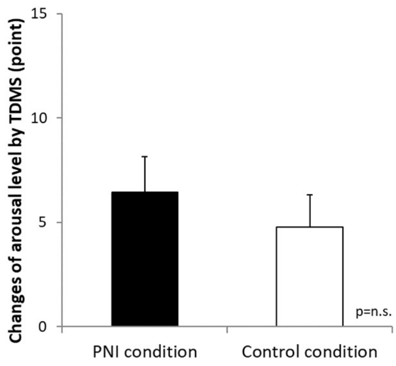

Figure 4 Arousal level by TDMS

3.2. EEG

The PNI condition (*M* = 28.47, *SD* = 9.79) had significantly higher value ($p < .05$) than the CON condition (*M* = 18.35, *SD* = 8.03) on the brain activation – β-band power ratio – via EEG (Figure 5).

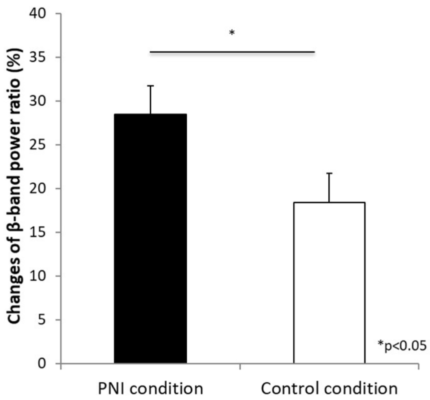

Figure 5 β-band power ratio

3.3. Racing Performance
Racing performance is shown in Figure 6. The PNI condition (*M* = -3.64, *SD* = 2.53) significantly outperformed the CON condition (*M* = -1.18, *SD* = 2.25) on racing performance, measured by racing speed ($p < .05$).

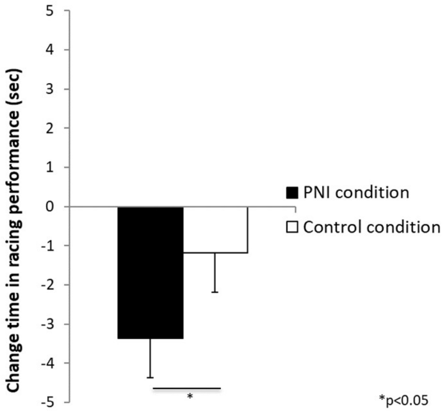

Figure 6 Racing performance

4. Discussion
The purpose of this study was to investigate the psychophysiological effects of arousal in esports during a racing-game under positive and negative ion environments. Although no difference was found between the PNI and CON condition on TDMS, the PNI condition had the higher values than the CON condition on the EEG – the brain activation. Importantly, the PNI condition outperformed the CON condition on the racing or esports performance, assessed by racing speed. How esports performance can be enhanced is interesting for researchers and esports players, and our study showed that changing an environment using positive and negative ions enhanced esports performance, along with increasing brain activation.

One of the research questions was whether *simultaneously* using both positive and negative ions influenced esports performance. Although the esports task was not used, training under combined positive and negative ions might suggest increasing the beta wave power ratio with increased performance relative to a nutral environment in a recent study (Hagiwara et al., 2020). Whether use of higher concentrations of both ions differed from lower concentrations on cognitive performance and physiological measurements was examined (Wallner et al., 2015). Results showed that, although there was no difference on lung function and well-being, the higher concentrations outperformed the lower concentrations on cognitive performance. Specifically, reasoning ability and perceptual speed were measured as cognitive performance, which are closely related to esports performance. Wallner and collogues (2015) concluded that increasing air ions concertation enhanced one's psychological and physiological performance.

Currently, how using both ions affect *esports* performance has not been examined in the literature. However, the meta-analysis performed by Pereza and colleagues (2013) examined how positive and/or negative ions has been used to evaluate mood outcomes. For instance, negative ions generally reduced depressed symptoms. Although the effect of negative ions expressed various advantages including higher ratings of alertness, freshness, and environmental warmth, the effects of positive ions were not explicitly discussed (Harkins, 1981). In fact, the same meta-analysis showed that positive ions have not been demonstrated any meaningful positive outcomes on one's psychological states. However, one study demonstrated the positive contribution in increasing levels of arousal though positive ions (Charry & Hawkinshire, 1981). Future studies are encouraged to examine how positive or negative ions, or a combination of both ions influence *esports* performance, along with the underlying mechanism of the performance outcomes.

How arousal influence performance allowed us to examine the underlining mechanics of increased esports performance in this study, and the relationships between the arousal and sports performances have been assessed (e.g., Perkins et al., 2001; Gould & Krane, 1992; Hagiwara et al., 2020). Badminton players with higher arousal levels had a significantly higher success rate of shots (Yamazaki & Sugiyama, 2009). Additionally, high EEG was associated with shooting performance in air-pistol shooting athletes at the Olympic level (Fronso et al., 2016). Among elite collegiate swimmers, those who had high arousal levels measured by EEG and questionnaire tended to have effective performance. Thus, arousal level positively impacted on sports performance. This study suggested that positive ions might enhance the arousal level of esports players, in turn, enhanced esports performance.

Some limitation should be acknowledged. First, future studies are encouraged to increase the sample size. Although the effect of negative ions offers various advantages than positive ions on psychological and performance outcomes, our study found that a combined both positive and negative ions enhanced *esports* performance than the natural (i.e., CON) condition. We were not exactly sure how each (e.g., positive, or negative) iron influenced the participant's psychological function, the brain activation, and the esports performance. Future studies should examine a longitudinal experiment to evaluate how the brain activation has been sifted from the beginning to the end of the performance, instead of simply taking the average of each trial, to provide rich understanding on this matter.

In sum, the purpose of the research was to examine whether using combination of positive and negative ions influenced psychophysiological measures of arousal and esports performance. Our research demonstrated that esports performance – measured by racing-game performance – was enhanced by the experimental environment, along with higher EEG values. Esports have currently been one of the most growing sports in the world and how performance could be enhanced is attractive from various angles. Interestingly, a recent review focused on how *instructors* can provide practice conditions to players to enhance esports performance from instructors' perspective as coaching application (Iwatsuki et al., 2021). Various research line in esports has been emerged in this past five years, and we expect to see more research on how environmental factors such as using positive or/and negative ions influence esports performance as researchers, instructors, and players look for ways to enhance *esports* performance like traditional sports.

Author Contributions

Conceptualization, G.H.; methodology, G.H., H.F., M.M., Y.K., S.T., H.O., D.A.; software, G.H.; validation, G.H., M.M. and D.A.; formal analysis, G.H.; investigation, G.H., H.F, M.M., Y.K., S.T., H.O., D.A.; resources, D.A.; data curation, D.A.; writing—original draft preparation, G.H.; writing—review and editing, T.I.; visualization, T.I.; supervision, G.H., T.I.; project administration, G.H.; funding acquisition, H.F., M.M., Y.K., S.T., H.O.; All authors have read and agreed to the published version of the manuscript.

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Conflicts of interest

This study was funded by Sharp Corporation. M.M., H.F. Y.K., S.T. and H.O. are employees of Sharp Corporation.

Institutional Review Board Statement

The study was conducted according to the Declaration of Helsinki, and approved by the Institutional Review Board of the National Institute of Fitness and Sports in Kanoya (No.5-1, 22 April 2020).

Informed Consent Statement

Informed consent was obtained from all participants involved in the study.

Data Availability Statement

Not applicable

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