

Article

Effectiveness of Positive and Negative Ions for Elite Japanese Swimmers' Physical Training: Subjective and Biological Emotional Evaluations

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Abstract: The purpose of this study is to examine the subjective and objective arousal of elite swimmers during physical training under a positive and negative ion environment. The participants were 10 elite Japanese collegiate swimmers participating in the Fédération Internationale de Natation (FINA) Swimming World Cup (age: 20.80 ± 1.39 , five males and five females). Each participant went through two experiments (they were subjected to both the positive and negative ion environment and the control environment) within a four-week interval. The training task was a High-Intensity Interval Training (HIIT) routine for the swimmers. The subjective arousal state was measured using a Two-Dimensional Mood Scale (TDMS). In addition, biological emotional evaluations in the form of an electroencephalogram (EEG) were conducted to assess the arousal state of the elite swimmers. The examination of the change in the arousal level at rest and during training demonstrated that both subjective and objective arousal levels were significantly higher in the positive and negative ion environment than in the control environment. In addition, the average training performance scores were also significantly higher in the positive and negative ion environment than in the control environment. This study posits that the positive and negative ion environment has a positive effect on sports training.

Keywords: training environment; sports; athletes; interval training; biological emotional evaluation; sports sciences

1. Introduction

Arousal is a human psychological state and is defined as being “worked up” or energized [1]. In addition, Oxendine [2] proposed that high levels of arousal would benefit, or be essential for, maximal performance; thus, several studies investigated the relationships between arousal and sports performance [1,3,4]. Yamazaki and Sugiyama [4] examined the relationships between subjective arousal level and sports performance and the results indicated that, among Japanese collegiate badminton players, athletes with higher arousal levels had significantly higher shot success rates. In addition, Fronso et al. [5] used an electroencephalogram (EEG) to assess the biological arousal level in Olympic athletes participating in air-pistol shooting, and investigated the relationships between arousal level and sports performance. The results demonstrated that higher levels of arousal were associated with controlled shooting performance. Although subjective evaluations about arousal level have been

conducted using questionnaires [1,4,6], few studies about the biological evaluations of psychological arousal level have been attempted.

Air ions are small particles that exist in nature and are positively or negatively charged molecules or atoms in the air [7]; positively charged ions are positive ions and those negatively charged are negative ions [8]. In addition, air ions containing positive and negative ions have certain abilities such as purification of the atmosphere and deodorization [9]. Thus, several studies have been conducted on the relationship between air ions and human emotions.

Previous studies on the relationship between air ions and emotion in humans have been conducted [10]. Flory et al. [11] conducted an experiment where 18 women stayed in a high-density ion environment for over 12 consecutive days and the results indicated that the high-density negative ion environment reduced depression. In addition, other studies that examined the relationship between negative ions and depression [12–15], lower stress [16], and increased well-being [17] have been conducted. Several studies also suggest that relationships exist between positive ion environments and human emotion [10]. For instance, Gianinni et al. [18] examined the correlation between positive air ions and emotion and found that 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 [18,19].

Although there is some skepticism in the study of ions, the results of the above-mentioned studies confirm that they are connected to emotional changes. In addition, little research has been done on the relationship between positive and negative ions and the emotion and performance of athletes in the field of sports science, and no such research is found in Japan. Thus, the purpose of this study was to examine the subjective and objective arousal of elite Japanese swimmers during physical training in a positive and negative ion environment.

2. Materials and Methods

2.1. Participants and Study Design

Institutional review board approval was obtained from the corresponding author's research institute (National Institute of Fitness and Sports in Kanoya, Institutional Review Board, No.11-6). The participants were informed of the instructions and purpose of this study before the experiment.

The participants were 10 elite Japanese collegiate swimmers participating in the Fédération Internationale de Natation (FINA) Swimming World Cup (age: 20.80 ± 1.39 , 5 males and 5 females). Each participant underwent two experiments within a four-week interval. Two types of experimental environment were prepared: a condition in which positive and negative ions were filled up the atmosphere in the experimental room (PNI condition), and a condition in which ions were not generated (control condition). The conditions were blinded by randomly changing the experimental environment to prevent the participants from knowing to which condition they were subjected. The details of randomization are described as follows.

The first experiment was conducted within two days. On the first day, we created a PNI condition and conducted experiments while filling the atmosphere with air ions. The participants were randomly assigned and trained in one of the two environments (in the first experiment, three female and two male athletes performed in the PNI condition). After the experiment in the PNI condition was completed, the experimental laboratory was opened for one day to stop the ionizers and release the PNI from the room. Thereafter, it was confirmed that there were no PNI and the remaining five people (three women, two men) conducted experiments in a control condition. Four weeks after the first experiment, the participants underwent the same procedure and the second experiment was conducted.

The PNI condition was delivered by six PlasmaclusterTM ionizers (Sharp Corporation, Sakai-shi, Osaka, Japan) and exposed the participants to positive and negative ions (147,000–164,000 PNI/cm³). The details of the process for generating positive and negative ions were based on previous research [8]. First, molecules in the air are decomposed by applying positive and negative high voltages to each

discharge brush electrode of the ion generation devices, and the devices generate positive ions and negative ions [20].

The ion concentrations were determined by an ion counter (MY1210S, Asahi System Inc., Osaka-shi, Osaka, Japan) by means of the double concentric circle tube method [20]. The room condition was a temperature of $24.0\text{ }^{\circ}\text{C} \pm 0.5$ and humidity was $60\% \pm 2.0$.

The experimental procedure is as follows (Figure 1). First, participants were asked to put on an EEG device for two minutes to investigate their baseline degree of arousal before training. An EEG is an electrical signal generated by the brain and can be used to measure the psychological state of humans in real time. The participants then answered a questionnaire which evaluated their subjective emotional state before the training. A training task was then assigned. The training task was a High-Intensity Interval Training (HIIT) routine for swimmers. Participants conducted eight sets of 20 s of hard exercise and 10 s of rest using a swimming ergometer (Concept2 Inc., Morrisville, VT, USA) (Figure 2). After 8 sets, participants rested for 10 min and then again performed HIIT for 20 s, with one set at maximum power. After the training task, the average load (W) for 8 sets of intervals and the maximum power set of training load (W) after a 10-min rest were evaluated. The training load was set to the load used by the participants in their daily practice. Thus, the training load was set to eight for males and six for females. Thereafter, the EEG of the participants was measured for two minutes to investigate their degree of arousal after training, after which they were required to answer a questionnaire again.

In this study, EEG was also measured during interval training but, since it was accompanied by large movements during training, accurate data could not be acquired due to noise. Therefore, the measurement values were compared for two minutes before and after training. In addition, this study used the same method as a previous study [21] that adopted two minutes to investigate the baseline degree of human emotion.

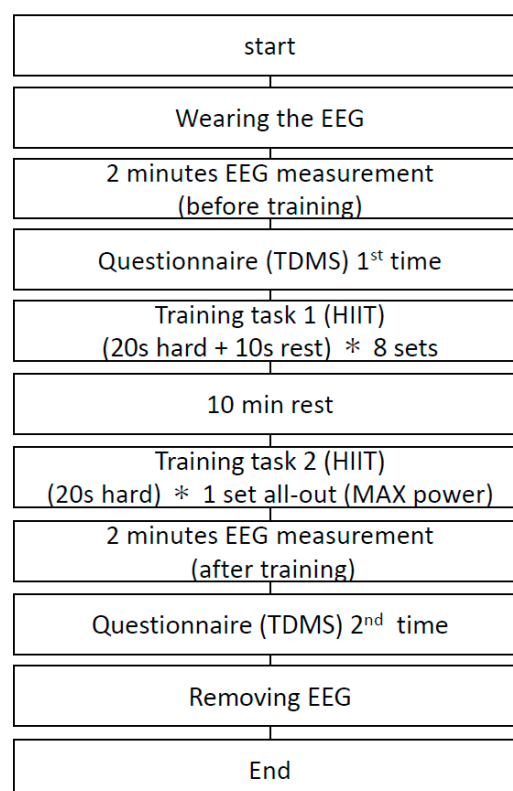


Figure 1. Experimental procedure.



Figure 2. High Intensity Interval Training (HIIT) Training.

2.2. Emotional Evaluation

Subjective emotional evaluation was measured using a Two-Dimensional Mood Scale (TDMS) [22]. The TDMS is composed of eight items and four factors: activity, stability, comfort, and arousal. This study used the arousal score to evaluate the elite swimmers' emotional state.

A biological emotional evaluation in the form of an EEG was also conducted to assess the arousal state of the elite swimmers. In addition, the EEG measurement was used in this study because it is more easily measured in a daily living environment compared to other brain activity measurements. 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). Since Fp1 is located on the left frontal lobe, there is no need to worry about the possible noise interference caused by hair. The EEG obtained from Fp1 has been found to be suitable for obtaining data on people's psychological condition [23,24]. Thus, this study also assessed the Fp1 to estimate arousal level.

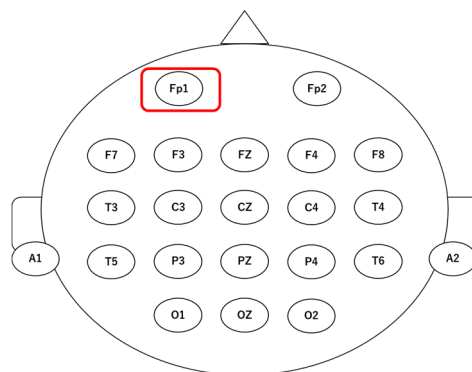


Figure 3. Measurement points of the international 10–20 system.

The electrical activity in the brain is often used as an objective evaluation index that employs biological data. Brainwaves are generally classified into four types according to their frequency range:

0.5–4 Hz: delta waves, 4–8 Hz: theta waves, 8–13 Hz: alpha waves, and 13–40 Hz: beta waves. Emotions are associated with each type [25] (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 study focused on the beta wave band. The EEG data obtained were recorded in a smartphone and the Kansei Module Logger [26]. This method produced the data output as sensitivity values were used. In addition, the Kansei Module Logger was set so that the occurrence ratio of the beta wave band was defined as the arousal level, and the value was easily displayed as a value from 0 to 100. Hagiwara et al. [27] posited that the arousal level output by the Kansei Module Logger correlates with the subjective arousal level. The basic concept of 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 by the fast Fourier transform, and the amplitude spectra can be obtained in the frequency range of 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 then calculated, and the ratio included in the total of 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, we took the average value of the power of each frequency band and obtained the representative value of that frequency band. 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 this study concerns the beta wave band (13 Hz to 40 Hz), when $x = \beta$, it becomes (13, 40) [Hz], and the numerical value is applied to $(F_{max}^x - F_{min}^x)$ in Formula (1). Next, the sum of the power averages (P_{sum}) in each frequency band is calculated by Formula (2). The ratio (R_x) included in the total power of the beta wave band was calculated in Formula (3).

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

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

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

Based on the above calculation method, the Kansei Module Logger normalized the power ratio that can be taken in the beta band to the value of 0–100.

2.3. Analysis

For subjective data, the difference between the average value of arousal level by TDMS before and after training was used as the change value, and t-test was used to compare the PNI condition and control condition. For biological data, the difference between the average value of arousal measured before training and the average value of arousal measured after training was used as the amount of change. The paired t-test was then used to compare the difference between the PNI condition and the control condition. In the training data, the average load (W) for 8 sets of intervals and maximum

power set of training load (W) after a 10-min rest were compared between the PNI condition and the control condition.

3. Results

3.1. Comparison of Changes in Arousal by TDMS before and after Training in PNI and Control Conditions

As a result of comparing the amount of change in arousal by TDMS before and after training in the PNI and the control conditions, the amount of change in the arousal level under PNI condition ($M = +7.30$, $SD = 1.90$) was found to be significantly higher than that in the control condition ($M = +3.3$, $SD = 1.24$) ($t = 3.52$, $p < 0.01$) (Figure 4).

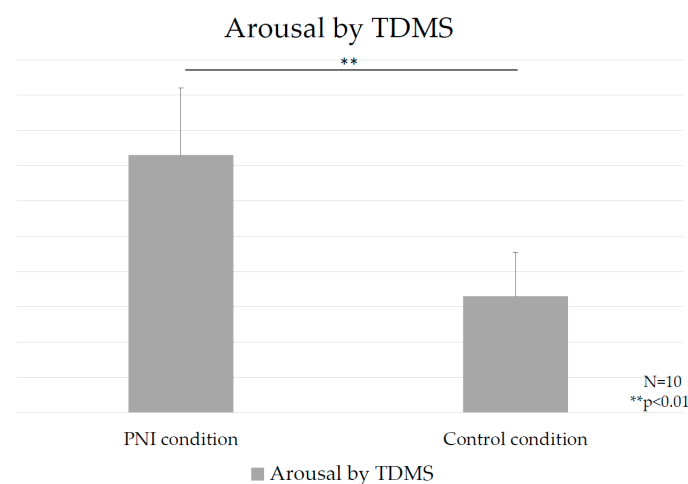


Figure 4. Comparing the amount of change in arousal by a Two-Dimensional Mood Scale (TDMS) in Positive-Negative Ions (PNI) and control conditions.

3.2. Comparison of Changes in Arousal by EEG before and after Training in the PNI and the Control Conditions

As a result of comparing the amount of change in arousal by EEG before and after training in the PNI and the control conditions, the amount of change in the arousal level under PNI condition ($M = +8.16$, $SD = 2.14$) was also found to be significantly higher than that in the control condition ($M = +2.75$, $SD = 2.24$) ($t = 2.84$, $p < 0.05$) (Figure 5).

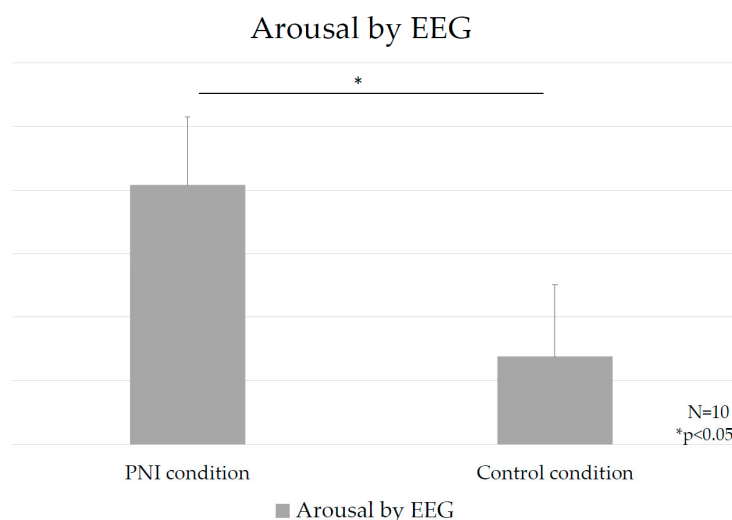


Figure 5. Comparing the amount of change in arousal by electroencephalogram (EEG) in PNI and control conditions.

3.3. Comparison of the Average Load (W) for Eight Sets of Interval Training in PNI and Control Conditions

As a result of comparing the average load (W) of interval training in the PNI and the control conditions, the average load (W) under PNI condition ($M = 146.22$, $SD = 13.54$) was shown to be significantly higher than that recorded in the control condition ($M = 141.14$, $SD = 12.32$) ($t = 1.46$, $p < 0.10$) (Figure 6).

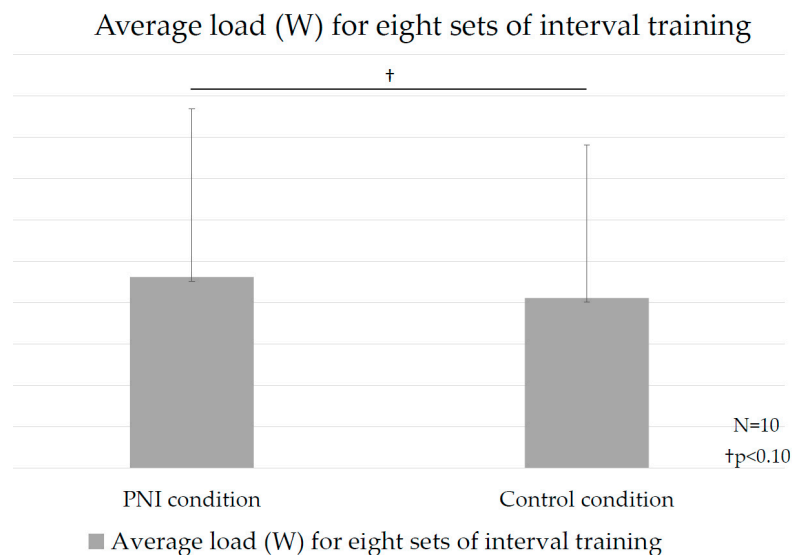


Figure 6. Comparing the average load (W) for 8 sets of interval training in PNI and control conditions.

3.4. Comparison of the Average of Training Load (W) during the Maximum Power Set in PNI and Control Conditions

As a result of comparing the average of training load (W) during the maximum power set in the PNI the and control conditions, the average load (W) under PNI condition ($M = 192.78$, $SD = 19.36$) was also found to be significantly higher than that in the control condition ($M = 181.67$, $SD = 16.03$) ($t = 1.99$, $p < 0.05$) (Figure 7).

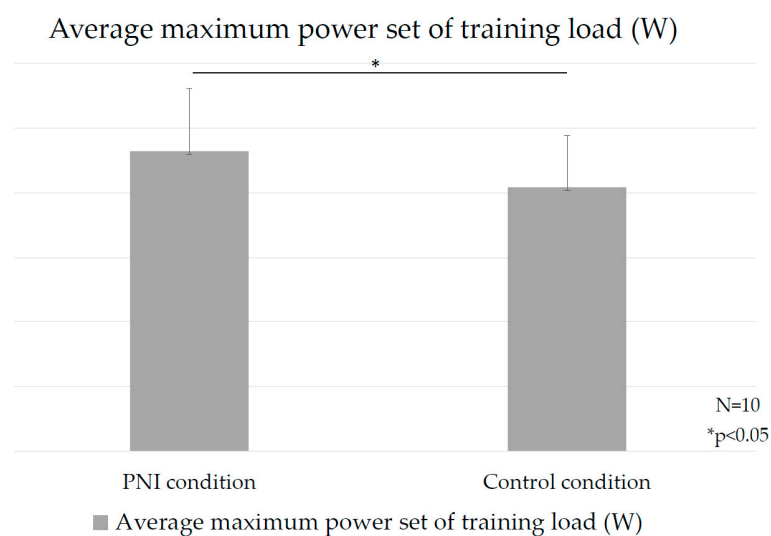


Figure 7. Comparing the average of training load (W) during the maximum power set in PNI and control conditions.

4. Discussion

This study aimed to investigate the psychological effects of both the subjective and objective arousal levels of elite Japanese swimmers during physical training under a positive and negative ion environment.

First, the results of the comparison of the subjective arousal level indicated that the PNI condition significantly improved the arousal level compared to the control condition. Previous studies [12–15] have clarified the relationship between negative ions and positive emotions by using subjective evaluation. In addition, subjective research has also shown the relationship between positive ions and emotions in previous studies [18,19]. In this study, as a result of verifying the subjective arousal level in an environment in which PNI are simultaneously generated, it is suggested that athletes may have a higher arousal level under the PNI condition. These results are considered to be new findings in the literature on PNI and emotions.

Second, the results of the comparison of the objective arousal levels obtained from EEG indicated that the PNI condition significantly improved the arousal level compared to the control condition. A few studies in the past [28,29] tried to clarify the relationship between negative ions and emotions using brain waves. Watanabe et al. [29] examined the effect of negative air ions on EEG, and the results indicated that the alpha wave tended to be higher in the negative ion condition than in the control condition. On the other hand, the results of this study indicated that the PNI condition demonstrated a significantly higher arousal level (beta band power level) than the control condition. Therefore, the results of this study differ from the previous studies that were mentioned earlier. A subjective evaluation study by Charry and Hawkinshire [19] showed that positive ions contribute to the improvement of tension. In this study, since the experiments were conducted in the environment in which positive ions were also generated, it is speculated that positive ions may affect the arousal level extracted from the EEG. As mentioned, it might demonstrate the existence of relationships between PNI conditions, and states of subjective and objective arousal. However, as mentioned previously, there is some skepticism in the study of ions; thus, it would be necessary to further study the relationships between air ions and athletes' emotions in the field of sports science.

Finally, the results of comparing the average load (W) of interval training under the PNI and the control conditions show the average load (W) under the PNI condition tended to be significantly higher than that recorded in the control condition. Moreover, the result of comparing the average of training load (W) during the maximum power set under the PNI condition was that it was recorded as significantly higher than under the control condition.

Several researches have examined the association between physical exercise and negative ions [30,31]. Ryushi et al. [30] demonstrated that, under the negative ion condition, the levels of serotonin and dopamine were decreased in the recovery period after moderate endurance exercise than those recorded under the control condition. Thus, it suggested that the negative ion condition might affect the feeling of relaxation after endurance training. This study also found that the load on the maximum power set after a 10-min rest was significantly higher, and that negative ion effects reduced dopamine and serotonin during the rest which led to a more relaxed state. There is a possibility that the PNI condition might have affected the maximum power set results for the participants.

5. Conclusions

This study suggests that the PNI condition may have a positive effect on sports training. However, there are limitations to this study. We conducted the experiments on 10 elite swimmers, but it is necessary to expand the sample size in order to generalize this study. It is thus necessary that future studies be conducted with more participants. In addition, although this study conducted the experiment twice in an environment in which the athletes were randomly switched, it is recognized that emotions may change depending on the condition of the athlete on that day. Therefore, it is suggested that conducting a longitudinal experiment on the same participants might shed more accurate findings on the matter.

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