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IMAGE & SIGNAL PROCESSING

A Novel Cue-Induced Abdominal Reaction Analysis for Internet Gaming Disorder

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Abstract
Individuals with Internet gaming disorder (IGD) frequently play online games to achieve satisfaction. Numerous signal processing questions regarding the negative consequences and characteristic respiration in a long-term sitting posture remain unanswered. This study recruited 50 individuals with high-risk and low-risk IGD (HIGD and LIGD); these participants were taught to perform a specific respiration during game-film stimuli. The instantaneous frequencies on abdominal movement (f_{DF}) were calculated with ensemble empirical mode decomposition (EEMD). The difference value (Δf_{DF}) between rest and stimulus statuses was calculated and found that HIGD showed Δf_{DF} values of 0.060 during positive stimuli and 0.055 during negative stimuli before the exercise but 0.020 and 0.016, respectively, after the exercise. However, the Δf_{DF} value for those with LIGD during negative stimuli before the exercise was 0.013, and it increased to 0.025 after the exercise. This is the first approach to IGD discrimination toward abdominal response with EEMD.

Keywords Abdominal muscle · Abdominal respiration · Abdominal wall movement · Internet gaming disorder · Ensemble empirical mode decomposition

Introduction

To date, the Internet Telecommunications Union report that approximately 3.9 billion persons use Internet worldwide. Most users are able to use the Internet appropriately, but some users tend to lose control, leading to overuse of Internet experiences. The first well-known diagnostic questionnaire for describing the phenomenon of Internet addiction (IA) was proposed by Young in 1996 [1]. Numerous researchers have published concepts related to IA, such as online games addiction [2]. The Diagnostic and Statistical Manual of Mental Disorders mentioned Internet gaming disorder (IGD) in 2013 also encouraged researchers to decide whether IGD should be added as a mental disorder [3]. Moreover, the World Health Organization declared that gaming disorder was included in the International Statistical Classification of Diseases as a mental condition in 2018 [4]. Because individuals with IGD can persist in playing online games for prolonged periods, researchers have argued that sympathetic overarousal may be associated with the mechanism of autonomic dysregulation and distressed personality [5]. However, few articles have explored the progressive processes of psychophysiological reactions to continue playing.

IGD Individuals experience excessive difficulty when confronting stress and always escape and relieve unpleasant feelings by playing online games [6]. They play games to gain satisfaction, immersion, and pleasant feelings. However, they usually exhibit withdrawal symptoms when unable to play; withdrawal symptoms manifest as angry, sad, and anxious states [7]. Regarding psychophysiological reactions, researchers observed cue-induced gaming cravings with electrocardiographic, breathing, pulse wave, and other signals in

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individuals with IA or IGD. For example, Lu et al. reported that breathing rate (BR) and pulse rate of 11 individuals with high-risk IA (HIA) were higher than those of 41 individuals with lower-risk IA (LIA) during Internet use [8]. Hsieh et al. experimented on emotional stimuli and extracted spontaneous respiratory features. The results indicated that 15 HIA abusers decreased the power of thoracoabdominal wall movement (TAM) under positive film and picture stimuli [9], and 15 HIA subjects increased the respiratory sinus arrhythmia value under positive film stimuli [10]. Kim et al. measured 57 individuals with IGD while watching video clips; the standard deviation of heart rate (HR) and mean BR of individuals with mild to severe IGD were higher during video watching than at baseline [11]. Chang et al. observed individuals with excessive online gaming habits; their HRs and BRs were higher when playing game than at baseline, and 22 individuals with excessive online gaming habits had higher BRs than did 22 control groups [12].

Researchers have observed psychophysiological properties in individuals with HIA and in individuals with high-risk IGD (HIGD); an investigation of treatment methods is warranted. Breathing is physiological reaction that has been controlled to regulate the psychology and behavior those with IA, for example, breathing exercises have been used to deal with anxiety of individuals with IA [13] and to enhance attention and regulate emotion in those with IGD [14]. One method of breathing is to maintain respiratory movement toward the abdominal wall; this is called abdominal breathing (AB). Respiratory muscles play a core role for the breathing process; muscular contraction and relaxation drive inspiration and expiration [15]. Those activities involving respiratory muscles can be investigated in the context of TAM [16]. A study argued that individuals with HIA exhibit increased amplitude of thoracic or abdominal muscle contraction under negative film stimuli relative to the amplitude under positive film stimuli [9].

Breathing exercises have been suggested as a method to alleviate some symptoms of IGD, but few studies have considered whether breathing exercises can affect psychophysiological reactions in persons with IGD during cue-induced game craving. The aim of this study was to provide a novel cue-induced abdominal reactions analysis procedure and to investigate the effect of AB on abdominal muscles and respiratory wall movement reactions in individuals with HIGD and low-risk IGD (LIGD) during game-film stimuli. The frequencies of abdominal wall movements and those of other respiratory muscles were calculated with ensemble empirical mode decomposition (EEMD) and fast Fourier transforms (FFT). The analytical results indicated that AB was an effective method to decrease abdominal muscle reactions and respiratory wall movement reactions; these reactions could be an index for the psychological and physiological regulation of HIGD.

Material and methods

Participants

Under the approval of Research Ethics Committee for Human Subject Protection (NCTU-REC-102-009-e), a total of 50 participants were recruited from National Chiao Tung University (NCTU), Taiwan. These 14 women and 36 men were 20 to 36 years old (23 ± 3.7) without psychiatric symptoms. Before the experiment, participants signed informed consent documents.

Questionnaire

To evaluate each participant's IA symptoms, IGD symptoms, and emotional scores, the questionnaire of Chen Internet addiction scale (CIAS) [17], IGD questionnaire (IGDQ) [3], and self-assessment manikin (SAM) [18] are used respectively. The CIAS consisted of 26 items, and each item was measured using a 4-point Likert scale from 1 (extreme disagreement) to 4 (extreme agreement). The cut-off score of the CIAS was 63/64. The IGDQ consisted of nine criteria, with dichotomous scale of 1 (yes) and 0 (no). The cut-off score of the IGDQ was 4/5. The SAM consisted of two factors, emotional valence and emotional arousal, and each factor was answered according to a 9-point Likert scale.

Emotion-eliciting film

Published articles [9, 10] have argued that positive and negative emotions can elicit different psychophysiological reactions. Regarding the emotion-eliciting materials, the present study followed a precedent [19] by selecting most popular films on the NCTU campus about MapleStory (Nexon Corp., Seoul, Korea), League of Legends (Riot Games, Inc., Los Angeles, USA), and Resident Evil (Capcom Co., Ltd., Osaka, Japan). These three films were treated as neutral, positive, and negative stimuli, respectively.

Experimental procedure and signal acquisition

Each participant was asked to sit in a comfortable chair to fill out demographical information and a CIAS questionnaire. After that, each participant rested and gazed at a gray picture to become familiar with the environment (3 min). Next, we asked the participant to complete protocol I, the AB exercise, and protocol II, with three trials in each protocol (modified from [19]). Each trial had four steps. First, the participant was asked to gaze at a gray picture to relax his or her body (2 min, rest status). Second, the participant was asked to watch a game film (2 min, stimulus status). Third, the participant filled out a SAM questionnaire (unlimited). Fourth, the participant was asked to view the gray picture again (2 min, recovery status) to relax and release any psychophysiological condition that might have been caused by film stimuli. In the AB exercise segment, the participant learned to breathe from the abdomen at a rate of 6 cycles/min for 10 min. The participant filled out an IGDQ and a questionnaire concerning most frequently played game genres at the end of the experiment.

Respiratory inductance plethysmography (RIP, RIPmate Inductance Belt Abdomen Kit, Adult, Alice 5, Ambu Inc., Denmark) was adopted for measuring abdominal respiratory movement. A DAQCard (USB 6218, NI Corp., Austin, USA) with a sampling rate of 1000 Hz was used to acquire signals and input them to a personal computer (Acer Veriton M2610, 64 bits, i5-2500, 3.6 GHz, Windows 7 Professional, Acer Inc., Taiwan). All programs for data acquisition and data processing were developed in a LabVIEW environment (v.2016, NI Corp., Austin, USA). All equipment and analysis programs had performed well in the past [9, 10, 20, 21].

Signal processing

A total of 600 RIP data sets were collected because the design contained one abdominal wall movement signal, protocol I and protocol II, three trials, rest and stimuli statuses, and 50 participants ($1 \times 2 \times 3 \times 2 \times 50$). As in [16], the RIP signals were decomposed into related components abdominal muscle of TAM. The components were related to and respiratory wall movement that were extracted by significant test and corresponding frequency bands [9, 22]. Figure 1 illustrates the signal processing, which consisted of preprocessing, feature extraction, and transformation sections.

The preprocessing consisted of four steps: an integral step, a baseline correction, a down sampling, and EEMD. In the integral step, the respiratory wall movement signal was summarized with time to estimate the volume change of the abdominal cavity. Simpson's rule [23] was used and expressed as

$$x[n] = \frac{1}{6}\sum_{n=0}^{N-1}(s[n-1] + 4s[n] + s[n+1]), \quad (1)$$

where $s[n]$, N, and $x[n]$ denoted the raw signal, the number of signals, and the integrated signal, respectively. Second, a linear fit was adopted for baseline correction. Next, the sampling rate was reduced from 1000 Hz to 50 Hz and was treated as source data regarding decomposition. The nonlinear, nonstationary, and non-phase-distorted properties of empirical mode decomposition were applied in the final step. The source data were decomposed into different oscillatory modes, known as intrinsic mode functions (IMFs). The processing procedure was descripted and expressed as in [16, 24]. After decomposition, the source signal was expressed as

$$x[n] = \sum_{i=1}^{m} c_i[n] + r[n], \quad (2)$$

where $c_i[n]$, m, and $r[n]$ represented the ith IMF, the total number of extracted IMFs, and the residue of $x[n]$, respectively. Since the IMFs always consist of mode mixing, white noise was added, and EEMD, a noise-assisted data analysis method, was adopted [25]. To manage the mode mixing problem, this study designed 50 ensemble times with different white noise samples, set 0.02 as the value of the standard deviation threshold, and defined eight IMFs for respiratory signal decomposition.

For feature extraction, each IMF has an individual frequency band and a corresponding physical meaning. For example, our previous study indicated that the high frequency (IMF_{HF}) band and dominant frequency (IMF_{DF}) band of IMFs are relative to abdominal muscle and respiratory wall movements, respectively [9, 22]. The significant test with averaged period and energy density was used for IMF band examination [26]. The energy density was calculated as

$$P_i = \frac{1}{N}\sum_{n=1}^{N} {c_i}^2[n], \quad (3)$$

where P_i denoted the energy density of the ith IMF. The extreme peak was treated as IMF_{DF}, and the other IMFs with higher frequency than IMF_{DF} were treated as IMF_{HF}. For transformation, the weighted average frequency of IMF_{HF} and IMF_{DF} represented f_{HF} and f_{DF}, and were calculated using FFT.

Statistical analysis

Two types of statistical test, the Wilcoxon signed-rank test and the Mann-Whitney U (MWU) test [27], were conducted in this study. The Wilcoxon signed-rank test (two-tailed) was carried out to examine the median difference between two related sample sets. This testing method was used to examine the difference value of f_{HF}/f_{DF} ($\Delta f_{HF}/\Delta f_{DF}$) by subtracting rest status from game-film stimulus for the same respiratory condition, and then the statistical significance levels of $\Delta f_{HF}/\Delta f_{DF}$ differences between protocol I and II were examined. The procedure of the Wilcoxon signed-rank test for two sets (a, b) with N_s samples was to

(1) calculate each absolute value ($D_i = |a_i - b_i|$ for $i = 1, 2, \ldots, N_s$),
(2) rank all values and order the indices of nonzero values with $1, 2, \ldots, N_r$,
(3) sum the indices ($\sum_+$) of the positive difference ($a_i > b_i$) and the indices ($\sum_-$) of the negative difference ($a_i < b_i$),
(4) compute the Wilcoxon value ($W = \min(\sum_+, \sum_-)$) and z-score ($z = \left(W - \frac{N_r(N_r+1)}{4}\right) / \left(\sqrt{\frac{N_r(N_r+1)(2N_r+1)}{24}}\right)$), and
(5) determine the critical level from the table of critical values for Wilcoxon signed-ranks test.

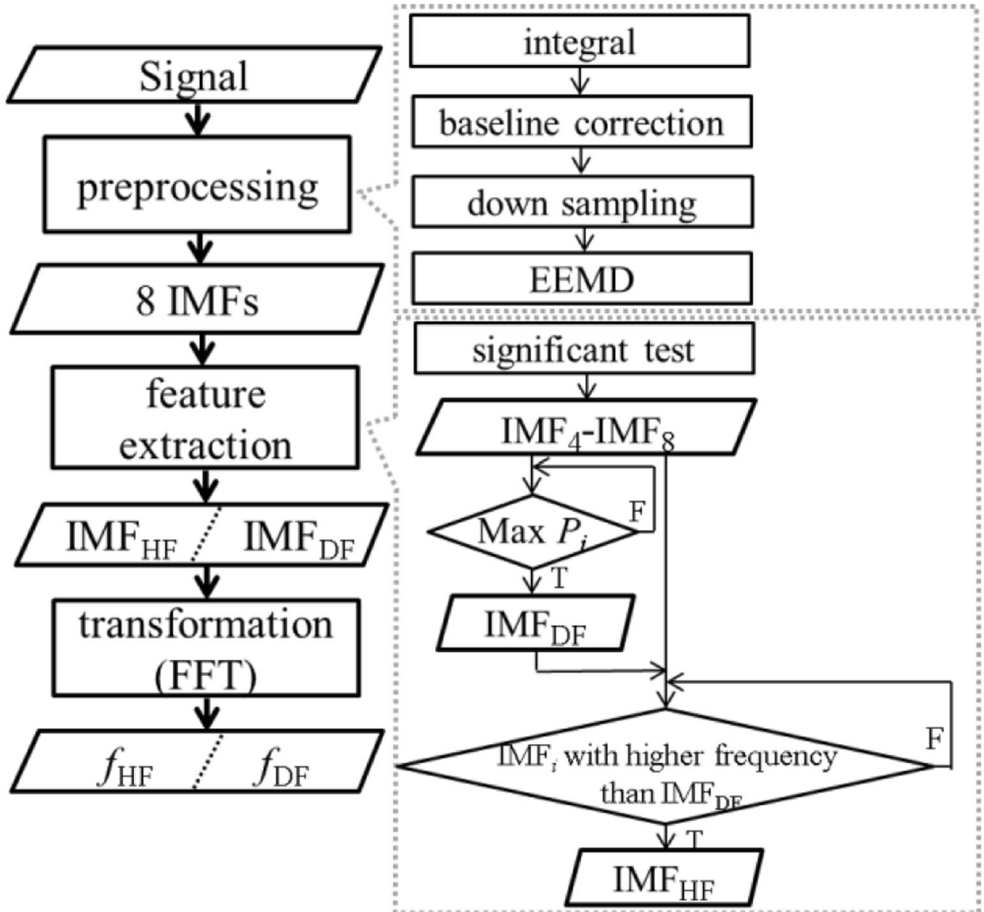

Fig. 1 Three main sections: preprocessing, feature extraction, and transformation. First, the preprocessing executes the processing of integral, baseline correction, down sampling, and EEMD. The function of feature extraction obtains the significant test results to concentrate on the dominant feature of the original signal. The final processing step transfers the time-domain feature into the frequency-domain message, i.e., f_{DF} and f_{HF} for the frequency of respiratory wall movements and abdominal muscle contraction/relaxation, respectively ($i = 4$–8 in this study)

The MWU test (two-tailed) was used to examine the distribution differences between two independent sample sets; these differences included the difference in $\Delta f_{HF}/\Delta f_{DF}$ between participants with HIGD and LIGD. The test procedure for two sets (c, d) with N_c and N_d samples was to

(1) rank two sets and order the indices with $1, 2, \ldots, N_c + N_d$,
(2) sum the indices ($\sum_c$) and indices ($\sum_d$) individually,
(3) compute the MWU values ($U_c = N_cN_d + 0.5N_c(N_c + 1) - \sum_c$, $U_d = N_cN_d + 0.5N_d(N_d + 1) - \sum_d$, and $U = \min(U_c, U_d)$) and z-score ($z = \left(U - \frac{N_cN_d}{2}\right) / \left(\sqrt{\frac{N_cN_d(N_c+N_d+1)}{12}}\right)$), and
(4) determine the critical level from the table of critical values for the MWU test.

Results

The participants with HIGD (16 men and 4 women) and LIGD (20 men and 10 women) can be categorized by reference to the cut-off score of the IGDQ. IGD is usually considered a type of IA; therefore, one participant with LIA and HIGD and nine participants with HIA and LIGD were excluded. The mean ages of individuals with HIGD and LIGD were 24.11 ± 5.32 and 22.62 ± 1.79 years old, respectively. Regarding the acquired respiratory signal, seven data points were omitted; these points comprised one data point under negative film stimuli during protocol I, one data point under positive film stimuli during protocol II, two data points under negative film stimuli corresponding to rest during protocol II, one data point under neutral film stimuli corresponding to rest during protocol II, one data point under neutral film stimuli during protocol II for those with HIGD, and one data point under positive film stimuli during protocol I for those with LIGD.

For analysis of cue-induced respiratory reactions, those with HIGD and LIGD were subject to protocol I (without AB) and protocol II (with AB). We investigated the f_{HF} and f_{DF} values of participants with HIGD and LIGD during three game-film stimuli and corresponding rest statuses in each protocol. Regarding the effects of AB exercise, Fig. 2 presents box plots of the Δf_{DF} and Δf_{HF} of those with HIGD and LIGD for three game-film stimuli with protocol I and protocol II. After performing AB exercise during positive and negative stimuli, participants with HIGD demonstrated significantly low Δf_{DF} ($p < 0.05$). Those with HIGD showed median of Δf_{DF} values of 0.060 during positive stimuli and 0.055 during

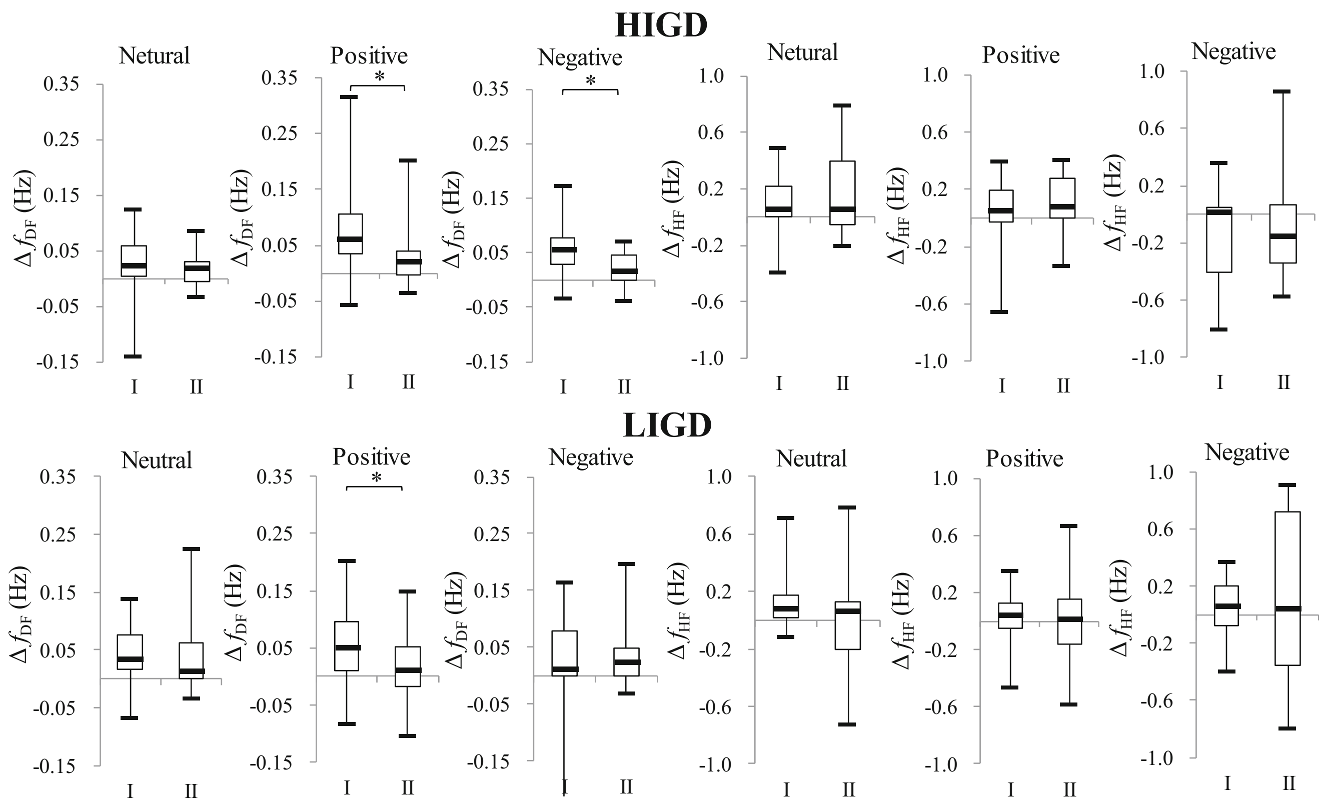

Fig. 2 Box plots of the Δf_{DF} and Δf_{HF} in those with HIGD and LIGD during neutral, positive, and negative stimuli. A comparison of protocol I with protocol II revealed statistically significant differences (*: $p < 0.05$) according to a Wilcoxon signed-rank test

negative stimuli before the exercise but 0.020 and 0.016, respectively, after the exercise. Participants with LIGD only exhibited significantly lower Δf_{DF} after performing AB exercise during the positive stimulus ($p < 0.05$). Those with LIGD showed median of Δf_{DF} values of 0.052 during positive stimuli before the exercise but 0.012 after the exercise. Regarding Δf_{HF} or Δf_{DF} compared between those with LIGD and HIGD, those results exhibited no statistically significant differences under protocol I and II. But the median of Δf_{DF} value for those with LIGD during negative stimuli before exercise was 0.013, and it increased to 0.025 after the exercise. In protocol II, the median of Δf_{HF} (0.042) of those with LIGD during negative stimuli was higher than did (−0.155) those with HIGD.

Discussion

Breathing response is a physiological phenomenon that can regulate responses to stimuli. This research considered three types of film stimuli, and the corresponding respiratory responses are discussed in this section. A 6 cycles/min AB exercise was used as an initial respiratory condition before protocol II; the different conditions with and without 6 cycles/min AB exercise were also investigated. This study considered participants with HIGD and LIGD who performed AB exercise, in the context of differences in respiratory responses.

Protocols I and II represent the emotion-eliciting trials before and after performing AB exercise, that is to say, all stimuli in protocol II should be considered to have been influenced by AB exercise. If f_{DF} represents TAM, then f_{HF} can be inferred from the vibration level on respiratory muscle. The shift levels of f_{DF} or f_{HF} through AB exercise are discussed in this section. First, a comparison of the Δf_{DF} for protocol II with the Δf_{DF} for protocol I proved that the median of Δf_{DF} in emotional film stimuli with protocol II were lower than the median with protocol I, except for negative film stimuli for participants with LIGD. Clinical research has proven that deep and slow breathing can activate the parasympathetic nervous system (PNS) [28] and inhibit hyperventilation [29]. Moreover, individuals with IA can alleviate anxiety using breathing exercises [13], and those with IGD can focus on breathing to regulate emotion [14]. Our findings are consistent with those of the empirical research discussed previously. Second, a comparison of the Δf_{HF} for protocol II with the Δf_{HF} for protocol I confirmed that no significant differences existed between the medians of Δf_{HF} values for three emotional film stimuli. A possible explanation for this is that respiratory wall movement is driven by different respiratory muscle contractions or relaxations [15]; thus, muscular regulation of TAM must be considered [16, 30]. In addition, PNS activity can relax muscles [15]. In this study, we observed whether an AB exercise would relax respiratory muscles, and the results indicate that further research is warranted to explore the regulative responses of TAM muscles under different emotional stimuli with AB exercise.

The median of Δf_{DF} in all film stimuli without or with AB exercise illustrated no statistically significant difference between HIGD and LICD participants. It is possible that the recruited sample sizes of participants with HIGD and LIGD were too small to present any effective distinction. The noteworthy topic on negative stimuli for those with LIGD is that the median of Δf_{DF} in protocol II was higher than that in protocol I, and the median of Δf_{HF} in protocol II was higher than did those with HIGD. During negative stimulus, our previous study indicated that those with HIA had a lower respiratory sinus arrhythmia value than did those with LIA; we inferred that participants with HIA had a greater tendency to express negative emotions [10]. Kim et al. stated that Internet gaming addicts tended to sense negative affectivity more than nonaddicted gamers [5]. Mehroof et al. also argued that the level of online gaming addiction is positively associated with neuroticism, (e.g., feeling unpleasurable emotions) [31]; King et al. found that individuals with IGD exhibited tolerance because they feared that stopping play would cause them to lose game-related achievements and thus they would lose social status with their friends [32]. Our finding in this study indicated that participants with HIGD exhibited better respiratory regulation than did those with LIGD during a prolonged period of negative emotional stimulus. We would like to recruit more participants to support this finding in a future study.

This study applied AB exercise as a regulation practice and investigated the corresponding respiratory influences during game-film stimuli. The experimental results indicated that protocol II had a smaller increasing range of respiratory frequency during stimuli than did protocol I. However, this research has three limitations. First, compared with action games, real-time strategy or role-playing games have a higher correlation between playing time and IGDQ score [33]. The selected films in this study were acquired from the most popular online games on the NCTU campus and were treated as emotion-eliciting materials for effective respiratory responses. However, some participants described various playing experiences from other online games. The corresponding breathing responses elicited from famous and obscure gaming stimuli must be investigated. Second, most online games elicit interaction from participants. In this study, each participant was simply asked to sit in a comfortable chair and to accept visual stimuli without any physical interaction. The corresponding breathing responses of visual stimuli with and without any physical interaction are not discussed in this paper. Moreover, the instantaneous breathing responses and time-lag cross-correlation during stimuli were not examined in this study. Finally, the small sample size of this study affected the significant difference between respiratory responses of individuals with HIGD and those of individuals with LIGD. We must recruit more participants for further work.

Despite the aforementioned limitations, the present findings contribute to scholarly understanding of the effects of AB exercise on the respiratory regulation of those with HIGD during emotional stimuli; negative stimuli with AB exercise affect psychophysiological responses that may effectively discriminate between persons with HIGD and LIGD. Our findings might lead researchers to explore and understand some effects of AB exercise in the respiratory regulation of people with HIGD. The variables f_{HF} and f_{DF} might be physiological valuable indexes in research on the psychological and physiological control processes of persons with HIGD. In the near future, we wish to investigate instantaneous psychophysiological reactions in those with HIGD who play role-playing games with AB exercise, and to observe the mechanism of psychophysiological regulation in such persons.

Conclusion

In this study, we found that AB exercises were associated with the control of psychophysiological responses in those with HIGD. AB exercises are an effective method to diminish psychophysiological responses in persons with HIGD. The level of IGD is negatively associated with the Δf_{HF} or Δf_{DF} during negative stimuli with AB exercise. The Δf_{DF} during negative stimuli may be adopted to discriminate between HIGD and LIGD. The f_{HF} and f_{DF} variables might serve as psychophysiological indexes of the progressive processes within the psychophysiological reactions of persons with IGD. Based on our approach, we hope to explore instantaneous respiratory control during role-playing games played by participants who practice AB exercise, and to research the dynamic mechanism of psychophysiological regulation in those with HIGD.

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Compliance with Ethical Standards

Conflict of Interest All authors have no conflict of interest to disclose. All authors approved the manuscript for publication.

Ethical Approval This study received approval by the Research Ethics Committee for Human Subject Protection, National Chiao Tung University (Hsinchu, Taiwan) under the research project (Approval No: NCTU-REC-102-009-e).

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