ORIGINAL ARTICLE

Experimental Verification of Psychophysiological Index of Excitement

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Abstract: There is a demand for the objective evaluation of emotion. Thus, $\rho_{\min}$ has previously been suggested as a psychophysiological excitement index to meet this demand in various applications. $\rho_{\min}$ is the minimum value of the cross-correlation coefficient between the respiratory sinus arrhythmia components of heart rate variability (HRV) and the respiratory wave, considering the lag time. In this study, the feasibility of using this index was verified in an experiment in which the $\rho_{\min}$ values of the physiological responses of individuals playing games, which were classified according to the level of difficulty, were analyzed. Three major results were obtained in the analyses. First, the $\rho_{\min}$ values of the responses changed significantly while playing the game. Second, the $\rho_{\min}$ values of the responses changed linearly with the game's level of difficulty, and the rank correlation was found to be significant. Finally, the variation in the $\rho_{\min}$ value corresponded with the subjects' self-reported excitement scores. The HR and indexes of the autonomic nerve activities were investigated simultaneously by means of the HRV spectrum; however, no change or correlation with the game's difficulty level was found. The feasibility of using $\rho_{\min}$ values as the psychophysiological index of excitement was therefore verified.

Keywords: *Index of excitement, $\rho_{\min}$, Computer game*

1. INTRODUCTION

Because of a desire for emotional excitement, we watch sports and play computer games, which generate joy and excitement. On the other hand, excitement related to anger can cause heart disease [1]. Therefore, excitement is closely associated with some emotions in our daily life, and it has somatic responses.

An objective evaluation of the human excited state using physiological parameters is important for the development of entertainment devices, games [2], music [3], movies, and videos. Moreover, it would be applicable to criminal investigation [4] and help understand the emotions of patients who cannot speak.

To evaluate some emotions objectively, some studies [5,6] have analyzed the relevant bio-signals, including blood circulation, the physiological control mechanism of which is fairly clear [7,8].

It is known that emotions can be distinguished in terms of autonomic nervous system activity [9,10]. Thus, many psychophysiological researches have studied the differential physiological responses to emotions [11]. The correlation between the blood circulation parameters under different emotion modes differ in terms of the lag time, which is dependent on the physiological control mechanism and physical distance [5,6]. Thus, it was found that it is possible to characterize a specific emotion according to the blood circulation parameters by considering the lag time between these parameters [5,6].

For example, it was found that the minimum value of the cross-correlation coefficient of the respiratory sinus arrhythmia (RSA) component of the heart rate variability (HRV) and the respiratory wave, called $\rho_{\min}$, correlated with the subjective evaluation score of excitement. Therefore, $\rho_{\min}$ has been suggested as an index of emotional excitement [5]. The $\rho_{\min}$ values evidenced the physiological response to both "pleasant" and "unpleasant" excitement states, which were elicited by the subject watching action and horror videos, respectively. Moreover, $\rho_{\min}$ has the advantage of allowing time domain analysis.

In this study, the feasibility of using $\rho_{\min}$ values as the physiological excitement index was verified by analyzing the responses in individuals playing games, which were classified into four levels according to difficulty. The results show the $\rho_{\min}$ responses while playing the game, rank correlation between the $\rho_{\min}$ responses and levels, and subjective evaluation scores. The obtained values were compared with those of autonomic nerve activity [12].

2. PSYCHOPHYSIOLOGICAL EXCITEMENT INDEX $\rho_{\min}$

It is not easy to accurately evaluate the excited state in humans. Usually, a questionnaire is administered to estimate the subjective emotional state. However, some doubt remains about the objectivity of this method. If a physiological index was developed, an objective evaluation could be achieved.

It is well known that the sympathetic nerve is activated in the excited state, and the heart rate (HR) then increases [9]. However, in many cases under laboratory conditions, even though the subject was stimulated by an exciting video showing common daily life situations, their HR did not change [5]. This means that the stimulus was not strong enough to increase the HR, and a sensitive physiological index that would register the response to a weak stimulus such as that mentioned above is required. $\rho_{\min}$ was therefore developed as a psychophysiological excitement index. The HRV has an RSA component [13] that changes the HR with the respiratory wave (Figures 1 and 2). There is a lag between the RSA component and respiratory wave. The coefficient for the strongest correlation between them, considering the lag time, was evaluated as $\rho_{\min}$. This physiological mechanism has been described in the literature [5]. For example, Figure 3 shows the result of

Figure 1: RSA component of HRV.

Figure 2: HRV spectra.

Figure 3: Response of $\rho_{\min}$ caused by watching exciting K1-fight video [5].

the $\rho_{\min}$ response caused by watching an exciting K1-fight video [5]. It has been confirmed that for some emotions, this excitement index correlated with the subjective evaluation scores of the subjects' excited state, which was elicited by emotional video stimuli ($\rho = -0.63$, $p < 0.01$).

3. METHODS

The Ethics Committee of the Hokkaido Institute of Technology approved this study. Twelve healthy men, 21–22 years of age, participated in the experiments after giving their informed consent. The experiments were performed from 14:00 to 17:00. The subjects were requested not to eat, drink, or smoke for 3 h before the experiments. The experiments were performed in a shielded room, at a temperature of 24–25 °C and humidity of 50–60%. The ECG measurements were taken using a standard lead II on the chest, and the respiratory wave was measured using a thermistor sensor placed in front of the subject's nostrils. All the data were recorded using a data recorder with 16-bit, 200-Hz sampling, and then analyzed using a computer program.

The projector, which was positioned behind the subject, projected the PlayStation3 (SONY) game screen onto the screen in front of the subject. The soccer simulation game "Winning Eleven, 2009" was used in the experiment, and four levels of difficulty were set. The experimenter and subject each held a game controller. The experimenter set the game conditions and each match condition at each difficulty level, keeping his operations on screen out of the subject's sight. The experimenter also controlled the start and end of the match. The settings for the teams were fixed, and the opponent was the machine. Level 0 involved simply watching a demonstration match. In levels 1 to 3, the subject played matches against an opponent whose speed and exercise intensity increased according to the difficulty level.

The experimental protocol was as follows. After a 10 min rest, four game sessions were executed at each level of difficulty. In the session, each subject first watched the static image of the start of the match for 90 s, then played the game for 3 min, and finally watched the static image of the end of the match for 1 min. Herein, the timing of the most excitement while playing a game differed between the subjects, even though the game conditions were the same. In the sessions, each subject experienced each level of game difficulty in random order. Finally, the subject evaluated the degree of his excitement after each session on a 6-grade scale, from 0 for "not at all excited" to 5 for "very excited," and filled out a questionnaire.

The calculation method of $\rho_{\min}$ was as follows. To calculate the minimum value of the cross-correlation coefficient between the RSA component of HRV and the respiratory wave, the time series of the RSA component of 0.15–0.4 Hz (Figure 2) was extracted using a band pass filter (BPF) composed of the fast Fourier transform (FFT) (Figure 4). There are correlations between the blood circulation parameters and the lag times between them [5,6]. Taking the lag time into consideration, the optimal coefficient was then determined.

First, time windows were defined as 10 s in order to collect at least one cycle of respiratory wave data. The cross-correlation coefficients between the 10-s respiratory wave data and the time series of the RSA component in the 10-s window were then calculated, sliding the window by 5 ms from -2 s to +2 s. Finally, the minimum value of the correlation coefficient between the parameters was determined (Figure 5).

The minimum value was adopted because the HRV increases in the inspiratory phase, and in this experimental system, the respiratory wave decreased.

A decrease in the absolute value of $\rho_{\min}$ means that the effect of the respiratory wave on the HRV is decreased; that is, the function of reducing the energy consumption of the cardio-pulmonary system, which is a feature of the RSA [14], is considered to decrease.

Next, the time series of $\rho_{\min}$ data were analyzed as follows. The analyzed sections were determined as rest 0, rest 1, stim.1, ... stim.6, rest 2. Rest 0 represented the average of the first 60 s of data, and the other subsequent sections represented the average of 30 s of data each. Here, the $\rho_{\min}$ values were presented as the normalized

Figure 4: Respiratory wave and RSA component of HRV.

Figure 5: Minimum value of cross-correlation coefficient.

values, which were calculated by dividing the sectional average while playing the match by the average during the first 60 s of the initial rest period (rest 0).

Statistical analyses were performed with Analysis of Variance (ANOVA) with a Bonferroni multiple comparison procedure and Spearman's rank correlation test.

4. RESULTS

Figure 6 shows an example of the variations in the HRV, respiratory wave, and $\rho_{\min}$. The absolute value of $\rho_{\min}$ decreased while the subject was playing the match.

Figure 7 shows the most typical variation in $\rho_{\min}$ at game level 3. To compare the strongest responses to the playing-a-game stimulus against the rest sections, stim.1 at level 3 section was selected. The normalized value of $\rho_{\min}$ changed significantly in the analyzed section of stim.1 ($p < 0.01$). Figure 8 shows the average value of $\rho_{\min}$ during each match with the level of difficulty. The absolute value of $\rho_{\min}$ decreased as the level of difficulty increased. The rank correlation coefficient between the difficulty level and $\rho_{\min}$ was $\rho = -0.39$ and was significant ($p < 0.01$). To check the correlation of the strongest response during the playing of the game in each level with the levels, the rank correlation of the minimum value of $\rho_{\min}$ between the stimulus sections with each level is

Figure 6: Variation in HRV, respiratory wave and $\rho_{\min}$ while playing game.

Figure 7: Variation in $\rho_{\min}$ at level 3.

shown in Figure 9. Even from this perspective, the absolute value of $\rho_{\min}$ decreased as the level of difficulty increased and significantly correlated with the difficulty level ($\rho = -0.39$, $p < 0.01$).

HR increases as the sympathetic nerve activity increases and is thought to increase during excitement. The HR of each subject was therefore analyzed, and the results are shown in Figure 10. However, no change in the heart rate was observed and no correlation with the level of game difficulty was found.

Next, to confirm the autonomic nerve activities during the game, the low-frequency (LF) component (0.04–0.15 Hz) and high-frequency (HF) component (0.15–0.4 Hz) of the HRV, which are commonly used, were calculated and the HF component and LF/HF ratio were analyzed.

Figure 8: Rank correlation between $\rho_{\min}$ and level of difficulty.

Figure 9: Rank correlation between minimum value of $\rho_{\min}$ and level of difficulty.

Figure 10: Variation in HR with level of difficulty.

The results are shown in Figure 11 and Figure 13. Here, in the same way as in the analysis of $\rho_{\min}$ and HR, individual data were normalized, that is, each value obtained in the stimulating section was divided by each value obtained during the rest period (rest 0). The results are shown in Figure 12 and Figure 14.

The HF component is thought to be the index of parasympathetic nerve activity, and the LF/HF ratio is commonly thought to be the index of sympathetic nerve activity. As shown in Figures 11 to 14, the indexes do not change with the level of difficulty, and there is no correlation between the score and level of difficulty. Thus, HRV spectral analysis was found to be incapable of evaluating the subjects' degree of excitement.

Figure 11: Variation in HF component of HRV with level of difficulty.

Figure 12: Variation in normalized value of HF component of HRV with level of difficulty.

Figure 13: Variation in LF/HF ratio with level of difficulty.

For respiration, respiratory frequency, respiratory amplitude, and their standard deviations (SDs), which represent the degree of disturbance in the cyclic rhythm of respiration, were analyzed. Their rank correlation coefficients were 0.08, -0.07, 0.32, and 0.03 for frequency, amplitude, SD of frequency, and SD of amplitude, respectively. As a result, the SD of respiratory frequency rank correlated weakly and significantly with the levels ($\rho = 0.32$; $p < 0.05$).

Figure 15 shows the subjective excitement scores, which were evaluated at the starting point of the experiment and after each session. Generally, the subjective excitement score increased with the level of difficulty.

The relation between the subjective excitement scores and $\rho_{\min}$ values is shown in Figure 16. Although the

Figure 14: Variation in normalized value of LF/HF with level of difficulty.

Figure 15: Subjective excitement score with level of difficulty.

Figure 16: Variation in $\rho_{\min}$ vs. subjective excitement score.

variances are different because different amounts of data number were used for the subjective scores, the changes in the $\rho_{\min}$ values correspond to the excitement score ($\rho = -0.45$, $p < 0.01$).

Because a disturbance in respiration would become greater when the subject was excited, the average SD of the respiratory frequency to the self-rating excitement score was investigated. However, the average SD to a self-rating score of 5 (SD = 1.53) was smaller than that to scores of 3 (SD = 1.62) and 4 (SD = 1.92).

5. DISCUSSION

This experiment with a computer game was performed to verify the feasibility of the psychological excitement index, $\rho_{\min}$. The normalized $\rho_{\min}$ decreased significantly in one of the playing-a-game sections (stim.1) compared to rest, and a rank correlated change was observed with the level of difficulty. Moreover, the normalized $\rho_{\min}$ was also rank correlated with the subjective excitation score. Therefore, these results appeared to show that $\rho_{\min}$ corresponded to the subject's level of excitation.

Normally, in the human excited state, sympathetic nerve activity increases and adrenalin is secreted; the HR then increases. However, the strength of the stimulus from an activity such as playing a game, as in the experiment, does not always increase the HR, and no correspondence was found between the HR and the game's difficulty level.

Moreover, there was no correlation between the indexes of the sympathetic and parasympathetic nerve activities and the difficulty level. Originally, in order to estimate the parasympathetic nerve activities from the HF component of the HRV, a respiration control was required [15]. However, it was impossible to apply this to this experiment. This inadequacy may be one of the reasons for the non-correspondence.

Generally speaking, respiration changes with excitation. Therefore, some features of respiration were investigated. The SD of the respiratory frequency rank correlated weakly with the levels ($\rho = 0.32$), but its coefficient was smaller than that of $\rho_{\min}$ ($\rho = -0.39$). Moreover, the finding that the average SD to a self-rating score of 5 was smaller than that to scores of 3 and 4 indicated an improper feature of SD for the psychological excitement index.

Here, excitement is one of the basic emotions of Wundt's model [16] and Russell's circumplex model [17]. Furthermore, the subject's excitement that derived from playing a game might be a mixture of the emotions of excitement, activity, interest, and enthusiasm, and these were shown by the Positive and Negative Affects Schedule [18].

Concerning the relationship of subjective excitement score with the level of difficulty, the score at level 3 was not greater than that at level 2. According to the interviews of the subjects that were conducted immediately after the sessions, this was thought to be because the subject could not correctly evaluate his excited state during the match because he had been defeated by a strong opponent and felt slightly disappointed when reporting his excitement evaluation 1 min after the match. The slight increase in the HR at level 3 which is shown in Figure 10 supports this idea. Here, disappointment had a relationship with unpleasant feelings or depression, which is the opposite side of excitement in Russell's model.

These results show the difficulty involved in objectively evaluating emotional excitement and the feasibility of using $\rho_{\min}$ analysis for this purpose.

6. CONCLUSIONS

To confirm the feasibility of the psychophysiological excitement index, $\rho_{\min}$, the physiological parameters of subjects during a computer game were measured and analyzed. The HR, which increases with sympathetic nerve activity and has been thought to correlate with excitement, and the LF/HF ratio, which was thought to correspond to sympathetic nerve activity, did not show any change with the difficulty level of the game being played. However, the $\rho_{\min}$ values changed significantly and correlated adequately with the difficulty level and with the subjective excitement score. Therefore, the feasibility of using the psychophysiological excitement index, $\rho_{\min}$, was verified.

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