

# Feature Classification of Heart Rate Variability Depending on Difficulty Levels of a Puzzle Game

Amane Suganuma, Shunta Ohara, Hiroto Inoue and Nobuji Tetsutani  
Tokyo Denki University  
Tokyo, Japan

17fmi17@ms.dendai.ac.jp, h-inoue@mail.dendai.ac.jp, tetsutani@mail.dendai.ac.jp

**Abstract**—Heart rate variability is a biological reaction that is affected by physical and psychological states. The interval between successive heartbeats is known as the R-wave to R-wave interval (RRI). Correspondingly, low RRI values indicate higher heart rates. Stress and fatigue can be quantified from the differences in RRIs between work and rest [1], [2]. The same test can only be used in cases when a subject is engaged in a task requiring dexterity and creativity [1], [2]. In this study, we demonstrate the use of our method during the play of the video game puzzle Minesweeper in an effort to expand the method’s applicability scope. In order to clarify impressions of the video game that can be evaluated based on heart rate variability, a procedure was implemented and repeated three times, whereby participants rested with their eyes closed in a sitting position for 3 minutes, and then spent another 3 minutes playing Minesweeper. We related the volunteers’ responses to a questionnaire conducted after the completion of the experiment and the RRI differences between rest and during Minesweeper play. The RRI values were lower when volunteers played Minesweeper compared to their RRIs at rest. We also analyzed the correlation between the questionnaire responses and the differences between the median RRIs at rest and during Minesweeper play. The analyses showed that the ‘fatigue’ responses during play at the highest difficulty level were negatively correlated with the median RRI values ( $\rho = -0.605$ ,  $p < 0.05$ ), while the responses of ‘regretted’ and “the wish to make another try” during play at the standard difficulty level elicited positive correlations with the median RRI values ( $\rho = 0.558$  and  $\rho = 0.573$ ,  $p < 0.05$ , respectively).

**Keywords**—*kansei/affective engineering; wearable sensing; heart rate variability.*

## I. INTRODUCTION

Heart rate variability is a biological reaction that is affected by physical and psychological states. The interval between successive heartbeats is known as the R-wave to R-wave interval (RRI). A high RRI value indicates a slow heartbeat, while a low RRI value indicates an increased heartbeat. According to RRI analyses, stress-induced feelings can be predicted, such as the case of workers who are exposed to stress. It is useful to quantify the stress level based on the frequency analysis of LF/HF, which are indicated by the balance between low-frequency (LF) and high-frequency (HF) components of RRI data. Stress- or fatigue-induced feelings can also be predicted from the differences of RRIs between work and rest,

according to our previous studies [1], [2]. The differences between RRIs during noncreative work (e.g., during execution of spot differences) were not significantly correlated with stress, but the differences between RRIs during creative work (e.g., Marshmallow challenge [3]) were significantly and positively related to stress with elicited Spearman’s correlation coefficients greater than 0.7 (maximum  $\rho = 0.840$ ,  $p < 0.001$ ). Therefore, the feelings of stress and fatigue can be predicted simply from the differences in RRIs between the rest period before and during the work, without the need for frequency analyses of LF/HF, in the cases where the subject is engaged in tasks requiring dexterity and creativity. The cost of this analysis is low compared to the frequency analyses of LF/HF. Additionally, it is practically easier to apply small measuring instruments and wearable devices that measure RRIs.

In this study, we demonstrate use of our method on video games, in an effort to expand the scope of its applicability. Video games constitute one of the most important fields in the entertainment industry. If we can predict feelings of stress and fatigue from the biological data (e.g., heart rate variability and RRIs) elicited during video games at low cost, we can contribute to the development of this industry. In this study, we related the responses of participants to a questionnaire and their RRI values after playing the puzzle game Minesweeper to clarify the impressions elicited during the video game that can be evaluated based on heart rate variability.

## II. EXPERIMENTAL

In this experiment, a total of 23 university students aged 20–24, 16 males and 7 females, participated by playing Minesweeper. The RRIs of the participants were measured using wearable heart rate meters (Union Tool, WHS-1). Figure 1 shows an image capture of the “homemade version of Minesweeper 2” [4]. Minesweeper is a single-player puzzle video game, and some squares of the grid contain mines. The number of squares in the grid is  $12 \times 12 = 144$ . Additionally, this Minesweeper has three levels of difficulty: (1) standard, (2) difficult, and (3) very difficult. The number of mines that should not be revealed out of the total of 144 squares is 10 at the standard difficulty level, 15 at the difficult level, and 20 at the very difficult level. In the experiment, participants had played Minesweeper three times, once at each of the three levels.



Fig. 1. Captured image of Minesweeper. Minesweeper is a single-player puzzle video game. Some squares of the grid contain mines. The player must avoid them and must click on all other squares. As a hint, some squares indicate a number which denotes how many adjacent squares contain mines. The player can use this information and mark a flag on the squares. In these experiments, we counted how many times the game terminated in a three-minute period.

TABLE I. LIST OF QUESTIONS IN QUESTIONNAIRE

No.	Question keyword (in Japanese)
1	Tension (KINCHOU-SHITA)
2	Impatience (IRAIRA-SHITA)
3	Boring (TAIKUTSUNA)
4	Fatigue (TSUKARETA)
5	Tired (AKITA)
6	I wish to quit (YAMETAI)
7	Hard to operate (SOUSA-SHIZURAI)
8	This game is difficult (MUZUKASHII)
9	Sense of accomplishment (TASSHEI-KAN)
10	Stressful (SUTORESUSU)
11	Want to stop (YAMETAI)
12	Regretted playing (KUYASHII)
13	Wish to make another try (SAICHOUSEN-SHITAI)
14	Diverting (OMOSHIROI)
15	Refreshing (SUGASUGASHII)
16	I was able to concentrate (SHUUCHUU-SHITA)
17	Satisfactory (OMOIDOORI-NI-DEKITA)

This list was used to clarify the player's impressions while playing Minesweeper. The order of questions was random in order to reduce influences owing to the order of the questions.

The participants were asked to close and rest their eyes in a sitting position for 3 minutes, and then spend 3 minutes to play Minesweeper. This procedure was repeated three times. All the individuals played at all three levels of difficulty. While playing Minesweeper, a timekeeper began a countdown in the last minute of play (e.g., a "last 1 minute" instruction). We measured the RRI of each participant during a total experimental period of 18 minutes. We asked permission from the participants to record the number of times they won while playing Minesweeper. During the experiment, participants played Minesweeper three times, but the three instances needed to be independent. If the play continued to the next play instance, the RRI value would have been affected by the previous play. We have also provided the participants with rest time before playing Minesweeper to reduce mutual influence between successive plays. The order of the difficulty levels was random. Finally, the participants responded to a questionnaire on their impressions during the period they played Minesweeper. Table 1 shows the list of question keywords. The participants did not know the order of levels they played, so they responded to a self-assessment questionnaire with the following format:

- Did you experience a feeling of 'fatigue' during the time you played Minesweeper for the first time?
- Did you experience a feeling of 'fatigue' during the time you played Minesweeper for the second time?
- Did you experience a feeling of 'fatigue' during the time you played Minesweeper for the third time?

The participants selected one of the following five choices as the answer to the question:

1. I do not think so
2. I only slightly think so
3. I slightly think so
4. I think so

5. I very much think so

These choices have an ordinal relationship. Table 1 shows the response format of the five choices.

### III. RESULTS AND DISCUSSION

In order to suppress the influence of outliers, we extracted the median RRIs from the time series data that spanned 3 minutes during rest, and 3 minutes during Minesweeper play. Four participants were excluded since numerous outliers were detected in the measured RRIs. Figure 2 shows boxplots of the median RRIs for 19 participants. The horizontal axis shows the median RRIs, while the vertical axis shows the six periods.

The median RRI of the all participants during the first rest period was 808.0 ms. The median RRI values during Minesweeper play respectively decreased to 782.0, 767.0, and 758.0 ms, for the standard, difficult, and very difficult levels of play. As it can be seen, the median RRIs were lower during Minesweeper play than the median RRIs during rest, with respective noted differences of 26.0, 41.0, and 50.0 ms. The median RRIs for the second and the third rest times were 824.0 and 813.0, respectively, which show the trend of the recovered median RRIs that decreased during Minesweeper play. These results are similar to those reported in previous studies [1], [2].

As it can be seen, this trend is shown in Figure 3a. In contrast, Figure 3b shows a different trend. The median RRIs increased while the participants played Minesweeper compared to the median RRIs during rest. The number of participants who exhibited a small increase in RRI is similar to the number of participants who exhibited a large decrease. Thus, in Figure 2, the result of Friedman's test showed no significant differences in the representative values of these distributions.

To clarify the difference between participants with decreasing RRI, and those with increasing RRI, we analyzed

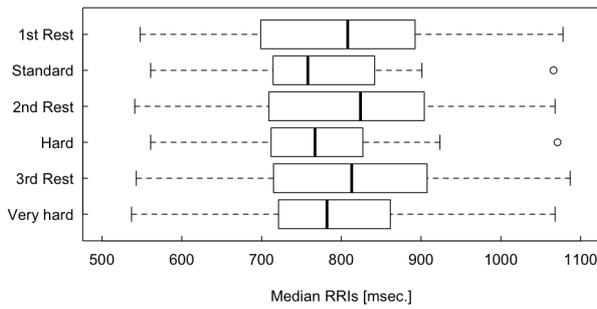


Fig. 2. Box and whisker plot of the median RRIs for each period. The median RRIs for each participant were replaced in the order of the three levels of difficulty, namely, standard, difficult, and very difficult. This is because of the indicated difference between the median RRIs of each period.

the correlation between the questionnaire responses and the differences between the median RRIs at rest and while playing Minesweeper. According to the analyzed results, the variability in median RRIs yielded significant correlations ( $p < 0.05$ ) in three cases, as follows:

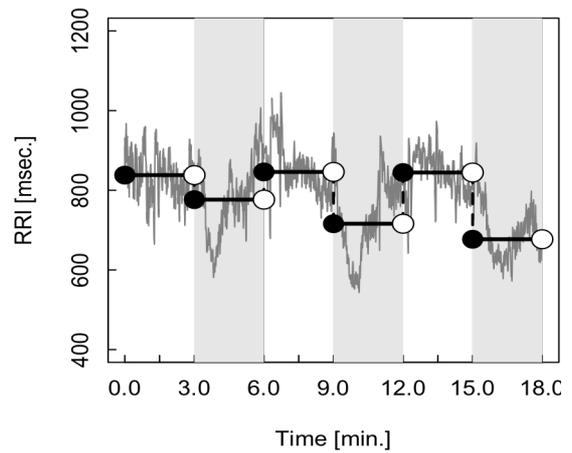
- ‘Fatigue’ at the very difficult level
- ‘Regretted’ at the standard difficulty level
- “Wish to make another try” at the standard difficulty level

Figures 4a, 4b, and 4c show scatter plots of the difficulty levels and the questionnaire responses showing significant correlation.

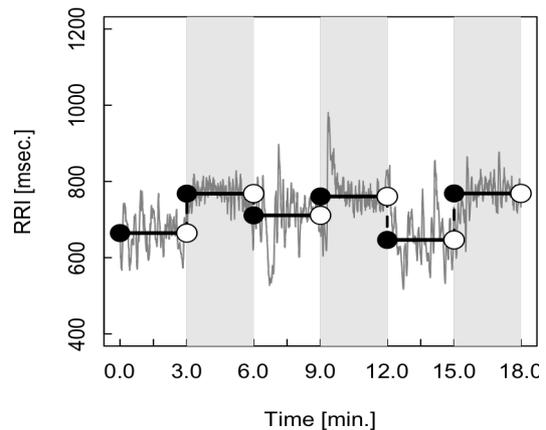
Figure 4a is a scatter plot of the differences of the median RRIs of each participant at the very difficult level and the number of ‘fatigue’ responses from the questionnaires. The vertical axis shows the number of “fatigue” responses on the questionnaires, while the horizontal axis shows the differences in the median RRIs that yield a negative correlation ( $\rho = -0.605$ ,  $p < 0.05$ ) in the case of play at the very difficult level. In simple terms, the RRIs were lower during the period the participants played Minesweeper (i.e., their heart rates increased) compared to the resting values, and the feeling of fatigue was stronger.

Figure 4b is a scatter plot of the differences of the median RRIs of each participant at the standard difficulty level and the number of “Regretted” responses on the questionnaires that yielded a positive correlation ( $\rho = 0.558$ ,  $p < 0.05$ ) in the case of play at the standard difficulty level. In effect, the RRIs were higher while participants played Minesweeper (i.e., their heart rates decreased) compared to the resting values, and the feeling of regret was stronger.

Figure 4c is a scatter plot of the differences of the median RRIs of each participant at the standard difficulty level and the number of “wish to make another try” responses on the questionnaires that yielded a positive correlation ( $\rho = 0.573$ ,  $p < 0.05$ ) at the standard difficulty level. In effect, the RRIs were higher while the participants played Minesweeper (i.e., their



(c) A participant who exhibited a large decrease in RRI.

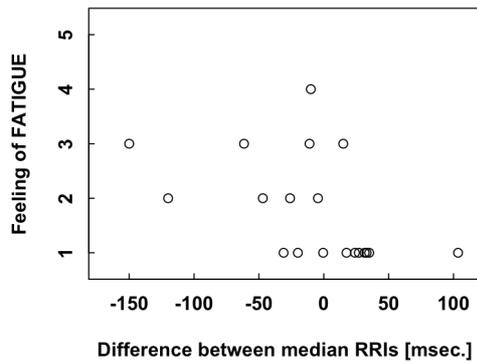


(d) A participant who exhibited a small increase in RRI.

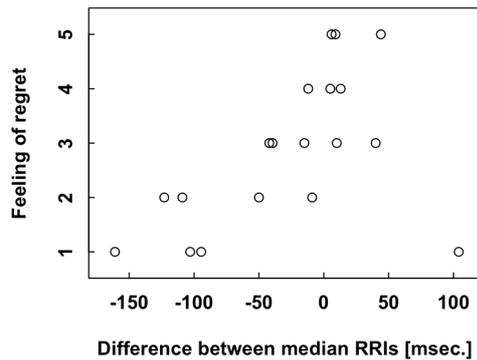
Fig. 3. Examples of participants’ RRI variations in all tested periods. The differences between (a) and (b) refer to intra-participant variability differences, i.e., whether there were considerable RRI increases or decreases during the periods of Minesweeper play. The stepped lines in the figure show the median RRIs in each period. The vertical axis shows the RRI value, while the horizontal axis the time evolution of the experiments.

heart rates decreased) compared to the resting values, and the feeling of the wish to attempt another try was stronger.

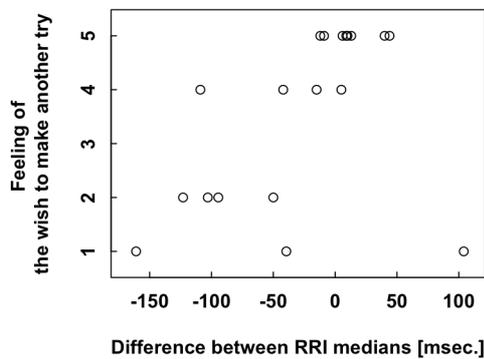
As shown in these scatter plots, participants had feelings of regret or wished to make another try while playing Minesweeper at the very difficult level, but did not have the feeling of fatigue. It can be inferred that the individual players’ proficiency levels had influenced the experimental results. It seems that participants with high proficiency in Minesweeper did not feel fatigue at the standard difficulty level, but at the higher difficulty level their RRI values decreased, thereby yielding more intense fatigue feelings. Conversely, it seems that participants with low proficiency in Minesweeper barely felt regret or the wish to attempt another try at the standard difficulty level, and could hardly play Minesweeper at the very difficult level, thereby explaining the increases in their heart rates. However, this correlation analysis used the differences of



(d) A scatterplot of 'fatigue' at the very hard difficulty level. ( $\rho = -0.605, p < 0.05$ ).



(e) A scatterplot of 'Regrettable' at the standard difficulty level. ( $\rho = 0.558, p < 0.05$ ).



(f) A scatterplot of "wish to make another try" at the standard difficulty level. ( $\rho = 0.573, p < 0.05$ ).

Fig. 4. The scatter plots of three significant correlation between the questionnaire responses and each difficulty level. In order to calculate the difference between the median RRIs, the median RRI while first resting was taken as the reference value.

the median RRIs of participants elicited during play and rest. Therefore, as shown in Figure 2, as the difficulty of Minesweeper play increased, the RRI value elicited during play approached the RRI value elicited during rest, and the RRI differences became smaller. It seems that it becomes difficult to

predict psychological reactions when the degree of difficulty of the work increases.

#### IV. CONCLUSION

In order to clarify impressions of the video game that can be evaluated based on heart rate variability, we analyzed in this study the RRI variability during Minesweeper play. According to the analyzed results, the correlation between the RRIs and the questionnaire responses were as follows:

- The median RRIs recorded while playing Minesweeper at various difficulty levels were lower than those recorded during rest, thereby indicating that the heart rate increased during the time participants played the video game
- The relationship between RRI differences and psychological response of "fatigue" were negatively correlated at the very difficult level of play. As the difficulty level decreased, the correlation decreased. Additionally, as the difficulty of Minesweeper play increased, the RRI value during the period the game was played approached the corresponding value during rest, thereby yielding smaller RRI differences between play and rest. It seemed that it became difficult to predict psychological reactions when the degree of difficulty of the work increased to some extent
- There was a positive correlation of the "Regretted" and "wish to make another try" responses at the low difficulty levels. Higher difficulty levels yielded no significant correlations

Therefore, as the difficulty level decreased it became more difficult to predict the feeling of "fatigue" based only on the decrease in median RRIs, but it was possible to predict psychological states, such as the feelings of "regret" and "the wish to make another try." The results of this experiment may be related to the proficiency levels of individual players. A future task is to consider whether it is possible to predict psychological states from RRI data while taking individual proficiency level into account.

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#### REFERENCES

- [1] Ohara S., Nakagawa T., Inoue H., Koshimizu S. and Nobuji T., "A Feature Classification of Heart Rate Variability Depending on Types of Work," Proceedings of the 11th Annual Japan Sensory Engineering Association Spring Competition.
- [2] Nakagawa T., Inoue H., Koshimizu S., "A Fundamental Study on Differences in Heart Rates During Creative Work and Non-creative Work," Applications in Health, Safety, Ergonomics and Risk Management, Vol.9745, pp.568-575, 2016.
- [3] <https://www.tomwujec.com/design-projects/marshmallow-challenge/>
- [4] <http://www.vector.co.jp/soft/winnt/game/se509331.html>