Chapter 18
Measurement of Wakuwaku Feeling of Interactive Systems Using Biological Signals

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Abstract To evaluate the kansei values of interactive systems, subjective evaluation methods such as questionnaires are commonly used, even though they have some drawbacks such as linguistic ambiguity and interfusion of experimenter and/or participant intention to the results. We began our research to objectively evaluate interactive systems by quantifying sensations using biological signals to redeem the above questionnaire drawbacks. We utilize biological signals to estimate participants' feelings of relaxation, comfort, and excitement, which are considered positive sensations. However, relaxation and comfort are considered static compared with dynamic feelings such as excitement. We focus on a positive and dynamic feeling called "wakuwaku" in this chapter, and construct various systems to evaluate the kansei values used to derive wakuwaku feelings using biological signals, in order to clarify the relationship between the wakuwaku feeling and biological signals. In addition, we derive a kansei model of interactive systems using biological signals to objectively evaluate their wakuwaku degree.

18.1 Introduction

Recently, the kansei value has become very important in manufacturing in Japan. Following function, reliability, and cost, the kansei has been determined as the fourth value axis of industrial products by the Japanese Ministry of Economy, Trade and Industry (METI). According to METI, it is important not only to offer new functions and competitive prices but also to create a new value to strengthen Japan's industrial competitiveness. Focusing on kansei as a new value axis, METI launched

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the “Kansei Value Creation Initiative” in 2007 [1, 2] and held a kansei value creation fair called the “Kansei-Japan Design Exhibition” at Les Arts Decoratifs (Museum of Decorative Arts) at the Palais du Louvre, Paris, in December 2008. Launched as an event of the “Kansei Value Creation Year”, the exhibition had more than 10,000 visitors during its ten-day run and was received favorably [3].

To evaluate the kansei values of interactive systems, subjective evaluation methods such as questionnaires are commonly used, even though they suffer from the following drawbacks:

- linguistic ambiguity;
- interfusion of experimenter and/or participant intention into the results;
- interruption of the system’s stream of information input/output.

Solving these problems is crucial in order to evaluate the degree of interest in and/or excitement of a constructed interactive system, and to identify the moment of excitement. Evaluating the kansei value of an interactive system by using only subjective evaluation methods such as questionnaires is almost impossible.

We began our research into objectively evaluating interactive systems by quantifying sensations using biological signals that offer the following merits, and can be used to redeem the above questionnaire drawbacks:

- can be measured using physical quantities;
- avoids influence from the intentions of experimenter and participants;
- can be measured continuously.

Many previous researches have measured mental sensations using biological signals. Some researchers have used biological signals to measure mental stress or simulator sickness [4–7], which are considered negative sensations. On the other hand, some research have looked at relaxation or comfort [8, 9]. We have previously utilized EEG alpha waves to estimate participant feelings of relaxation [10]. Relaxation and comfort are considered to be positive sensations.

In this chapter, we focus on a feeling called “wakuwaku”, which is a Japanese word for the positive sensation caused when someone feels something exciting or captivating. The word means “thrilling” or “exhilarating” in English. A wakuwaku feeling is also considered a positive sensation, as are relaxation and comfort. However, a big difference exists between those sensations; a wakuwaku feeling is considered dynamic, especially compared to the static sensations of relaxation and comfort. Little previous research exists on positive and dynamic sensations such as the wakuwaku feeling.

The purposes of this chapter include the following:

- to clarify the relationship between the dynamic, positive feeling of the wakuwaku sensation and biological signals;
- to derive a kansei model of interactive systems using biological signals to objectively evaluate their wakuwaku degree.

Based on Russel's circumplex model [11], we propose a two-dimensional model called the wakuwaku model by the following procedures:

1. evaluation of the wakuwaku sensation by studying indexes;
2. construction of examples of interactive systems;
3. evaluation of the constructed systems;
4. derivation of the model.

18.2 Indexes of the Wakuwaku Model

Our survey for wakuwaku experiences included the following items:

1. How would you describe your wakuwaku experience?
2. Why do you think you felt wakuwaku?
3. How else would you describe your feeling except wakuwaku?

From the questionnaire answers of 176 student participants in their twenties, we extracted keywords related to the wakuwaku sensation, such as excitement, pleasure, happiness, enjoyment, astonishment, and fright. Since the most commonly related keyword to wakuwaku was excitement, we employed "exciting" as the horizontal axis to construct a two-dimensional model called the wakuwaku model. Although other candidates such as happiness and fright were also considered, we chose "enjoyable" as the vertical axis (Figure 18.1).

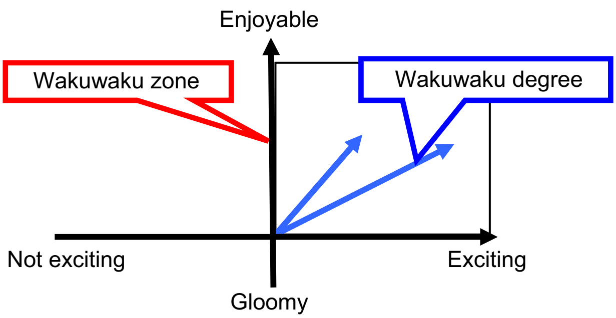

Figure 18.1 Wakuwaku model

18.3 Evaluation Experiment

18.3.1 Construction of Evaluation Systems

We constructed various systems based on a whack-a-mole game to evaluate their degrees of wakuwaku. After setting parameters and their factors (Table 18.1), eight types of systems were constructed (Table 18.2).

Table 18.1 Parameters and their factors

Parameters	Factor 1	Factor 2
Input device	Hammer	Keypad
Sound (BGM and effects)	With	Without
Target	Mole	Ball

Table 18.2 Constructed systems

System	Input device	Sound	Target
A	Keypad	With	Mole
B	Keypad	With	Ball
C	Keypad	Without	Mole
D	Keypad	Without	Ball
E	Hammer	With	Mole
F	Hammer	With	Ball
G	Hammer	Without	Mole
H	Hammer	Without	Ball

Figure 18.2 shows the system diagram for the interactive systems. For a wide viewing angle and high resolution, a 100-inch screen with rear projection was employed as the system's visual output device. The auditory output device was a pair of speakers. The input device was a hammer device or a keypad. Figure 18.3 shows the hammer, and Figure 18.4 shows a mole and a ball for the target. A PC was employed for the system display. The game took place as follows:

1. The experimenter explains the game (Figure 18.5 (a)).
2. After the game begins, players try to hit the targets with the input device (hammer or keypad) to increase their scores (Figure 18.5 (b)).
3. After a particular number of targets appear, the speed with which the target appears increases.
4. After another particular number of targets appear, the game is finished, and the results are displayed (Figure 18.5 (c)).

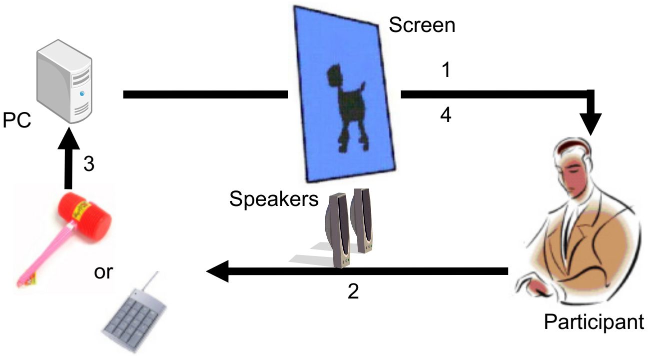

Figure 18.2 System diagram

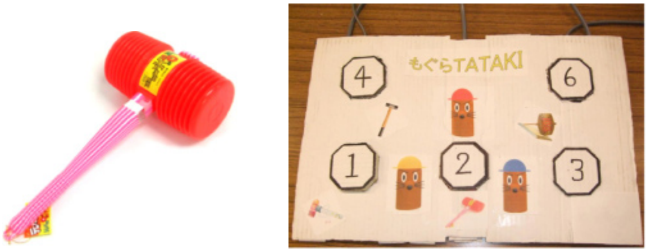

Figure 18.3 Hammer (left: hammer part, right: input part)

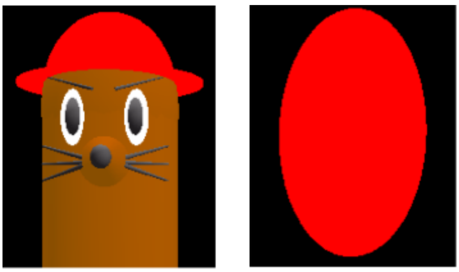

Figure 18.4 Targets (left: mole, right: ball)

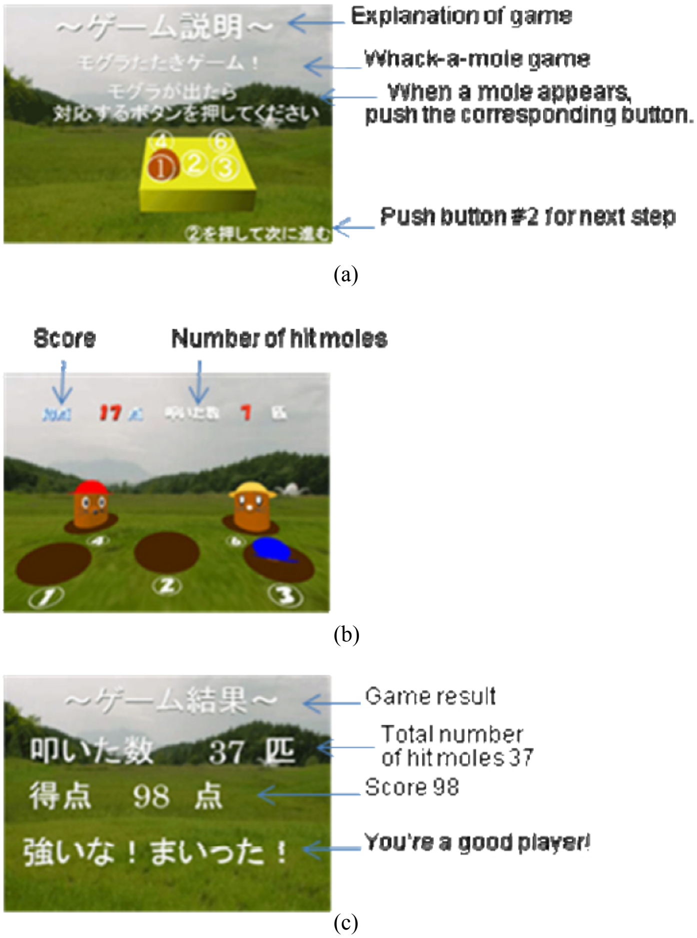

Figure 18.5 Screen shots: (a) explanation, (b) start of the game, and (c) results

18.3.2 Experiment to Evaluate the Systems

A questionnaire and biological signals were employed to evaluate the wakuwaku degrees of the constructed systems. We employed two types of questionnaire: five-scale evaluation and free description. For the former, 30 items were employed such as “enjoyable”, “exciting”, and “interesting”. The free description questionnaire contained the following questions:

- When did you feel excited during the game?
- When did you feel enjoyment during the game?
- What do you consider the game’s exciting aspects?

- What are its good points?
- What are its bad points?

The following biological signals were measured: galvanic skin reflex (GSR), heart rate, and breathing rate. GSR, which is affected by states of emotion, was used as a physiological index to detect emotions such as anxiety and mental stress. Heart rate is changed not only by physical exercise but also by mental factors such as anxiety and stress. In addition, breathing rates and patterns can also be used as indexes of stress and anxiety. Specific sensors for each biological signal described above, BIOPAC measurement equipment (BIOPAC Systems, Inc.), and a PC were used to measure these biological signals.

The experimental procedure was as follows:

1. Participants sat on chairs.
2. The experimenter explained the experiment.
3. Participants wore electrodes.
4. Participants remained quiet for 30 s.
5. Participants played one of eight possible games.
6. Participants answered questionnaires.
7. Steps 5 and 6 were repeated four times.

The participants played four out of eight games per day and completed all eight games over two days. The biological signals were constantly measured during the experiments.

18.3.3 Experimental Results

Experiments were performed with eight male students in their twenties who served as volunteers. Figure 18.6 shows a scene of the experiment. The orders of the eight games were counter-balanced.

Figure 18.6 Experiment in progress

From the questionnaire results, averages scores for all 30 items were calculated. Figure 18.7 shows the result of “enjoyable” as an example of the averaged scores. These questionnaire results show that the existence of sound and the mole images of the target effectively increased the “enjoyable” scores. On the other hand, differences between the hammer and the keypad as input devices were not obvious.

Next, we did a three-factor analysis of the variance, with input device, sound, and image of target as factors. Table 18.3 shows the results for “enjoyable”. Sound and target have significant main effects at a 1% level. Three-factor analysis results for the other items closely resembled this result.

The following results were confirmed:

- the degree of wakuwaku depends on both sound and target;
- the degree of wakuwaku is independent of the input device.

From the results of the free descriptions, the most common moments of excitement were as follows:

- when the mole’s speed increased;
- when its movement got faster;
- when participants heard the sound effects.

The first two statements show the effectiveness of the speed change of the mole movement for increasing participant excitement. In addition, the third shows the effectiveness of sound for increasing excitement.

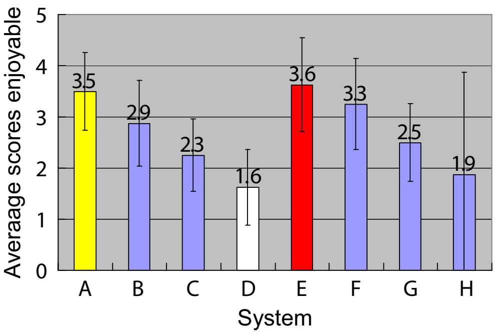

Figure 18.7 Questionnaire results (for “enjoyable”)

Table 18.3 Analysis of variance (for “enjoyable”)

Factor	Sum of squared deviation	DOF	Mean square	F-value	P-value
Input device	1.00	1	1.00	1.10	0.30**
Sound	27.56	1	27.56	30.41	0.00**
Target	9.00	1	9.00	9.93	0.00**
Error	54.38	60	0.91		
Total	91.94	63			

Like the free description results for the moment of enjoyment during the game, some participants cited the moment of hitting the moles, which shows that the hammer effectively promotes enjoyment. In addition, participants listed the following as the game's most popular good points:

- sound effectively increases the feeling of enjoyment;
- hitting the moles with a hammer is fun.

These answers suggest that the hammer as an input device, the existence of BGM and the sound effects, and the mole as a target all effectively increase the game's wakuwaku feeling – as we intended.

The effectiveness of the sound and the mole as a target were confirmed both by the five-scale evaluation and the free description. However, the effectiveness of the hammer as an input device was confirmed only by free description and not by the five-scale evaluation, as mentioned above. To solve this contradiction, the answers for the final free description question were very helpful because they provided a list of some of the bad points of the game.

These answers suggest the difficulty of using the hammer, which explains the contradiction between the five-scale evaluation and the free description, where the feeling of the enjoyment at the moment of using the hammer may be reduced by the difficulties of its continuous operation. This assumption might indicate a limitation of the five-scale evaluation.

18.3.4 Derivation of Wakuwaku Model

Based on our previous experiments [11–14], we selected the following physiological indexes for the model:

- average GSR;
- average heart rate;
- variance of heart rate;
- average R-R interval;
- variance of R-R interval;
- number of breaths;
- average breath magnitude;
- variance of breath magnitude.

Because the temporal change of GSR moves in one direction, the averaged GSR value reflects the magnitude and repetition of its temporal change. The averaged heart rate and its variance are defined as the average number of heart beats per minute and its variance, respectively. The average R-R interval and its variance are defined as the average interval time between the R-waves of the ECG and its variance, respectively. These indexes are known as the indexes for stress, uneasiness, or relaxation, and are used to measure dynamic feelings [11–14].

The number of breaths and the variance of breath are defined as breaths per minute and its variance, respectively. The breath magnitude is defined as the difference of the maximum and minimum values in one indrawn breath. As already mentioned, our wakuwaku model consists of "exciting" and "enjoyable" axes. We derived equations to explain both axes using a neural network as follows:

- *input*: all the physiological indexes listed above were calculated from when the speed of the target appearance increased at the end;
- *output*: averaged score of "exciting" for each system;
- *method*: clipping;
- *hidden layer*: one;
- *sample data for learning*: 60%.

Table 18.4 shows the neural network results for "exciting". We expressed the "exciting" axis as follows:

$$\text{exciting} = 0.55 * \text{average breath} + 0.45 * \text{average heart rate}. \quad (18.1)$$

In the same manner (see Table 18.5), the "enjoyable" axis was expressed as follows:

$$\text{enjoyable} = 0.71 * \text{average heart rate} + 0.45 * \text{variance of breath}. \quad (18.2)$$

Table 18.4 Results of neural network (for "exciting")

Psychological indexes	Relative importance
Average breaths	0.546 233
Average heart rate	0.445 581
Variance of heart rate	0.382 679
Average GSR	0.305 76
Number of breaths	0.288 106
Variance of breath	0.186 697

Table 18.5 Results of neural network (for "enjoyable")

Psychological indexes	Relative importance
Average heart rate	0.709 154
Variance of breath	0.450 969
Average breaths	0.350 584
Average R-R interval	0.333 264
Number of breaths	0.266 689
Variance of heart rate	0.252 472

18.3.5 Confirmation of Wakuwaku Model

Using the two derived equations, our wakuwaku model was applied to the eight systems. Figure 18.8 shows the results for each system, where the values of the horizontal axis were calculated from Equation 18.1, and the values of the vertical axis were calculated from Equation 18.2.

System E, where the input device is a hammer, sound exists, and the targets are moles, has the highest scores both for "exciting" and "enjoyable". On the other hand, system D has the lowest score, where the input device is a keypad, sound doesn't exist, and the targets are balls:

$$E > G > F > H > A > B > C > D, \tag{18.3}$$

where the first four systems use a hammer as an input device.

From this result, the system with the most wakuwaku has the following combination of parameters:

- *input device*: hammer;
- *sound*: yes;
- *target*: mole.

The system with the least wakuwaku has the following combination of parameters:

- *input device*: keypad;
- *sound*: no;
- *target*: ball.

These results are the same as the five-scale evaluation results shown in Figure 18.7.

However, Figure 18.8 shows that the effect of a different input device is stronger than the effects of sound and different target images, which is completely different from the five-scale evaluation results (Figure 18.7). On the other hand, these results agree with the free description that shows that using the hammer effectively increased participant enjoyment. This fact suggests the appropriateness of our proposed model.

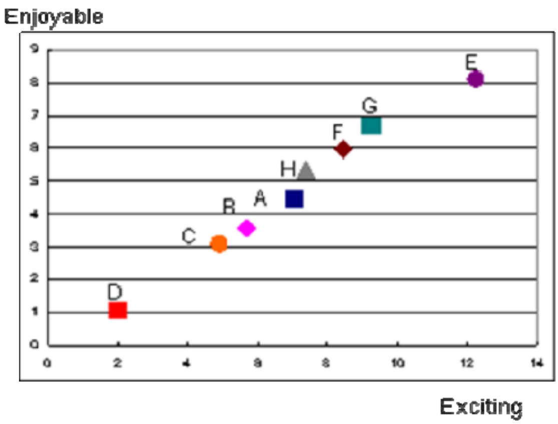

Figure 18.8 Results of wakuwaku model

Deriving a two-dimensional wakuwaku model based on biological signals using neural networks, we can reasonably explain the varieties of the wakuwaku degree of eight constructed systems (Figure 18.8). Moreover, the limitation of the five-scale evaluation as a questionnaire was overcome by employing this model, suggesting its effectiveness based on biological signals to qualify the degree of the wakuwaku feeling of the interactive systems.

18.4 Experiment 2

This section introduces another experiment to measure the wakuwaku feeling using biological signals.

18.4.1 System Construction

We constructed various systems based on a treasure chest game to evaluate the degrees of wakuwaku feeling. Compared with the previous experiment, these constructed systems have various complicated components to promote the wakuwaku feeling, such as the appearances of figures, their combination, and the actions of the combined figures. The parameters of these systems were the design of the boxes and the sound, the BGM and effects, as shown in Table 18.6. The three box designs are shown in Figure 18.9. The constructed systems are shown in Table 18.7.

Table 18.6 System parameters

Parameters	Factor 1	Factor 2
Box design	Designs[1]	White
Sound (BGM and effects)	With sound	Without sound

[1] Shown in Figure 18.9

Figure 18.9 Three types of boxes

Table 18.7 Constructed systems

System	Box design	Sound
A	Decorated	With
B	Decorated	Without
C	White	With
D	White	Without

The procedures of the game were as follows:

1. Confirm the figures in the boxes (Figure 18.10 (a)).
2. Choose one of the boxes (Figure 18.10 (b)).
3. Watch the figure in the chosen box (Figure 18.10 (c)).
4. Repeat the above procedures (Figure 18.10 (d)).
5. Watch the combinations of the two figures (Figure 18.10 (e)).
6. Watch the combined figure (Figure 18.10 (f)).

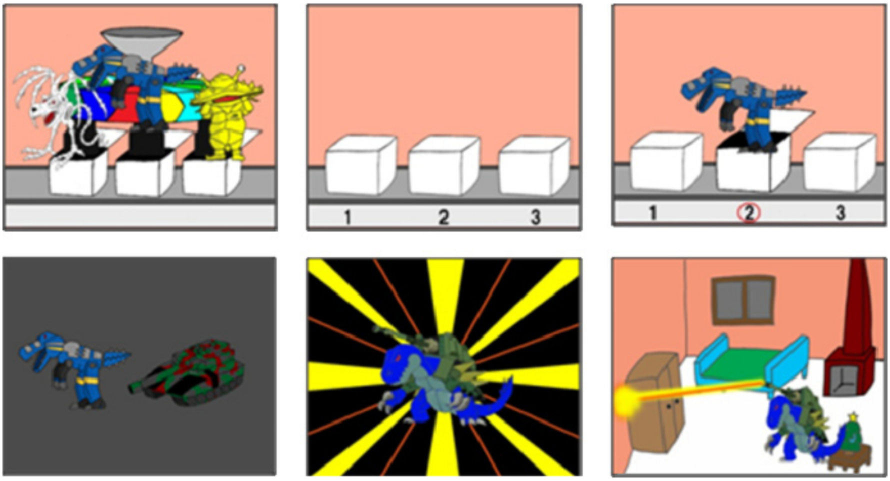

Figure 18.10 System flow

These procedures were designed to promote wakuwaku feelings when expecting a figure's appearance from the chosen box and when combining two figures. Questionnaires and biological signals were employed to evaluate the degree of wakuwaku feeling of each system.

Figure 18.11 shows the system diagram. The input device was a keypad, and the output devices were a 17-inch LCD display and a pair of speakers. Biological signals were measured by sensors and BIOPAC measurement equipment. Two PCs were employed for system display and to measure the biological signals.

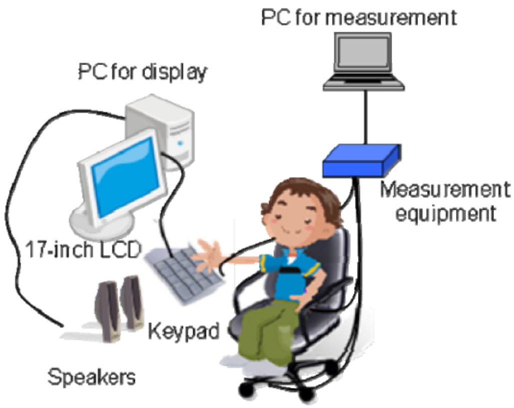

Figure 18.11 System setup

18.4.2 Experiment to Evaluate the Systems

18.4.2.1 Experimental Method

The participants randomly played the four games shown in Table 18.7 and answered questionnaires about each system. The questionnaire about the wakuwaku feeling consisted of 23 items of paired seven-point evaluations such as "fun–boring," and five items of unpaired five-scale evaluation, such as "pounding." For the paired seven-point evaluation items, 4 indicates neutral, 7 the best, and 1 the worst. For the unpaired five-point evaluation items, 5 indicates the best and 1 the worst. In addition, participants were asked some free description questions after playing the final game.

The following biological signals were measured constantly during the experiments to detect the degree of wakuwaku feeling: galvanic skin reflex (GSR), electrocardiogram (ECG), and breathing rate.

18.4.2.2 Experimental Results

Experiments were performed with 12 male students in their twenties who served as volunteers. From the results of the analysis of variance for each questionnaire item with parameters in Table 18.6, the main effect of sound was found to be significant for almost all questionnaire items, including "exciting" and "enjoyable." On the other hand, the main effect of the box design was not significant for almost all items. Table 18.8 shows the result of the analysis of variance for "enjoyable." In the free description answers, some participants pointed out that the BGM and the sound effects were good points of the system, suggesting that sound is effective for creating wakuwaku feelings.

For the biological signals, we selected the same physiological indexes as the previous experiment described above. Since we designed the game flow with various events to promote wakuwaku feelings, we chose the following three moments for analysis:

- *moment I*: when the first box opened;
- *moment II*: when the second box opened;
- *moment III*: just after combining the two figures.

The first and second moments were in the first half of the game, while the third moment was in the second part. Using a paired difference test, the heart rate at each moment of the first and the second choices of boxes was found to be significantly different between the systems with different box designs. On the other hand, the heart rate at moments I and II was not significantly different between the systems with and without sound. However, the averages of GSR at moment III were significantly different only between the systems with and without sound. Table 18.9 summarizes the results of all tests.

Table 18.8 Analysis of variance (enjoyable)

Factor	Sum of squared deviation	DOF	Mean square	F-value	P-value
Sound	20.02	1	20.02	14.47	0.00**
Box design	0.19	1	0.19	0.14	0.71
Error	62.27	45	1.38		
Total	82.48	47			

Table 18.9 Results of difference tests

Physiological index	Parameter	Moment I	Moment II	Moment III
Averages of GSR	Box design	–	–	–
Averages of GSR	Sound	–	–	*
Heart rate	Box design	**	**	–
Heart rate	Sound	–	–	–
R-R Interval	Box design	**	**	–
R-R Interval	Sound	–	–	–

–: Not significant, *: significant at 5% level, **: significant at 1% level

18.4.3 Discussion

The above experimental results suggest that heart rate and GSR averages may show the wakuwaku feeling of the users of interactive systems. Moreover, the heart rate results are related to the system's former part, and the results of the GSR averages are related to its latter part. Since the questionnaire results agreed with the results of the GSR averages and disagreed with the heart rate results, they might reflect the wakuwaku feeling of the latter part of the systems. The questionnaires may reflect the wakuwaku feeling of the system's last part because that is the only part the participants can remember.

18.5 Conclusion

To evaluate the kansei values of interactive systems, we utilized biological signals for objective evaluations. We evaluated wakuwaku, which is a positive and dynamic feeling in Japanese, of interactive systems using biological signals and proposed a two-dimensional model that followed these procedures:

- reviewed indexes to evaluate wakuwaku sensations;
- constructed several systems;
- conducted evaluation experiments of the constructed systems;
- derived a wakuwaku model using a neural network.

We designed and constructed eight different systems based on a whack-a-mole game for various wakuwaku degrees. From the experimental results, we derived two equations with biological indexes as parameters to form the wakuwaku model. The results of the model showed that the derived wakuwaku model based on biological signals reasonably explained the wakuwaku degree of the constructed systems.

We conclude that our proposed model can play a role in the evaluation of the kansei values of interactive systems from the aspects of positive and dynamic sensations by qualifying biological signals.

In addition, we performed another experiment to measure the degree of wakuwaku feeling by constructing systems based on a treasure chest game. From analysis of the experimental results, we obtained the following useful knowledge:

- the degree of wakuwaku feeling may vary depending on such parameters as object design and sound effects;
- the degree of wakuwaku feeling may be measured by biological signals such as GSR and ECG.

The measurement of such positive and dynamic feelings as wakuwaku derived by interactive systems is considered an evaluation of the kansei value of the interactive systems. Thus, these works above are the first step in objectively evaluating the kansei value of interactive systems by measuring biological signals. Future work will include more detailed research.

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