# The influence of the sensation of rhythm on comfort and productivity

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## ABSTRACT

Recently, an evaluation of stress and comfort by using physiological information has been being researched as a quantitative and objective evaluation method. Moreover, sounds which improve productivity introduced into an environment where people work are in demand. In this research, first, to investigate comfortable rhythmical sounds, we conducted a sound quality evaluation, by a subjective evaluation as well as the objective evaluation that used heart rate and salivary amylase. We prepared two sounds: rhythmical sounds which were a metronome sound and an operation sound emitted by a multifunctional peripheral (MFP). From these results, it may be stated that subjects felt more comfortable when they heard a rhythmical sound whose rhythm was a little slower than their heart rate. Moreover, it may be stated that it is possible to evaluate the influence of the sensation of rhythm on comfort by using heart rate and salivary amylase. In the second evaluation, the subjects calculated two-digit number additions, with the presentation of the metronome sound and the operation sound emitted by the MFP used in the first evaluation. Consequently, the number of calculations per minute increased when they heard a rhythmical sound whose rhythm was a little faster than their heart rates.

Keywords: Rhythm, Cyclic sound, Comfort  I-INCE Classification of Subjects Number(s): 63.7

## 1. INTRODUCTION

In recent years, there has been a great demand for the sounds emitted by machines such as office equipment, home electrical appliances and IT products, to be quieter and more pleasant. Moreover, in the office space, comfortable environments and improved productivity are in demand.

To achieve comfortable sounds, a sound quality evaluation is needed (1, 2). The sound quality evaluation has been conventionally performed by the subjective evaluation by using questionnaires, for example; the SD method, and the paired comparison method. But these methods have problems due to inter-subject variation of the understood meaning of the questionnaires. Additionally, it is difficult to evaluate sound that varies over time in real time. Further it is difficult to evaluate sound over long durations. Considering this situation, there is a great demand for the sound quality evaluation method to gain a quantitative, objective, real time and long duration evaluation. To solve these problems, the quantitative and objective evaluation methods of human sensation that uses physiological information have been researched (3). However, the environments for measuring physiological information are limited, because precise and large measurement equipment is immobile. Moreover, the objective sound quality evaluation by using physiological information often has large data variations caused by small body movements, even if the subject sits in a chair. Furthermore, if the subject must keep the same posture, it often makes the subject feel stressed.

We have been conducting the quantitative and objective sound quality evaluation by using physiological information (4-7). But, we have not conducted the relationship among the influence of the sensation of rhythm on comfort or productivity, the frequency of the rhythmical sounds and subject's heart rate in detail (8).

In this research, first, we focused on which types of rhythmical sounds were comfortable to listen

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to. To investigate comfortable rhythmical sounds, first, we conducted the sound quality evaluation by the conventional subjective evaluation, and the objective evaluation by using heart rate and salivary amylase activity as well. We also focused on the relationship among the influence of the sensation of rhythm on comfort, the frequency of the rhythmical sounds and subject’s heart rate. We prepared two sounds: rhythmical sounds which were the metronome sound and the operation sound emitted by the multifunctional peripheral (MFP) that integrates several functions such as copying, printing, faxing, or scanning into one device. Furthermore, we investigated whether it is possible to use heart rate and salivary amylase activity to evaluate the influence on comfort due to the sensation of rhythm.

Next, we investigated whether a rhythmical sounds affect productivity. In the evaluation, the subjects calculated two-digit number additions, with the presentation of two sounds which were the metronome sound and the operation sound emitted by the MFP, used in the previously mentioned sound quality evaluation. Additionally, we investigated the relationship among the number of calculations, the frequency of the rhythmical sounds and subject’s heart rate.

Before experiments, we got informed consent, and permission to evaluate all subjects.

## 2. OBJECTIVE EVALUATION METHODS BY USING PHYSIOLOGICAL INFORMATION

We investigated the influence of the sensation of rhythm on comfort by the conventional subjective evaluation, and the objective evaluation by using heart rate and salivary amylase activity as well.

### 2.1 Heart Rate

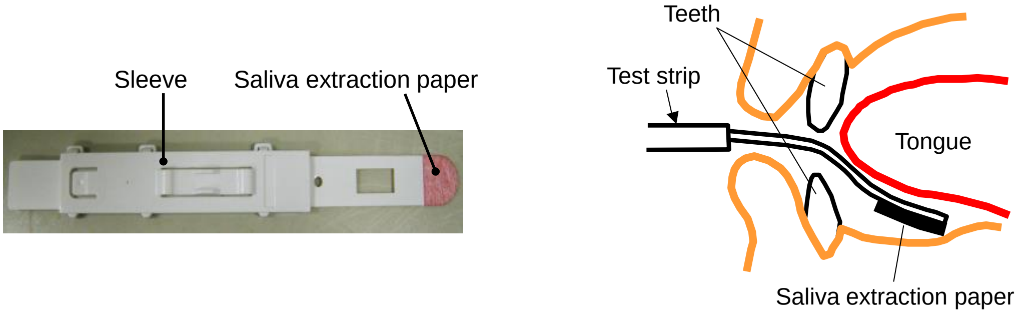
It is known that when a human feels stressed, the sympathetic nerves of the peripheral nervous system become dominant. A heart rate variability (HRV) provides estimates of the sympathetic nerve activity level and the parasympathetic nerve activity level. The high frequency band (0.15-0.50 Hz, HF) based on the electrocardiographic (ECG) data indicates the parasympathetic nerve activity level, the low frequency band (0.04-0.15 Hz, LF) indicates the sympathetic nerve activity level and the parasympathetic nerve activity level, and LF/HF indicates a balance of the sympathetic nerve activity level and the parasympathetic nerve activity level as well.

We focused on heart rate when evaluating the influence of the sensation of rhythm on comfort, and we used calculated LF/HF as a sympathetic nerve activity index. We used an ambulatory wireless ECG which can reduce the burden of the subject. Thus, the subjects do not feel stressed by measuring ECG during the evaluations.

### 2.2 Salivary Amylase Activity

It is known that when a human feels stressed, salivary amylase activity rises. We focused on salivary amylase activity when evaluating the influence of the sensation of rhythm on comfort.

We used a stress monitor for the evaluation (9). The stress monitor is used to measure salivary amylase activity; it is composed of a main device and a disposable test strip as shown in Figure 1 (a). The test strip is equipped with saliva extraction paper and amylase reagent paper. The subject has only to hold the test strip in his mouth under the tongue to extract saliva as shown in Figure 1 (b). Thus, the subjects do not feel stressed by measuring salivary amylase activity during the evaluations.




(a) (b)

Figure 1 – Extracting saliva, (a) Test strip, (b) Schematic view of extracting saliva

# 3. EVALUATION OF INFLUENCE ON COMFORT DUE TO SENSATION OF RHYTHM

First, we evaluated the influence on comfort due to the sensation of rhythm by the conventional subjective evaluation, and the objective evaluation by using heart rate and salivary amylase activity as well. We also focused on the relationship between the sensation of rhythm of sound and subject's heart rate. Furthermore, we investigated whether it is possible to use heart rate and salivary amylase activity to evaluate the influence on comfort due to the sensation of rhythm.

## 3.1 Evaluation Sounds of Sound Quality Evaluation

We prepared two types of rhythmical sounds. One of the sounds was the metronome sound. Another sound was the operation sound emitted by the MFP (10, 11).

### 3.1.1 Metronome Sound

A first evaluation sound is the metronome sound which is a fundamental rhythmical sound. We adjusted the timing of the emitted sounds by 0%, +/-10%, +/-20% of the subject’s heart rate. Thus, we investigated the relationship between the frequency of the emitted evaluation sounds and the subject’s heart rate.

### 3.1.2 Operation Sound Emitted by MFP

A second evaluation sound is the operation sound emitted by the MFP, which is the operation sound emitted by the mechanical product, whose sound quality is different form the metronome sound.

Figure 2 shows the sound pressure (SP) data of 10 consecutive copies (12). A microphone was placed at 0.25 m in front of the machine’s front surface and at a height of 1.5 m, in accordance with a standard of ISO 7779. Many kinds of transient sounds and steady sounds are included. In Figure 2, we define transient sound 1, transient sound 2, transient sound 3, transient sound 4 and transient sound 5 as T1, T2, T3, T4 and T5 respectively. Starting from the second copy, cyclic periods, which consist of T3, T4 and T5, are repeated for each copy not including the first copy. Figure 3 shows one cyclic period including T3 which consists of the transient 3-1 (T3-1) and the transient 3-2 (T3-2), T4 and T5. The cyclic period is 1.3 s.

We also prepared evaluation sounds by editing the recording of the operation sound by the MFP, as shown in Figure 4. The cyclic periods from the original data were contracted or expanded from 1.0 s to 1.9 s. In this evaluation, the cyclic period was continuously repeated five times.

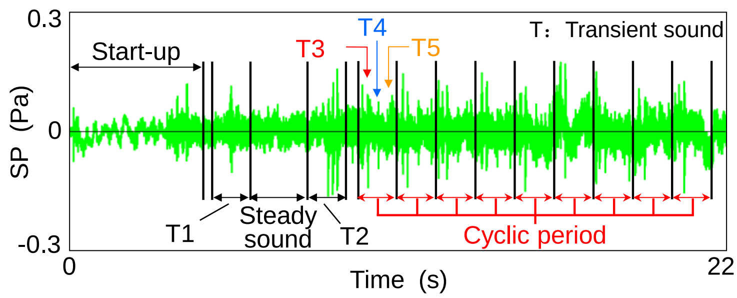



Figure 2 – Sound pressure (SP) data of 10 consecutive copies

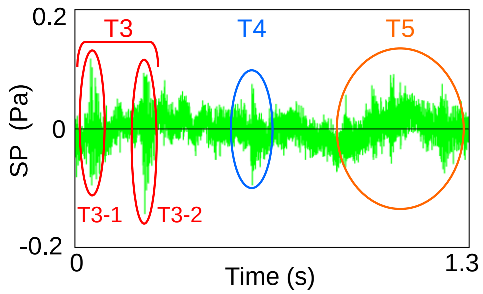



Figure 3 – Sound pressure (SP) data of one cyclic period

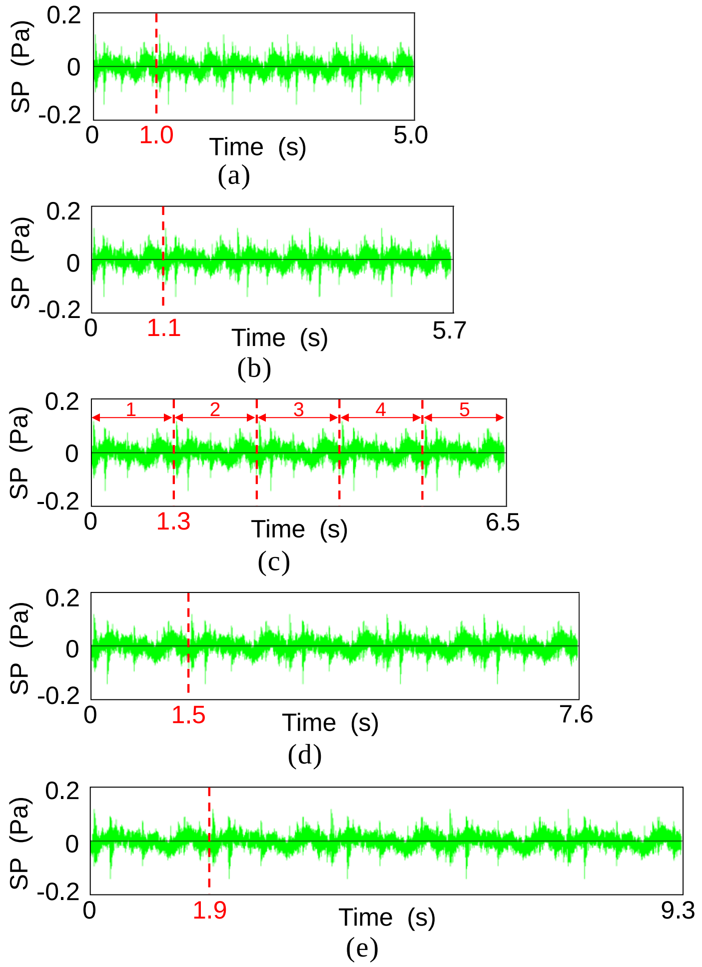



Figure 4 – Rhythmical cyclic sounds whose periods are contracted or expanded from the original sound, cyclic periods are (a) 1.0 s, (b) 1.1 s, (c) 1.3 s (Original cyclic period), (d) 1.5 s, (e) 1.9 s

## 3.2 Evaluation Method of Sound Quality Evaluation

### 3.2.1 Method of Sound Quality Evaluation with Metronome Sound

We conducted the conventional subjective evaluation, and the objective evaluation by using heart rate and salivary amylase activity as well. Six Japanese males aged between 21 and 24 participated in the evaluation.

Figure 5 shows the time protocol for the evaluation. First, the subject sat in a chair, and rested for sixty seconds. After twenty seconds from the start of the rest, the subject held the test strip in his mouth for forty seconds to extract saliva. After that, the test strip was removed and measured in the main device to determine salivary amylase activity.

In the next stage, when using the main device to measure salivary amylase activity, a standard rhythmical sound, which was the averaged frequency of the subject’s heart rate, was presented from a speaker for sixty seconds. After twenty seconds from the start of presenting sound, the subject held another test strip in his mouth for forty seconds to extract saliva, and then salivary amylase activity was measured.

In the next stage, when using the main device to measure salivary amylase activity, one of the evaluation sounds which were mentioned in 3.1.1 was presented for sixty seconds. After twenty seconds from the start of presenting evaluation sound, the subject held another test strip in his mouth for forty seconds to extract saliva, after that salivary amylase activity was measured.

Simultaneously, ECG was measured continuously from the start of the evaluation. Finally, the subjects conducted the subjective evaluation by answering whether they felt stress or not on a scale of one to five. The evaluation was conducted in an anechoic chamber.

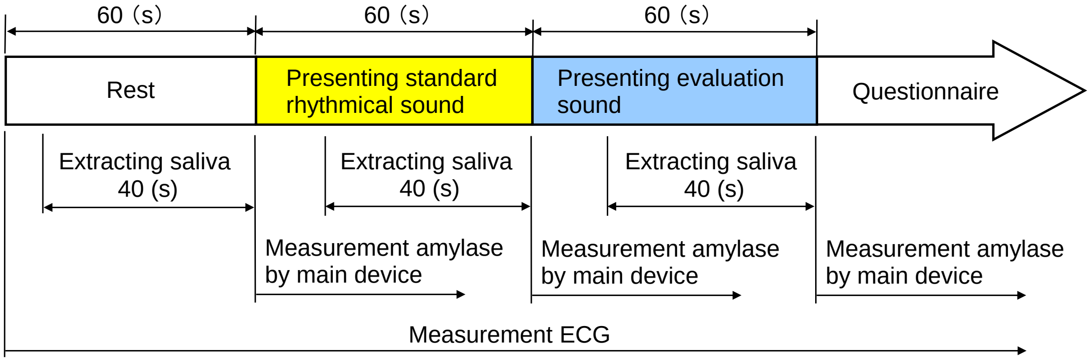



Figure 5 – Time protocol for evaluating of the influence on comfort due to the sensation of rhythm with the presentation of the rhythmical sound

### 3.2.2 Method of Sound Quality Evaluation with Operation Sound Emitted by MFP

We conducted the subjective evaluation by the paired comparison method. Seventeen Japanese males aged between 21 and 24 participated in the subjective evaluation. The subject sat in a chair and listened to the pair of evaluation sounds from a speaker in the anechoic chamber. Following this, the subject answered which sound was more comfortable.

We also conducted the objective evaluations by using heart rate and salivary amylase activity. Five Japanese males aged between 21 and 24 participated in the evaluation. The procedure of the evaluation is in the same way as the previously mentioned evaluation with the metronome sound. In this evaluation, first, the original sound which was the measured data was presented. Then, one of the evaluation sounds which were the edited sounds, was presented.

## 3.3 Results of Sound Quality Evaluation

### 3.3.1 Results of Sound Quality Evaluation with Metronome Sound

Figure 6 shows the results of the subjective evaluation, and the objective evaluation by using heart rate. In Figure 6, the plotted data of the subjective evaluation is indicated on the left vertical axis as the calculated average of score of all subjects, which also shows that the subject did not feel stressed in the upper direction, on the other hand, the subject felt stressed in the lower direction. In this calculation, every evaluation datum was divided by the datum with the presentation of sound of the subject's heart rate. The plotted data of the objective evaluation is indicated on the right vertical axis as the calculated average of LF/HF, which also shows that the subject felt stressed in the upper direction, on the other hand, the subject felt pleasant in the lower direction. In this calculation, every measurement datum was divided by the averaged measurement data of each subject. In order to easily compare the trends between results of the subjective evaluation and the objective evaluation, the lines were shifted so that the results of the subject's heart rate data were set to 0. The plotted data on the horizontal axis represents the frequency of the emitted evaluation sounds, which are differential frequencies based on each subject's heart rate.

Figure 6 indicates that the subjects felt more stressed as the frequency of the emitted evaluation sound became faster. From the result, it may be stated that the subjects feel more comfortable when they hear a rhythmical sound whose rhythm is a little slower than their heart rate. Additionally, the result of the objective evaluation by using heart rate almost matched that of the subjective evaluations. Therefore it may be stated that it is possible to use heart rate to evaluate the influence of the sensation of rhythm on comfort.

Figure 7 shows the results of the subjective evaluation, and the objective evaluation by using salivary amylase activity. In Figure 7, the plotted data of the objective evaluation is indicated on the right vertical axis as the calculated average of salivary amylase activity, which also shows that the subject felt stressed in the upper direction, on the other hand, the subject felt pleasant in the lower direction. In this calculation, every measurement datum was divided by the averaged measurement data of each subject. In order to easily compare the trends between results of the subjective evaluation and the objective evaluation, the lines were shifted so that the results of the subject's heart rate data were set to 0.

Figure 7 indicates that the subjects felt more stressed as the frequency of the emitted evaluation sound became faster. From the result, it may be stated that the subjects feel more comfortable when

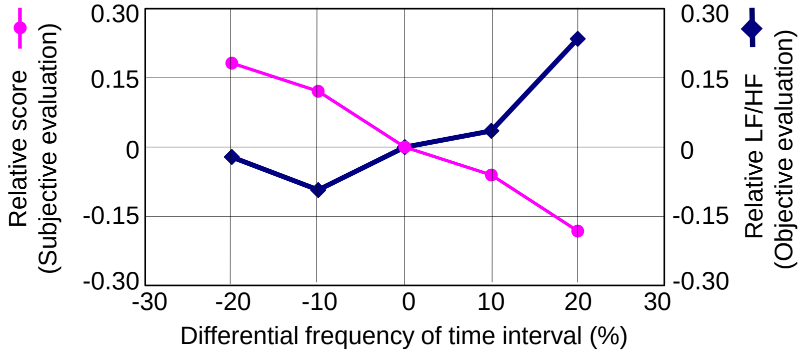



Figure 6 – Evaluation result by the subjective evaluation, and the objective evaluation by using HRV with the presentation of the metronome sound

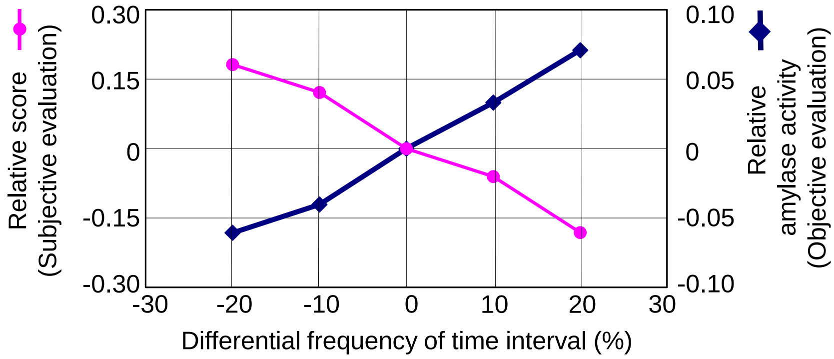



Figure 7 – Evaluation result by the subjective evaluation, and the objective evaluation by using amylase with the presentation of the metronome sound

they hear a rhythmical sound whose rhythm is a little slower than their heart rate. Additionally, the result of the objective evaluation by using salivary amylase activity almost matched that of the subjective evaluations. Therefore it may be stated that it is possible to use salivary amylase activity to evaluate the influence of the sensation of rhythm on comfort.

### 3.3.2 Results of Sound Quality Evaluation with Operation Sound Emitted by MFP

Figure 8 shows the results of the subjective evaluation by the paired comparison method, and the objective evaluation by using heart rate. In Figure 8, the plotted data of the subjective evaluation is indicated on the left vertical axis, which also shows that the subject felt pleasant in the upper direction, and the plotted data of the objective evaluation is indicated on the right vertical axis as the calculated average of LF/HF, which shows that the subject felt stressed in the upper direction. The plotted data on the horizontal axis represents the frequency of the emitted transient sounds which subjects feel a sensation of rhythm by. The data are differential frequencies based on each subject's heart rate. The subjects' comment was that when they heard the evaluation sound, they felt the sensation of rhythm between two transient sounds whose sound pressure level was large, or whose sound quality was different from other transient sound.

Figure 8 indicates that the subjects felt more stressed as the frequency of the emitted transient sounds which subjects felt a sensation of rhythm by, became faster or the frequency became too slower. Additionally, the result of the objective evaluation by using heart rate almost matched that of the subjective evaluations.

Figure 9 shows the results of the subjective evaluation, and the objective evaluation by using salivary amylase activity. The result of the objective evaluation indicates that the subjects felt more stressed as the frequency of the emitted evaluation sound became faster or the frequency became too slower. Additionally, the result of the objective evaluation by using salivary amylase activity almost matched that of the subjective evaluations.

From the results, it may be stated that the subjects feel more comfortable when they hear a rhythmical sound whose rhythm is a little slower than their heart rate. Moreover it may be stated that it

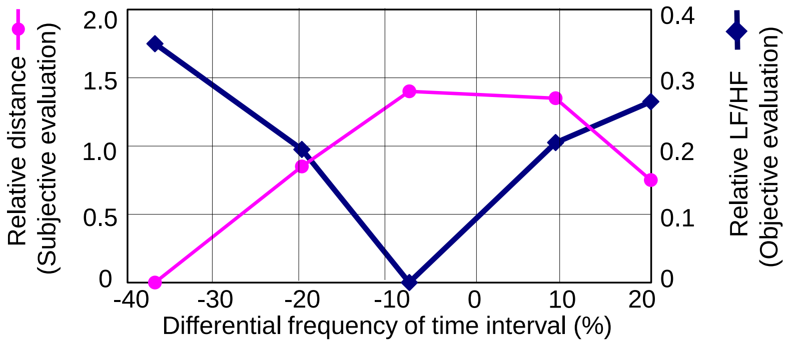



Figure 8 – Evaluation result by the subjective evaluation, and the objective evaluation by using HRV with the presentation of the operation sound emitted by the MFP

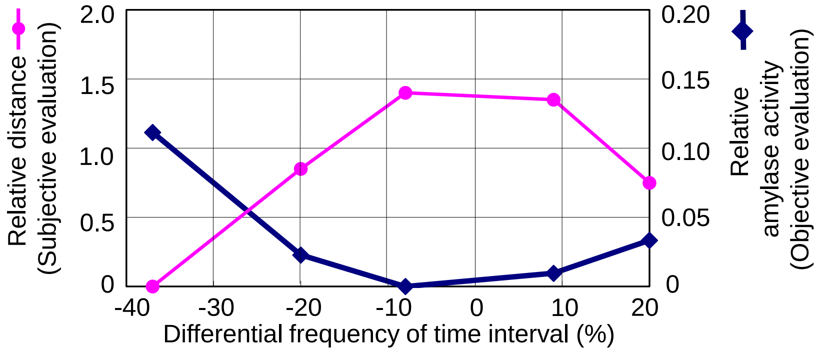



Figure 9 – Evaluation result by the subjective evaluation, and the objective evaluation by using amylase with the presentation of the operation sound emitted by the MFP

is possible to use heart rate and salivary amylase activity to evaluate the influence of the sensation of rhythm on comfort.

## 4. EVALUATION OF WHETHER RHYTHMICAL SOUNDS AFFECT PRODUCTIVITY

Next, we investigated whether rhythmical sounds affected productivity. In the evaluation, the subjects calculated two-digit number additions, with the presentation of the rhythmical sounds. Additionally, we investigated the relationship among the number of calculations, the frequency of the rhythmical sounds and subject's heart rate.

### 4.1 Evaluation Sound of Productivity

We prepared two rhythmical sounds which were the metronome sound and the operation sound emitted by the MFP, used in the previous evaluation.

### 4.2 Evaluation Method of Productivity

We conducted evaluation of whether the rhythmical sounds affected productivity. Five Japanese males aged between 21 and 24 participated in the evaluation. In this evaluation, the subject sat in the chair, and calculated two-digit number additions for one minute, with the presentation of evaluation sounds from a speaker as shown in Figure 10. The evaluation was conducted in the anechoic chamber.

### 4.3 Evaluation Results of Productivity

#### 4.3.1 Evaluation Results of Productivity with Metronome Sound

Figure 11 shows the result of the evaluation with the presentation of the metronome sound. In Figure 11, the vertical axis represents the percentage difference from the average of the number of calculations subjects completed at their base heart rates. In this, every evaluation datum was a differential ratio of the

Figure 10 – Evaluation of whether the rhythmical sounds affect productivity

number of calculations completed during each presented evaluation sound, over the number of calculations completed during the presentation of the evaluation sound matching each base heart rate. On the other hand, the plotted data on the horizontal axis represents the frequency of the emitted evaluation sounds, which are differential frequencies based on each subject's heart rate.

Figure 11 indicates that the number of calculations increased when they heard the rhythmical metronome sound whose rhythm was a little faster than their heart rates. Especially, when the frequency of the emitted evaluation sound was about 20% faster than heart rate, the number of calculation significantly increased.

### 4.3.2 Evaluation Results of Productivity with Operation Sound Emitted by MFP

Figure 12 shows the results of the evaluation with the presentation of the operation sound emitted by the MFP. In Figure 12, the vertical axis represents the data which is in the same way as the evaluation with the presentation of the metronome sound. On the other hand, the plotted data on the horizontal axis represents the frequency of the emitted transient sounds, which is mentioned in 3.3.2.

Figure 12 indicates that the number of calculations increased when they heard the rhythmical sound emitted by the MFP, whose rhythm was a little faster than their heart rates. Especially, when the

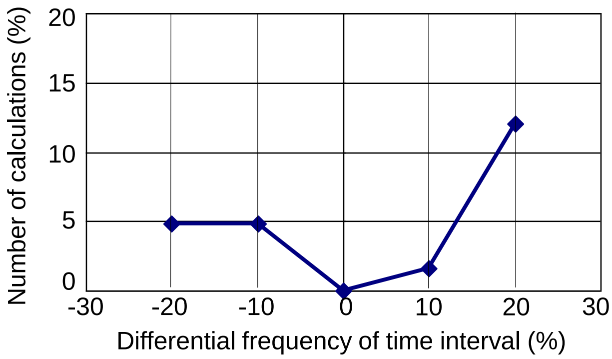



Figure 11 – Evaluation result of productivity with the presentation of the metronome sound

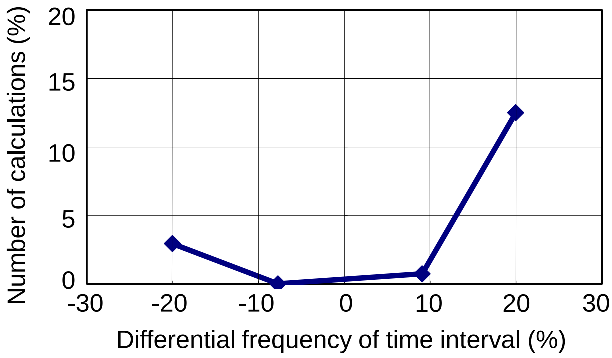



Figure 12 – Evaluation result of productivity with the presentation of the operation sound emitted by the MFP

frequency of the emitted transient sound which subjects felt the sensation of rhythm by, was about 20% faster than heart rate, the number of calculations significantly increased.

Consequently, it may be stated that a rhythmical sounds affect productivity, and the number of calculations increase when the subjects hear a rhythmical sound whose rhythm is a little faster than their heart rates.

## 5. CONCLUSIONS

In this research, first, to investigate comfortable rhythmical sounds, we conducted the sound quality evaluations, by the subjective evaluation as well as the objective evaluation that used heart rate and salivary amylase. We prepared two sounds: rhythmical sounds which were the metronome sound and the operation sound emitted by the MFP. From these results, it may be stated that the subjects feel more comfortable when they hear a rhythmical sound whose rhythm is a little slower than their heart rate. Moreover, it may be stated that it is possible to evaluate the influence of the sensation of rhythm on comfort by using heart rate and salivary amylase.

Next, we investigated whether the rhythmical sounds affect productivity. In the second evaluation, the subjects calculated two-digit number additions, with the presentation of the rhythmical sounds which were used in the sound quality evaluation. Additionally, we investigated the relationship among the number of calculations, the frequency of the rhythmical sounds and subject’s heart rate. Consequently, the number of calculations per minute increase when they hear a rhythmical sound whose rhythm is a little faster than their heart rates.

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