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Prediction of TTS for Hand Intermittent Vibration

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Abstract: Temporary Threshold Shift (TTS) is often used as an indicator of the effect of hand-transmitted vibration on the human body. An experiment for the prediction of TTS in exposure to intermittent vibration was conducted in the present study to examine the exposure equivalent rule, as well as the equations for growth and recovery TTS. It was found that the prediction of TTS obtained here was in good agreement with measured TTS. This estimation procedure for predicting TTS was compared with the notification of the Labor Ministry in Japan, in which control of the operation time and the rest time for hand-vibrating tools was described. The results suggest that the rest time of five minutes for a continuous exposure time of 30 minutes with low-level of vibration tools should be extended to 10 minutes of rest time.

Key words: TTS, Hand-transmitted vibration, Intermittent vibration, Vibration perception

Introduction

A great deal of research involving the subjective response to vibration of the hand and fingers has been conducted in the area of determination of thresholds. The applications suggested for threshold measurement include the measurement of temporary threshold shifts (TTS)[1] produced by vibration as an indication of the relative response to different vibration stimuli. TTS is defined as a different threshold value before and after disturbed vibration exposure, is often used as an indicator of the effect of vibration on the human body[2,3]. It would be a proper means of predicting the effects of intermittent vibration exposure by measuring the TTS values.

At the work place, workers using hand-held tools such as impact wrenches and breakers are exposed daily to the vibrations generated by these tools. Some research has been carried out on TTS of hand-transmitted vibration by the single exposure of sinusoidal vibrations[4-6]. However, workers do not use these tools throughout the entire day, but are exposed to vibration intermittently during the day. Therefore, the results of these single- exposure studies could not be applied intermittent vibrations in the work place because if the rest time between vibration exposures is short, recovery of the TTS of the first exposure will not yet be completed (residual TTS), and this residual effect increases the second TTS value. It is also predicted that many frequency components from the vibrations of hand-held tools produce larger TTS values than that of sinusoidal vibrations due to the critical band effect[7,8].

Interruptions in vibration exposure have a beneficial effect on health (1). In one of the clauses in the notification concerning the prevention of vibration disorders issued by the Labor Ministry of Japan[9], control items for operating time are specified as follows: 1) The work plan should be established so as to limit the work to two hours per day. 2) When work is being performed continuously, the work should

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be limited to ten minutes, and a rest of more than five minutes should be taken when chipping hammer, riveter or impact tools are being used. For other tools such as a grinder, one continuous work period should be limited to 30 min, and more than five minutes rest should be taken following 30 min of work. As described in the second section of the notification, we could not find any scientific results or evidence to support the description in the second section. In this time we attempted to obtain TTS following exposure to the intermittent vibrations of hand-held tools, in order to establish prediction equations of TTS for vibrations in the work place, and to apply these equations to the experimental simulation of actual field conditions. It was also examined whether notify the Labor Ministry is proper through comparison with the results of these equations.

Experiment

In work places in which hand-held tools are used, workers are normally intermittently exposed to vibrations from the tools. In the case of intermittent exposure to vibrations, rest breaks in intermittent exposure to vibration are effective in reducing exposure to vibrations.

Experimental apparatus and experimental methods

The present study used the experimental apparatus shown in Figure 1. Vibrations applied to human hands were generated by a vibration exciter with an amplifier through an electric signal oscillator and a one-octave band filter. An oscillator with a filter can generate random signals. Vibration acceleration levels were measured using a vibration meter through the vibration acceleration transducer setting on the model handle of the vibration exciter. Gripping force was also measured using a static pressure meter to maintain constant pressure as a monitor during the experiment. Vibration perceptional thresholds were measured using a vibrotactile measurement system (RION type AU-02A). The experimental conditions are shown in Table 1.

Stimuli

Primarily, the vibrations of two types of hand-held tools (tools A and B) were used as stimuli to examine TTS when human subjects were intermittently exposed to vibrations with different exposure times, rest times and vibration acceleration levels, as shown in Figure 2 and Table 1. Eight kinds of vibrations and were used, and they were applied to subjects in a random sequence, is shown in Figure 2. The total exposure time was six minutes.

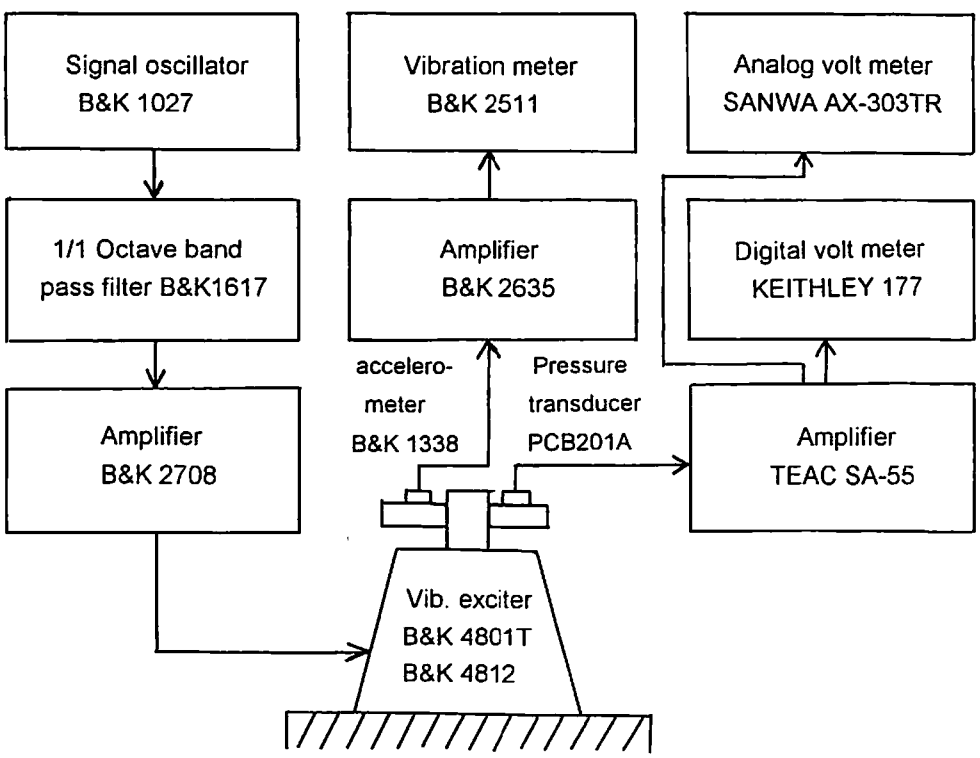

Fig. 1. Experimental apparatus

Prior to the present experiment, a preliminary experiment[10] was conducted using sinusoidal intermittent vibrations with a constant acceleration level, exposure time, and rest time. The TTS was observed under the condition of five repetitive vibrations. The exposed vibration frequency was 31.5 Hz at 120 dB, and the test frequency was 63 Hz for the preliminary experiment. The seven subjects were all healthy male students between the age of 19 and 25 years.

Subjects

Four subjects participated in the present study. Their mean age was 22.5 years. All subjects were healthy male University students with no history of neuromuscular or vascular disorders. None of the subjects had any occupational experience operating hand-held tools nor had ever suffered any injuries to the upper extremities.

Table 1. Experimental conditions

Exposure time	1, 2 min
Exposure vibration	Electric grinder A, Electric grinder B
Repetitive times	4 times
Test frequency	125 Hz
Vibration acceleration. Level*	97, 108 dB
Gripping force	0.5 Kg
Room temperature	25°C

*($dB=20 \log_{10} a/a_0$; $a_0=10^{-5} m/s^2$)

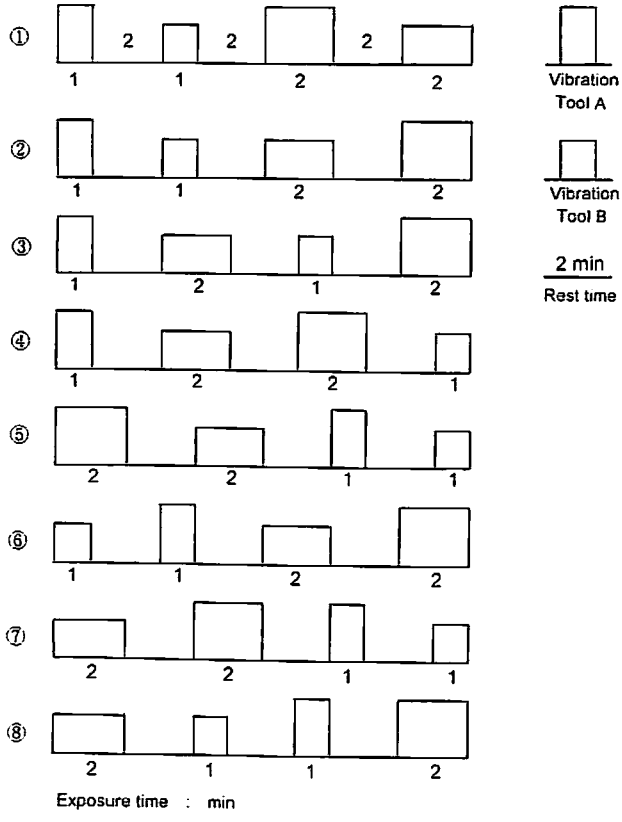

Fig. 2. Pattern of hand-transmitted intermittent vibration exposure

Procedure

In order to study the TTS in fingertip vibratory sensation, the vibratory sensation threshold was measured just before and after exposure to hand-transmitted intermittent vibration. The measurement time itself was less than 30 sec. The experiment was carried out in a soundproof room. The room temperature was maintained at approximately 25°C. Vibration was applied to the right hand through a handle. The subjects were instructed to clasp the handle tightly and constantly with the palm in a relaxed posture. The static pressure of the gripping force was to maintain 0.5 Kg by watching the monitor of the pressure meter. The threshold of 125 Hz vibratory sensation was measured at the tip of the right index finger. Vibration thresholds were determined through the use of the vibrotactile sensation meter. Vibrotactile thresholds were determined according to the adjustment method. In this method, the measurement was performed three times. Thresholds were calculated based on the mean values of three measurements. The TTS was defined as the difference (in decibels) between the vibrotactile thresholds determined before and after vibration exposure. The noise level during the vibration experiment was 55 dB(A).

Estimation Equations of TTS for Growth and Recovery

It is necessary to establish an estimation equation to calculate TTS for random exposure and rest time of intermittent vibrations in the working field. Previous experiments[11] calculated equations to estimate the growth and recovery of TTS at 125 Hz of the test frequency, as follows:

$$\text{for the growth of TTS, } TTS = -11.76 - 8.59 \log_{10} T + 0.16\,V + 0.2\,V \log_{10} T \quad (1)$$

where T is the exposure time (in min) and V is the vibration acceleration level (in dB).

$$\text{For the recovery of TTS, } TTSi = TTS\,(1 - 0.7836 \log_{10} (i/0.5)) \quad (2)$$

where TTSi is the TTS at after i time (in min) and TTS is growth of the TTS.

Exposure equivalent rule

To predict TTS following the exposure to intermittent vibrations, the exposure equivalent rule established by the authors was used. It is a rule that a residual TTS (dB) converts into exposure time (min). After the first t_1 minutes of vibration exposure, the TTS_1 will be A dB according to equation (1), and at the end of the t_2 (rest time), residual TTS_2 will be B dB from equation (2), although there is little recovery, as shown in Figure 3. This residual TTS_2 (B dB) could be converted into exposure time t_i using equation (1). This t_i is an equivalent exposure time. Then, TTS_3 after the next t_3 minutes of vibration exposure when be C dB using exposure time T ($T=t_i + t_3$) and equation (1) are used.

Algorithm of estimation TTS for intermittent vibrations

After the first vibration exposure to intermittent vibrations, TTS_1 (A dB) of the first exposure time t_1 could be calculated using equation (1) and after t_2 minutes, TTS_2 (B dB) could be calculated using the equation (2), and if TTS_2 becomes 0, TTS_3 of the second exposure can be obtained using equation (1). In addition, if TTS_2 is not 0, TTS_2 could be converted into the equivalent exposure time (t_i) using the exposure equivalent rule and equation (1). Following the second vibration exposure, TTS_3 will be calculated using exposure time T ($t_3 + t_i$) and equation (1). These procedures will then be continued until the vibration exposure of the intermittent vibrations is complete.

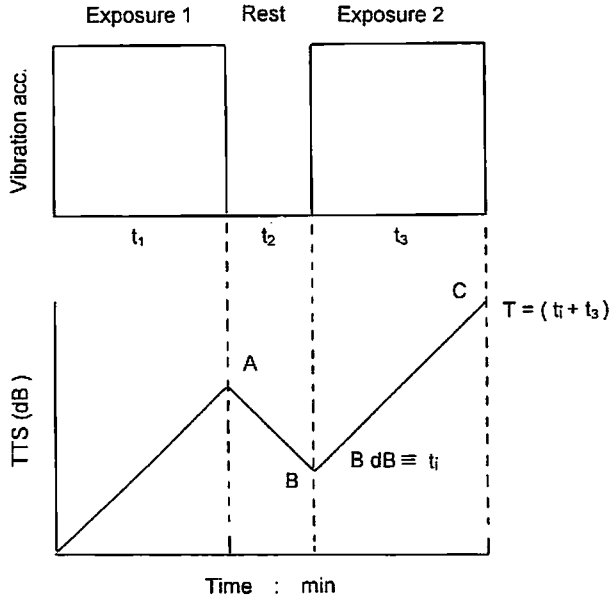

Fig. 3. The form of the exposure equivalent rule

Results and Discussion

Preliminary experiment

Figures 4-a, b show the results of the preliminary experiment. It was found that repeated exposure made a growth of TTS and an increment of residual TTS gradually from the first exposure to the fifth exposure with repetitive times, under the conditions of five minutes for the exposure time and one minute for rest time. An extended period was required for the TTS to recover under these experimental conditions. It resulted in an increase in TTS growth and residual TTS along with the vibration acceleration level. These results clarify that intermittent vibrations accumulate physiological effects in terms of TTS in the human body in the case of a longer exposure time compared to a rest time for the vibrations, as shown in Figure 4-a.

To recover the TTS, five minutes was adopted as one of rest times for the intermittent vibrations. The results show that an extended rest time reduced the of residual TTS from approximately 15 dB to 2 dB and TTS value reached to saturate promptly. This five-minute increase in the rest time,

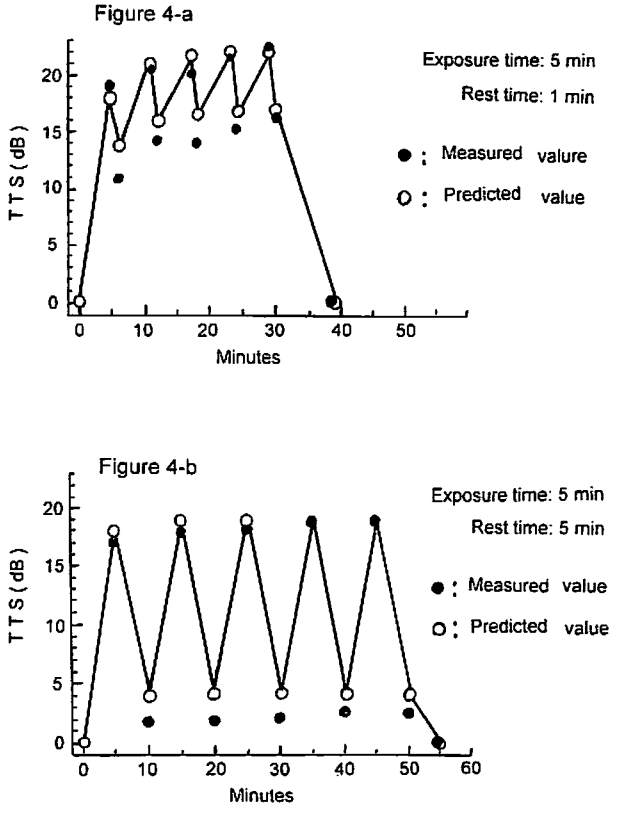

Fig. 4. Results of preliminary experiment using sinusoid and predicted values

however, did not result in the TTS recovering completely to reach a measured value of zero dB, shown in Figure 4-b.

The estimated TTS values were plotted in Figure 4. It was found that the estimated values of growth TTS were in good agreement with the measured values, although the test frequency differed between the preliminary experiment (63 Hz) and the present experiment (125 Hz). This prediction, however, overestimated the estimated residual TTS compared with the measured values in the cases in which the rest time was one minute and five minutes. This overestimation may due to the use of sinusoidal vibrations and a difference in test frequency.

Present experiment

Figures 5-a–d show four results among eight experimental results as examples, as the tendencies of the results are very similar. As shown in Figure 4, we could obtain an increase in growth TTS and residual TTS values under conditions of an extended exposure time, high magnitude of acceleration level, and the short rest time in this experiment. There was a remarkable agreement between the estimated TTS values and the measured values in each result shown in Figure 5. From these results, it is clear that the TTS following exposure to intermittent vibrations in the work place could be predicted according to the exposure equivalent rule, the growth equation, and the equation for the recovery process of TTS.

We attempted to apply this procedure for estimation TTS in the present study to notification of the Labor Ministry in Japan, which recommended a rest time of more than five minutes for a continuous exposure time of 10 min with large vibration, from tools, and of 30 min with small vibrations from tools. Factors in the estimation of TTS the exposure times of 10 min and 30 min, the rest time of 5 min, a vibration acceleration level of 110 dB, and the total net exposure time of 120 min. The results are shown in Figures 6-a, b. Repetitive exposure contributed to increase TTS only in the first and second exposures among the five time exposures, and to maintain a constant TTS thereafter. There was still residual TTS in with a rest time of five minutes. This indicates that five minutes is insufficient for the TTS to recover at the exposure time described in the notification above.

Then next trial was conducted to estimate sufficient rest time the TTS to recover completely at an exposure time of the 10 min and 30 min according to the exposure equivalent

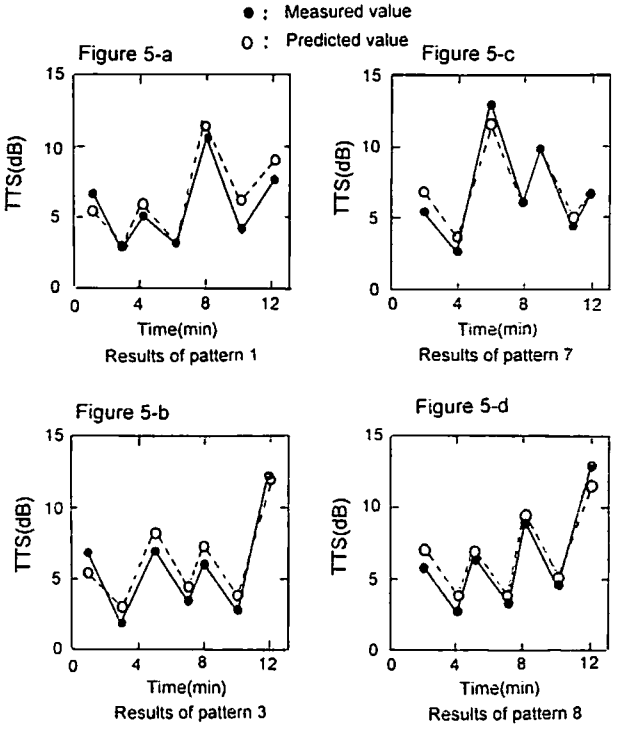

Fig. 5. Results of present experiment using vibration of hand-held tools and predicted Values

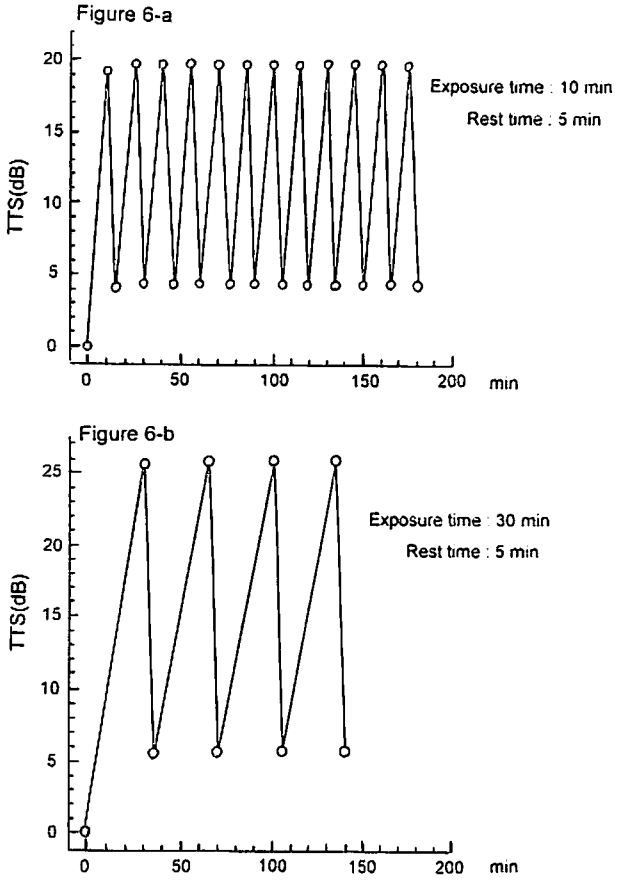

Fig. 6. Prediction TTS values for short rest time

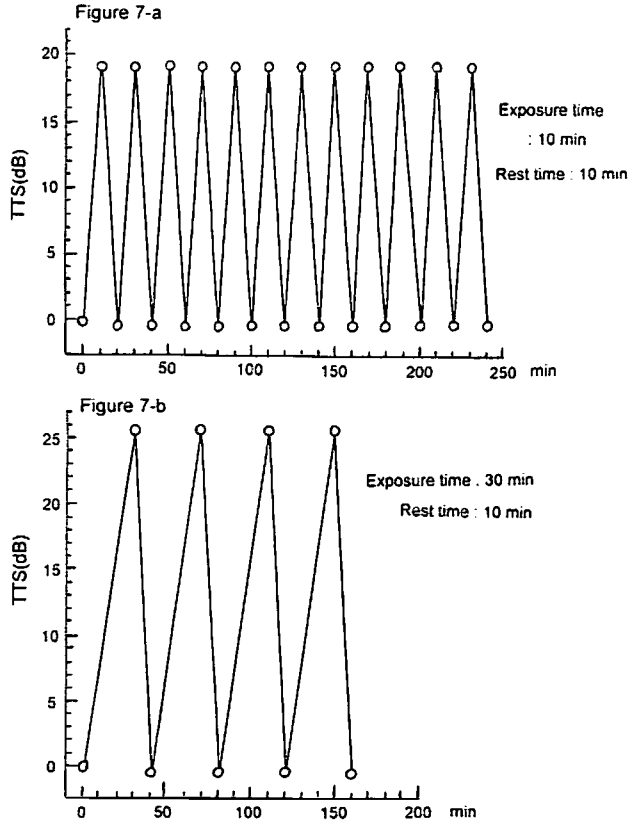

Fig. 7. Prediction TTS values for long rest time

rule and the equations. The results were plotted in Figures 7-a, b. These results suggest to the notification of the Labor Ministry that it is better to change the rest time of five minutes to 10 min for exposure times of both 10 min and 30 min in the continuous operation of hand-held tools.

In the case of continuous exposure of 30 min, it is noticeable that TTS values at 30 min are larger by approximately 6 dB than those at 10 min. From these results, it may be undesirable to maintain vibration exposure of 30 min in one continuous exposure.

Conclusion

1) The estimation procedure for predicting TTS following exposure to intermittent vibrations in the work place has been developed according to the exposure equivalent rule and the equations for both growth and recovery TTS.

2) It was found that this prediction TTS value was in good agreement with the measured value even in cases in which random intermittent vibrations from hand-held tools were used as stimuli, as in the workplace.

3) It was suggested that it is preferable to change the rest time of five minutes to 10 min for exposure times of 10 min and 30 min in the notification to the Labor Ministry in Japan.

4) It may be undesirable to maintain vibration exposure for 30 min in one continuous exposure.

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