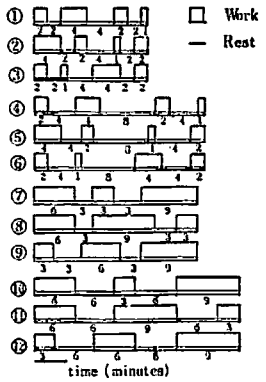

Fig. 3 Patterns of intermittent vibration exposure used in Experiment 1.

3.1.2 Subjects

The subjects were used in this experiment. The mean and standard deviation (SD) of their ages was 21.5 (SD 1.04) years. All subjects were healthy male students at Kinki University, having no history of neuromuscular or vascular disorders.

3.1.3 Procedure

In order to study the TTS in fingertip vibratory sensation, the vibratory sensation threshold was measured before and after subjects were exposed to hand-transmitted vibration. The experiment was carried out in a sound-proof room. Room temperature was held at about 25 ℃. Vibration was applied to the left hand through a handle attached to an electrodynamic vibrator (B&K type 4801T, B&K type 4812). Each subject was seated with his left forearm laid on a horizontal arm stand and clasped the vibrating handle. The vibrating handle diameter was 0.03 m. The push and pull forces were controlled at zero. The subjects were instructed to clasp the handle tightly and constantly with the fleshy part of the palm with the required grip force in a relaxed posture. The grip force was 0.5 kg. Each subjects watched a meter to maintain his grip force to 0.5 kg. In order to prevent the subject's hand from being too cool, the temperature of the handle was thermostatically controlled at 30℃. The test sequences of Fig. 3 were presented in a random order.

The threshold of 125 Hz vibratory sensation was measured at the tip of the left hand. Vibration thresholds were determined with the vibrotactile sensation meter (RION type AU-02A). Vibrotactile thresholds were determined by the method of adjustment. In this method, the measurement was performed three times. Thresholds were calculated by the mean values of three measurements. The TTS was defined as the difference (in decibels) of the vibrotactile thresholds before and after vibration exposure. Consecutive sessions were separated by at least 12 hours. The noise level during the vibration experiment was 55 dB(A). During the measurement of the vibratory sensation thresholds, before and after the vibration exposure, the noise level was 35 dB(A).

3.1.4 Results

Table 4 shows the results of Experiment 1. Even though the total frequency-weighted energy was the same value, the TTS after exposure to vibration depended on the rest time. The TTS decreased with increasing rest time.

Table 4 Measured TTS (dB) in Experiment 1 (measured value mean±SD).

Exposure patterns	Measured value (dB)
1	8.37±0.78
2	9.72±1.29
3	14.62±1.27
7	17.21±1.92
8	12.29±2.67
9	16.93±2.19
4	7.60±2.55
5	9.55±0.91
6	8.69±1.28
10	16.97±2.88
11	10.84±1.45
12	13.69±0.51

3.2 Experiment 2 (Maeda & Kume, 1986)[10]

3.2.1 Stimuli

Twenty five kinds of intermittent vibration similar to line work were used as stimuli as shown in Fig. 4. The duty cycle was 4, 16, 60, 120 and 240 seconds. In this experiment, the 'on fraction' was defined by the following equation:

$$\text{on fraction } R=T/(T+t)=T/D$$

where, D is the duty cycle, and T is the on time (vibration exposure duration) within the duty cycle. The fraction was 0.2, 0.4, 0.5, 0.6, and 0.8. The total exposure time of the stimuli was 30 minutes. The vibration was again an octave band of random vibration with a centre frequency of 125 Hz. Other experimental conditions are shown in Table 5.

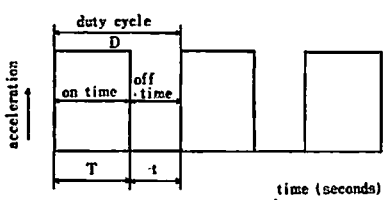

Fig. 4 Patterns of iutermittent vibration exposure of short duration used in Experiment 2.

Table 5 Experimental conditions of Experiment 2.

On fraction actual exposure time (minutes)	0.2 6	0.4 12	0.5 15	0.6 18	0.8 24
$a_{hw(eq,8h)}$	0.250	0.354	0.396	0.434	0.501
$a_{hw(eq,4h)}$	0.354	0.501	0.560	0.613	0.708
Duty cycle (seconds)	4, 16, 60, 120, 240				
Grip force	0.5 kg				
Room temperature	25℃				
Subjects	4 (21 to 24 years old)				
vibrations handle temperature	30℃				

3.2.2 Subjects

The subjects were the same in Experiment 1.

3.2.3 Procedure

The experimental apparatus and the vibrotactile measurement method were the same as in Experiment 1. The vibrotactile threshold measurement was performed before and after vibration exposure to each individual stimuli shown in Table 5. Consecutive sessions were separated by at least 12 hours.

3.2.4 Results

Table 6 shows the results of Experiment 2. When the total frequency-weighted energy was the same value, the TTS after exposure to vibration had the same value.

Table 6 Measured TTS (dB) in Experiment 2

	on fraction				
Duty cycle	0.2	0.4	0.5	0.6	0.8
4	8.23±1.57	9.79±0.41	10.03±0.02	12.36±1.26	15.58±2.57
16	6.96±0.58	9.54±0.44	9.55±1.84	11.50±1.27	15.95±0.87
60	5.42±1.28	8.59±2.18	9.16±1.65	11.50±1.28	14.29±5.15
120	7.60±0.84	9.01±0.92	11.22±0.48	13.12±0.50	14.29±0.80
240	8.69±0.38	9.18±0.88	9.44±0.93	10.95±1.43	14.01±0.92
$a_{hw(eq,8h)}$	0.250	0.354	0.396	0.434	0.501
$a_{hw(eq,4h)}$	0.354	0.501	0.560	0.613	0.708

3.3 Experiment 3 (Maeda, 1991)[9]

3.3.1 Stimuli

Four kinds of repeated shock vibration such as occurring during percussive metal work were used as stimuli (see Fig. 5). The four vibration stimuli were formed from cycles of 100 Hz sine waves. The repetition rate of the cycles varied from 5 s^{-1} to 100 s^{-1} while the r.m.s. acceleration measured over a 5 minute exposure was held constant. The frequency-weighted r.m.s. acceleration value was $a_{hw(eq,8h)}=0.286\ ms^{-2}$ r.m.s. (or $a_{hw(eq,4h)}=0.404\ ms^{-2}$r.m.s.).

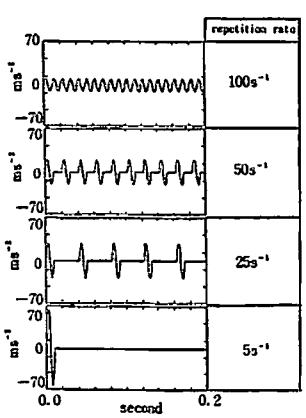

Fig. 5 Patterns of repeated shock vibration exposure used in Experiment 3.

3.3.2 Subjects

Four subjects aged 22 to 39 participated in the study. The mean and standard deviation

(SD) of their ages were 29.3 (SD 6.5) years. All subjects were healthy male research workers at the University of Southampton, having no history of neuromuscular or vascular disorders. The mean and standard deviation (SD) of body height were 174.3 (SD 6.2) cm and body weight 70.3 (SD 2.7) kg.

3.3.3 Procedure

The instruction sheet shown in Appendix A was presented to each subject before the experiment began.

In order to study the TTS in fingertip vibratory sensation, the vibratory sensation thresholds were measured before and after the subjects were exposed to hand-transmitted vibration. The experiment was carried out in a sound-proof and thermo-regulated room. Room temperature was held at about 20 to 24℃. Vibration was applied to the left hand through a handle attached to an electrodynamic vibrator (VP4, Derritron, Hastings, England) for five minutes. Each subject was seated with his left forearm laid on a horizontal arm stand and clasped the vibrating handle. The push and pull forces were controlled at zero.

The subjects were instructed to clasp the handle tightly and constantly with the fleshy part of the palm with the required grip force in a relaxed posture. The grip force was 10% of the maximum grip force of each subject. The grip force and pushing-pulling force were monitored by calibrated strain gauge bridges attached to the handle. The subject watched a meter to maintain his grip force at the appointed level. The handle temperature was controlled with a control master (RTL621, Raytel). In order to prevent the subject's hand from being too cool, the temperature of the handle was thermostatically controlled at 30℃ and the acceleration of the applied vibration was maintained at 2.8 ms^{-2} r.m.s.. The test sequences were presented in a random order.

The threshold of 125 Hz vibratory sensation was measured at the tip of the index finger of the left hand. The vibrotactile apparatus consisted of a counter-balanced vibrator carrying a 6 mm diameter perspex-tipped circular contactor, extending up through a 10 mm diameter solid perspex surround. This contactor touched the finger with a force of 1 Newton. The von Bekesy method was employed: the subject depressed a hand-held response button when he could feel the vibration. The rate of stimulus change was rapid over the first change of response to ensure that the threshold would be quickly reached even if it lay some distance from the initial level. Thresholds were calculated by a microcomputer from the mean of six successive decisions of the subject. This procedure took about 60 to 120 seconds for each threshold determination. Consecutive sessions were separated by at least 12 hours. The sequence of events in each session is shown in Appendix B. The noise level during the vibration experiment was 50 to 59 dB(A). During the measurement of the vibratory sensation thresholds, before and after vibration exposure, the noise level was 30 to 32 dB(A).

3.3.4 Results

Table 7 shows the results of Experiment 3. Even though the total frequency-weighted energy had the same value, the TTS after exposure to vibration depended on the shock repetition rate. The TTS decreased with decreasing shock repetition rate from 100 s^{-1} to 5 s^{-1}. Compared with the control condition in which the handle was clasped without exposure to vibration, the vibration at each repetition rate induced a significant ($p<0.05$) increase in TTS

except at 5 shocks per second, according to the test of the difference between means for independent groups. Fig. 6 and Table 8 show the results and the analysis of variance. The

Table 7 Measured TTS (dB) in Experiment 3 immediately following vibration exposure.

Repetition rate	Subject 1	Subject 2	Subject 3	Subject 4
100 s^{-1}	14.36	17.55	8.29	9.02
50	7.48	14.93	7.52	9.00
25	3.61	7.76	5.34	8.59
5	1.32	3.76	1.04	1.51
Control	1.33	2.19	2.35	2.00

repetition effect was statistically significant ($p<0.05$) and the subject effect was also statistically significant ($p<0.01$). This subject effect may be partially due to the difference in the maximum grip force of each subject which affected the grip used in this experiment.

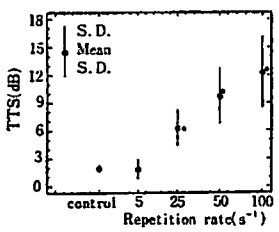

Fig. 6 The results of the test of the difference between means.
(*$p<0.05$ difference from control condition according to the test of the difference between means)

Table 8 Analysis of variance summary table for Experiment 3.

Factors	SS	df	MS	F
Subjects	242.84	3	80.947	14.96**
Repetition	67.668	3	22.556	4.17*
Error	48.714	9	5.4127	
Total	359.22	15		

(* $p<0.05$, ** $p<0.01$).

4. Discussion

In ISO 5349 and BS 6842, there is no special allowance for intermittent exposure: the same equivalent value is obtained for a particular total duration of vibration exposure irrespective of whether it is continuous or contains rest periods.

The results of Experiment 1 indicate that the frequency weighting and time weighting of the standards do not account for the effects of hand-transmitted intermittent vibration on TTS in vibration perception.

The results of Experiment 2 suggest that the energy-time dependency may be appropriate to predict the TTS after vibration exposure with various duty cycles.

The International Standard also states that it is provisionally applicable to "repeated shock type excitations". From the results of Experiment 3, the TTS after exposure to shock vibration is much less than after exposure to continuous vibration when the frequency weighted energy transmitted to the hand by the shock vibration and the continuous vibration were the same. The major difference between the stimuli may be related to the amount of recovery between successive shocks. The faster rate of repetition did not allow recovery before the ensuing shocks caused a greater amount of TTS.

In the case of the repeated shock vibration, and with vibration including the long rest times, the standard frequency weighting and time weighting did not account for the effects of hand-transmitted vibration on TTS.

5. Conclusion

In order to clarify the relation of the energy time-dependency and TTS (temporary threshold shift), this investigation has compared the effects of three types of vibration: intermittent vibration (such as occurs in chain saw work-Experiment 1); intermittent vibration (such as occurs in line work-Experiment 2); and repeated shock vibration (such as occurs in percussive metal-work-Experiment 3). The results showed the following:

1. TTS following intermittent vibration exposure (such as in chain saw work) is not predicted by the energy time-dependency given in ISO 5349 and BS 6842;

2. TTS following intermettent vibration exposure (such as in line work) may be predicted by the methods in ISO 5349 and BS 6842;

3. TTS following repeated shock vibration exposure (such as in percussive metal-work) cannot be predicted by the methods in ISO 5349 and BS 6842;

4. the equal energy hypothesis underlying BS 6842 and ISO 5349 is an inappropriate basis for predicting TTS produced by intermittent vibration having a long rest time, or the TTS produced by repeated shock vibration.

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APPENDIX A

Subject Instructions

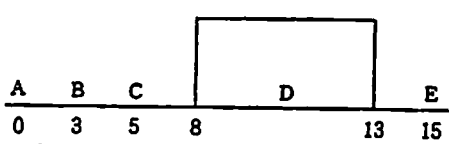
The following are instructions that were given to the subjects taking part in the experiment on the exposure to continuous and shock vibration to the hand.

Instructions to subjects

The aim of this experiment is to clarify the relation between the effects of hand-transmitted continuous and shock vibration on tempoary threshold shifts of fingertip vibratory sensation.
Before the vibration exposure, the vibratory sensation threshold and the maximum grip force of your hand will be measured.
You will be seated with your left forearm laid on a horizontal armstand and clasping the vibrating handle.
Vibration will be applied to the left hand through a handle attached to an electro-dynamic vibrator for five minutes. The handle will vibrate at a frequency-weighted r.m.s. accelviberation of 2.8 ms^2 r.m.s.
Your task is to clasp the vibrating handle with 10% of your maximum grip force during ration exposure.
After five minutes vibraton exposure, the vibratory sensation threshold of your fingertip will be measured.
You may stop the experiment at any time by pressing the STOP button.
Thank you for taking part in this experiment

APPENDIX B

An Experimental Session Table



Experimental Time Table

A : Instruction sheet presented to subjects before the start of the experiment.
B : Maximum grip force measurement. (only first session).
C : Fingertip vibratory sensation threshold measurement.
D : Vibration exposure with 10% maximum grip force.
E : After vibration exposure, immediately, fingertip vibratory sensation threshold measurement.