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Energy time-dependency and temporary threshold shifts in vibration perception produced by hand-transmitted vibration※

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In order to investigate the energy time-dependency and the TTS (temporary threshold shift) in vibration perception induced by vibration exposure, three experiments have been conducted. In experiment 1, the vibration was intermittent such as arising from chain saw work. In experiment 2, the intermittent vibration such as arising from line work was used. In experiment 3, repeated shock vibration similar to percussive metal-work was used. Subjects were exposed to vertical hand-transmitted vibration in each experiment. The hypothesis to be tested was that the energy time-dependency according to ISO 5349 and BS 6842 was appropriate to the prediction of TTS produced by the various vibration exposure patterns. It was found the TTS following intermittent vibration exposure such as in chain saw work could not be predicted using the method of vibration assessment in ISO 5349 and BS 6842. The TTS following intermittent vibration exposure (such as from line work) could be predicted with methods in the standards. The TTS following exposure to repeated shock vibration (such as in percussive metal-work) could not be predicted with the energy time-dependency given in the standards.

Key words: TTS, temporary threshold shifts, hand-transmitted vibration, vibration, energy time-dependency, vibration perception

1. Introduction

International Standard 5349 (1986)[1] and British Standard 6842 (1987)[2] are primarily con-

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cerned with protecting workers from incurring vibration-induced white finger (VWF) or hand-arm vibration syndrome. The frequency-weighted acceleration that is used in the present standards is intended for assessing hand-transmitted vibration exposure in terms of the number of years before finger blanching indicates vascular disorders.

Both ISO 5349 and BS 6842 provide information on how the vibration magnitude associated with 10% prevalence of vascular symptoms may depend on daily and lifetime vibration exposure periods. The assessment of hand-transmitted vibration is based on daily exposure expressed as 8 h or 4 h 'energy equivalent' frequency weighted root-mean-square acceleration. This procedure defines a time-dependency in which the vibration magnitude may be doubled if the exposure time is reduced by a factor of four. The guidance on the relation between vibration magnitude and exposure duration might be used to decide on the maximum daily exposure, but current vibration measurement standards do not specify a method of obtaining an annual of life-time vibration does or the influence of any long-term intermittency in vibration exposures. From a consideration of the approximate relation between vibration magnitude and the average duration of exposure before vibration-induced white finger symptoms develop, it has been suggested that the severity of vibration may be assumed to increase in linear proportion to the equivalent daily weighted vibration magnitude. Therefore, if the equivalent daily weighted vibration magnitude is unchanged, even though the vibration exposure pattern of daily work is varied, the severity of vibration at the end of a working day has a same value. This time-dependency is convenient because it enables exposures to be quantified using root-mean-square averaging, but its adoption has not been based on the results of experimental research or epidemiological studies.

Radzyukevich (1969)[3] suggested that the temporary threshold shifts (TTS) in vibration sensation thresholds at the end of a working day were correlated with the permanent threshold shifts (PTS) which develop over a longer period. Malinskaya (1964)[4] found that the mean TTS of workers after a day of work that included vibration exposure, corresponded to the PTS of vibratory sensation that occurred in that group after 10 years of exposure. This suggests that the TTS after daily vibration exposure might be used to indicate PTS after prolonged vibration exposure.

The study of TTS prediction after exposure to vibration has been investigated by various researchers[5)-14)] (e.g. Harada, 1978a, 1978b; Nishiyama and Watanabe, 1981; Hayward, 1984; Maeda, 1991; Maeda and Kume, 1986, 1987, 1989, 1991; Harada and Griffin, 1991), and results have been obtained for effects of many parameters, such as the frequency of sinusoidal vibration, amplitude of continuous vibration, exposure time, shock vibration, and grip force. But the time-dependency involved in the production of TTS after exposure to various vibration patterns is not well understood.

In order to clarify the role of the energy time-dependency in TTS, this investigation was undertaken to compare the results of three experiments which had already been completed. The operating hypothesis was that the energy time-dependency according to ISO 5349 and BS 6842 is appropriate to the prediction of TTS produced by the various vibration exposure patterns.

2. Energy Time-Dependency According to ISO 5349 and BS 6842

2.1 British Standard 6842 (1987) : Measurement and evaluation of human exposure to vibration transmitted to the hand

BS 6842 (British Standards Institution, 1987) provides guidance on factors which influence the severity of hand-transmitted vibration and describes how the severity of vibration exposures should be quantified. An annex provides information on how the vibration magnitude associated with 10% prevalence of vascular symptoms may depend on daily and lifetime exposure periods. A separate annex suggests some preventative procedures. This standard was compiled by persons perticipating in the evolution of International Standard 5349. Although BS 6842 is compatible with ISO 5349 there are some differences.

The British Standard emphasizes that many factors may influence vibration severity and offers some detailed practical guidance on measurement methods (from the selection and mounting of transducers to difficulties to be avoided when using recording equipment). A frequency weighting, W_h is given in a form compartible with the weightings in British Standard 6841[15] for whole-body vibration. This weighting illustrated in Fig. 1.[16] The asymptotic acceleration weighting has slopes of 0 dB per octave below 16 Hz and 6 dB per octave above 16 Hz and is therefore compatible with the frequency-dependent limits in BS DD 43 (British Standards Institution, 1975).[17] However, the band-limiting filters are set at 6.3 and 1250 Hz so as to restrict the standard to the assessment of vibration in the frequency range 8 to 1000 Hz.

The assessment of hand-transmitted vibration is based on daily exposures expressed as 8 h 'energy-equivalent' frequency-weighted root-mean-square (r.m.s.) acceleration, $a_{hw(eq,8h)}$

$$a_{hw(eq,8h)}=\left[\frac{1}{T_{(8)}}\int_{t=0}^{t=T}[a_{hw}(t)]^2 dt\right]^{1/2}$$

where $T_{(8)}$ is 28800 s (i.e. 8 h), $a_{hw}(t)$ is the instantaneous value of the frequency-weighted acceleration (ms^{-2}) and T is the total duration of the working day.

If it is known that an exposure lasts for t seconds at a frequency-weighted acceleration magnitude of a_{hw} r.m.s., then the 8 h energy-equivalent acceleration is given by:

$$a_{hw(eq,8h)}=a_{hw}\left[\frac{t}{T_{(8)}}\right]^{1/2}$$

or

$$a_{hw(eq,8h)}=\left[\frac{1}{T_{(8)}}\sum_{i=1}^{i=n}(a_{hwi})^2\cdot t_i\right]^{1/2}$$

A similar expression may be used to calculate the 8 h energy-equivalent frequency-weighted value from unweighted third-octave band (or octave band) spectra. If k_n is the frequency weighting for the centre frequency of band n having an r.m.s. acceleration a_{hn} and lasting t seconds during the day

$$a_{hw(eq,8h)}=\left[\frac{1}{T_{(8)}}\sum_{i=1}^{i=n}(k_i\cdot a_{hi})^2\cdot t\right]^{1/2}$$

For normal tool usage it is suggested that vascular symptoms do not usually occur with frequency-weighted acceleration magnitudes below about 1 ms^{-2} r.m.s.. A tool with a frequen-

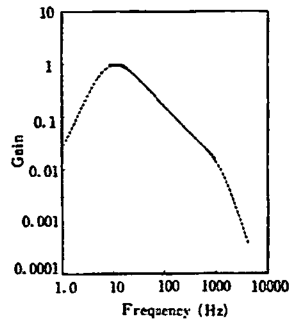

Fig. 1 Comparison of asymptotic and realisable frequency weighting, W_h for hand-transmitted vibration as defined in BS 6842 (from Griffin, 1990)[16].

cy-weighted acceleration of 4 ms^{-2} r.m.s. used regularly for 4 h day^{-1} may be expected to give blanching in about 10% of exposed persons after about 8 years of regular daily exposure. Using the above daily and yearly time-dependency, Table 1 shows the frequency-weighted vibration magnitudes which might be expected to give rise to a 10% prevalence of symptoms for other daily durations (from 15 min to 8 h) and other lifetime exposures (from 0.5 to 16 years). The annex indicates that various factors can influence the prevalence of symptoms in a vibration-exposed group; it does not define a procedure for calculating any prevalence of VWF other than 10%.

Table 1 Frequency-weighted acceleration magnitudes (ms^{-2} r.m.s.) which may be expected to produce finger blanching in 10% of exposed persons according to BS 6842 (British Standards Institution, 1987b).

Daily exposure (h)	Life-time exposure (years)					
	0.5	1	2	4	8[a]	16
0.25	256.0	128.0	64.0	32.0	16.0	8.0
0.5	179.2	89.6	44.8	22.4	11.2	5.6
1	128.0	64.0	32.0	16.0	8.0	4.0
2	89.6	44.8	22.4	11.2	5.6	2.8
4	64.0	32.0	16.0	8.0	4.0	2.0
8	44.8	22.4	11.2	5.6	2.8	1.4

[a] Values correspond to a proposed 'action level'.

2.2 International Standard 5349 (1986) : Mechanical vibration ——Guidlines for the measurement and the assessment of human exposure to hand-transmitted vibration

In ISO 5349 the total daily exposure to vibration is expressed in terms of the 'energy-equivalent' frequency-weighted acceleration for an arbitrary period. The method is illustrated using a 4 h energy-equivalent value, $a_{hw(eq,4h)}$

$$a_{hw(eq,4h)}=\left[\frac{1}{T_{(4)}}\int_{t=0}^{t=T}[a_{hw}(t)]^2dt\right]^{1/2}$$

where $T_{(4)}$ is 14400 s (i.e. 4 h), $a_{hw}(t)$ is the instantaneous value of the frequency-weighted acceleration (ms^{-2}) and T is the period of time during which vibration exposure may occur (i.e. the total duration of the working day). If the frequency-weighted r.m.s. acceleration can be assumed to be constant at a_{hw1} for a period of t_1 seconds, and constant at a_{hw2} for a period t_2 seconds, etc., then

$$a_{hw(eq,\,4h)}=\left[\frac{1}{T_{(4)}}[(a_{hw1})^2t_1+(a_{hw2})^2t_2+(a_{hw3})^2t_3+...]\right]^{1/2}$$

Therefore, for exposure to a single period of constant r.m.s. frequency-weighted acceleration a_{hw} for t seconds

$$a_{hw(eq,\,4h)}=a_{hw}\left[\frac{t}{T_{(4)}}\right]^{1/2}$$

where, again, $T_{(4)}$ is 14400 s (i.e. 4 h). This procedure defines a time-dependency in which the vibration magnitude may be doubled if the exposure time is reduced by a factor of four. In consequence, high magnitudes are required to obtain a significant 4 h energy-equivalent frequency-weighted acceleration magnitude if the duration is very short (see Table 2). There is no special allowance for intermittent exposures; the same equivalent value is obtained for a particular total duration of vibration exposure irrespective of whether it is continuous or contains rest periods.

Table 2 Magnitudes of hand-transmitted vibration (ms^{-2} r.m.s.) corresponding to an 'action level' given by a 2.8 ms^{-2} r.m.s. energy-equivalent 8-h exposure (i.e. $a_{hw(eq,8h)}=2.8$ ms^{-2} r.m.s.) (from Griffin, 1990).

Frequency (Hz)	Exposure duration										
	1 s	4 s	16 s	1 min	4 min	16 min	1 h	4 h	8 h	16 h	24 h
8	475	237	119	61	31	15	7.9	4.0	2.8	2.0	1.6
16	475	237	119	61	31	15	7.9	4.0	2.8	2.0	1.6
31.5	935	468	234	121	60	30	15.6	7.8	5.5	3.9	3.2
63	1871	936	468	242	121	60	31.2	15.6	11.0	7.8	6.4
125	3712	1856	928	480	240	120	61.9	30.9	21.9	15.5	12.6
250	7425	3712	1856	959	479	240	123.7	61.9	43.8	30.9	25.3
500	14849	7425	3712	1917	959	479	247.5	123.7	87.5	61.9	50.5
1000	29699	14849	7425	3834	1917	959	495.0	247.5	175.0	123.7	101.0

All types of vibration spectra are to be assessed using the overall frequency-weighted method of analysis. If octave or one-third octave band analysis is employed, the overall frequency-weighted value, a_{hw}, should be calculated from the square root of the sums of the squares (i.e. r.s.s.) of the accelerations, a_{hi}, in each band multiplied by the weighting, k_i, for the centre frequency of each band

$$a_{hw}=\left[\sum_{i=1}^{i=n}\left(k_i\cdot a_{hi}\right)^2\right]^{1/2}$$

The weighted value should be determined over the eight octave bands (i.e. $n=8$) from 8 to 1000 Hz or over the 24 one-third octave bands (i.e. $n=24$) from 6.3 to 1250 Hz. The 'straight-line' weighting defined in the standard is the same as that in BS 6842.

Annex A to ISO 5349 offers a dose-effect relationship between the 4 h energy-equivalent frequency-weighted acceleration, in the dominant axis of vibration, and the exposure period before the onset of vascular disorders (i.e. finger blanching). The proposed relation between these parameters is illustrated in a figure. For prevalence rates between 10 and 50% and frequency-weighted acceleration magnitudes from 2 to 50 ms^{-2} r.m.s., the exposure periods are also provided in a Table 3. It is stated that the dose-response relationship can be approximated by the relation

$$\text{percentage affected} = C \simeq \left[\frac{a_{hw(eq,4h)} \cdot E}{95}\right]^2 \cdot 100$$

where E is the exposure time (in years) before blanching occurs. Fig. 2 presents the values given by this expression and Table 3 compares these values with those tabulated in the standard.

The International Standard also states that it is provisionally applicable to "repeated shock type excitations".

Table 3 Number of years before blanching develops in various percentiles of a vibration-exposed population according to Annex A of ISO 5349 (International Organization for Standardization, 1986b) : the values in parentheses were calculated using the equation given in the text.

Weighted acceleration, $a_{(eq.4h)}$ (ms^{-2} r.m.s.)	Percentage of population affected by finger blanching				
	10	20	30	40	50
2	15 (15.0)	23 (21.2)	>25	>25	>25
5	6 (6.0)	9 (8.5)	11 (10.4)	12 (12.0)	13 (13.4)
10	3 (3.0)	4 (4.2)	5 (5.2)	6 (6.0)	7 (6.7)
20	1 (1.5)	2 (2.1)	2 (2.6)	3 (3.0)	3 (3.4)
50	<1 (0.6)	<1 (0.8)	<1 (1.0)	1 (1.2)	1 (1.3)

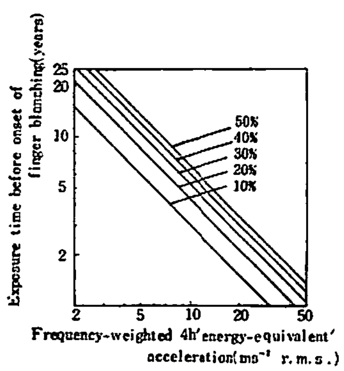

Fig. 2 Years of exposure to 4 hour energy-equivalent frequency-weighted hand-transmitted vibration required for the production of finger blanching in 10, 20, 30, 40 and 50% of exposed persons according to Annex A of ISO 5349 (from Griffin, 1990)[16].

3. Review of Three Experiments

3.1 Experiment 1 (Maeda & Kume, 1991)[13]

3.1.1 Stimuli

Twelve kinds of the intermittent vibration such as chain saw work were used as stimuli as shown in Fig. 3. The total exposure time of stimuli from one to six was 9 minutes (540 seconds), and the stimuli from seven to twelve was 18 minutes (1080 seconds). The vibration was random with an octave bandwidth centred on the frequency 125 Hz. The frequency-weighted r.m.s. acceleration was $a_{hw(eq,8h)}=0.307$ ms^{-2} r.m.s. (or $a_{hw(eq,4h)}=0.434$ ms^{-2} r.m.s.) when the exposure time was 9 minutes, and $a_{hw(eq,8h)}=0.434$ ms^{-2} r.m.s. (or $a_{hw(eq,4h)}=$ 0.613 ms^{-2} r.m.s.) when the exposure time was 18 minutes.

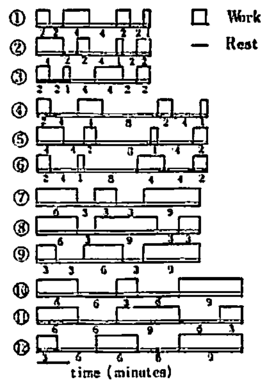

Fig. 3 Patterns of intermittent vibration exposure used in Experiment 1.

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.

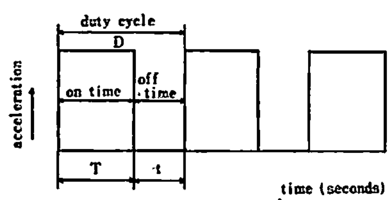

Fig. 4 Patterns of jutermittent vibration exposure of short duration used in Experiment 2.

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.).

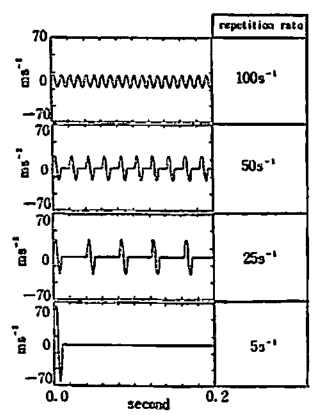

Fig. 5 Patterns of repeated shock vibration exposure used in Experiment 3.

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.

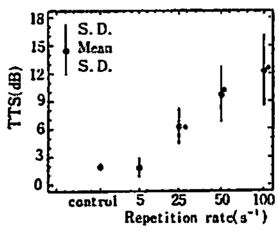

Fig. 6 The results of the test of the difference between means.
(*$p<0.05$ difference from control condition according to the test of the difference between means)

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

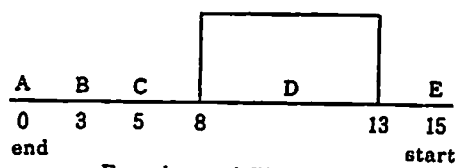
The following are instructions that were given to the subjects taking part in the experiment on the exposure to continuous and shock vibration to the hand.

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. accelvibration 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.