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TEMPORARY THRESHOLD SHIFTS IN FINGERTIP VIBRATORY SENSATION FROM HAND-TRANSMITTED VIBRATION AND REPETITIVE SHOCK

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ABSTRACT

Temporaty threshold shifts (TSSs) in vibrotactile perception produced by continuous vibration and repetitive shocks having one complete cycle of a 100 Hz sine wave and exponential decays. The repetition rate of the cycles was 5, 25, 50, or 100 /s, while the root-mean-square (r.m.s.) acceleration measured over exposure of five minutes was held constant (weighted according to British Standard (BS) 6842 and International Standard (ISO) 5349). When exposed to five shocks per second at each of the three frequency-weighted acceleration magnitudes, the subjects developed a small TTS. Exposure to 100 shocks per second (continuous vibration) at each of the three frequency-weighted acceleration magnitudes caused a large TTS, although the total frequency-weighted energy was the same as when exposed to five shocks per second. The results suggest that the equal energy hypothesis underlying BS 6842 and ISO 5349 is inappropriate for the prediction of the TTS produced by repetitive shocks.

Key Words: Temporary threshold shifts, TTS, Repetitive shock vibration, Shock repetition rate, Hand-transmitted vibration, Energy equivalent frequency-weighted acceleration

INTRODUCTION

The International Standard (ISO) 5349[1)] and the British Standard(BS) 6842[2)] are primarily concerned with protecting workers from incurring vibration-induced white finger (VWF) and other aspects of the so-called hand-arm vibration syndrome. These standards use measures of frequency-weighted acceleration to express the severity of hand-transmitted vibration exposure in terms of the predicted number of years before finger blanching indicates vascular disorders. Both standards provide information on how the vibration magnitude associated with 10% prevalence of vascular symptoms may depend on daily and lifetime periods of exposure to vibration. The assessment of hand-transmitted vibration is based on daily exposure to vibration expressed as eight hour of four hour "energy equivalent" frequency-weighted root-mean-square (r.m.s.) 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. This time dependency is convenient because it enables exposures to be quantified using r.m.s. averaging, but its adoption has not been based on the results of experimental research or epidemiological studies.

Radzyukevich[3)] suggested that the temporary threshold shifts (TTSs) in vibrotactile thresholds at the end of a working day were correlated with the permanent threshold shifts (PTSs), which develop over a longer period. Malinskaya et al.[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 the group after 10 years of exposure. These findings might suggest that the TTS

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after daily exposure may be used to indicate the PTS after prolonged exposure to vibration. It would therefore be desirable to be able to predict the TTS from measurements of the daily exposure to vibration. Such studies will be of interest in evaluating the risks of damage to neurological processes involved in vibrotactile sensation, but they may not be relevant to vascular changes.

The prediction of TTSs after exposure to continuous vibration has been investigated by various researchers.[5–12] Results have been obtained showing the effects of variables such as the frequency of sinusoidal vibration, the magnitude of continuous vibration, the exposure time, and the grip force. The relative importance of shocks and continuous vibration in the production of the various vibration injuries and vibrotactile TTSs is not well understood. The TTS after exposure to the repetitive shock characteristics of many vibrating tools cannot be predicted from the results of previous studies.

This investigation was undertaken to compare measurements of the short term effects of repetitive shock and continuous vibration on vibratory perception thresholds with the methods given in the current International and British standards for evaluating hand-transmitted vibration. The operating hypothesis was that exposure to continuous vibration and repetitive shocks would produce equal vibrotactile TTSs when the repeated shocks and the continuous vibration have equal frequency-weighted r.m.s. acceleration.

STIMULI

Many percussive metal working tools generate high magnitude shocks that recur at some rate, often between 5 and 100 /s.[13,14] To compare the effects of continuous vibration and shocks with equal frequency-weighted r.m.s. acceleration on the TTSs, two groups vibration stimuli were used in this experiment. In the first group, the four vibration stimuli were formed from cycles of 100 Hz sine waves. In the second group, the four vibration stimuli were formed from the following equation:

$$S(t) = \exp^{-t/r}\sin(6.28ft)$$

where r is the decay time-constant of the envelope and f is the frequency of a sinusoidal carrier signal. In this investigation, r was 0.016 and f was 100 Hz. The repetition rate of the cycles was 5, 25, 50, or 100 /s, while the r.m.s. acceleration measured over a 5 minutes exposure was held at 2.5, 5, 10, or 2.8 m/s^2 r.m.s. (weighting according to BS 6842 and ISO 5349). Fig. 1 shows examples of the desired acceleration time histories. The stimuli were generated using the HVLab computer system.[15]

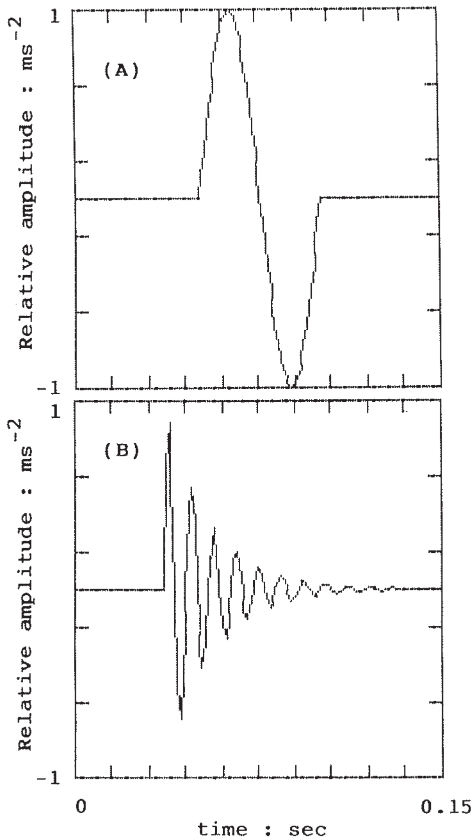

Fig. 1. Acceleration time histories achieved on handle of vibrator. (A) one complete cycle of a 100 Hz sine wave; (B) exponential decay waveform.

SUBJECTS

Four subjects aged 22 to 31 participated in the first group study. All were healthy male research workers at the University of Southampton with no history of neuromuscular of vascular disorders. None had suffered any serious injuries to the upper extremities, nor had any subject previous occupational experience operating powered hand tools.

Five subjects aged 21 to 22 years participated in the second group experiment. All were healthy male students at Kinki University with no history of neuromuscular or vascular disorders.

PROCEDURE OF FIRST GROUP

To study the TTSs 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 and thermoregulated room. Room temperature was held in the range 20 to 24°C.

Vibration was applied to the left hand through a handle attached to an electrodynamic vibrator (VP30, Derritron, Hastings, England) for five minutes. Each subject was seated with his left forearm laid on a horizontal arm stand and clasping the vibrating handle. The push and pull forces were controlled at zero. The subject was instructed to grip the handle tightly and constantly with the fleshy part of the palm using the required hand grip force in a relaxed posture. The grip force was 10% of the maximum hand grip force of each subject. 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. To prevent the subject's hand from being too cool, the temperature of the handle was thermostatically controlled at 30°C.

The vibrotactile threshold measurement system used in the present study has been described previously. 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 counterbalanced 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 contact force of 1 N. The push force (force applied on the contactor and surround by the subject's finger tip) was 1 N, and it was monitored by using a feedback system to the subject. The method of minimal change was employed, the subject depressing a hand-held response button when he could feel the vibration. The rate of stimulus change was rapid over the first change of response so as to ensure that the threshold would be quickly reached even if it lay some distance from the initial level. The threshold was calculated by a microcomputer from the mean of six successive decisions of the subject. This procedure took 60 to 120 seconds for each threshold determination. Consecutive sessions were separated by a least 12 hours. The noise level during the vibration exposure was 50 to 59 dB(A). During the measurement of the vibratory sensation thresholds (before and after the vibration exposure) the noise level was 30 to 32 dB(A).

The subjects took part in thirteen sessions. Twelve sessions involved exposure to one of three acceleration levels at one of four repetition rates. The acceleration of the applied vibration was maintained at 2.5, 5 or 10 m/s^2 r.m.s., and the repetition rate was either 100 /s (continuous sinusoidal vibration) or 50, 25, or 5 /s. One session involved no exposure to vibration. The test sequences were presented in random order.

PROCEDURE OF SECOND GROUP

The experiment was carried out in a sound proof room. Room temperature was held in the range 23 to 27°C. Vibration was applied to the right hand through a handle attached to an electrodynamic vibrator (Bruel and Kjaer type 4801T, 4812) for five minutes. Each subject was seated with his right forearm laid on a horizontal arm rest with the right hand clasping the vibrating handle. The subject was instructed to grip the handle tightly and constantly with the fleshy part of the palm using a hand grip force of 5 N in a relaxed posture. The grip force was monitored by a calibrated force gauge attached to the handle. The subject watched a meter to maintain his grip force at the appointed level.

The threshold of 125 Hz vibratory sensation was measured at the tip of the index finger of the right hand. Vibration thresholds were determined with 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 from the mean values of three measurements obtained within a period less than one minute after the end of the vibration exposure. 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 6 hours. The noise level during the vibration exposure was 55 dB(A). During the measurement of the vibration sensation thresholds before and after the vibration exposure, the noise level was 35 dB(A).

The subjects attended for five sessions. Four sessions involved exposure to one of four repetition rates of the shocks, and the remaining session was a control condition in which subjects clasped the handle but not exposure vibration. The order of presentation of stimuli in the five sessions was random.

RESULTS

Fig. 2 shows the threshold shifts in the first group. Although the frequency-weighted "energy" was equal for all 12 vibration stimuli, the TTS after exposure to vibration clearly depended on the shock repetition rate.

The TTS decreased for decreasing shock repetition rates from 100 /s to 5 /s for each of the three levels of frequency-weighted r.m.s. acceleration. Compared with the control condition in which subjects clasped the handle but were not exposed to vibration, the exposure to vibration induced a significant ($p<0.05$) increase in TTS according to the test of the difference between means for independent groups. The one exception was with the lowest shock repetition rate of 5 /s and the lowest acceleration magnitude of 2.5 m/s^2 r.m.s..

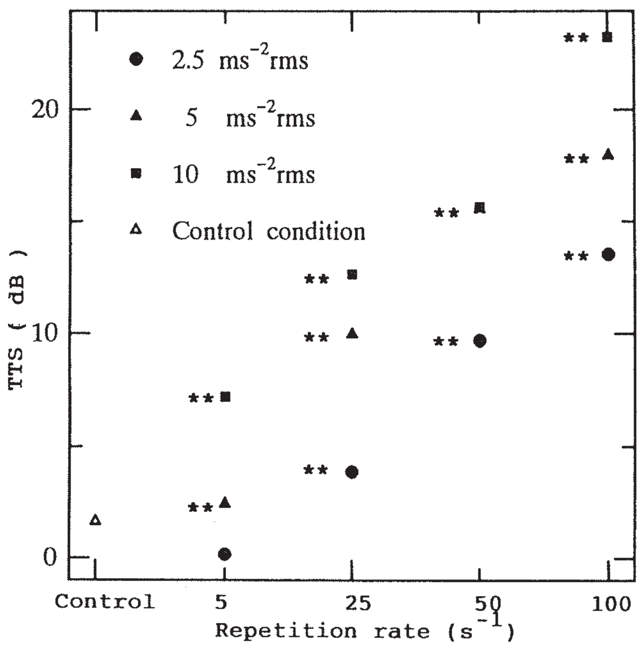

Fig. 2. Mean of TTS of one complete cycle of a 100 Hz sine wave. (**$p<0.01$: significant difference from control condition according to the test of difference between means).

Table 1 shows the results of multifactor analysis of variance.

The effect of the magnitude of the frequency-weighted r.m.s. acceleration was statistically significant ($p<0.01$). The effect of the repetition rate was also statistically significant ($p<0.01$). The subject effect was statistically significant ($p<0.05$), and may have been partially due to the difference in the maximum hand grip force of each subject. This affected the grip used in the experiment and may have altered the vibration transmitted to the hands of different subjects.

Table 1. Analysis of variance summary table for vibrotactile threshold data in the first group.

Main effects	Sums of squares	Degree of freedom	Mean square	F Ratio
A(acceleration)	668.33	2	334.17	66.07**
B(repetition)	1624.6	3	541.54	107.07**
C(subjects)	75.856	3	25.285	5.00*
A * B	29.265	6	4.8776	0.96
A * C	31.819	6	5.3032	1.05
B * C	54.761	9	6.0846	1.20
Errors	91.044	18	5.0580	
Total	257.7	47		

* p < 0.05; ** p < 0.01

Fig. 3 shows the mean threshold shifts measured in the five experimental conditions in the second group. Although the frequency-weighted "energy" was equal for all four vibration stimuli, the TTS after exposure to vibration depended on the shock repetition rate.

This trend was similar to that of the Fig. 2 of the first group experimental results. The TTS decreased with decreasing shock repetition rate from 100 /s to 5 /s. 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 according to the test for the difference between means for independent groups.

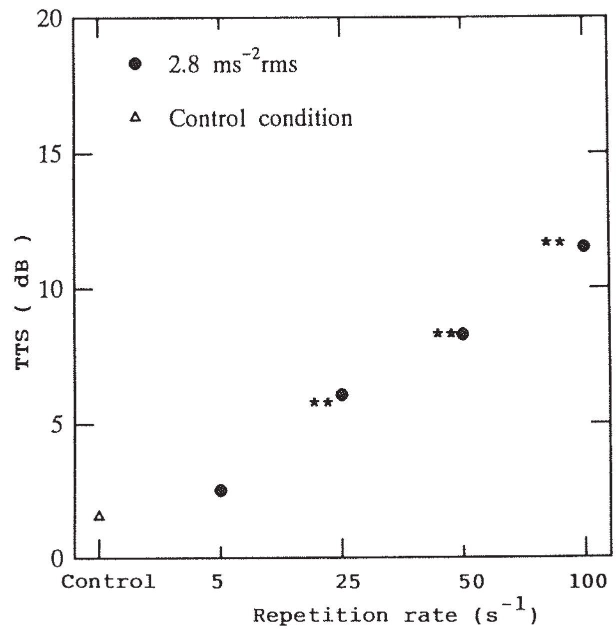

Fig. 3. Mean of TTS of exponential decay waveforms. (**$p<0.01$: significant difference from control condition according to the test of difference between means).

Table 2 shows the results and the analysis of variance.

The effect of the shock repetition rate was statistically significant ($p<0.05$), the subject effect was not significant.

Table 2. Analysis of variance summary table for vibrotactile threshold data in the second group.

Main effects	Sums of squares	Degree of freedom	Mean square	F Ratio
A(subjects)	6.2201	3	2.0734	0.66
B(repetition)	171.30	3	57.099	18.27**
Error	28.133	9	3.1258	
Total	205.65	15		

** $p < 0.01$

DISCUSSION

In Fig. 2 and Fig. 3, the TTS after exposure to shocks was seen to be much less than after exposure to continuous vibration, even though the frequency-weighted energy applied to the hand by shocks and the continuous vibration was the same. The principal difference between the stimuli may be the amount of recovery between successive shocks: perhaps the faster rate of repetition dose not allow recovery before the ensuing shocks cause a greater amount of TTS.

When the frequency-weighted vibration magnitude was constant according to British and International standards, the effects on vibratory sensation threshold should have remained constant if the weighting system was effective in preventing neurological impairment. The results indicate that the vibration frequency weighting and time weighting did not account for the effects of hand-transmitted shock on the TTS. The results of these experiments suggest that the equal energy hypothesis underlying both BS 6842 and ISO 5349 is an inappropriate basis for predicting the TTS produced by exposure to repetitive shock vibration.

The comparative importance of shocks and continuous vibration in the production of the various vibration injuries is not well understood, but there is some evidence that injury to the bones and joints is particularly associated with tools producing low frequency shocks.[13)] The TTS in vibrotactile sensitivity after exposure to shock vibration is also not well understood. From Fig. 2 and Fig. 3 of the present study, it was clear that the TTS decreased if the frequency-weighted r.m.s. acceleration was held constant when the repetition rate decreased.

The physiological mechanisms responsible for the present results are not clear. It would seem useful to conduct further research on the TTS after exposure to shock vibration with variable repetition rates, variable frequency-weighted r.m.s. acceleration, and variable vibration frequency.

Knowledge of the influence of many physical parameters, such as the spectral content, the duration, the wave form, the repetition rate, the exposure time, the vibration magnitude, the grip force, and the contact area, is required if safety criteria for hand-transmitted repetitive shock and vibration relevant to neurological disorders are to be properly established.

CONCLUSION

The study investigated the TTS produced by continuous vibration and repetitive shock having one complete cycle of a 100 Hz sine wave and the exponential decay waveforms. The conclusions are:

(1) when the vibration transmitted to the hand repetitive shocks and continuous vibration had equal frequency-weighted r.m.s. acceleration (weighted according to ISO 5349 and BS 6842), the TTSs after exposure were not of equal magnitude;

(2) the rate of repetition of shocks is a significant variable in determining the TTS;

(3) the 'equal energy' hypothesis underlying ISO 5349 and BS 6842 is an inappropriate basis for predicting the TTS produced by repetitive shocks;

(4) the growth of TTS after exposure to hand-transmitted repetitive shock having a constant frequency-weighted r.m.s. acceleration is proportional to the logarithm of the shock repetition rate;

(5) the TTS decrease when the frequency-weighted r.m.s. acceleration is held constant and the shock repetition rate is decreased.

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