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Relationship between vibration dose and the absorption of mechanical power in the hand

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Objectives The aim of this study was to examine the relationship between calculated vibration dose and the measured absorption of vibration power in the human hand, as well as the measured grip and feed forces applied by the subjects.

Methods The study was carried out with 10 healthy subjects. A special handle was used during the measurements. The influence of 4 different vibration levels with different durations during a test period of 5 minutes was investigated. The number of exposure intervals varied between 1 and 5. The same overall equivalent acceleration was used in all the experiments.

Results There is a significant difference between the calculated vibration dose and the amount of measured absorption of power. A higher acceleration level leads to significantly higher absorption. Furthermore, the outcome shows that rest periods contribute to a lower absorption of power in the hand and also lower feed forces.

Conclusions This study supports the hypothesis that vibration-free rest periods give the human organism an opportunity to recover.

Key terms assessment, hand force, hand-transmitted, hygiene, machine, tools.

The detrimental effects of vibrating handheld tools on humans have been known for a long time, and systematic studies started at the beginning of the 20th century. Today it is known that the vibration syndrome is an important occupational disease, which includes effects on the peripheral circulation, the peripheral nerves, or the musculoskeletal system (1). However, the vibration exposure required to cause the disorder is not known, either with respect to vibration intensity or with respect to daily exposure time and the total exposure period (1).

In most countries, risk prediction for hand-transmitted vibration is based on the model in annex A of international standard ISO 5349 (2). According to the standard, vibration measurements should be expressed in terms of the frequency-weighted acceleration, measured on the vibrating surface in contact with the hand, and the exposure time. An exposure-response relationship is presented in the annex to the standard. The assessment of vibration exposure is based primarily on daily exposure. In order to facilitate comparison between different durations of exposure, the daily exposure must be expressed in terms of the energy-equivalent frequency-weighted acceleration for a period of 4 hours, $a_{hw(eqv.4h)}$, according to the following formula:

$$a_{hw(eqv.4h)} = \sqrt{\frac{1}{4} \cdot \int_{t=0}^{t=T} (a_{hw}(t))^2 \, dt} \qquad \text{(formula 1).}$$

In the formula, t is the total duration of exposure in hours for the instantaneous frequency-weighted acceleration of $a_{hw}(t)$. The energy-equivalent acceleration for 4 hours can be obtained from measurements made during the whole workday or, more commonly, calculated from measurements made during appropriate representative shorter sample periods for the various conditions and times and their intermittence. The calculated energy-equivalent acceleration (ie, a second-power relationship) represents the amplitude of continuous acceleration during a corresponding exposure period. This calculation is convenient for instrumentation development, although there is a lack of scientific evidence for it (3).

The international literature contains discussions as to the relationship between exposure duration and the harmful effects of vibration on the user of vibrating handheld tools. According to several authors (see reference 3 for

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additional references) it would be better to divide the exposure into short exposures rather than to use one continuous exposure. The explanation is that shorter exposure duration offers the human organism the opportunity to recover during rests (1). This argumentation implies that one 8-hour exposure during a workday is more harmful than eight 1-hour exposures at the same acceleration spread over 8 different days. This statement of the usefulness of vibration-free periods has also been incorporated into several standards, including ISO 5349. However, no evidence for it has been presented in the scientific literature.

A possible method of measuring vibration dose could be to determine the quantity of the power transmitted to and absorbed by the user (4, 5). The quantity of power per unit of time (P) to which the hand and arm system are exposed can be expressed in terms of the transmitted force (F) and the velocity (v), namely, as $P = F \times v$ (Nm/s). Moreover, the total quantity of the power can be divided into 2 components – one real and one imaginary (6). The real component reflects the power-absorbing part of the system, due to the transformation into heat of friction within the tissues. The imaginary component reflects the power-storing part of the system, which does not consume any vibration power. The phase angle between the force and velocity signals therefore plays an important part in the power flow, and, if the angle is close to zero, most of the power transferred to the hand is absorbed by the system. On the other hand, if the angle is close to $\pi/2$, most of the power is stored in the form of kinetic and potential energy. The average transferred power could also be expressed in the frequency domain within the cross-spectrum (6). Since the cross-spectrum is complex, the coincident spectrum describes the power-absorbing part.

One of the theories concerning the mechanism by which vibration may cause injury or reduce comfort is the quantity of absorbed power (5). The quantity of absorbed power is not only influenced by vibration intensity, but also by several other factors, such as frequency, transmission direction, grip and feed forces, hand-arm postures, and individual factors (7, 8).

The purpose of the present investigation was to study the relationship between vibration dose, calculated according to ISO 5349, and the measured absorption of vibration power in the human hand. Moreover, the aim was also to study the relationship between calculated dose and the measured grip and feed forces applied by the subjects.

Subjects and methods

Subjects and studied variables

Ten healthy subjects [age 24—61 (mean 42.2) years, height 159—186 (mean 172.9) cm, weight 49—90 (mean 69.5) kg], 5 men and 5 women, with no previous work exposure to vibration, participated in the study. All the subjects gave their informed consent to participation in the study, and the project was approved by the Ethical Committee of Umeå University.

The subjects were exposed to vibration in 16 experiments (figure 1). Four different frequency-weighted acceleration levels of 3, 4.25, 6, and 9 m/s², in accordance with ISO 5349, were used. The amplitude and duration of the exposures were chosen so that the energy-equivalent acceleration was 3 m/s², for the whole exposure time of 5 minutes, calculated in accordance with formula 1. The number of exposures varied between 1 and 5, and the duration ranged between 6.5 and 300 seconds. The accuracy of the amplitude values was ±3%, and the corresponding accuracy for the length of the exposure duration was ±15 milliseconds. The order of exposure for and between subjects was determined through "counterbalancing" (9).

Apparatus

The technique used to determine the quantity of absorbed power in the hand-arm system was based on measurements of vibration force as close as possible to the surface of the hand, vibration velocity, and the phase between these parameters. The measurements were obtained by using a specially designed handle (8) mounted on an electrodynamic shaker, equipped with 2 force transducers and 1 accelerometer for force and velocity measurements, respectively. The handle was also equipped with strain gauges for measurements of both the grip and the feed force applied by the subject to the handle.

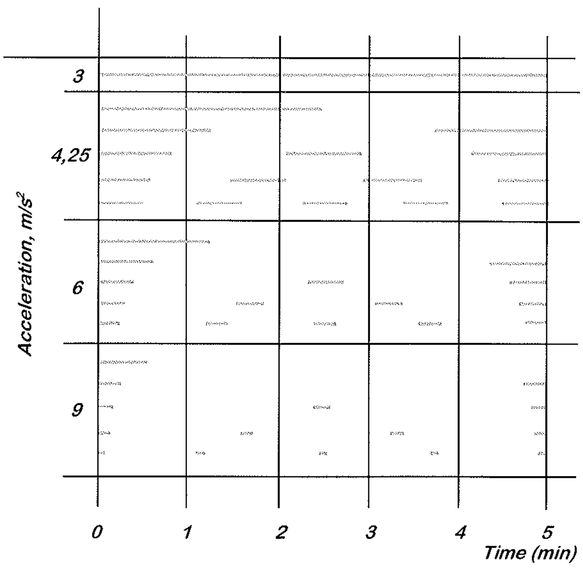

Figure 1. Distribution of exposure and its duration for each experiment. The lines represent the exposure duration during each experiment.

The vibration that affected the subjects through the handle was recorded beforehand on a DAT (digital audio tape) recorder. The recorded signals consisted of random vibration from a signal generator, within the frequency range of 4—2000 Hz. These signals were fed through a spectrum shaper and were adjusted so that the vibration at the handle had a constant velocity spectrum (1/3-octave band) independently of frequency and dynamic load. The spectrum represented an acceleration spectrum, which increases with frequency (6 dB/octave) and, after frequency weighting according to ISO 5349, gives a constant spectrum within the frequency range of 16—1250 Hz.

The outputs from the transducers and the strain gauges were amplified and fed to a DAT recorder for later analysis. A dual-channel real-time analyzer was used in the analysis for the calculation of the cross-spectrum between the force and velocity signal. The analyzed cross-spectrums were transferred to a computer for the calculation of absorbed power for each of the 1/3 octave bands with center-frequencies from 6.3 to 2000 Hz, in accordance with IEC 225 (10). The total quantity of absorbed power within the actual frequency range was then calculated. These calculations also included subtraction of the additional dynamic force produced by the handle itself (6). The recorded signals for the grip and feed forces were also transferred to a computer for further analysis. A 12-bit analogue-digital card with a sampling frequency of 5 samples per second was used for the analyses. The grip force was defined as the measured voltage on the lower strain gauge bridge of the handle, and the feed force was the measured difference in voltage between the upper and lower strain gauge bridges of the handle. (For more-detailed information about the apparatus see references 6 and 7.)

Experimental procedure

All the subjects were asked to wear ordinary office clothes and to remove rings, watches, and the like to minimize any possible effects on the results. The subjects were also asked to wear earmuffs. Thereafter, the subjects were placed in a sitting posture and instructed to grip the handle with their right hand and with an outstretched arm (abduction 0 degrees, flexion 180 degrees, for a definition see reference 6). In accordance with ISO 5349, this position refers to an excitation of the hand in the X_h direction. The subjects were requested to keep the grip and feed forces at a "normal" level during exposure. The instruction was, "Grip the handle with a force that corresponds to a normal grip on a bicycle handlebar". The subjects were unaware that the grip and feed forces were continuously measured during the experiment, and they were informed only that the absorption of vibration power in the hand was being studied. Each experiment took about 10 minutes to conduct, during which the duration of exposure was 5 minutes. Every subject participated in only 2 experiments each day to avoid the effects of fatigue.

Statistics

Analyses of variance for repeated measurements were used (11) to investigate the influence of the studied variables on the absorbed vibration power and grip and feed forces.

Two different analyses of the data were performed. In the 1st analysis, the summarized power absorption

Table 1. Power absorption for different experimental conditions.

Acceleration	Power absorption (Nm/s²)									
	1 exposure		2 exposures		3 exposures		4 exposures		5 exposures	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
3 m/s²	0.0195	0.0048	.	.	.	.	.	.	.	.
4.25 m/s²	0.0202	0.0049	0.0182	0.0038	0.0178	0.0031	0.0177	0.0039	0.0176	0.0047
6 m/s²	0.0226	0.0060	0.0188	0.0042	0.0182	0.0030	0.0179	0.0030	0.0177	0.0041
9 m/s²	0.0229	0.0062	0.0205	0.0030	0.0212	0.0050	0.0213	0.0046	0.0193	0.0044

Table 2. Grip and feed forces for different experimental conditions. [exp = exposure(s)]

Acceleration	Grip force (N)										Feed force (N)									
	1 exp		2 exp		3 exp		4 exp		5 exp		1 exp		2 exp		3 exp		4 exp		5 exp	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
3 m/s²	14.6	3.3	.	.	.	.	.	.	.	.	19.4	4.4	.	.	.	.	.	.	.	.
4.25 m/s²	13.7	3.2	12.1	2.5	12.0	2.1	11.4	2.5	12.5	2.2	19.0	4.6	16.9	3.5	16.2	2.9	16.3	3.5	15.9	2.9
6 m/s²	15.2	4.0	12.6	2.8	11.5	3.4	12.8	2.0	13.0	2.8	20.5	5.5	17.0	3.8	16.5	2.8	17.1	2.7	16.4	3.8
9 m/s²	14.7	5.2	13.9	2.1	14.1	3.4	14.3	3.1	12.4	2.9	21.2	5.2	18.5	2.7	19.7	4.4	19.3	4.2	17.7	4.1

within the frequency range of 6.3—2000 Hz was used. The number of observations was 160 (10 subjects, 16 experimental conditions). In the 2nd analysis, the influence on the grip and feed forces was investigated. The number of observations for each force was 160 (10 subjects, 16 experimental conditions). The probability level accepted for statistical significance was α=0.05.

Results

The mean value and standard deviation of the total quantity of absorbed power within 1/3 octave bands, with center frequencies from 6.3 to 2000 Hz, are shown in table 1. In the table, the absorption of power for different amplitudes and numbers of exposure periods has been calculated for the whole experimental period of 5 minutes.

Acceleration has a significant influence on the absorption of vibration power in the hand ($F_{2,18}$ =10.01, P=0.001) and the number of exposures also has a significant influence on the absorption ($F_{4,36}$ =6.56, P=0.0007). Furthermore, the analysis showed that there is an interaction between the number of exposures and the amplitude of the vibration stimuli ($F_{8,72}$ =3.86, P=0.001).

Table 2 shows the means and standard deviations for the grip and feed forces over the whole test period and for the different experimental conditions.

The statistical analysis showed that the acceleration amplitude had no significant influence on the grip forces ($F_{2,18}$=3.16, P=0.079) but, on the contrary, the amplitude affected the feed forces ($F_{2,18}$=6.27, P=0.031). The analysis of the number of exposures showed the same pattern, significant influence on the feed forces and no influence on the grip forces ($F_{4,36}$=3.91, P=0.031; $F_{4,36}$=1.41, P=0.250). Moreover, no interaction on the forces was found between the number of exposures and the vibration amplitude.

Discussion

The outcome of the present study revealed a difference between the calculated vibration dose according to ISO 5349 and the measured quantity of absorbed power. The absorption increased by about 20% at higher amplitudes, although the calculated energy-equivalent acceleration was the same. With regard to the unsubstantiated premise that a higher quantity of absorbed power represents an increased risk of vibration injuries, we conclude that application of the risk prediction model in annex A of ISO 5349 would lead to an increasing underestimation of the true risk for increasing frequency-weighted acceleration.

The results also showed that hand forces are affected when the amplitude of the acceleration is changed. These results are also in accordance with those of earlier studies (6, 12, 13). One possible explanation could be the so-called tonic vibration reflex (TVR). It is known that TVR leads to an increased contraction of the muscles when the hand-arm system is exposed to vibration (14—16). It has also been found that this reflex is related to the acceleration level (16, 17).

There are physiological reasons for the recommendation of the number and the length of vibration-free interruptions during the vibration exposure in order to give the organism an opportunity to recover. In ISO 5349, very little attention is given to rest periods, their length or number. Results from this study showed, however, that absorption decreases if rest periods are included. Exposure containing only 1 rest period gives a reduction of 10% to 20% in the quantity of absorbed power. If the hypothesis is that lower absorption corresponds to lower risk, it can be concluded that rest periods have a positive influence on risk assessment. One explanation could be that the feed forces decrease due to the rest period. Changes in the feed forces have been shown in earlier investigations to contribute significantly to the absorption of power, mostly due to changes in the transmission of vibration (18). Since the hand forces decreased with the number of rest periods in this investigation, one can speculate that the observed differences were attributable to changes in feed forces.

One of the main difficulties in estimating the daily vibration dose is that there are no epidemiologic data available that can clarify the effect of daily exposure time, intermittent tool use, and rest periods. The results of this study must be interpreted with caution, therefore, since there is very little knowledge about the relevance of acute effects in the development of chronic and permanent injuries. However, the present results support the hypothesis that vibration-free periods have a positive influence on the human organism.

Acknowledgments

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References

1. Gemne G, Lundström R, Hansson J-E. Disorders induced by work with hand-held vibrating tools: a review of current knowledge for criteria documentation. Stockholm: Arbetsmiljöinstitutet, 1993. Arbete och Hälsa 6.
2. ISO 5349. Mechanical vibration — guidelines for the meas-

urement and the assessment of human exposure to hand-transmitted vibration. Geneva: International Organization for Standardization, 1986.
3. Griffin MJ. Handbook of human vibration. London: Academic Press, 1990.
4. Anderson JS, Boughtflower RAC. Measurement of the energy dissipated in the hand and arm whilst using vibratory tools. Appl Acoust 1978;11:219—24.
5. Lidström I-M. Vibration injury in rock drillers, chiselers, and grinders: some views on the relationship between the quantity of energy absorbed and the risk of occurrence of vibration injury. In: Wasserman DE, Taylor W, Curry MG, editors. International Occupational Hand-Arm Vibration Conference — 1975. Cincinnati (OH): National Institute for Occupational Safety and Health (NIOSH), 1977:77—83. DHEW (NIOSH).
6. Burström L, Lundström R. Absorption of vibration energy in the human hand and arm. Ergonomics 1994;37:879—90.
7. Burström L. The influence of biodynamic factors on the absorption of vibration energy in the human hand and arm. Nagoya J Med Sci 1994;57:159—67.
8. Burström L. The influence of individual factors on the absorption of vibration energy in the hand and arm. Cent Eur J Public Health 1996;4:50—2.
9. Girden ER. ANOVA repeated measurements. Sage: Sage University, 1992. University paper, no 84.
10. International Electrotechnical Commission (IEC) 225. Octave, half-octave and third-octave band filters intended for the analysis of sound and vibrations. Geneva: IEC, 1966.
11. Norusis M. SPSS for windows: advanced statistics. Release 6.0. Chicago (IL): SPSS Inc, 1993.
12. Mishoe JW, Suggs CW. Hand-arm vibration, part II: vibrational responses of the human hand. J Sound Vibr 1977; 53:545—58.
13. Reynolds DD, Wasserman DE, Basel R, Taylor W. Energy entering the hands of operators of pneumatic tools used in chipping and grinding operations. In: Brammer AJ, Taylor W, editors. Vibration effects on the hand and arm in industry. New York (NY): John Wiley & Sons, 1982:133—46.
14. Pyykkö I, Färkkilä M, Toivanen J, Korhonen O, Hyvärinen J. Transmission of vibration in the hand-arm system with special reference to changes in compression force and acceleration. Scand J Work Environ Health 1976;2:87—95.
15. Pyykkö I, Starck J. Vibration syndrome in the aetiology of occupational hearing loss. Acta Otolaryngol (Stockh) 1982; 386 suppl:296—300.
16. Radwin RG, Armstrong TJ, Chaffin DB. Power hand tool vibration effects on grip exertions. Ergonomics 1987; 30:833—55.
17. Gurram R, Rakheja S, Gouw GJ. A study of hand-grip pressure distribution and EMG of finger flexor muscles under dynamic loads. Ergonomics 1995;38:684—99.
18. Burström L. The influence of ergonomic factors on the absorption of mechanical energy in the hand and arm. In: Gemne G, Brammer A, Hagberg M, Lundström R, Nilsson T, editors. Proceedings of the Stockholm Workshop 94: hand-arm vibration syndrome: diagnostics and quantitative relationships to exposure. Stockholm: National Institute for Working Life, 1995:11—15. Arbete och Hälsa 5.

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