

Effects of impulse vibration on the hand-arm system

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DUPUIS H, SCHÄFER N. Effects of impulse vibration on the hand-arm system *Scand J Work Environ Health* 12 (1986) 320–322. Theoretical considerations and published research show that hitherto there is insufficient knowledge to establish whether it is necessary to include the impulsiveness of vibration in the assessment of health risk. Experiments have been carried out to examine whether there are different acute effects of impulse and nonimpulse vibration from hand-held tools on the hand-arm system. Ten male subjects were exposed to simulated Z vibration of different hand tools under laboratory conditions. The human response was evaluated from measurements of (i) the biodynamic behavior of the hand-arm system (wrist, elbow), (ii) muscle activity (flexor carpi ulnaris, biceps, and triceps muscles), (iii) peripheral circulation (skin temperature), and (iv) perception. No general significant differences in the acute effects were found between shock-type vibration and nonimpulsive vibration for short duration exposure (up to 8 min) to vibration with the same frequency-weighted acceleration. It was concluded that no assessment of impulse vibration more stringent than that proposed by the International Organization for Standardization seems justified.

Key terms: biodynamic behavior, impulsiveness, muscle activity, perception, peripheral circulation, vibration assessment.

The impulsiveness of the vibration of vibrating tools is influenced by different work procedures and depends on the operating principles of the tool in question. The assessment of such shock-type vibration has to take into consideration the following questions: (i) are the acute and chronic effects of impulse vibration on man different from those of nonimpulse vibration, and (ii) if there are significant differences in the effects, which assessment and evaluation methods are suitable for representing them? The first question should be answered before one tries to develop assessment methods that differ from those for nonimpulsive vibration. It has been suggested, on the basis of theoretical consideration, that impulse vibration may excite shock waves of higher intensity and to larger areas in the body tissues than nonimpulse vibration does (7, 11). The waves may occur in peripheral tissues, as well as in bones and joints. Starck (10) pointed out that large peak accelerations may contribute to vibration hazards in soft tissues through two different mechanisms. It may powerfully distort the skin tissues and shear the endothelium of capillary beds and therefore create leakage and capillary dilatation (6). This phenomenon may be responsible for the erythema and swelling of the fingers that occur after vibration exposure (12). Large acceleration peaks may also affect the peripheral nerves. According to Starck's (10) hypothesis, since impulse vibration may spread to

larger body areas, more receptors would be affected. Therefore, the sensory responses to vibration would be enhanced. As a result, impulse vibration may facilitate somatosensory reflexes and thereby contribute to vibration-induced injuries (8).

But these are only theoretical considerations. In epidemiologic literature we have been unable to find any results showing specific chronic effects of impulse vibration on peripheral circulation and nervous function. With respect to acute effects it has been found (4) that the higher the amplitude and duration of the impulse (ie, high energy content) the lower the vibration perception threshold. Impulse vibration caused more threshold shift than sinusoidal vibration. Further research (5) has shown that "pulsating" sinusoidal vibration (vibration interrupted by pauses) causes a less intense sensation than continuous vibration exposure of the same amplitude.

The effects of sinusoidal vibration and impulse vibration on the electrical activity of the triceps brachii muscle have been studied (3). With a pushing force of 50 N muscle activity was lower under impulse than under sinusoidal vibration exposure. However, when the force was 100 N, there was no significant difference in the electromyograms. In other research (4) using synthetic shock-type vibration from hand-held tools, the electrical activity of the triceps brachii muscle was not influenced by the different types of vibration signals.

To improve this lack of knowledge, research has been carried out and described originally in detail elsewhere (9) and reviewed here. The aim of the research was to clarify the question of whether impulse vibration from hand-held tools requires a more severe evaluation than that currently recommended in the international standard ISO/DIS 5349 (2).

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Subjects and methods

Acceleration signals from six different hand tools (grinder, chain saw, hammer drill, pneumatic hammer, riveting hammer, and nailer) were chosen for simulation in the Z direction by an electrodynamic simulator. The simulated signals were only modified so that their frequency-weighted acceleration (a_{zhw}) (ISO-DIS 5349) would have the same root-mean-square (rms) value (6.3 m/s^2). But they differed in terms of frequency distribution and impulsiveness (9).

Ten male subjects were tested in a small laboratory room [air temperature $22.0 \pm 1.0^\circ\text{C}$, noise level $< 63 \text{ dB(A)}$]. The hand-arm position (elbow angle 120°), the gripping force (25 N), and pushing force (50 N) of the vibration-exposed right hand-arm system were held constant. Vibration was measured with small accelerometers (weight 2 g) fixed on the handle, wrist, and elbow joint as tightly as feasible in order to measure the best possible representation of hand-arm vibration. Electrical muscle activity of the flexor carpi ulnaris, biceps brachii, and triceps brachii muscles was measured with surface electrodes, recorded on tape, and analyzed by digital computer. As an indirect indicator of the peripheral circulation, the skin temperature of the fingertip was measured by thermo elements fixed on digits II—V of the (exposed) right hand and on digit IV of the (unexposed) left hand. Furthermore, simulated chain-saw vibration, a typical type of nonimpulse vibration, was compared with the vibration of the other hand tools. The subjects were exposed first to chain-saw vibration as the "standard vibration" for 30 s. Immediately thereafter they were exposed to the shock-type "test vibration" of one of the other hand tools. They were asked to adjust the vibration intensity, by turning a potentiometer, to reach the same subjective vibration perception (9).

Results

In the determination of biodynamic behavior, the rms acceleration at the wrist and at the elbow remained at approximately the same level regardless of the impulsiveness of the tool tested. — Under vibration stress with increasing impulsiveness only the triceps muscle reacted more strongly because it is the muscle that acts mainly against vibration stress. In fact the electrical activity of this muscle increased by up to 185 % when exposed to the most impulsive vibration (nailer, crest factor 10.2).

The skin temperature of the fingertips decreased by about 1.5 to 3.0°C after 8 min of exposure to a static force and vibration stress. From this result it can further be deduced that, for each finger, there are no significant differences in peripheral circulation related to the impulsiveness of vibrating hand tools.

The results regarding subjective perception demonstrated that, generally, there is no significant

difference between the different types of impulse vibration. Only the riveting hammer was judged subjectively to be more intense than the other types of simulated vibration.

Discussion

The research was controlled in such a way that the frequency-weighted acceleration level (a_{zhw}) was the same for the simulated vibration of the six different hand tools. Therefore possible differences in the acute effects on man should have been caused by the impulsiveness of the tools.

The experiments demonstrated that the impulsiveness of vibration has no influence on the vibration transmission from the vibrating handle to the wrist and elbow joint. It was further shown that the frequency characteristics of shock-type vibration play an important role in the transmissibility. If the hand-arm system is exposed to harmonic, random, or shock-type vibration with main frequencies in the range of 10—25 Hz, it will be excited into resonances (1). This was the case only for the pneumatic hammer (16 Hz). Resonances mean a high degree of strain in the body tissues exposed. The resonance effect, rather than the impulsiveness, is probably the main reason for damage of the bones and joints (elbow and wrist) found in workers exposed to pneumatic hammer vibration (about 7 500 cases compensated in the Federal Republic of Germany).

In the electromyographic experiments, only the activity of the triceps muscle increased with increasing impulsiveness. But since the increase in muscle activity was small in comparison to practical work conditions, this result may not be very relevant from the physiological point of view.

As regards peripheral circulation, it was scarcely to be expected that circulation would decrease more with increasing impulsiveness. This assumption was due to the fact that, in the Federal Republic of Germany, the vasospastic syndrome has been found mainly in workers using tools with low crest factors but with a high frequency of vibration (chain saws and grinders). In fact the experiments have proved that the impulsiveness of the vibration has no influence on the acute skin temperature of the fingertip.

Thus, in general, on the basis of the evaluation criteria used in our studies and for the chosen vibration intensity and short-time exposure (up to 8 min), the impulsiveness of the vibrating tools tested had no influence on the acute measures of biodynamic behavior, muscle activity, peripheral circulation, and perception. In summary, it may be concluded that it is justified to use the method of ISO/DIS 5349 for evaluating shock-type vibration until further knowledge from epidemiologic research suggests otherwise.

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References

1. Dupuis H, Hartung E, Hammer W. Biomechanisches Verhalten, Muskelreaktion und subjektive Wahrnehmung bei Schwingungserregung der oberen Extremitäten zwischen 8 und 80 Hz. *Int Arch Occup Environ Health* 37 (1976) 9—34.
2. International Organization for Standardization. Guide for the measurement and the assessment of human exposure to vibration transmitted to the hand. Geneva 1983. (ISO/DIS 5349).
3. Kramer H, Mücke R, Krause P. Die mittlere bioelektrische Aktivität von statisch beanspruchten Armmuskeln bei Einwirkung von sinusförmiger und impulsförmiger Vibration gleichbewerteten Effektivwertes. Untersuchungsbericht. *Wiss Tech Z Arbeitssch Minist Bauw DDR*, Berlin 1976.
4. Krause P. Untersuchungen zur Einwirkung impulsartiger Vibration auf das Hand-Arm-System bei der Arbeit mit handgeführten Maschinen. TU Dresden 1977. (Dissertation).
5. Miwa T. Evaluation methods for vibration effect: Part 7. The vibration greatness of the pulses. *Ind Health* 6 (1968) 143—164.
6. Nerem RM. Vibration-induced arterial shear stress: The relationship to Raynaud's phenomenon of occupational origin. *Arch Environ Health* 26 (1973) 105—110.
7. 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* 2 (1976) 87—95.
8. Pyykkö I, Hyvärinen J, Färkkilä M. Studies on the etiology mechanism of the vasospastic component of vibration syndrome. In: Brammer AJ, Taylor W, ed. *Vibration effects on the hand and arm in industry*. John Wiley & Sons, New York, NY 1982, pp 13—24.
9. Schäfer N, Dupuis H, Hartung E. Acute effects of shock-type vibration transmitted to the hand-arm system. *Int Arch Occup Environ Health* 55 (1984) 49—59.
10. Starck J. High impulse acceleration levels in hand-held vibratory tools. In: Starck J. *Characteristics of vibration, hand grip force, and hearing loss in vibration syndrome*. University of Kuopio, Kuopio 1984. (Original reports, 4/1584, natural sciences). (Doctoral dissertation).
11. Starck J, Färkkilä M, Aatola S, Pyykkö I, Korhonen O. Vibration syndrome and vibration in pedestal grinding. *Br J Ind Med* 40 (1983) 426—433.
12. Taylor W, Pelmear PL, Pearson J. Raynaud's phenomenon in forestry chain saw operators. In: Taylor W, ed. *The vibration syndrome*. Academic Press, London 1974, pp 121—139.