Scand J Work Environ Health 1990;16(1):39-43

<https://doi.org/10.5271/sjweh.1824>

Issue date: 1990

Psychological aspects of occupational vibration.

by [Kjellberg A](#)

Affiliation: National Institute of Occupational Health, Solna, Sweden.

This article in PubMed: www.ncbi.nlm.nih.gov/pubmed/2189218

This work is licensed under a [Creative Commons Attribution 4.0 International License](https://creativecommons.org/licenses/by/4.0/).

Psychological aspects of occupational vibration

by Anders Kjellberg, PhD¹

KJELLBERG A. Psychological aspects of occupational vibration. *Scand J Work Environ Health* 1990; 16(suppl 1):39–43. A short review is given of the subjective responses to vibration (primarily whole-body vibration) and of its performance and psychophysiological effects. The subjective importance of the basic physical vibration parameters and the effects of whole-body vibration on performance of tasks requiring manual control and visual acuity have been well covered by research, whereas knowledge of the effects on cognitive performance is rather meager.

Key terms: discomfort, performance, psychophysiology.

The increased mechanization of work has resulted in a widespread occupational exposure to both whole-body vibration and local vibration. Whole-body vibration is transmitted from a vibrating surface on which the body rests, eg, a driver's seat or a vibrating floor. Local (segmental or hand-arm) vibration refers to when vibration is applied to a certain part of the body, most often the hand-arm system, by vibrating handtools.

The most well-known effect of vibration exposure is the circulatory disorder known as vibration-induced white fingers. Although this disorder has now been recognized for about 80 years, it remains a common problem among workers using grinders, chain saws, and other vibrating tools. It is now apparent that not only is the circulation affected by such exposure, but it may also lead to neurological disturbances and to bone and joint disorders (1). An understandable consequence of these clear-cut health effects of hand-arm vibration is that the interest in the behavioral effects of local vibration has been rather slight.

It should be pointed out that there is a well founded suspicion that long-term exposure to whole-body vibration also may lead to health problems, primarily in the form of back and stomach disorders (2, 3). However, in the case of whole-body vibration it has been more difficult to separate the effects of vibration from those of potential confounding factors such as heavy lifting and unfavorable work postures. Thus there has been a greater demand for data on the subjective and performance effects of whole-body vibration, eg, in the establishment of exposure standards. The purpose of the present paper is to give a short review of these effects and of the acute physiological responses to whole-body vibration. The effects of hand-arm vibration have not been treated separately but have been briefly commented upon when the corresponding effects of whole-body vibration are discussed.

International standard for whole-body vibration

One point of departure for a description of the effects of whole-body vibration is the exposure limit curves given in standard ISO 2631 of the International Organization for Standardization (ISO) (4), shown in figure 1, which suggests acceptable exposure levels for different vibration frequencies (1–80 Hz). Different curves are given depending on the exposure time (1 min–24 h) and the direction of the vibration [vertical (z), lateral (y), and fore-aft (x)]. The standard defines exposure limits based on the following three criteria: (i) health and safety, (ii) fatigue-decreased proficiency, and (iii) comfort. Subjective data obviously provide the only possible basis for a comfort limit, and performance data should be critical for a fatigue-decreased proficiency limit. Thus the health and safety limit is the only one for which the critical data need not be of a psychological nature. However, in the absence of dose-response data for health risks, this limit too is largely based on subjective data.

Biomechanical effects of vibration

In contrast to, eg, noise, whole-body vibration does not have one specific target organ, but affects all parts of the body to some degree. In other words it may give rise to qualitatively different effects depending upon how vibration is transmitted to different parts of the body. A general rule is that the higher the vibration frequency, the faster the vibration is attenuated during its propagation through the body. Thus, if one stands on a platform which vibrates with a high frequency, a very small part of the vibration will be transmitted beyond the legs, whereas very low-frequency vibration (eg, that experienced in a ship) will reach the head unattenuated. The transmission is complicated by the fact that different parts of the body have different resonance frequencies, ie, vibration within a certain frequency range is amplified in certain parts of

¹ National Institute of Occupational Health, Solna, Sweden.

Figure 1. Limits for vertical (z) and transverse (x, y) whole-body vibration as given in standard 2631 of the International Organization for Standardization (4). (rms = root mean square)

the body. Therefore the amplitude of the vibration may vary between different parts of the body, and thus the vibration may lead to compression and stretching within the body. The major resonance frequencies of the body under exposure to vertical (z) vibration lie between 2 and 6 Hz. One exception to this statement is the eye, which has a resonance frequency of 20–25 Hz. [For a detailed account of the biodynamics, see the report by Dupuis & Zerlett (5)].

Subjective responses

Research treating the subjective responses to vibration is far more sparse than the corresponding noise research. However, there are several laboratory studies on the influence of the subjective vibration magnitude of basic parameters like acceleration, frequency, and duration. For a more comprehensive review of these studies see the report by Dupuis & Zerlett (5). Field studies have, with very few exceptions, treated passenger comfort rather than occupational problems. [See the review by Osborne (6).]

Acceleration

Laboratory studies have generally shown that the function relating subjective magnitude to acceleration (in

meters per square second, which is the most commonly used unit of vibration magnitude) is approximately linear both for whole-body vibration (7, 8) and for local vibration (9). Therefore a doubling of the vibration acceleration is also experienced as approximately a doubling of the subjective intensity; this statement seems to be true for a wide range of vibration frequencies.

Frequency

As a consequence of resonance phenomena a person's sensitivity to vibration depends very much on its frequency. This phenomenon is reflected in the ISO standard which proposes different exposure limits for different vibration frequencies (figure 1). The highest sensitivity, and thus the lowest exposure limits, are found in the 4–8 Hz frequency range for vertical vibration. Vertical vibration within this frequency range is primarily found in smaller vehicles such as small forklift trucks, whereas lower frequencies are dominant in larger vehicles. In the x and y directions a person is the most sensitive to vibration in the 1–2 Hz frequency range. This frequency dependency appears to be similar at all acceleration levels. Thus curves describing the tolerance limits at different frequencies have the same general appearance (5).

Real-life vibration does not contain just one frequency, but is always stochastic. In order to obtain a single estimate of the severity of such vibration, a frequency-weighted acceleration value can be computed. Filters based on these sensitivity curves then are used in a way analogous to the measurement of a decibel A-weighted value for noise.

Exposure time

The effect of exposure time on the subjective response to whole-body vibration has been a subject of some controversy (10–12). However, it is now generally agreed that discomfort increases with exposure time but at a much slower rate than is indicated by the difference between the 1-min and 24-h curves in ISO 2631 (figure 1). Thus on the basis of reported results the difference between the 1- and 8-h exposure limits should be reduced.

Other vibration characteristics

Most laboratory studies have used sinusoidal vibration, and it has therefore been important to investigate possible differences between the response to such vibration and to random whole-body vibration (13). Another issue has been how the presence of shocks of short duration affects the response to whole-body vibration (14, 15). Finally, there has been increasing interest in more complex and realistic vibration with simultaneous motion in two or three directions and in vibration containing rotary motions around one or more of the x, y, and z axes (roll, pitch and yaw, respectively) (16–18).

Performance effects

Vibration may affect performance during exposure by interfering with peripheral motor or sensory functions. Thus whole-body vibration may lead to deteriorated performance by impairing the control of both hand-arm movements and visual acuity. Likewise, it is conceivable that vibration from handheld tools could impair the performance of tasks requiring finger dexterity by reducing tactile sensitivity. However, the only reported study treating this problem did not find any such effects (19). Vibration may also affect the functions of the central nervous system during and immediately after exposure, eg, by raising the arousal level, and thus have more generalized effects on performance. Such effects have only been studied in connection with whole-body vibration in spite of the fact that Soviet researchers have claimed that hand-arm vibration may even lead to a disease originating in the central nervous system. [For a critical discussion of this “diencephalic syndrome,” see the report by Gemne (20).] The following short review is therefore limited to whole-body vibration and primarily deals with the effects on tracking tasks and visual acuity.

Tracking

Tracking tasks are tests of visuomotor coordination which typically require the subject to move a target (eg, a spot on a video display) along a predetermined path with a joystick. Since whole-body vibration may cause involuntary movements of the hand, it obviously may make such tasks more difficult. These effects on manual control are probably those most commonly treated in the studies, almost all of which have been conducted in a laboratory. A comprehensive review of these studies has been given by Lewis & Griffin (21).

For vibration with frequencies below 10 Hz the performance decrements are a direct effect of the transmission of the vibration to the hand-arm system. Thus the greatest decrements are produced by 4- to 5-Hz vibration in the vertical axis and 1- to 3-Hz vibration in the x and y axes. The degree of impairment also depends on the relation between the direction of vibration and the required movements of the control, and it may sometimes be reduced by appropriate arm rests or seat belts which put some restraints on body motion (21). However, it is to be noted that such restraints also may aggravate the vibration conditions by increasing the transmission to the hand (through the seat back and the arm rest) (22).

Vibration above 10–20 Hz may produce disturbances of the proprioceptive feedback such as to give an incorrect impression of the position of the stimulated arm (23). In the higher frequency range this effect seems to contribute somewhat to the performance decrement, as shown by Lewis & Griffin (24).

It has also been suggested that the impaired visual acuity might contribute to the effects of whole-body vibration on tracking. However, according to Lewis & Griffin (21), the visual demands in these tasks are generally not high enough for the effects to be of any importance.

Since whole-body vibration obviously makes tracking more difficult, a reasonable hypothesis would be that, due to fatigue, performance deteriorates more rapidly during exposure to whole-body vibration than otherwise. There is, however, no support for such a notion. Generally no time-related effects have been found, and, when such effects have been obtained, they have been in the opposite direction, ie, vibration has reduced the fatigue effects, probably by increasing arousal. See the review by Lewis & Griffin (21).

Visual acuity

Whole-body vibration may lead to blurred vision by making the image oscillate on the retina. The visual impairment depends both on the character of the vibration (frequency, magnitude, direction) and on the design of the display. A review of these effects has been given by Griffin & Lewis (25) and by Dupuis & Zerlett (5).

Vibration frequency is critical for the effects on vision for three reasons. One is that below 2–3 Hz

it is possible to compensate for the vibration by eye movements which keep the image focused on the same retinal location. However, as frequency is increased, the efficiency of the compensatory eye movements is gradually reduced, and only partial compensation is possible. The other reasons are the increased attenuation of the vibration as the frequency is increased and the resonance characteristics of various parts of the body. As a result of these factors the most critical frequency range for visual effects seems to be 2–20 Hz. In cases in which the subject vibrates and looks at a stationary display, vertical vibration around 5 Hz yields the most severe effects, whereas vibration in the x and y axes seem to be of little consequence (26). However, in the more common case in which both the subject and the object vibrate, vibration in the x and y axes will cause relative movements between the object and the eye and therefore may create serious reading problems (27).

In vibrating work environments the most critical visual task is generally the reading of various types of displays. In such cases it is usually possible to avoid the problem through appropriate design of the instruments (28).

Performance effects mediated by the central nervous system

Systematic research on the effects of whole-body vibration on the performance of cognitive tasks and other tasks reflecting functions of the central nervous system has been rather sparse, and the results have been inconsistent. Furthermore, in the cases in which an effect has been found, the task design may make it difficult to exclude an explanation in terms of visual acuity or impaired hand-arm control (29).

Poulton (30) has argued that vibration may, in some cases, raise the arousal level and thereby improve performance in long monotonous vigilance tasks. According to him such an arousing effect is most likely from vibration with frequencies around 5 Hz. This notion is supported by two studies, but a systematic review of relevant studies shows that results have by no means been consistent in this respect (31). Typically one has reported a performance decrement or an unaffected performance during vibration exposure. Another complication is that electroencephalographic measurements of wakefulness during exposure to sinusoidal vibration indicate that such vibration has a sleep-provoking rather than an arousing effect (32).

Thus no firm conclusions can be drawn about the performance effects of whole-body vibration other than those caused by mechanical interference. However, there is reason to believe that such effects will be revealed by more systematic studies on the effects of whole-body vibration in cognitive tasks. An obvious way to proceed would be to use some of the experimental paradigms that have been found fruitful in noise research, such as divided attention and incidental

learning tasks and the testing of the aftereffects of vibration exposure.

Acute physiological effects

The acute physiological reactions to whole-body vibration may have different origins. Some responses might be elicited by the sheer mechanical effect produced by the vibration in various organs. One clear example is the hyperventilation caused by the passive movement of vibration through the abdominal wall (5). In other cases a response might be a result of an attempt to counteract the effect of vibration. Finally, whole-body vibration probably contributes to a person's stress level or to other psychological responses associated with physiological changes. Only a very short account will be given of studies pertaining to the two latter types of effects, and the reader is referred to Dupuis & Zerkett (5) for a thorough review of the physiological responses to whole-body vibration.

During exposure to random vibration a person typically produces static tension of major muscle groups as a way of reducing the resonance effects. Sinusoidal vibration gives rise to dynamic muscle action, tension, and relaxation in synchrony with the vibration (5).

Increased heart rate, peripheral vasoconstriction, and other cardiovascular responses have been observed, but generally seem to be of short duration and thus probably represent habituating arousal responses to the onset of whole-body vibration. More persistent responses have only been observed at very high vibration levels (5).

As has already been mentioned, high-frequency whole-body vibration (>20 Hz) may cause proprioceptive disturbances and thereby also affect postural control. Extremely low-frequency vibration (<0.5 Hz) may also have such an effect, but in this case it is mediated by disturbances of vestibular functions and is accompanied by dizziness and nausea (motion sickness, kinetosis) (5). However, most vehicles produce vibration which predominantly lies outside these frequency regions.

Concluding remarks

Research on whole-body vibration has been focused on the basic subjective responses and on performance effects mediated by mechanical interference. Thus far too little is known about other types of performance effects and about the possible contribution of whole-body vibration to psychophysiological reactions. In view of the large groups of workers exposed to whole-body vibration, a more systematic study of these problems would be of great importance. Furthermore, vibration exposure is, of necessity, combined with exposure to noise to some degree. Several studies of vibration-noise interactions have been conducted (33), but our knowledge of these effects is still very meager.

References

1. Wasserman DE. Human aspects of occupational vibration. Amsterdam: Elsevier, 1987.
2. Seidel H, Heide R. Long-term effects of whole-body vibration: a critical survey of the literature. *Int Arch Occup Environ Health* 1986;58:1—26.
3. Hulshof CTJ, Veldhuizen van Zanten OBA. Whole body vibration and low back pain — a review of epidemiological studies. *Int Arch Occup Environ Health* 1987; 59:205—20.
4. International Organization for Standardization. Guide for the evaluation of human exposure to whole-body vibration. Geneva: International Organization for Standardization, 1978. (ISO 2631.)
5. Dupuis H, Zerlett G. The effects of whole-body vibration. Berlin: Springer Verlag, 1986.
6. Osborne DJ. A critical assessment of studies relating whole-body vibration to passenger comfort. *Ergonomics* 1976;19:751—74.
7. Jones AJ, Saunders DJ. A scale of human reaction to whole-body, vertical, sinusoidal vibration. *J Sound Vib* 1974;35:503—20.
8. Shoenberger RW, Harris CS. Psychophysical assessment of whole-body vibration. *Hum Factors* 1971;13:41—50.
9. Verrillo RT, Fraoli AJ, Smith RL. Sensory magnitude of vibrotactile stimuli. *Percept Psychophysics* 1969;6: 117—20.
10. Clarke MJ. A study of the available evidence on duration effects on comfort and task proficiency under vibration. *J Sound Vib* 1979;65:107—23.
11. Griffin MJ, Whitham EM. Duration of whole-body vibration exposure: its effect of comfort. *J Sound Vib* 1976;48:333—9.
12. Kjellberg A, Wikström BO. Whole body vibration: exposure time acute effects: a review. *Ergonomics* 1985; 28:535—44.
13. Griffin MJ. Subjective equivalence of sinusoidal and random whole-body vibration. *J Acoust Soc Am* 1976;60: 1140—5.
14. Griffin MJ, Whitham EM. Discomfort produced by impulsive whole-body vibration. *J Acoust Soc Am* 1980;68: 1277—84.
15. Wikström B-O, Kjellberg A, Örelus M. Helkroppsvibrationer: en prövning av olika metoder för utvärdering av stötar [Whole-body vibration: a test of different methods for evaluation of shocks]. Solna (Sweden): National Board of Occupational Safety and Health, 1987. (Arbete & hälsa 1987:15.)
16. Hansson JE, Wikström BO. Comparison of some technical methods for the evaluation of whole-body vibration. *Ergonomics* 1981;24:953—63.
17. Leatherwood JD, Dempsey TK, Clevenson SA. A design tool for estimating passenger ride discomfort within complex ride environments. *Hum Factors* 1980;22: 291—312.
18. Shoenberger RW. Subjective effects of combined-axis vibration: comparison of y-axis and y-plus-roll vibrations. *Aviat Space Environ Med* 1984;55:387—90.
19. Collier SG, Mabey MH, Graves RJ, McK, Nicholl AG. Testing for temporary effects of hand-arm vibration. In: Osborne DJ, ed. *Contemporary ergonomics* 1985. London: Taylor & Francis, 1985:187—96.
20. Gemne G. Autonomic integration of external and internal stimuli, and the Soviet concept of "diencephalic syndrome." *J Low Freq Noise Vib* 1983;1(special issue): 63—8.
21. Lewis CH, Griffin MJ. A review of the effects of vibration on visual acuity and continuous manual control, part II: continuous manual control. *J Sound Vib* 1978; 56:415—57.
22. Lovesay EJ. The helicopter — some ergonomic factors. *Appl Ergon* 1975;6:139—46.
23. Goodwin GM, McCloskey DI, Matthews PCB. The contributions of muscle afferents to kinaesthesia shown by vibration induced illusions of movements and by the effects of paralysing joint afferents. *Brain* 1972;95: 705—48.
24. Lewis CH, Griffin MJ. Mechanisms of the effects of vibration frequency, level and duration on continuous manual control performance. *Ergonomics* 1979;22: 855—89.
25. Griffin MJ, Lewis CH. A review of the effects of vibration on visual acuity and continuous manual control, part I: visual acuity. *J Sound Vib* 1978;56:383—413.
26. Lewis CH, Griffin MJ. Predicting the effects of vibration frequency and axis, and seating conditions on the reading of numeric displays. *Ergonomics* 1980;23: 485—501.
27. Hayward RA. The effect of horizontal vibration on reading performance of seated subjects. In: Hall LC, ed. *Proceedings of the United Kingdom informal group on human response to vibration*. Shrivenham (United Kingdom): Royal Military College of Science, 1986.
28. Moseley MJ, Griffin MJ. A design guide for visual displays and manual tasks in vibration environments: part 1: visual displays. Southampton Institute of Sound and Vibration Research, University of Southampton, 1986. (Technical report no 133.)
29. Shoenberger RW. An investigation of human information processing during whole-body vibration. *Aerospace Med* 1974;45:143—53.
30. Poulton EC. Increased vigilance with vertical vibration at 5 Hz: an alerting mechanism. *Appl Ergon* 1978;9: 73—6.
31. Sherwood N. Vibration and cognition: joining the boundaries. In: Hall LC, ed. *Proceedings of the United Kingdom informal group on human response to vibration*. Shrivenham (United Kingdom): Royal Military College of Science, 1986.
32. Landström U, Lundström R. Changes in wakefulness during exposure to whole body vibration. *Electroencephalogr Clin Neurophysiol* 1985;61:411—5.
33. Harris CS, Shoenberger RW. Combined effects of broadband noise and complex waveform vibration on cognitive performance. *Aviat Space Environ Med* 1980; 51:1—5.