

Guide to

Measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock

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- AFRC Institute of Engineering Research
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- University College of Wales

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Foreword

BS 6841 was prepared under the direction of the General Mechanical Engineering Standards Committee. It replaces Draft for Development DD 32:1974, which is therefore withdrawn.

ISO 2631:1985, being broadly similar to DD 32:1974, suffers similar limitations in that it does not define an adequate or reasonable procedure for measuring vibration exposures and specifies vibration limits which are not generally accepted. Growing international recognition of these problems lead to commencement of work on a revision of the International Standard during 1979. International agreement on the revision of ISO 2631 is not yet complete.

The principal differences between BS 6841 and DD 32 (and, therefore, between BS 6841 and ISO 2631:1985) are the provision of greater guidance on vibration effects without defining vibration limits, the elimination of the concept of fatigue-decreased proficiency, the inclusion of a simple time-dependency and a method of assessing repeated shocks and intermittent vibration (i.e. the vibration dose value), the modification and more complete definition of necessary frequency weightings, the definition of a standard means of assessing the discomfort caused by rotational vibration on the seat and translational vibration at the feet and seat back of seated persons, and the inclusion of more quantitative guidance on motion sickness (i.e. the motion sickness dose value).

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 24, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

1 Scope

Transport (air, land and water), machinery (e.g. in industry and agriculture) and industrial activities (such as piling and blasting) expose the human body to mechanical vibration and repeated shock.

This British Standard guide gives methods for quantifying vibration and repeated shocks in relation to human health, interference with activities, discomfort, the probability of vibration perception and the incidence of motion sickness.

The guide is applicable to motions transmitted to the body as a whole through the supporting surfaces: the feet of a standing person, the buttocks, back and feet of a seated person or the supporting area of a recumbent person. Vibration is often complex, containing many frequencies, occurring in several directions and changing over time.

Vibration limits are not presented. However, the methods have been given so that they may be used as the basis of limits which may be prepared separately. Various appendices provide current information on the possible effects of vibration.

The guidance is intended to be a fair compromise based on the available data and should satisfy the need for recommendations which are simple and suitable for general applications. The guidance is presented in numerical terms to avoid ambiguity and to encourage precise measurements. When using the recommendations it is important to bear in mind the restrictions placed on their application. More precise information may sometimes be obtained from the scientific literature.

NOTE The titles of the publications referred to in this standard are given on the inside back cover.

2 Effects of whole-body vibration and repeated shock

2.1 General

Exposure to whole-body vibration causes a complex distribution of oscillatory motions and forces within the body. This may cause unpleasant sensations giving rise to discomfort or annoyance, result in impaired performance (e.g. degraded vision) or present a health risk (e.g. tissue damage or deleterious physiological change).

There are many factors which influence human response to vibration. The variables include the following.

Intrinsic variables

- Population type (age, sex, size, fitness, etc.)
- Experience, expectation, arousal, motivation, financial involvement
- Body posture
- Activities

Extrinsic variables

- Vibration magnitude
- Vibration frequency
- Vibration axis
- Vibration input position
- Vibration duration
- Seating, restraints, etc.
- Other environmental influences (noise, heat, acceleration, light)

The four principal effects of vibration are considered to be:

- a) degraded health;
- b) impaired activities;
- c) impaired comfort;
- d) motion sickness.

2.2 Effects on health

Any part of the body may be injured by exposure to a sufficient magnitude of vibration. The parts of the body most likely to be injured during exposure to whole-body vibration will depend on the distribution of motion within the body and this will depend on the vibration frequency and axis and the coupling of the body to the vibrating source.

The probabilities and extents of particular health effects from prolonged exposures to whole-body vibration have not been established. There is a shortage of conclusive evidence relating specific injuries to definite causes. Therefore, it is not yet possible to provide a definitive dose-effect relationship between whole-body vibration and injury or health damage.

Biodynamic models and a knowledge of the physical properties of body tissue may be used to predict injury. Subjective data concerning vibration magnitudes which cause discomfort and pain may give some indication of the possibility of injury for various conditions, although it is recognised that sensations may not necessarily correlate with pathological damage.

In this standard, data from all of the above methods have been used to provide the best possible general guidance on methods of assessing vibration and shock with respect to impaired health.

NOTE Epidemiological studies suggest that back complaints are associated with exposure to prolonged periods of vibration and repeated shock but there are currently inadequate data to define a precise dose-effect relationship. Similarly, it is not yet possible to provide a definitive dose-effect relationship between whole-body vibration and any other injury.

2.3 Effects on activities

Vibration of the body may affect:

- a) the acquisition of information via the senses;
- b) information processing;
- c) levels of arousal, motivation or fatigue;
- d) intentional actions.

Vision is the perceptual mechanism most easily affected by vibration since even small movements of an image on the retina of the eye can degrade visual acuity. There is some evidence that the senses of touch and hearing may also be influenced by vibration but the effects are often small. The perception of body orientation and postural stability can also be affected by vibration.

There is little evidence that whole-body vibration directly affects cognitive processes. It is often difficult to separate direct effects from those caused by changes in arousal or motivation.

Arousal, motivation and fatigue are aspects of the behavioural state of an individual and, although they are not readily quantifiable, their effects can be very great. Vibration has been observed both to improve and to reduce task performance. This may be because it fatigues or arouses or, because of increased task difficulty, motivates. At present, these effects of vibration cannot be reliably predicted and are not quantified in this standard.

Actions performed by a person are often accomplished by speech or movements of the hands or feet. Whole-body vibration may cause a modulation of speech but under normal listening conditions this does not degrade intelligibility. Where an activity requires fine movements of the limbs, whole-body vibration can have a large effect on proficiency. Tasks involving gross locomotor movements, or lifting or carrying, are most likely to be affected by low frequency vibration. The precise effects of vibration on task performance are highly dependent on the task characteristics: detailed guidance cannot be provided in this standard.

2.4 Effects on comfort

The complex distribution of oscillatory motion and force within the body during whole-body vibration produces complex sensations. The location and character of the sensations vary greatly according to the vibration frequency, axis and other factors.

In this standard the term “discomfort” is applied to the sensations arising directly from the vibration. A wider term is sometimes used in transportation systems to include reactions to other aspects of the environment (e.g. noise) and the effects of motion on common activities (e.g. reading and writing).

In this standard a method is defined to enable the discomfort of two or more complex vibrations to be compared. Whether a degree of discomfort is acceptable will depend on many factors. A limiting value should be selected by the user for specific applications: different limits for discomfort will apply in different circumstances.

For some applications, knowledge of whether vibration can be perceived is useful. This standard therefore also defines the probability of perceiving low magnitudes of whole-body vibration.

NOTE Although pleasurable sensations may be experienced with some types of oscillatory motion they are outside the scope of this standard and they will not usually be confused with those causing discomfort.

2.5 Motion sickness

Low frequency (less than about 0.5 Hz) oscillation of the body can cause the motion sickness syndrome characterized principally by pallor, sweating, nausea and vomiting. Although other types of stimulation may cause similar symptoms, this standard is solely concerned with kinetosis (i.e. motion sickness) due to low frequency vertical z-axis oscillation of the human body. The guidance is formulated so as to enable the probability of vomiting in a given population to be predicted.

3 Vibration measurement and frequency weighting

3.1 Units of vibration magnitude

The primary quantity for expressing vibration magnitude is the weighted root-mean-square acceleration in m s^{-2} for translational vibration and rad s^{-2} for rotational vibration.

Root-mean-square (r.m.s.) measures of acceleration may be used when the crest factor does not exceed 6.0. However the severity of motions which are intermittent or contain occasional high peak values and have crest factors in excess of 6.0 will often be underestimated by r.m.s. measures. This standard gives alternative methods for the evaluation of these motions.

NOTE The crest factor of the motion is to be determined from the peak and r.m.s. value of the acceleration after it has been frequency weighted by the appropriate frequency weighting network. [Crest factor = (weighted peak acceleration)/(weighted r.m.s. acceleration)]. The peak and r.m.s. values are to be determined over the full period of vibration exposure which it is desired to assess.

3.2 Direction of measurement

Vibration should be measured according to a coordinate system centred at the interface with the body. The principal relevant basicentric systems are shown in Figure 1.

In many situations it is not feasible to obtain precise alignment of vibration transducers with the preferred basicentric axes. The sensitive axes of transducers may deviate from the preferred axes by up to 20 degrees where necessary. Where a person is seated on an inclined seat the relevant orientation should be determined by the axes of the body and the z-axis may not be vertical.

Transducers located at one measurement position have to be orthogonally positioned. Translational accelerometers orientated in different axes at a single measurement position should be as close together as possible.

3.3 Preferred measurement locations

Transducers should be located so as to indicate the vibration at the interface between the human body and the source of its vibration.

Where vibration enters the body from a rigid surface (e.g. floor or hard seat) it is sufficient to measure the motion of the surfaces adjacent to the principal areas of contact between the body and the surface (e.g. within 100 mm of the centre of this area).

Where vibration enters the body from a non-rigid or resilient material (e.g. seat cushion or couch) it is necessary to interpose the transducer between the person and the principal contact areas of the surface. This may best be achieved by securing the transducers within a suitably formed mount. The mount should not greatly alter the pressure distribution on the surface of the resilient material.

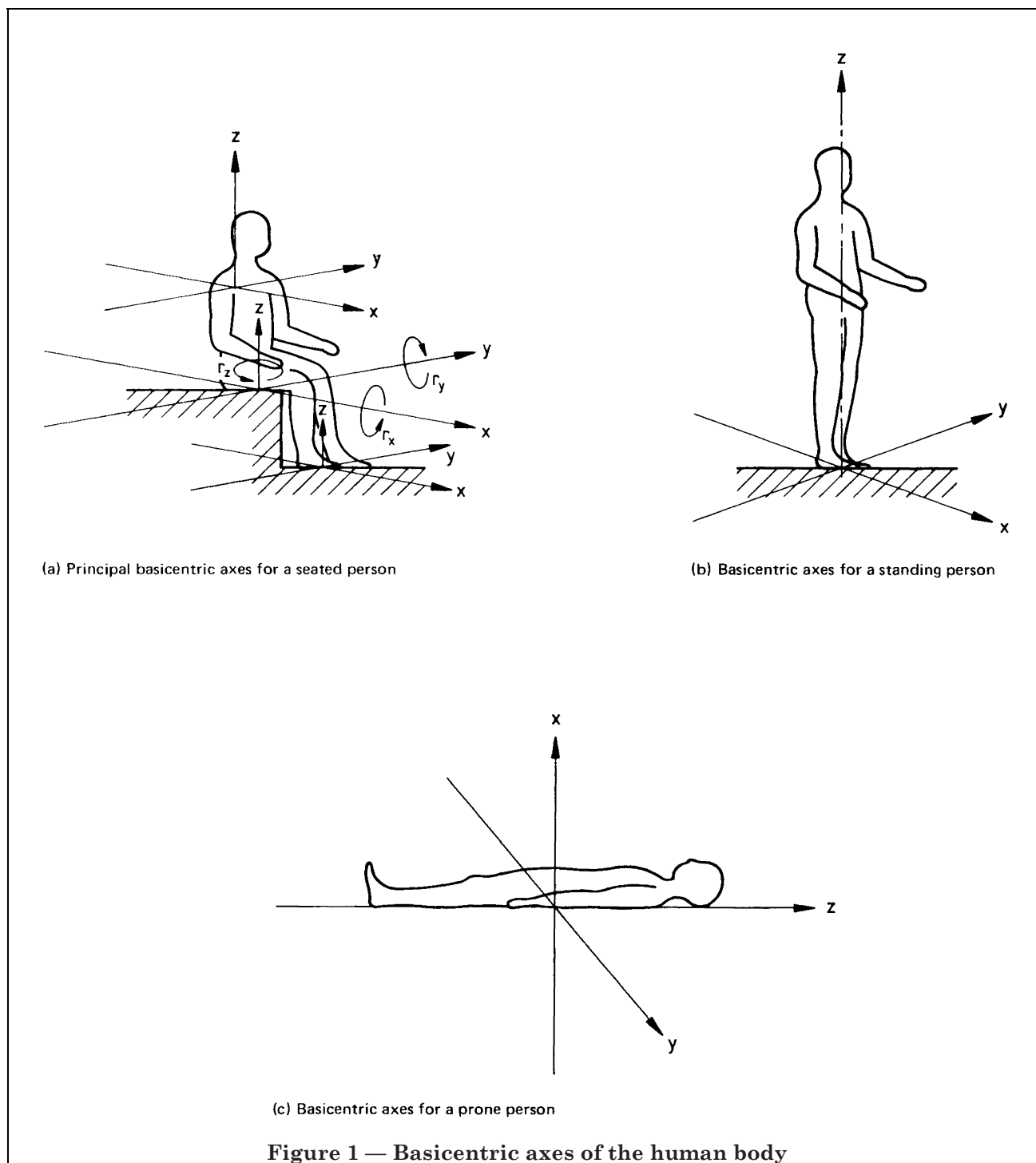


Figure 1 — Basicentric axes of the human body

Measurements obtained on non-rigid surfaces require that a live subject of appropriate characteristics adopts the normal position for the environment. Currently available dummies and representative masses do not normally provide the correct dynamic response since the mechanical impedance of man is not that of a pure mass.

NOTE 1 Two commonly used designs for accelerometer mounts will be found in the Society of Automotive Engineers standards SAE J1013 and SAE 770253¹⁾.

¹⁾ Society of Automotive Engineers standards may be purchased from Enquiry Section, BSI, Linford Wood, Milton Keynes MK14 6LE.

NOTE 2 The principal areas of contact between the body and a vibrating surface may not always be self evident. Clauses in this standard define three principal areas for seated persons: the supporting seat surface, the seat-back and the feet. Measurements on the supporting seat surface should be made beneath the ischial tuberosities. Measurements on the seat-back should be made at the position with the greatest effective vibration in contact with the body. Measurements at the feet should be made on the surface on which the feet are most often supported. Similar approaches should be used for other axes. In all cases the method of measurement should be fully reported.

NOTE 3 Where measurements at the person-seat interface are not practical, evaluation of the effects of vibration may be made on the basis of measurements taken at a rigid portion of the vehicle or building structure such as the centre of rotation or the centre of gravity. The use of such measurements for predicting human response is not recommended. If their use is unavoidable, the transfer function between the measurement position and the body interface is to be reported.

3.4 Frequency weightings

3.4.1 General. The manner in which vibration affects health, activities, comfort and motion sickness is dependent on the vibration frequency. Different frequency weightings are required for the different axes of vibration and for the different effects of vibration on the body (see Table 1).

The frequency weightings may be realized by either analogue or digital methods. They are defined in a mathematical form familiar to filter designers. The responses of the weightings are defined by both the expected filter responses and asymptotic approximations to the curves. (The asymptotic approximations have slopes of -6.0 , 0.0 , $+6.0$ and $+12.0$ dB per octave.)

In addition to the frequency weightings it is necessary to define band-limiting filters.

3.4.2 Frequency band limitation. Lower and upper frequency band limitations are achieved by two pole high-pass and low-pass filters respectively with Butterworth characteristics having an asymptotic slope of 12 dB per octave. The corner frequencies of the band-limiting filters are one-third of an octave outside the nominal frequency range of the relevant band.

Frequency weightings W_b , W_c , W_d , and W_e are to be used to assess vibration over the frequency range 0.5 Hz to 80 Hz: they have high and low-pass band-limiting filters at 0.4 Hz and 100 Hz respectively. Frequency weighting W_f is to be used for motions over the range 0.1 Hz to 0.5 Hz and has high and low-pass band-limiting filters at 0.08 Hz and 0.63 Hz respectively. Frequency weighting W_g may be applied over the range 1.0 Hz to 80 Hz and has band-limiting filters at 0.8 Hz and 100 Hz.

Table 1 — Outline guide to the application of frequency weightings

Clause reference	4	5		6		7
Frequency weighting	Health	Hand control	Vision	Discomfort	Perception	Motion sickness
W_b	z-seat	—	—	z-seat x-, y-, z-feet z-standing vertical lying	z-seat — z-standing vertical lying	—
W_c	x-back	—	—	x-back	—	—
W_d	x-seat y-seat	x-seat y-seat	— —	x-seat y-seat x-, y-standing horizontal lying y-, z-back	x-seat y-seat x-, y-standing horizontal lying	—
W_e	—	—	—	r_x , r_y , r_z seat	—	—
W_f	—	—	—	—	—	z-vertical
W_g	—	z-seat	z-seat	—	—	—

3.4.3 Frequency weightings. Table 2 gives the frequency weightings required to give an approximate quantification of the relative effects of different vibration frequencies on human health, performance, comfort, perception and motion sickness.

NOTE 1 The phase is defined by the filter characteristics and although it is not specifically employed in the vibration analysis procedure it may affect the crest factor.

NOTE 2 The frequency weightings defined by the equations should normally be used. Asymptotic approximations to the weightings (using straight line approximations) are presented in Table 3 for approximate use only.

NOTE 3 Frequency weighting W_g is consistent with the weighting for z-axis vibration given in BS 6472, ISO 2631 and ISO 8041 over the range 1.0 Hz to 80 Hz. In this British Standard, weighting W_g is only used to quantify the severity of motions which may interfere with activities when the dominant motion is in the range from 1.0 Hz to 80 Hz.