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Clinical Biomechanics 20 (2005) 372–380

CLINICAL BIOMECHANICS

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Absorbed power of small children

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Received 28 October 2003; accepted 2 December 2004

Abstract

Objective. To experimentally measure the seated vertical direction whole-body absorbed power characteristics of small children less than 18 kg in mass.

Background. Several studies have reported whole-body absorbed power for adult humans, but no data has been published previously for small children.

Methods. Eight children were tested in a laboratory test rig which incorporated safety features which satisfy existing international standards for human testing. Force and acceleration were measured at the point of input to a rigid seat at a sampling rate of 200 Hz, and analysis was performed over the interval from 1.0 to 45.0 Hz. A double normalised (both input acceleration and test subject mass) measure of absorbed power was used.

Results. The vertical whole-body power absorption characteristics of the small children were found to present differences with respect to those of adults. The mean frequency of peak absorption was found to be 7.4 Hz as opposed to approximately 4.0–5.0 for adults. The interval of absorption was found to be from approximately 3 to 16 Hz and the total double normalised absorbed power was found to be 86% that of adults.

Conclusions. The differences in dynamic response between small children and adults raise questions regarding the applicability of whole-body vibration guidelines such as ISO-2631 in the case of small children since these guidelines were developed from mechanical and subjective response data of adults.

Relevance

Knowledge of the differences in whole-body vibration response between small children and adults is useful towards the design of systems intended for children such as child seats. The child data may also prove useful should absorbed power find application as a screening tool in clinical settings.

Keywords: Children; Whole-body; Vibration; Absorbed; Power; Seat

1. Introduction

Numerous research studies have measured the whole-body vibration response of adult humans (Dupius and Zerlett, 1986; Griffin, 1990). One response property which has been proposed as a possible metric of the human susceptibility to the physically damaging effects of mechanical vibration has been the absorbed power. The use of absorbed power has origin in the assumption that energy absorbed by the body is energy which can strain and heat internal structures. There has been some debate (Lundström and Holmlund, 1998; Mansfield and Griffin, 1998) regarding the use of absorbed power, as opposed to frequency weightings derived from subjective responses, as a measure of damage potential. While the clinical interpretation of absorbed power requires further investigation, the measurements themselves remain important descriptions of human biomechanical response.

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doi:10.1016/j.clinbiomech.2004.12.001

The origins of the absorbed power approach can be traced to a study by Weis et al. (1964) which treated the theoretical framework and the possible uses of human driving point mechanical impedance measurements. The authors noted that the two quantities used to determine mechanical impedance also defined the instantaneous power

$$P(\omega) = F(\omega)V(\omega) \tag{1}$$

where $P(\omega)$ is the instantaneous power, $F(\omega)$ is the instantaneous force, $V(\omega)$ is the instantaneous velocity and ω the frequency of oscillation. The expression for the instantaneous power could therefore be rearranged in terms of impedance.

$$P(\omega) = Z(\omega)V(\omega)V(\omega) = Z(\omega) \mid V(\omega)|^2 \tag{2}$$

Since impedance $Z(\omega)$ is a complex measure the authors suggested inspecting the real and imaginary parts individually

$$Z_{\mathrm{Re}}(\omega) =\mid Z(\omega) \mid \cos \angle Z(\omega) \tag{3}$$

and

$$Z_{\mathrm{Im}}(\omega) =\mid Z(\omega) \mid \sin \angle Z(\omega) \tag{4}$$

The motion of a pure mass element, which does not absorb energy, is characterised by a velocity lag of 90° with respect to the force. Likewise, the motion of a linear spring which is also incapable of energy absorption is characterised by a velocity which leads the force by 90°. The motion of a linear (viscous) damper which dissipates energy is characterised by a velocity and force which are in phase. These observations suggest that only the real component of the power, and thus of a measured impedance, represents energy that is not returned to the vibrating surface from the body. Weis et al. noted that only the imaginary part of their whole-body data sets was significant at frequencies below 5 Hz, suggesting that the human body acted as a mass below this frequency. The data sets had large values of both the imaginary and the real parts of the impedance in the region from 5 to 15 Hz, and the balance between the two was found to be "complex and highly dependent on sitting posture" for frequencies greater than 15 Hz. The region from 5 to 15 Hz was therefore singled out as important due to the high transfer of energy into the body.

Lee and Pradko (1968) presented the results of what was described as "extensive testing" of seated human subjects. Tabulated values of impedance modulus, impedance phase angle and absorbed power were presented for the frequency interval from 0 to 12 Hz. Results for all three axis of seated whole-body vibration were presented as well as vertical absorbed power for the feet alone. Lee and Pradko suggested the potential superiority of absorbed power over driving point measurements of mechanical impedance due to absorbed power being a physically interpretable quantity and because, being a scalar, it could be easily summed along different axis.

Lundström et al. (1998) presented absorbed power data for 15 males and 15 females tested using sinusoidal vibration from 2 to 100 Hz at root mean square (r.m.s.) amplitudes from 0.5 to 1.4 m/s^2. Absorbed power was found to increase with frequency until 4–6 Hz after which it decreased. The frequency of maximum absorbed power decreased with increasing amplitude of vibration and when changing from an erect to a relaxed posture. The absorbed power was found to increase with the square of the input acceleration amplitude and proportionally with subject mass. To facilitate comparisons the authors mass normalised their data, and the resulting curves were found to be nearly identical to the 1968 Lee and Pradko results. A further point noted by the authors was the difference in the frequency dependence of their average absorbed power curves with respect to the frequency weightings of ISO 2631-1 (1997) which are based on subjective response data. The authors suggested that if absorbed power were found to be predictive of damage to biological tissue then the ISO weightings were overestimating the damage potential at frequencies below 6 Hz while underestimating the damage potential for frequencies greater than 6 Hz.

Lundström and Holmlund (1998) presented absorbed power data for the same group of 15 male and 15 female subjects, but along three axis of vibration. Sinusoidal vibration was used at frequencies from 1 to 80 Hz and r.m.s. amplitudes from 0.25 to 1.4 m/s^2. Absorbed power was found to increase with frequency up to a peak in the interval from 4 to 6 Hz for vertical vibration and to increase up to 3 Hz for fore-and-aft and lateral vibration. Females were found to absorb greater power per kilogram than males. The authors again noted the different conclusions that would be drawn by use of the ISO 2631 frequency weightings as opposed to a line of constant absorbed power.

Mansfield and Griffin (1998) measured seated absorbed power for 12 male subjects using random excitation in the interval from 0.2 to 20 Hz at r.m.s. acceleration amplitudes from 0.25 to 2.5 m/s^2. The authors noted that it was convenient to determine the absorbed power from the cross spectrum between the velocity and force as

$$P_{abs}(\omega) = P_{\mathrm{Re}}(\omega) =\mid G_{\mathrm{VF}}(\omega) \mid \cos(\theta(\omega)) \tag{5}$$

where $|G_{\mathrm{VF}}(\omega)|$ is the modulus and $\theta(\omega)$ the phase angle of the cross spectrum between the driving point input velocity and output force. Since absorbed power increases with the square of the acceleration the authors chose acceleration to normalise their data, compensating in this way any variations in the tests. The mean frequency of maximum absorption was found to be 5 Hz. This frequency was lower, and the absorption greater, at high vibration amplitudes. The authors compared