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A STUDY OF BODY POSTURE ON HUMAN COMFORT UNDER THE INFLUENCE OF WHOLE-BODY VIBRATIONS FOR THE RAIL PASSENGERS

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ABSTRACT

When traveling by train, passengers are exposed to vibration. A well designed seat will attenuate the vibration path to the person in the frequency region where it is the most perceptible, between 3 and 10 Hz.

This paper studies the relationship between posture and the human response to vibration.

The pressure on the spinal discs has been measured for different postures and it has been found that sitting in a relaxed posture results in a lower intervertebral discs pressure than standing; however, sitting in a upright posture without a suitable back support causes the greatest loading on the spine. Experiments have been performed to examine the perceived discomfort of sitting in a seat with varying backrest angles. Generally, as the backrest is reclined, the discomfort decreases.

It has been found that for a tense posture, both the magnitude and frequency of the resonant peak increase comparated to a relaxed posture. This paper concluded that the seat has a great influence on the posture adopted by the passenger, and that a seat with mechanical damping in the 3 to 10 Hz range and a design that encourages a relaxed posture with a slightly reclined backrest will minimize discomfort.

KEYWORDS: vibration, whole-body, vehicle seat, posture, health, comfort

1. INTRODUCTION

When traveling by train, passengers are exposed to vibration. The effects of the vibration depend on the waveform, magnitude, direction and duration, and can be broadly categorized in terms of issues of perception, comfort, health, performance (physical and cognitive) and motion sickness. It is important to minimize the effects of vibration on passengers and staff to protect their health, to maximize their productivity, in order to comply with relevant health and safety recommendations and legislation [1].

Kitazaki and Griffin (1998) [8] commented that workers in vibration environments are more likely to suffer from back problems than other workers not exposed to whole-body vibration (WBV).

Rehn *et al.* [14] concluded that exposure to shock and vibration which occur in vehicles may contribute to musculoskeletal disorders, as the driver/operator has tensed muscles in order to maintain balance and to work the controls.

Grieco (1986) [3] emphasized the importance of correct seat design in order to reduce stress and injury. Surveys of vehicle drivers have often found the prevalence of back pain to be greater than 25%, even when other risk factors, such as WBV, are small (e.g. Porter and Gyi (2002) [13], Porter *et al.* (1992) [12]). Therefore, when considering health risks due to any potential pathogen and/or confounder (e.g. WBV in a compromised posture) it is essential that comparisons of musculoskeletal symptoms are made with an appropriate control group.

Biomechanical studies on the effect of backrest inclination on health risk have focused on intervertebral discs pressures. In a later publication, Nachemson presented a wider range of postures [10], [11], the results of which were summarized by Goel *et al.* (1999) [2] as a set of relative scores as shown in Table 1.

Table 1. Loading on the spine for different postures as measured by Nachemson (1985).

Recumbent supine	43%
Sitting with a seat backrest angle 1000, seat reclined with armrest	57%
Sitting in an office chair	71%
Sitting in an office chair, arms extended holding 20N	100%
Standing	100%
Upright sitting without back support	143%

In a concluding remark, these authors commented that constantly changing position is important to promote the flow of nutritional fluid to the spine. The relevant results from their experiments (again normalized to the standing position) are shown in Table 2.

Table 2. Loading on the spine for different postures as measured by Wilke *et al.* (1999) [15].

Recumbent supine	20%
Sitting slouched	54%
Sitting relaxed without backrest	92%
Standing (relaxed)	100%
Sitting actively straightening back	110%
Sitting with maximum flexion	166%

Table 3. Spinal loading for different sitting positions as calculated by Kayis and Hoang [7]

Seat pan (deg)	Backrest angle (deg)	Posture	Disc force (relative %)
0	90	Upright	100
0	90	Slouched/slumped	126
0	90	Bent forward	146
0	110	Leaning backward, full backrest use	54
5	95	Erect trunk	95
5	95	Bent forward	122
5	115	Leaning backward, full backrest use	71
5	115	Leaning backward, partial backrest use	64
-5	-	Erect trunk, no backrest	105
-5	-	Leaning forward, no backrest	135
-5	105	Leaning backward, full backrest use	78

In a study of reclining office chairs, Lengsfeld *et al.* [9] examined the influence that chair design has on lumbar spine curvature and concluded that a chair which has a seat pan that tilts along with the seat back produces the minimum stress on the lower back. Kayis and Hoang [7] investigated the effects of posture, seat pan angle and backrest angle on the spinal disc loadings. They produced a computer model of the spine under differing conditions, calibrated it using data from human participants. The output of the model can be summarised as shown in Table 3.

Although the majority of people on a moving train are sitting, there are situations when passengers or staff would be travelling whilst standing in an upright posture (for example, passengers on a busy commuter train, or staff going about their usual business).

2. MEASUREMENTS AND DISCUSSION

The study was made on a total of five men and five women aged between 23 and 47 years, with weights between 56 and 91 kg. Train distance was 93km. These individuals were asked to stand, sit and supine on the bench. The basicentrics coordinate systems are according to SR ISO 2631-1 [4] (Fig. 1).

Positioning and calibration of the equipment were carried out according to ISO 2631-4 [5] and respectively ISO 5347-5 [6].

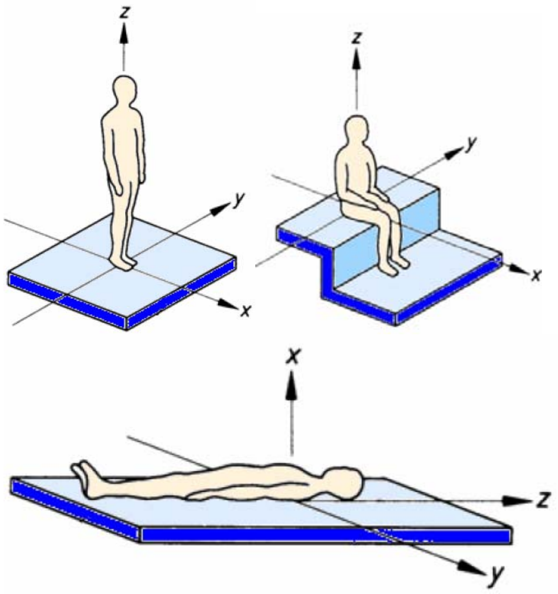

Fig. 1. Basicentrics coordinate systems. Directions for operating the mechanical vibration on the human body (SR ISO 2631-1)

The accelerations on the x, y and z axis were measured with MAESTRO vibrometers and with 01dB triaxial seat-pad accelerometers, set up at the seat/driver separation surface (see Fig. 2).

Fig. 2. MAESTRO vibrometer and 01dB triaxial seat-pad accelerometer

The threshold levels were then determined by the application of signal detection theory. No significant differences were found between male and female participants for vertical vibration stimuli. However, significant differences were found between perception thresholds for seated, standing and supine participants. It was concluded that participants tend to be more sensitive to vibration when lying than when sitting or standing. The results of the experiments using steady-state sinusoidal excitation are shown in Fig. 3.a to Fig. 3.g.

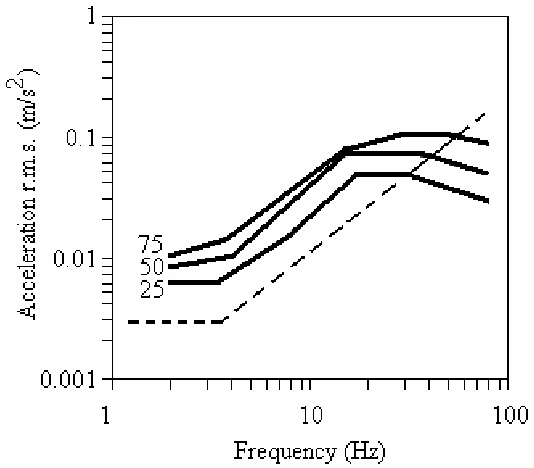

Fig. 3.a. Variation of acceleration for x-axis for the sitting position

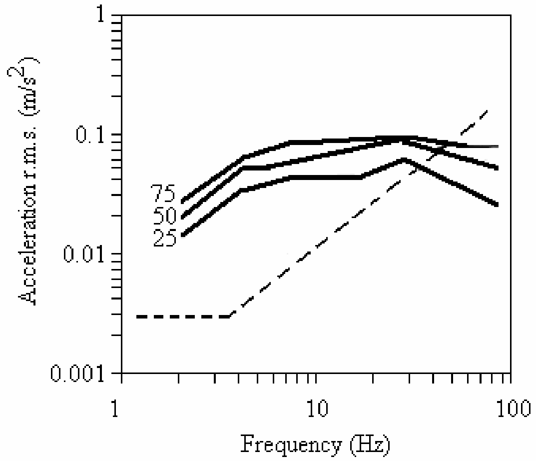

Fig. 3.b. Variation of acceleration for x-axis for the standing position

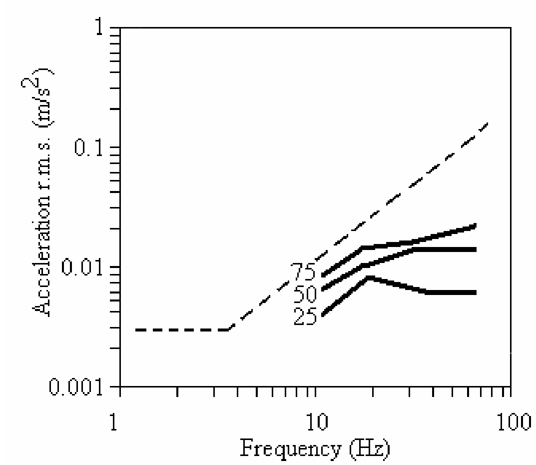

Fig. 3.c. Variation of acceleration for x-axis for the supine position

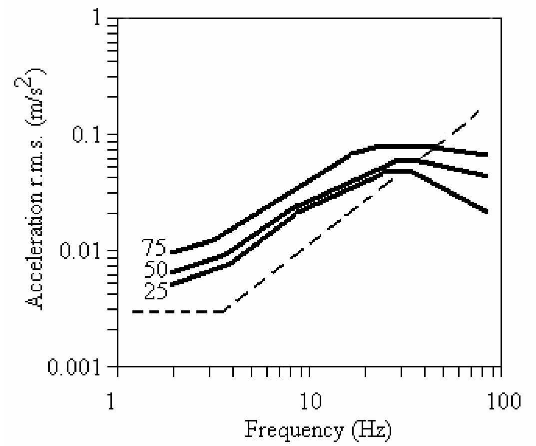

Fig. 3.d. Variation of acceleration for y-axis for the sitting position

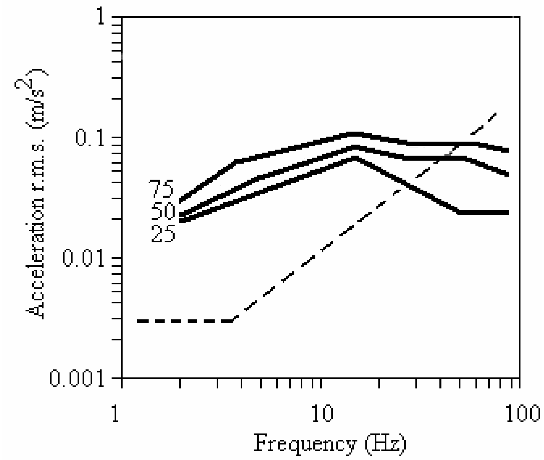

Fig. 3.e. Variation of acceleration for y-axis for the standing position

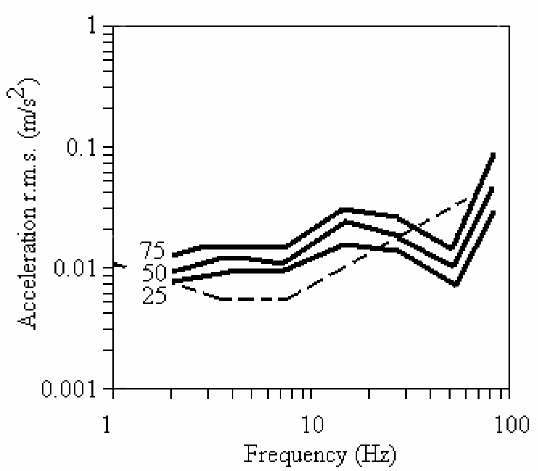

Fig. 3.f. Variation of acceleration for z-axis for the sitting position

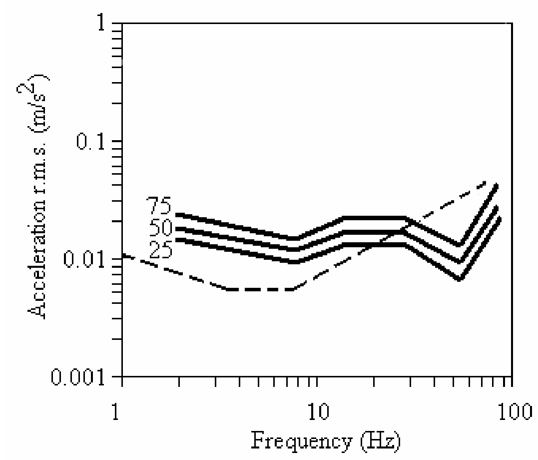

Fig. 3.g. Variation of acceleration for z-axis for the standing position

Fig. 3. presents a comparison of x-, y- and z-axis perception thresholds for sitting, standing and lying participants for 25^0, 50^0 and 75^0 inclination. (Note that the ISO curves in the z-axis are those from a superseded version of the standard) (dotted line - ISO 2631 curve).

The vibration discomfort was studied over a wide range of rigid seat backrest angles (from horizontal to vertical). It was found that the vibration induced discomfort increased with decreasing backrest angle (i.e. the 0 degree, recumbent, position was considered to be more uncomfortable than the 67.5 degree position).

The results are shown in Fig. 4, from which it can be seen that there is a smooth transition from 0 degrees to 67.5 degrees and that there is a maximum level of discomfort at 8 Hz. The results for a 90 degree (upright) are slightly different in that they show a higher level of discomfort than at 67.5 and 45 degrees, this is due to the un-natural posture that is enforced by sitting in a rigid seat with a 90 degree backrest angle – most seats have a backrest angle of around 80 degrees.

The physiological experiments consisted in placing transducers in the spine and measuring the intervertebral discs pressure.

These results are shown in Fig. 5, clearly demonstrating that increasing the size of the lumbar support reduces the intervertebral discs pressure.

3. CONCLUSIONS

This chapter has discussed the influence of posture on the human response to vibration. Standing, sitting and supine postures are discussed; however, the majority of the literature discusses seated postures.

Experiments are discussed in which the spinal intervertebral discs pressure had been measured with different postures (under a no-vibration condition), and it was shown that a relaxed sitting posture with a slightly reclined backrest was optimal.

It has also been shown that the angle of the seat backrest influences the perceived discomfort whilst under a vibration condition, discomfort decreasing as the backrest changes from upright to horizontal.

The seat has a great influence on the posture adopted by the passenger, and a seat with mechanical damping in the 3 to 10 Hz range and a design that encourages a relaxed posture with a slightly reclined backrest will minimise discomfort.

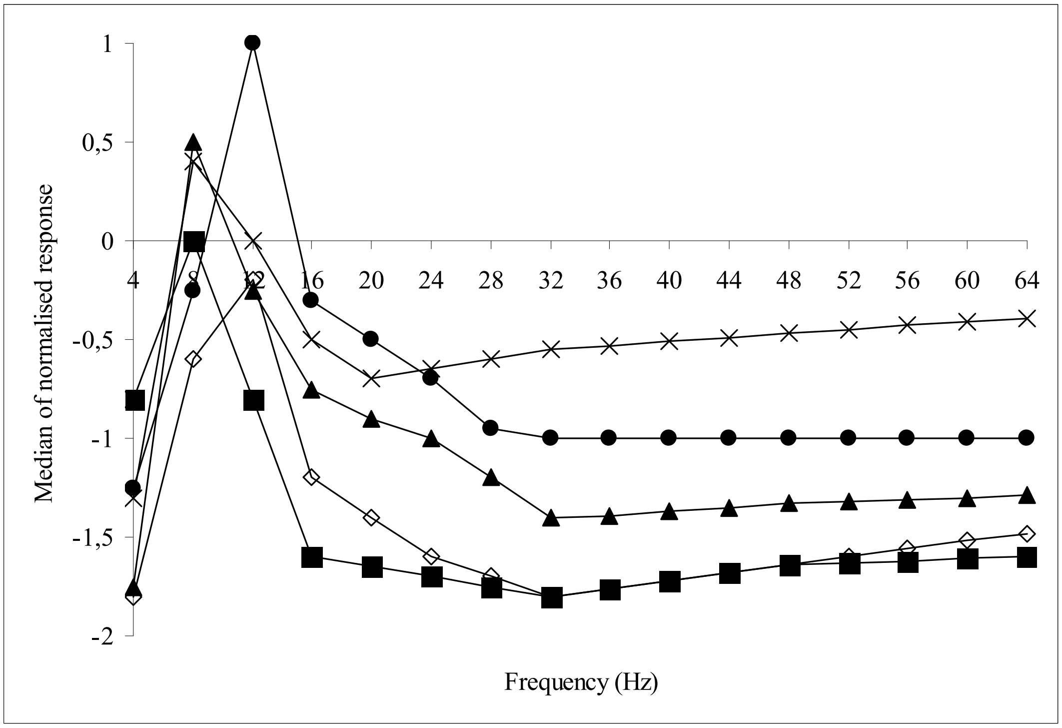

Fig. 4. Combined effects of backrest angle and frequency of vibration on the median normalised response (●) 0^0; (▲) $22,5^0$; (■) 45^0; (◊) $67,5^0$; (**X**) 90^0

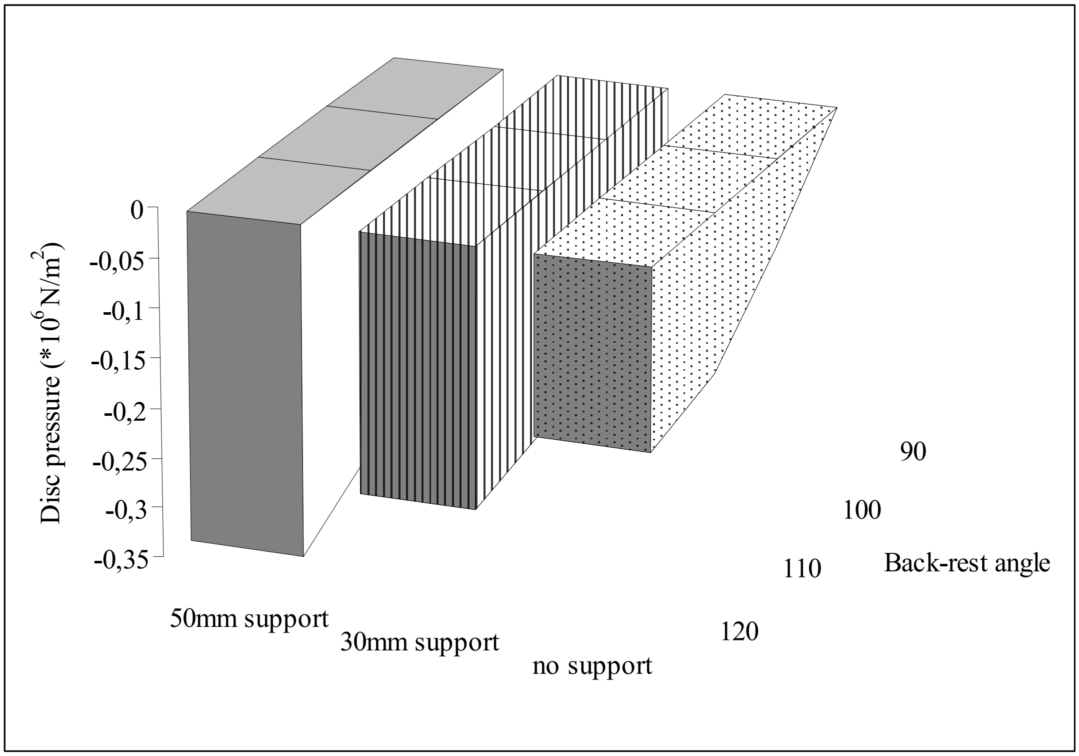

Fig. 5. The effects of backrest angle and size of lumbar support on intervertebral discs pressure of the spine (⧫) – No lumbar support, (●) – 30mm lumbar support, (■) – 50mm lumbar support

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