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Measurement of Whole-Body Vibration in Taxi Drivers

Mitsuhiko FUNAKOSHI[1], Kazushi TAODA[2], Hiroji TSUJIMURA[2] and Katsuo NISHIYAMA[2]

[1]Kyushu Institute for Social Medicine and [2]Department of Preventive Medicine, Shiga University of Medical Science, Japan

Abstract: Measurement of Whole-Body Vibration in Taxi Drivers: Mitsuhiko FUNAKOSHI, *et al.* Kyushu Institute for Social Medicine—In a previous epidemiological study we reported that the prevalence (45.8%) of low-back pain (LBP) and the two-year incidence (25.9%) of LBP in 284 male taxi drivers in Japan was comparable with rates reported for other occupational drivers in which LBP frequently occurs. LBP was significantly related with the level of uncomfortable road vibrations, and, importantly, increased with total mileage. The aim of this study was to measure whole-body vibration (WBV) on the driver's seat pan of 12 taxis operating under actual working conditions. The results were evaluated according to the health guidelines in International Standard ISO 2631-1:1997. Finally, the relation between total mileage and WBV was investigated. The majority of the frequency-weighted r.m.s. accelerations of the taxis fell into the "potential health risks" zone, under ISO 2631-1:1997. It was clear that the taxi drivers were exposed to serious WBV magnitudes. Therefore, occupational health and safety management should be carried out to help prevent adverse health effects in taxi drivers. In particular, reduction of WBV in taxis and shortening of driving time to reduce duration of WBV exposure should be considered. Moreover, because many taxi drivers work 18 h every other day, the shortening of working hours and taking of rest breaks while working should be considered. Frequency-weighted r.m.s. accelerations of taxis had a tendency to decrease as total mileage increased. The relation between total mileage and WBV should be investigated by taking measurements on the floor and the back rest in addition to the seat pan.
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Correspondence to: M. Funakoshi, Kyushu Institute for Social Medicine, 5–14–20 Chiyo, Hakata-ku, Fukuoka 812-0044, Japan (e-mail: funakosi@wc4.so-net.ne.jp)

In a previous epidemiological study we reported that the prevalence (45.8%) of low-back pain (LBP) and incidence (13.0%) of LBP in 284 male taxi drivers in Japan was comparable with rates reported for other occupational drivers in which LBP frequently occurs[1]. LBP was significantly related with the suitability of the driver's seat pan, total mileage on the taxi (total mileage), level of uncomfortable road vibrations, job stress and time employed as a taxi driver. Importantly, the prevalence of LBP increased as total mileage increased, a finding that had not previously been reported. Therefore, the findings of this study also suggest that ergonomic problems with driver's seat pans, whole-body vibration (WBV) and job stress may contribute to LBP in taxi drivers. We concluded that WBV during normal use of taxis should be measured to evaluate the relationship between WBV and LBP.

LBP occurring in professional drivers, such as bus drivers[2], truck drivers[3], agricultural tractor drivers[4–6], freight container tractor drivers[7] and forklift operators[8] has been investigated in several studies[9]. Moreover, measurements of WBV have been performed in the studies so as to evaluate the relationship between WBV and LBP. For example, Bovenzi and Zandini[10] found that the chance of low-back symptoms having occurred in drivers in the previous 12 months increased with greater exposure to WBV, expressed in terms of total vibration dose (years m^2/s^4), equivalent vibration dose (m/s^2) and duration of exposure (years of service).

Although taxi drivers are exposed to mechanical WBV under their normal work conditions and WBV is suspected as a causative factor of LBP, none of the studies showed that WBV in taxis has ever been researched. In Japan, there are about 4 times as many taxi drivers (approx. 400,000) as bus drivers (approx. 110,000)[11]. Therefore, measurement of WBV in taxis may be a significant factor in occupational and safety management. Additionally, the working hours of taxi drivers in Japan are very long; it is reported that drivers work 18 h every other day. Therefore, it may be very interesting to evaluate WBV in taxis in regard to the health effects of exposure to many

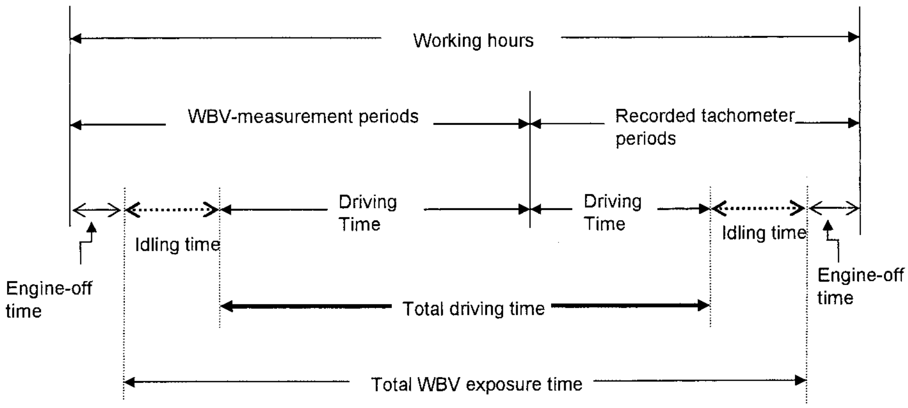

Fig. 1. Structure for measuring time.

hours of WBV.

The aim of this study was to measure vibration on the driver's seat pan in taxis with a measuring instrument that we had developed to measure long-duration WBV[12]. The results were evaluated according to the health guidelines in the International Standard ISO 2631-1[13]. Finally, the relationship between total mileage and WBV was investigated, which showed the prevalence of LBP to increase as total mileage increased.

Vehicles and Methods

Vehicles

Primarily 2 different types of special cars (Nissan Motor Co., Ltd., Crew; and Toyota Motor Corp., Comfort) are being used as taxis in Japan. We conducted the assessment of working conditions and WBV under actual working conditions with 12 of the Nissan Crew taxis (Nissan Motor Co., Ltd., Crew, 2000 cc displacement) and 12 drivers (mean age 53.8, mean body weight 64.9 kg; range 49–83 kg) from the same company. Because the prevalence of LBP increased when total mileage exceeded 150,000 km, 2 cars were selected from the under 100,000 km, 100,000–150,000 km, and 150,000–200,000 km total mileage categories, and 6 cars were selected from the over 200,000 km category, in order to examine the relationship between total mileage and WBV.

WBV in the taxis was measured for over 4 h as they were driven around Fukuoka City, Japan, under normal conditions. The roads in the area were fully paved and without excessive bumps. We therefore estimated that road conditions among taxis were similar. Vibration could not be completely measured throughout all the driving hours, but we estimated that the resulting values were representative of the true WBV experienced by the taxi drivers under different kinds of driving conditions, such as acceleration, deceleration and stopping.

Methods

WBV was measured on the driver-seat pan of the taxis under actual working conditions, according to the requirements of International Standard ISO 2631-1[13]. The company drivers worked an 18-h shift (0730–0130) every 2 d (18 h on, 30 h off). Therefore, measurement was performed from commencement of work up to the limit imposed by the capacities of the electrical batteries. WBV was measured at the driver/seat interface by using a RION PV-62 triaxial seat pad accelerometer. The 3-axis recorded signals were amplified, converted to voltage and filtered (1 Hz<) with a RION VX-10 3-channel charge amplifier and acquired at 1,000 samples per second with 16 bit resolution digitization in a TEAC Co., Ltd. DR-C2 PC Card recorder. From one-third octave band frequency spectra (1–80 Hz) of the signal recorded in the back-to-chest direction (x-axis), right-to-left direction (y-axis) and vertical direction (z-axis), frequency-weighted root-mean-square (r.m.s.) accelerations (a_{wx}, a_{wy}, a_{wz}) were obtained by using the weighting factors suggested by ISO 2631-1. The results were evaluated according to the health risk guidelines in Annex B of ISO 2631-1. Regarding comfort, the results were evaluated according to the health risk guidelines in Annex C of ISO 2631-1.

The 3 different working conditions (driving, idling and engine-off) were identified by using both the WBV results and the driving records from tachometers (Fig 1). We could distinguish the 3 different working conditions by the WBV results during the WBV-measurement period. Total driving time was obtained by adding up driving time both in and outside the WBV-measurement period. Finally, total driving time was defined as total time exposed to WBV. The total mileage of each taxi was confirmed from company records.

Table 1. Driving time, WBV magnitude and total mileage

Taxi	Total mileage (km)	WBV-measurement periods		Recorded tachometer periods	Total driving time c) (h:m)	a_{wz} (m/s²)	a_{wy} (m/s²)	a_{wx} (m/s²)	***Health*** (m/s²)	***Comfort*** (m/s²)
		Measuring time (h:m)	Driving time a) (h:m)	Driving time b) (h:m)						
A	58,032	9:06	3:59	4:10	8:09	0.30	0.14	0.15	0.42	0.37
B	96,320	10:31	7:04	2:50	9:54	0.34	0.14	0.18	0.47	0.41
C	129,888	17:55	11:50	0:14	12:04	0.33	0.18	0.23	0.52	0.44
D	142,486	17:16	6:06	0:39	6:45	0.31	0.17	0.18	0.46	0.39
E	166,431	14:54	8:59	2:52	11:51	0.32	0.18	0.19	0.49	0.41
F	170,000	17:39	14:01	1:25	15:26	0.31	0.16	0.14	0.43	0.38
G	240,426	7:41	5:51	7:10	13:01	0.29	0.15	0.14	0.40	0.35
H	242,303	15:36	11:03	1:40	12:43	0.31	0.15	0.16	0.43	0.38
I	244,385	15:04	12:57	3:34	16:31	0.29	0.16	0.16	0.43	0.37
J	266,952	16:11	11:31	1:40	13:11	0.30	0.16	0.18	0.45	0.38
K	300,071	14:56	8:53	2:15	11:08	0.30	0.16	0.13	0.41	0.36
L	302,000	16:55	11:03	0:51	11:54	0.26	0.13	0.13	0.37	0.32
Mean 1	196,608	14:29	9:26	2:26	11:53	0.31	0.16	0.16	0.44	0.38
Mean 2	215,878	14:44	10:19	2:27	12:46	0.31	0.16	0.16	0.44	0.38

a_{wz}, a_{wy} and a_{wz} are weighted root-mean-square accelerations on the seat pan with respect to the orthogonal axes x, y and z, according to ISO 2631-1: 1997. *Health* and *Comfort* defined by ISO 2631-1:1997 are the vibration total values for evaluation with respect to health and comfort if no dominant axis of vibration exists, Mean 1: All taxies, Mean 2: Except for A,D, c = a+b

Results and Discussion

WBV magnitude and total driving time

Because the mean total driving time of the measured taxis was 11:53 h (range 0645–1631), it was clear that the taxi drivers were exposed to many hours of mechanical vibration (Table 1), but, because some drivers attended meetings during working hours on the days of measurement, the total driving time of 2 of the 12 drivers was shorter than on ordinary days. Therefore, after taking into account these 2 drivers, the mean total driving time becomes 12:46 h (range 0954–1631).

Table 1 shows the mean values for the x-, y-, z-axes frequency-weighted r.m.s. accelerations measured on the seat pan. The z-axis weighted acceleration was the predominant directional component of vibration measured. The mean z-axis weighted acceleration was 0.31 m/s² (range 0.26–0.34 m/s²). These vibration magnitudes were smaller than those reported by Paddan and Griffin[14] in a recent survey of occupational exposure to WBV. Their survey found that the mean acceleration (vertical) of 25 cars in Great Britain was 0.43 m/s² (range 0.26–0.75 m/s²). The differences in WBV magnitudes may be due to the types of vehicles, as they measured many types (including small vehicles and four-wheel drive off-road vehicles).

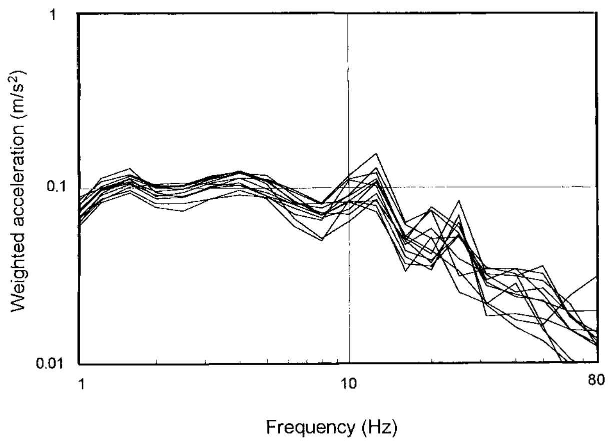

Fig. 2. Spectral analysis of the vertical vibration measured on the seat pans of 12 taxis.

Frequency analysis of the WBV

Frequency analysis of the vertical WBV measured on the seat pan of 12 taxis is shown in Fig. 2. Although there was variation in the spectra for the different measurements, the underlying trend was the same. Frequency analysis of the vibration recorded on the seat pan of taxis showed acceleration peaks at 1–6 Hz and 10 Hz. Biodynamic experiments have shown that the lumbar tract of the spine resonates in the 4–5 Hz frequency range

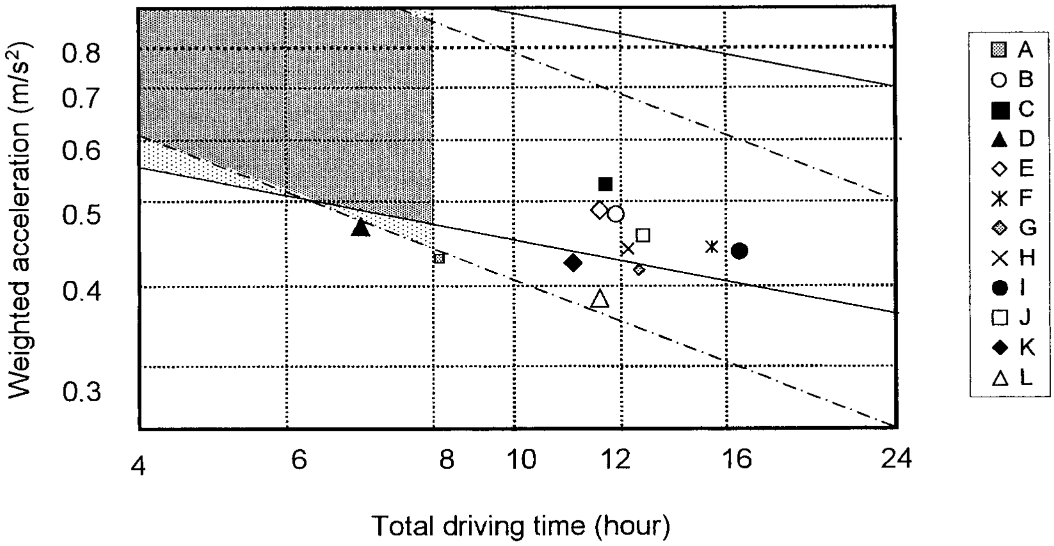

Fig. 3. Total driving time and *Health* in the health guidance caution zones from ISO 2631-1. The gray zone indicates a "potential health risks" zone.

in a seated subject exposed to vertical vibration[15, 16]. Under resonance large relative displacements between the lumbar vertebrae take place. Therefore, it was likely that the lumbar tract of the taxi drivers' spines was overloaded by mechanical vibration during actual driving conditions[17].

Health risk and comfort during exposure to WBV in taxis

According to the European Committee for Standardization (CEN)[18], an axis is regarded as dominant when the weighted r.m.s. value in each of the other two axes, multiplied by 1.4 in the case of x and y axes, is less than 66% of that in the dominant axis. Our results found that there was no dominant axis among the x-, y-, z-vectorial components of the frequency-weighted r.m.s. accelerations. Therefore, the vector sum of the frequency-weighted r.m.s. accelerations, ***Health***, was calculated to evaluate the health risk from exposure to WBV, according to the following formula from ISO 2631-1:1997:

$$\boldsymbol{Health} = [(1.4a_{wx})^2+(1.4a_{wy})^2+a_{wz}^2]^{1/2}$$

Additionally, the vector sum of the frequency-weighted r.m.s. accelerations, ***Comfort***, was calculated to evaluate comfort during exposure to WBV, according to the following formula from ISO 2631-1:1997:

$$\boldsymbol{Comfort} = (a_{wx}^2+a_{wy}^2+a_{wz}^2)^{1/2}$$

Figure 3 shows that the ***Health*** values of 10 of the 12 taxis drivers (83%) fall into the "potential health risks" zone. Except for the 2 taxis and 2 drivers that drove for a shorter time, all of the ***Health*** values for drivers fell into the "potential health risks" zone.

According to the equation (B.1, Annex B of ISO 2631-1) that gives the lower bound of the "potential health risks" zone, the daily WBV exposure time *T* was calculated by means of the following equation:

$$\boldsymbol{T} = (600{*}3^2)/a_w^2$$

Because the mean ***Health*** value of the 12 taxis was 0.44 m/s^2, the daily permitted WBV exposure time was 10:04 h (range 0533–1057), but the mean total driving time of 12 taxi drivers was about 12 h. Therefore, under the current vibration magnitude conditions, the taxi drivers should not be allowed to drive for 12 h in each shift.

It was clear that the taxi drivers were exposed to serious WBV magnitudes, but the risks of LBP might be reduced by their days off. The role of WBV in the aetiopathogenesis of LBP is not yet fully understood, but the combination of WBV exposure and ergonomic problems, such as suitability of the driver's seat may increase the risks of LBP[3, 19]. In most cases, only a combination of preventive actions, such as technical prevention aimed at the elimination or reduction of WBV at the source, organizational changes in the work place, personal protection and medical prevention, can be expected to lead to a successful reduction in vibration exposure[20]. Moreover, the EU Directive (2002/44/EC) defines "the minimum health and safety requirements" for the exposure of workers to the risks arising from vibration[21]. For WBV, the Directive defines an 8-h energy-equivalent "exposure action value" (EAV) of 0.5 m/s^2. The Directive says that on the basis of the risk assessment, once the EAV is exceeded, the employer shall,

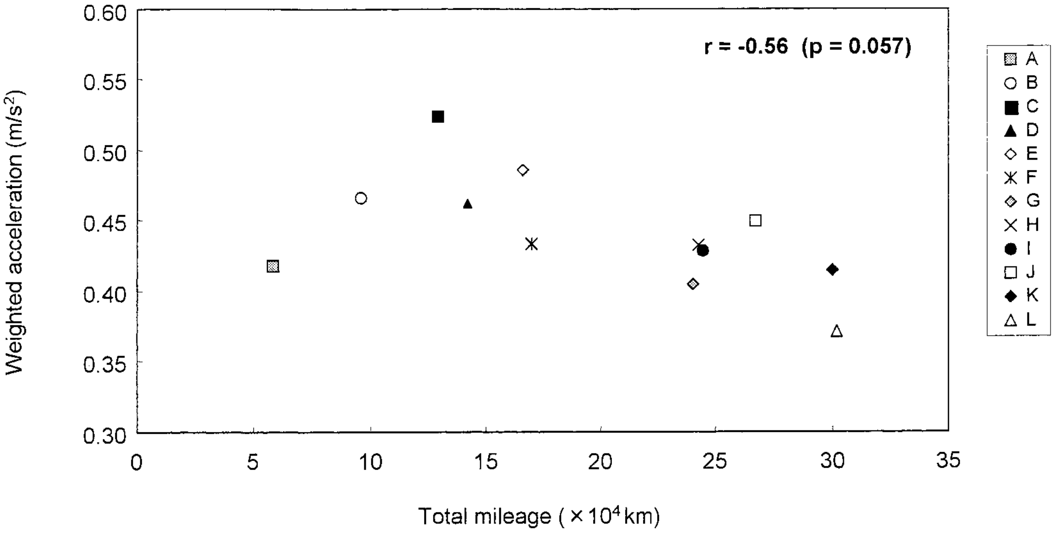

Fig. 4. Total mileage and *Health* defined by ISO 2631-1:1997.

in addition to health surveillance, establish and implement a program of technical and/or organizational measures to reduce to a minimum exposure to mechanical vibration and the attendant risks. Therefore, occupational health and safety management should be carried out to prevent adverse health effects in taxi drivers. In particular, reduction of WBV in taxis and shortening of driving time to reduce duration of WBV exposure should be considered.

In regard to ***Comfort***, the mean value was 0.38 m/s^2 (range 0.32–0.44 m/s^2), equivalent to "fairly uncomfortable" under Annex C of ISO 2631-1:1997, giving an indication of the likely reaction in public transport.

WBV magnitude and total mileage

Because our previous epidemiological study found that the prevalence of LBP in taxi drivers increased with total mileage, we had estimated that the ***Health*** values of the taxis would also increase with total mileage, but Fig. 4 shows that the ***Health*** values had a tendency to decrease as total mileage increased. As decreased hysteresis loss of the load-deflection characteristics of the urethane on the seat pan sometimes results in better response characteristics, it is possible that frequency-weighted r.m.s. accelerations on the seat pan might have a tendency to decrease as total mileage increases. Moreover, because of the rigidity of the body, the characteristics of the suspension, and the deterioration of the tires as total mileage increases, it is possible that frequency-weighted r.m.s. accelerations on the floor and the back rest increase. Consequently, it is possible that the prevalence of LBP in taxi drivers might increase with total mileage. This result suggests that, just as was comfort, the health effects of WBV should be further evaluated at the floor and back rest, in addition to the seat-pan evaluation. Therefore, it is necessary in the future to investigate the relationship between total mileage and frequency-weighted accelerations on the seat pan, floor and back rest.

Conclusion

Most of the frequency-weighted r.m.s. accelerations of the taxis were within the "potential health risks" zone according to ISO 2631-1:1997. It was clear that the taxi drivers were exposed to serious magnitudes of WBV. Therefore, occupational health and safety management should be carried out to prevent adverse health effects in taxi drivers. In particular, reduction of WBV in taxis and shortening of driving time to reduce the duration of WBV exposure should be considered. Moreover, because many taxi drivers work 18 h every other day, the shortening of working hours and taking of rest breaks while working should be considered.

Frequency-weighted r.m.s. accelerations of the taxis had a tendency to decrease as total mileage increased. It is necessary to further investigate the relationship between total mileage and WBV by taking measurements on the floor and back rest, in addition to the seat pan.

References

1) M Funakoshi, A Tamura, K Taoda, H Tsujimura and K Nishiyama: Risk factors for low back pain among taxi drivers in Japan. San Ei Shi 45, 235–247 (2003)
2) M Bovenzi and A Zadini: Self-related low back symptoms in urban bus drivers exposed to whole-body vibration and postural stress. Spine 17, 1048–1059 (1992)
3) ML Magnusson, MH Pope, DG Wilder and B Areskoug: Are occupational drivers at an increased risk

for developing musculoskeletal disorders? Spine 21, 710–717 (1996)

4) M Bovenzi and A Betta: Low back disorders in agricultural tractor drivers exposed to whole-body vibration and postural stress. Appl Ergon 25, 231–241 (1994)
5) A Kumar, M Varghese, D Mohan, P Mahajan, P Gulati and S Kale: Effect of whole-body vibration on the low back. A study of tractor-driving farmers in north India. Spine 24, 2506–2515 (1999)
6) M Futatsuka, S Maeda, T Inaoka, M Nagano, M Shono and T Miyakita: Whole-body vibration and health effects in the agricultural machinery drivers. Ind Health 36, 127–132 (1998)
7) K Nishiyama, K Taoda and T Kitahara: A decade of improvement in whole-body vibration and low back pain for freight container tractor drivers. J Sound Vib 215, 635–642 (1998)
8) K Miyashita, I Morioka, T Tanabe, H Iwata and S Takeda: Symptoms of construction workers exposed to whole body vibration and local vibration. Int Arch Occup Environ Health 64, 347–351 (1992)
9) Teschke K, Nicol A-M, Davies H, Ju S. Whole body vibration and back disorders among motor vehicle drivers and heavy equipment operators. A review of the scientific evidence. (Report to Worker’s Compensation Board of British Columbia) 1999: 1–21.
10) M Bovenzi and A Zadini: Self-reported low back symptoms in urban bus drivers exposed to whole-body vibration. Spine 17, 1048–1059 (1992)
11) Ministry of Land, Infrastructure and Transport. Rikuun Toukei Youran (summary of land transport statistics in Japan). Tokyo: Automobile Business Association of Japan, 2001: 1–10 (in Japanese).
12) H Tsujimura, K Taoda, T Kitahara, K Tomioa and K Nishiyama: Study on whole-body vibration exposure during normal use of forklift trucks. 10th Japan Group Meeting on Human Responses to Vibration, 161–167 (2002)
13) International Organization for Standardization 1997 ISO 2631-1, second edition. Guide for the evaluation of human exposure to whole body vibration. Prat 1: general requirements.
14) GS Paddan and MJ Griffin: Evaluation of whole-body vibration in vehicles. J Sound Vib 253, 195–213 (2002)
15) MJ Griffin: Handbook of Human Vibration. London: Academic Press, 1990: 171–220.
16) MH Pope, DG Wilder and ML Magnusson: A review of studies on seated whole body vibration and low back pain. Proc Inst Mech Eng [H] 213, 435–446 (1999)
17) M Bovenzi, I Pinto, and N Stacchini: Low back pain in port machinerry operators. J Sound Vib 253, 3–20 (2002)
18) European Committee for Standardization (1996) Mechanical vibration-Testing of mobile machinery in order to determine the whole-body vibration emission value-General. European Standard, EN 1032.
19) MC Battie, T Videman, LE Gibbons, H Manninen, K Gill, M Pope and J Kaprio: Occupational driving and lumbar disc degeneration: a case-control study. Lancet 360, 1369–1374 (2002)
20) MH Pope and ML Magnusson: Guidelines for whole-body vibration health surveillance. J Sound Vib 253, 131–167 (2002)
21) The European Parliament and the Council of the European Union (2002) On the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration). Directive 2002/44/EC; Official Journal of the European Communities, 6 July 2002; L177/13–19.