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4e Conférence internationale sur les risques liés à l'exposition aux vibrations transmises au corps entier

June 2 to 4, 2009, Montréal, Canada

4th International Conference on Whole Body Vibration Injuries

ACTES DE LA CONFÉRENCE

CONFERENCE PROCEEDINGS

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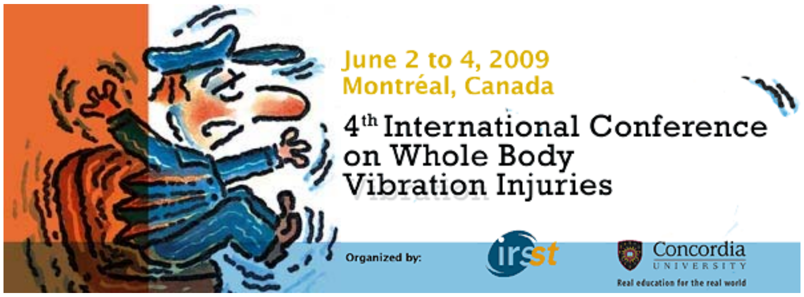

CONFERENCE PROCEEDINGS

SESSION 1: Epidemiology and Effects of Whole-Body Vibration

SESSION 2: Combined Effects of Whole-Body Vibration

SESSION 3: Biodynamics (1)

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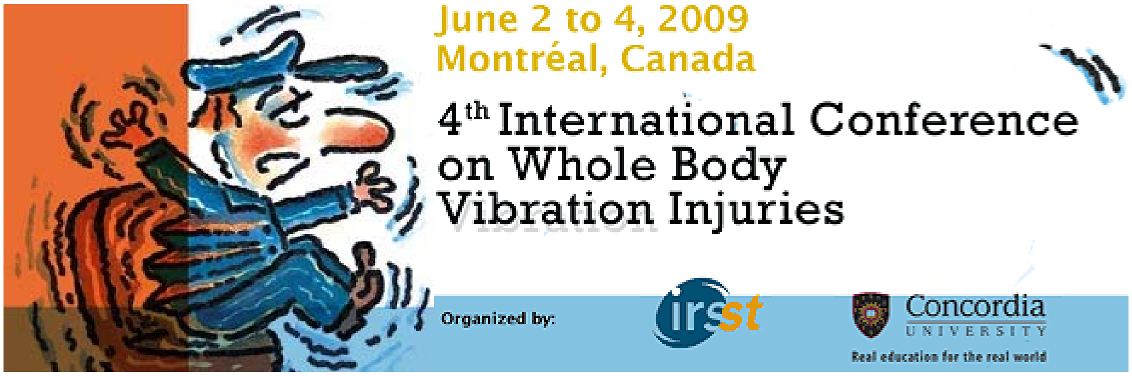

SESSION 1

EPIDEMIOLOGY AND EFFECTS OF WHOLE-BODY VIBRATION

LOW BACK PAIN IN DRIVERS EXPOSED TO WHOLE-BODY VIBRATION: THE VIBRISKS MULTICENTER STUDY

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Introduction

A multicenter research project on the risks of occupational vibration injuries (VIBRISKS) was conducted with financing from the European Commission. One of the objectives of this European multicenter study was to improve understanding of the risks of injury from exposure to whole-body vibration (WBV) at work by means of coordinated multi-national epidemiological field studies, supported by fundamental laboratory research and biodynamic modelling.

Methods

In four countries, Italy, Netherlands, Sweden, and the United Kingdom (UK), baseline and (one year) follow-up epidemiological surveys in groups of workers occupationally exposed to whole-body vibration (WBV) were conducted, using the same core protocol. Personal and occupational histories, low back pain (LBP) and general health were assessed by means of a standardised questionnaire, developed within the VIBRISKS project and translated into the four languages. Vibration measurements were performed on representative samples of the vehicles used by the driver groups in their daily activities. For all drivers, cumulative and daily vibration dose measures were assessed based on the vibration measurements and the exposure duration data from the questionnaire. The results of the studies in the four countries were published in a final technical report of the project [1] and in different papers in scientific journals. Various physical and, in some countries, psychosocial factors were found to be associated with an increased risk of LBP in some studies, but with different findings in the different countries. The Italian and the Dutch results were consistent with an increased risk of LBP in those with higher cumulative exposures to whole-body vibration, while the association between measures of daily vibration exposure and LBP differed between the two countries. Studies in Sweden and the UK did not find clear relationships between WBV and LBP.

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The individual data of the longitudinal studies in the four countries were also merged and stored into a common multicenter database. The purpose of this database is to enable analysis of comparable data from a large cohort of professional drivers in four European countries, offering additional opportunities for studying the relationship between exposure to WBV and health-related effects due to the larger population size and the wider distribution of the exposure.

Results

The study population of the multicenter study consists of drivers of a wide variety of vehicles such as earth-moving machines, fork-lift trucks, and public utility vehicles (Italy), forestry machines (Sweden), various industrial vehicles (Netherlands), and taxis and police cars (UK). The merged database includes comparable data from 1741 drivers and 484 'non-drivers' (UK police employees driving < 5 hours per week) at baseline and 1476 drivers and 300 non-drivers at the follow up (Table 1).

Table 1. Study population in four countries at baseline survey and at follow up survey

Country, population	**Baseline** (N)	**Follow up** (N)
Italy, drivers of earth-moving machines, fork-lifts, public utility vehicles	537	537
Netherlands, drivers of various industrial vehicles	318	265
Sweden, drivers of forestry machines	311	216
UK, taxi drivers	210	144
police drivers	365	219
police non-drivers (police employees driving < 5 hours per week)	484	300
Total	2225	1681

In general, the exposure to WBV ranged from low intensity (in the taxi and police drivers) to a higher intensity in the drivers of the earth-moving and forestry machines. Table 2 shows some preliminary LBP outcomes, point prevalence at baseline and one-year incidence, indicating that LBP is a prevalent symptom in the study population. Analysis of the relationship between various measures of WBV exposure, postural load, psychosocial aspects and various LBP outcomes in this pooled data is underway.

Table 2. Crude point prevalence and one-year incidence of low back pain (LBP) symptoms in the total study population (%)

LBP outcome measure	**Point prevalence at Baseline (N=2225)**	**Incidence at Follow up (N=1592)**
LBP last 7 days	22.2	7.8
LBP last 12 months	53.9	28.7
LBP Intensity (von Korff pain scale score ≥ 5) of respondents with LBP last 7 days	41.2	6.0
LBP disability (Roland Morris disability scale score ≥ 12) of respondents with LBP last 7 days or last episode	18.0	3.5

Conclusions

In a European multicenter research project, the relationship between exposure to WBV and LBP was studied in four countries. So far, the results have been analyzed on a national basis. Additional analysis on a merged dataset will be carried out.

References

[1] VIBRISKS Final Technical Report. (www.humanvibration.com/vibrisks/index.html)

A LONGITUDINAL STUDY OF LOW BACK PAIN AND DAILY VIBRATION EXPOSURE IN PROFESSIONAL DRIVERS

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Introduction

Occupational exposure to whole-body vibration (WBV) is associated with an increased risk of low back pain (LBP), [1]. The aims of this study were to investigate the incidence of LBP and the relation between LBP outcomes and measures of daily vibration exposure in Italian professional drivers recruited in a research project funded by the EU Commission (VIBRISKS).

Subjects and methods

The study population included 202 male professional drivers of earth-moving machines, fork-lift trucks, and public utility vehicles, who did not report LBP in the previous 12 months at the initial survey. They were investigated over a two-year follow up period (2004-06). Personal, occupational, and health histories were collected by means of a standardised questionnaire developed within the VIBRISKS project. LBP was assessed in terms of duration (days), intensity (numerical rating scale), and disability (Roland & Morris disability scale) treated as ordinal variables with three levels. Vibration measurements were performed on representative samples of the machines and vehicles used by the driver groups. The following measures of daily vibration exposure were obtained: (i) 8-h energy-equivalent frequency-weighted acceleration (highest axis), $A(8)_{max}$ in ms^{-2} r.m.s.; (ii) $A(8)_{sum}$ (root-sum-of-squares) in ms^{-2} r.m.s.; (iii) vibration dose value (highest axis), VDV_{max} in $ms^{-1.75}$; (iv) VDV_{sum} (root-sum-of-quads) in $ms^{-1.75}$. The associations between LBP (ordinal) outcomes and measures of daily vibration exposure were expressed as proportional odds ratios estimated by random-intercept ordered logistic regression using transition models (i.e. LBP outcome for subject i at time t (Y_{it}) was related to predictor variable(s) k at time t – 1 (X_{ikt-1}) and the outcome variable at time t – 1 (Y_{it-1})).

Results

The cumulative incidence of LBP over the follow up period was 38.6% (Table 1). The incidence of high pain intensity (Numerical Rating Scale score>5) and severe disability (Roland & Morris scale score>12) was 16.8 and 14.4%, respectively. In the study population $A(8)_{max}$ averaged 0.32 (SD 0.11) ms^{-2} r.m.s., $A(8)_{sum}$ 0.41 (0.16) ms^{-2} r.m.s., VDV_{max} 8.5 (3.7) $ms^{-1.75}$, and VDV_{sum} 9.3 (3.8) $ms^{-1.75}$. After adjustment for individual-, work- and health-related variables, alternative measures of daily WBV exposure were significantly associated with LBP outcomes (duration, intensity, disability) over the follow up period, with the exception of $A(8)_{max}$ (Table 2). Transition models including VDV provided better fits to incidence data than those including $A(8)$, for both measures derived from the highest axis and measures calculated from summation over axes. In multivariate data analysis, physical loading factors and previous LBP during follow up were significant predictors of LBP outcomes over time. Perceived psychosocial work factors were not associated with LBP.

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Table 1: Cumulative incidence of LBP outcomes over 2004-2006 in professional drivers with no LBP in the previous 12 months at baseline (n=202). Numbers (%) are given.

LBP in the previous 12 months		78 (38.6)
Duration of LBP in the previous 12 months (days)	0	124 (61.4)
	1-6	49 (24.2)
	≥7	29 (14.4)
Pain intensity in the previous 12 months (numerical rating scale score)	0	124 (61.4)
	1-5	44 (21.8)
	6-10	34 (16.8)
Disability due to the last episode of LBP (Roland & Morris disability scale score)	0	132 (65.3)
	1-12	41 (20.3)
	13-24	29 (14.4)

Table 2: Association between LBP outcomes over a two-year follow-up period and alternative measures of daily vibration exposure in professional drivers with no LBP in the previous 12 months at baseline (n=202). Proportional odds ratios (OR) and 95% confidence interval are estimated by random-intercept ordered logistic regression. The likelihood ratio (LR) statistics for the measures of daily vibration exposure are shown.

Models for the measures of daily vibration exposure		Duration of LBP OR (95% CI)	Pain intensity OR (95% CI)	Disability OR (95% CI)
Model 1: $A(8)_{sum}$ (ms^{-2} r.m.s.)	<0.3	1.0 (-)	1.0 (-)	1.0 (-)
	0.3-0.4	2.32 (1.22-4.44)	2.38 (1.24-4.55)	4.08 (1.31-12.7)
	>0.4	1.64 (0.82-3.29)	1.79 (0.89-3.60)	2.58 (0.94-7.05)
	LR statistic (χ^2, 2 *df*)	8.88 (p=0.012)	9.72 (p=0.008)	18.5 (p=0.0001)
	LR test for trend (χ^2, 1 *df*)	2.95 (p=0.086)	3.92 (p=0.048)	5.43 (p=0.02)
Model 2: $A(8)_{max}$ (ms^{-2} r.m.s.)	<0.25	1.0 (-)	1.0 (-)	1.0 (-)
	0.25-0.30	2.19 (1.13-4.25)	1.70 (0.89-3.26)	1.73 (0.88-3.40)
	>0.30	1.58 (0.82-3.03)	1.51 (0.79-2.86)	1.56 (0.81-3.00)
	LR statistic (χ^2, 2 *df*)	5.60 (p=0.061)	2.97 (p=0.23)	3.02 (p=0.22)
	LR test for trend (χ^2, 1 *df*)	1.04 (p=0.31)	1.10 (p=0.29)	1.29 (p=0.26)
Model 3: VDV_{sum} ($ms^{-1.75}$)	<6.5	1.0 (-)	1.0 (-)	1.0 (-)
	6.5-10.5	2.84 (1.42-5.68)	3.22 (1.61-6.44)	6.45 (1.53-27.1)
	>10.5	2.70 (1.27-5.71)	3.05 (1.43-6.50)	5.74 (1.27-25.9)
	LR statistic (χ^2, 2 *df*)	10.3 (p=0.006)	12.9 (p=0.0016)	16.5 (p=0.0003)
	LR test for trend (χ^2, 1 *df*)	4.86 (p=0.028)	6.34 (p=0.012)	7.51 (p=0.006)
Model 4: VDV_{max} ($ms^{-1.75}$)	<6.0	1.0 (-)	1.0 (-)	1.0 (-)
	6.0-9.1	2.79 (1.39-5.58)	3.17 (1.59-6.36)	4.94 (1.39-17.5)
	>9.1	2.44 (1.16-5.15)	2.77 (1.31-5.88)	4.14 (1.12-15.3)
	LR statistic (χ^2, 2 *df*)	9.30 (p=0.0095)	11.9 (p=0.0025)	14.2 (p=0.0008)
	LR test for trend (χ^2, 1 *df*)	2.61 (p=0.11)	3.47 (p=0.06)	4.16 (p=0.041)

Conclusions

This prospective cohort study confirms that regular WBV exposure is associated with an increased risk of LBP over time in professional drivers. Among the alternative measures of daily exposure to WBV, VDV gave better predictions of LBP incidence than *A*(8). Poor predictions were obtained with $A(8)_{max}$, which is the currently preferred measure of daily WBV exposure in European countries.

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LOW BACK PAIN AND RISK FACTORS FOR LOW BACK PAIN IN TAXI DRIVERS

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Introduction

Low back pain (LBP) is common in developed countries and affects most people at some time. Factors reported to be associated with LBP include whole body-vibration (WBV) (e.g. [1]), prolonged sitting (e.g. [2,3]), frequent lifting (e.g. [4-7]), and cigarette smoking (e.g. [5, 6, 8]). Information on the relationship between LBP and WBV in car drivers is unsatisfactory [9]. Car drivers are exposed to lower levels of WBV than the drivers of some heavy vehicles but some have long periods of driving and long exposures to WBV.

Methods

A target population of 861 taxi drivers was followed over time with repeated measurement (cross-sectional baseline and follow-up study) to investigate the persistence of health outcomes and risk factors for these health outcomes. Data were collected using self-administered postal questionnaires. The multi-axis vibration in representative taxis was measured and analysed in accord with International Standard 2631-1 (1997). The questionnaire data and the vibration measurements were combined to estimate daily and total life-time cumulative exposures to WBV.

Logistic regression was employed to investigate the association between LBP and selected variables. In the cross-sectional baseline, possible risk factors were detected by univariate and multiple logistic regression models. In the follow-up of the longitudinal study, analysis focused on participants who reported LBP in both the cross-sectional baseline study and the follow-up study. Variables entered in the regression models were those found to be significantly associated with the prevalence of LBP in the cross-sectional baseline study ($p < 0.05$).

Results

The response rate in the cross-sectional baseline study was 24%. From these 209 participating drivers, 155 questionnaires were returned in the follow-up study, giving response rate of 74%. In the cross-sectional study, the 12-month prevalence of LBP was 45%, the 4-week prevalence was 29%, and 7-day prevalence was 19%. In the follow-up study, the 12-month persistence of LBP was 67%, and the 4-week and 7-day persistence was 41%. In the cross-sectional baseline study, statistical analysis revealed that middle body stature (OR = 2.67), previous physical demands (OR = 2.01), and higher psychosomatic distress level (medium: OR = 4.53, poor: OR = 7.46) were significantly associated with increased prevalence of LBP experienced for at least one day during the past 12 months when controlling for the effects of all variables together (except driving information). Regression models where each aspect of driving information was separately entered together with the other significant factors revealed significantly increased prevalence of LBP for those driving for more than 9 hours per

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day (OR = 2.56), those with greatest daily driving exposure expressed as $A(8)$ (OR = 3.50), or $eVDV_{dom}$ (OR = 2.81), or total driving hours (OR = 2.57), or $eVDV_{Total\text{-}dom}$ (OR = 3.13).

In the follow-up study, possible risk factors (body stature, previous physical demands, and distress status) and age (as a variable of biological importance for LBP) were entered into the multivariate logistic model together and revealed increased persistence of LBP during the past 12 months with increased body stature (significant in both groups: medium stature OR = 5.55, tall stature OR = 16.56) and with high psychosomatic distress status (OR = 6.20). No significant association was found between the persistence of LBP and any variable reflecting driving when each aspect of driving information (i.e. measures of daily or lifetime driving exposure) was entered into separate regression models with other confounders selected from the cross-sectional baseline.

Conclusions

Focusing on low back pain experienced for at least one day during the past 12 months, the prevalence of low back pain in the cross-sectional baseline study of taxi drivers was broadly similar to that found in other studies of professional drivers (e.g. [5, 7, 8]). In the cross-sectional part of the study, an association was found between the prevalence of low back pain and increased psychosomatic distress (consistent with [8]), increased stature (consistent with [9]), repetitive heavy lifting in a previous job (consistent with [5-9]), and increased daily and cumulative life-time driving expressed in various metrics (consistent with [1, 7, 8]).
The follow-up study found associations between the persistence of low back pain in taxi drivers and both increased psychosomatic distress and increased body stature.

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HIGH CYCLE FATIGUE BEHAVIOUR OF FUNCTIONAL SPINAL UNITS

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Introduction

Vibrations and shocks are a potential risk factor for spinal failure. In particular the coincidence between long exposure durations and constrained sitting postures might enhance disc degeneration and endplate failure. This may occur when working with all-terrain vehicles, forklifts or wheel loaders. The associated risks are addressed by regulations limiting the permitted exposure to vibration per day (e.g. 2002/44/EG). The mechanisms and pathways by which external vibrations cause internal damages are not well understood - especially since in vivo studies are nearly impossible. A better understanding of this mechanism could improve the appraisal of occupational deceases; enable the determination of duty cycles for implants and ameliorate the development for future treatments. Numerical simulations could help in estimation of spinal loading, but to interpret the findings, spinal fatigue strength must be known. The aim of this study was to determine the fatigue strength of spinal specimens from male donors of working age. The influence of posture and individual spinal characteristics was also taken into account.

Methods

Lumbar spinal motion segments (L4/L5) from male donors were harvested after consent and kept frozen until testing. Bone mineral density (BMD) and endplate area (AREA) were determined based on computer tomography scans (CT). BMD was expressed as equivalent to the concentration of di-potassium phosphate in water (mg K_2HPO_4/cm^3). Specimens with pathologic deformities were eliminated. Specimens were harvested from younger adult donors (*YOUNG*: 20-40 yrs) as well as from donors at the end of the working age (*OLD*: 50-60 yrs). The former were tested in neutral and flexed posture, the later only in neutral posture. Thus, three groups with 6 specimens each were investigated: *YOUNG NEUTRAL*, *YOUNG FLEXED* and *OLD NEUTRAL*.

On the day of testing, muscles were removed after thawing while ligaments and the disc were left intact. For the two groups with neutral posture, the mid-plane of the segment's disc was potted parallel to the flange of metal holders (Ureol, Vantico, CH). For the flexed group both holders were angled 5° during potting resulting in 10° flexion when mounted in the hydraulic test machine (Bionix, MTS, MN).

After preconditioning (~90 min) the segments were exposed to 300,000 cycles (5 Hz) of sinusoidal compression (Bionix, MTS) to determine cycles to failure. A peak to peak load from 0 KN to 2 kN induced nucleus pressures up to 1.4 MPa, which was shown to resemble pressure at the upper physiological range [1]. During the fatigue measurements (~18 h) the biological degeneration within the 37°C ringer solution test environment was reduced by adding Penicillin/Streptomycin (PAA, Austria). Specimen height loss was continuously recorded in order to determine cycles to failure based on unsteadiness in the characteristic physiological creep curve. Significance level for statistical tests was set to $\alpha = 0.05$.

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Results

The BMD of the specimens in the three groups covered a wide range (Tab. 1); standard deviations ranged from 10 to 25% of the corresponding mean values. BMD values between the *OLD NEUTRAL* and *YOUNG FLEXED* were significantly different ($p = 0.041$). The endplate areas between groups were similar. None of the *YOUNG NEUTRAL* failed during the test period, whereas four of the *OLD NEUTRAL* did (those with low BMD; Tab. 2). For the later a linear relationship ($r^2 = 0.74$) between cycles to failure and the characteristic mechanical value (AREA * BMD) was found. In *YOUNG FLEXED*, two of the specimens failed during the test period. Failures were exclusively observed within the vertebral body.

Table 1: Group characteristics (n=6 per group, mean ± STD).

		OLD NEUTRAL	***YOUNG FLEXED***	***YOUNG NEUTRAL***
Age	**years**	53.5 ± 3.8	30.5 ± 8.3	29.0 ± 7.1
BMD	**mg K_2HPO_4/cm^3**	117.0 ± 28.8	161.8 ± 29.2	152.8 ± 15.4
AREA	**cm^2**	17.8 ± 3.1	16.7 ± 3.7	15.6 ± 2.1

Table 2: Spinal characteristics and cycles to failure for the respective specimens

		OLD NEUTRAL				***YOUNG FLEXED***	
		#1	**#2**	**#5**	**#6**	**#1**	**#3**
Age	**years**	48	56	56	59	20	39
BMD	**mg K_2HPO_4/cm^3**	99.9	114.7	88.3	88.8	136.4	205.8
AREA	**cm^2**	16.6	14.9	17.4	15.8	13.5	14.0
Cycles	**x 1,000**	28.9	18.0	1.6	1.8	140.0	215.6

Conclusions

Young donors' specimens showed an unexpected high resistance against fatigue load. Specimens from donors advanced in years only failed under high dynamic loads if BMD was low. The product between AREA and BMD (which decreases with age) might be used to predict fatigue strength. This agrees with measurements of the ultimate strength [2]. Two of the young specimens in the flexed posture failed. One of those (#1) with low BMD fits into the relationship derived for the old specimens whereas the second (#3) did not. Therefore, the influence of flexion remains unclear. This study presents strong evidence that age and individual characteristics, such as endplate area, have to be considered when spinal fatigue failure is to be regarded.

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WHOLE-BODY VIBRATION OCCUPATIONAL EXPOSURE ASSESSMENT FOR US WORKERS

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Introduction

Whole-body vibration (WBV) can adversely affect the digestive, respiratory, genital/urinary, and female reproductive systems [1, 2]. Effects of WBV on vision were reported as early 1965 [3]. The adverse health effect of greatest concern is lower back pain (LBP). NIOSH reported 15 of 19 WBV studies as supporting a positive association between WBV exposure and LBP [4]. WBV is present in occupational categories that include construction, military, transportation, agriculture, and industry with no recent comprehensive exposure assessment for all US occupations. Furthermore, there is a relatively low awareness of WBV in the US safety and health professional community. In a 2006 survey of WBV knowledge and awareness, 69.5% of the respondents self-reported a “less than a basic understanding of WBV” [5].

Two prior broad industrial-sector studies provided estimates of US WBV occupational exposure, most likely underestimating total WBV exposure. A 1974 investigation estimated 8,000,000 US workers as having vibration exposure [6]. This figure is cited in recent frequently accessed industrial hygiene publications [7, 8]. However, there are limitations with the 1974 study:

- No clear distinction between WBV and hand-arm vibration (HAV) was made,
- No quantitative measurements were made, and
- HAV with no WBV exposure was assumed for the coal mining sector.

However, the authors were explicit in stating that their estimate was a conservative figure. The NIOSH National Occupational Exposure Survey (NOES) (1981-1983) estimated a total of 1,082,217 US workers were exposed to WBV [9]. This assessment was based solely by observation, with no measurement. Kittusamy reported 540,000 construction operating engineers are exposed to WBV [10], which is approximately half the total estimated for all US workers by NOES. WBV levels were not reported in either of these studies.

More recently, Palmer et al. estimated WBV occupational exposure in Great Britain by means of a worker vibration self-reporting survey combined with known WBV levels for industrial equipment [11]. The vibration exposure findings were further examined and found to be reliable, more so for WBV than HAV [12]. These findings and methods can be used to assist in the determination of an updated estimate for total US WBV exposure.

Methods

US worker employment data were obtained from the Bureau of Labor Statistics [13]. A sample occupational sector, construction, was chosen to determine a preliminary exposure count. Using specific construction categories, an estimate was made regarding the percentage of WBV exposed workers, ranging from very little, 5%, to all, 100%. Two scenarios were used for calculations of eVDV $m/s^{1.75}$ where exposure existed for either 6 or 7 hours of and 8-hour workday. Acceleration values, a_{wz}, determined in prior studies were selected for equipment

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associated with the specific construction trade [11]. A daily equivalent vibration magnitude was calculated for each specific category, using $eVDV_i = 1.4\ a_{wzi}\ (60\ t_i/5)^{0.25}$.

Results

Using this method, it estimated that 13.8% (912,667 of 6,636,330) of the US construction workers may be exposed to eVDVs exceeding the action level of 8.5 $m/s^{1.75}$ and 2.3% (154,831 of 6,636,330) exceed the limit of 15 $m/s^{1.75}$. The respective percentages reported in the Great Britain study were 22% and 3.5%. Wasserman estimated 2,500,000 US construction workers to some form of vibration [6]; and, NOES reported 288,986 exposed to any WBV level [9].

Conclusions

Updated employment data and WBV levels specific to US occupations is needed to more accurately assess total exposure. This will assist in the justification and implementation of regulatory efforts and the identification and prevention of adverse health effects.

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EFFECTS OF INTENSE NOISE (AIRBORNE VIBRATION) ON HUMAN BODY VIBRATION RESPONSE

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Introduction

Exposure to high intensity low frequency noise (≤ 100 Hz) can cause whole-body vibration that affects human tolerance, performance, and possibly health. Military flight line and flight deck crews are vulnerable to airborne vibration exposures. Historical studies, focused on human subjective tolerance and symptoms [1], were used to develop current noise limits for non-auditory effects [2]. A more recent study was conducted that compared body acceleration characteristics and noise levels during military jet aircraft ground-based engine runs [3]. This paper characterizes and compares additional biodynamic response data collected during exposure to intense noise from ground-based engine runs and carrier deck catapult launches.

Methods

The subject was located along a line parallel to and approximately 12.5 m from the centerline of the aircraft. Triaxial accelerations were measured at anatomical sites on the subject's body including the head, chest, spine, and lower leg using lightweight accelerometer packs attached with double-sided adhesive tape. For the ground-based engine runs that included the EA-6B, F-14A, F/A-18 variants [3], and F-22 aircraft, measurements were made every three meters beginning at the outlet and moving aft. For the carrier-based catapult launches that included the EA-6B and F/A-18 variants, measurements were made at the outlet, midway between the outlet and jet blast deflector (JBD), and at the JBD. These locations were relative to the initial position of the aircraft just prior to launch. Engine power settings included military power (MP) and full after burner (AB). The third-octave acceleration spectra were calculated between 5 and 250 Hz. Selected noise spectra were also obtained.

Results

For all exposures, the highest accelerations occurred in the fore-and-aft (X) direction of the chest, coinciding with ground crew and subject reports of strong chest vibration. A notable peak in the chest X accelerations was observed between 60 and 100 Hz that was not observed in the noise levels during the ground-based engine runs, as noted in the shaded areas of Figure 1. The peak chest X accelerations during the ground-based tests increased as the subject moved aft of the outlet, as did the associated noise level and the perceived chest vibration (Fig. 1). During the carrier catapult launches, a similar peak was observed in the chest X accelerations between 60 and 100 Hz as observed in the shaded areas of Figure 2. During the launches, the engines would power up prior to release of the aircraft, resulting in variable acceleration levels depending on the timing of data collection. This made it more difficult to assess the effect of the subject location, although the chest accelerations were clearly higher at the JBD for the EA-6B (Fig. 2).

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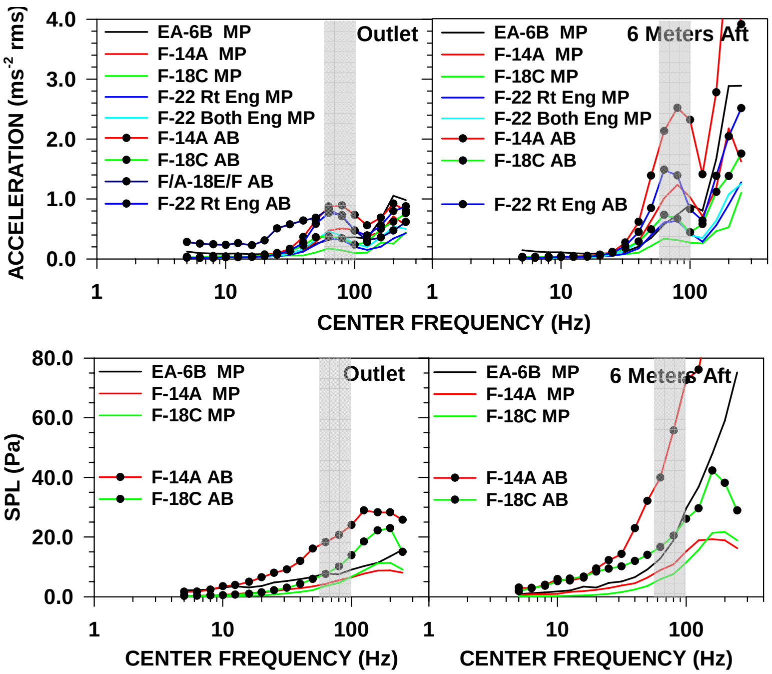

Fig. 1: Chest X Acceleration Spectra (top), and Associated Noise Levels (bottom) During Ground-Based Engine Runs

Conclusions

The peak chest X accelerations observed between 60 and 100 Hz during exposure to high intensity noise levels strongly support the occurrence of a body resonance in the upper torso structures, including the associated body cavities. This resonance coincides with the reported perception of strong chest vibration. For prolonged and repeated exposures, there may be consequences with regard to performance and health risk. Further studies are needed to evaluate the effects of anthropometry on the resonance behavior and vibration perception, and to provide controlled conditions for relating the resonance to the noise characteristics.

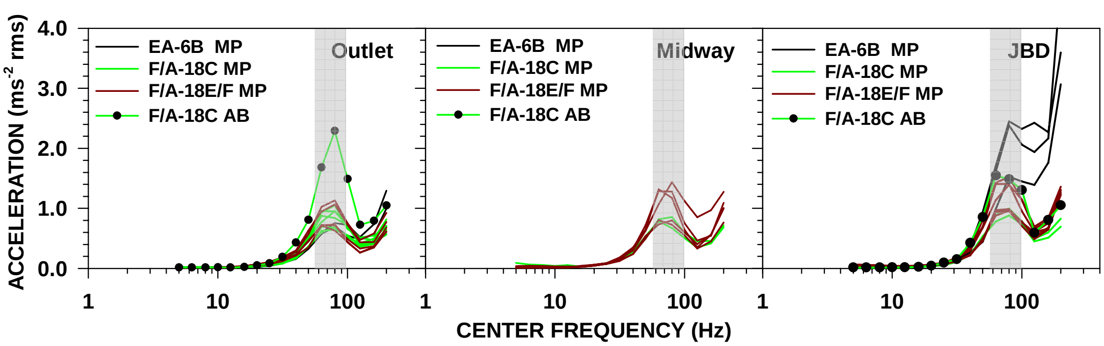

Fig. 2 : Chest X Acceleration Spectra for Carrier Catapult Launches

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EFFECTS OF EXPOSURE TO WHOLE-BODY VIBRATION ON PSYCHOLOGICAL TIME

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Introduction

Time is an essential information for daily activities. There is much evidence to show that psychological time can be lengthened or shortened by non-temporal factors. William James described that *"In general, a time filled with varied and interesting experiences seems short in passing, but long as we look back. On the other hand, a tract of time empty of experiences seems long in passing, but in retrospect short"* [1]. These suggest that psychological time for each person is more or less independent of objective time. The present study investigated if whole-body vibration (WBV) would disrupt time estimation by requiring participants to perform a temporal duration production task with or without WBV. Human exposure to WBV has been associated with a variety of changes in health, comfort, and occupational functioning (perceptual and cognitive performance) [2, 3]. Since, in general, subjective ratings of comfort become worse in a situation with WBV relative to that of without WBV, we hypothesized that exposure to WBV would affect time estimation (i.e., temporal duration productions).

Methods

Twelve experimentally naïve students from universities, raging in age from 19 to 23 (mean age = 21.5 years old, SD = 1.2), volunteered in return for payment. All participants gave written informed consent before taking part in this study. Participants were tested individually. At the beginning of the experiment, the participant was asked to remove his or her watch. Participants performed a temporal duration production task, which required them to produce a 30-seconds-duration with a stopwatch. The participant started the duration production by pressing a button on the stopwatch. After the subjective duration had elapsed, the participant ended the temporal production by pressing the same bottom on the stopwatch. Followed by a 5-trial practice block, the participant performed the task in four 10-trial experimental blocks: baseline block without vibration (0 Hz), 4 Hz-, 8 Hz-, and 16 Hz-vibration (frequency-weighted acceleration of 0.5 ms^{-2} r.m.s.) block. In the experimental blocks, the order of experimental blocks was randomized among participants. No feedback on temporal productions was given in all blocks. At the end of each block, participants reported on discomfort ratings of the exposed WBV and confidence in accuracy of 30-seconds-duration productions.

Results

<u>Temporal productions.</u> Mean temporal productions in each experimental block are shown in Figure 1. Productions were compared among four experimental blocks. The main effect of experimental block was not significant [p = .6823], suggesting that WBV did not interfere with temporal production.

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Discomfort. In Table 1, mean discomfort ratings of the exposed WBV are given for each block. Discomfort in the blocks with vibration was higher than that of without vibration. There was no significant difference in discomfort ratings among the three vibration blocks.
Confidence. Mean confidence in accuracy of 30-seconds-duration productions are listed in Table 1. The main effect of experimental block was significant [$F(3, 33) = 5.65$, $p = .0031$]. The confidence in the 4 Hz- and 8 Hz-block was significantly lower than that of 0 Hz-block (baseline without vibration).

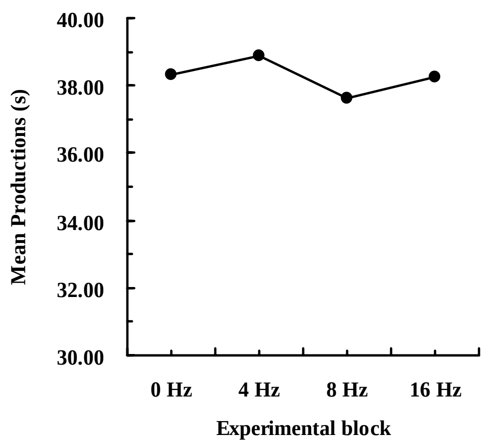

Fig. 1: Mean temporal productions as a function of experimental block

Table 1: Mean Discomfort and Confidence for each experimental block

	0 Hz	4 Hz	8 Hz	16 Hz
Discomfort	1.1 (0.3)	2.3 (1.2)	2.0 (1.0)	1.8 (1.1)
Confidence	69.2 (16.2)	55.0 (18.0)	58.8 (16.1)	63.3 (16.7)

Conclusions

The purpose of this study was to investigate effects of exposure to WBV on psychological time. Temporal duration productions, discomfort ratings, and confidence in accuracy of temporal duration productions were compared among four experimental blocks. Mean temporal productions in blocks with vibration did not differ significantly from that of without vibration. This suggests that WBV does not interfere with temporal duration production under the situation where a counting strategy was available. Almost all participants reported that they had applied a counting strategy to the temporal production. Considering that counting dose improve accuracy of time estimation [4], counting was not disrupted by WBV. On the other hand, subjective ratings of discomfort and confidence were affected by exposure to WBV. The confidence in accuracy of temporal productions with the 4 and 8 Hz-vibration was lower than that of 16 Hz and baseline block without vibration. Discomfort ratings in the blocks with vibration were worse than that of without vibration. Additionally, no significant difference of the discomfort was found among the three vibration blocks. These results suggested that WBV would not interfere with counting of subjective time during the temporal duration production. In conclusion, the present study showed that psychological time was not affected by whole-body vibration.

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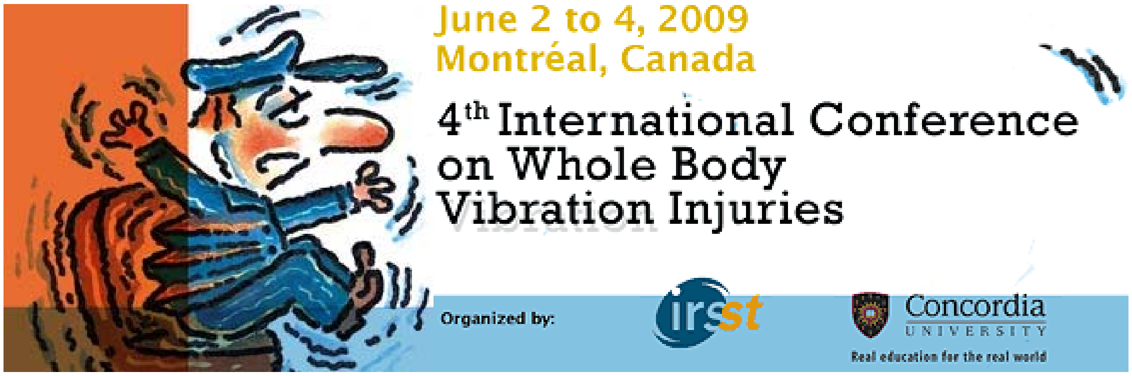

SESSION 2

COMBINED EFFECTS OF WHOLE-BODY VIBRATION

HUMAN RESPONSE TO SINGLE AND COMBINED SINUSOIDAL VERTICAL VIBRATION

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Introduction

Task performance decrement has been reported with exposure to combined vibration by Cohen et al, 1977. [1] In that study subjects were exposed to 3 different sinusoidal vertical vibration conditions: 2.5 Hz, 5 Hz, and a combination of 2.5 and 5 Hz, and asked to complete a task using all four limbs. It was shown that performance was the worst in the combination of 2.5 and 5 Hz. Although the study provides insight into human performance response to complex vibration, it does not provide any physiological or biomechanical measurements. The current study uses Cohen et al.'s methodology as a foundation, but includes collection of electromyography (EMG) to capture muscle activity. This study may explain the substantial decrease in performance during exposure to the combined vibration.

Methods

Fourteen, right-handed males volunteered for the study. The participants were exposed to three trials of four vertical vibration conditions: non-vibration control, vibration at 2.5 Hz, vibration at 5 Hz, and vibration combining 2.5 Hz and 5 Hz. Each vibration condition had an acceleration of 0.69 ms^{-2} rms, and lasted for 30 seconds per exposure. The vibrations were produced with a six-degree-of-freedom Hydraudyne motion platform (Bosch-Rexroth, Netherlands). During exposure, the participants sat upright in a steel tractor seat with no back support or physical postural reminders. The seat and posture assumed by the participants was identical to those in the Cohen et al. study. The subjects were asked to complete a simple four-limb task during the testing in order to resemble the previous study. [1] Surface electromyography (EMG) was used to capture the muscle activity of the left and right lumbar erector spinae (ES) muscles because the erector spinae muscles are primarily responsible for support during forward flexed tasks. [2] Two Ag-AgCl bipolar electrodes (Model D-100, Therapeutics Unlimited, Iowa City, IA, USA) with built in pre-amplification were placed on the left and right lumbar ES. Back muscle (EMG) activity was calibrated, recorded and ensemble-averaged. In order to compare information between subjects, a normalization taking body weight into account was performed. Two-way analysis of variance (ANOVA) was performed for main effects and interactions. The factors were "vibration condition," with four levels, and "participant," with 14 levels. The mean EMG voltages, the peak-to-peak EMG voltages, and the reaction times were examined.

Results

The mean rectified and smoothed EMG activity differed significantly between participants for the right ES (p=0.000), but not for the left ES (p=0.524). In terms of peak-to-peak rectified and smoothed EMG activity in the left ES, the interaction between participants and environment was significant (p=0.000). Differences detected via paired t-test between peak-to-peak left and right

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ES activity was significant (p=0.041). Analysis of the right ES activity showed that the response delay differed significantly with environment (p=0.03).

Table. 1: Frequency responses and number of participants (out of 14) who responded cyclically to each vibration condition

Vertical Vibration Condition						
	2.5 Hz		5 Hz		2.5 Hz and 5 Hz	
Response						
Erector Spinae	Left	Right	Left	Right	Left	Right
Frequency	2.5 Hz	2.5 Hz	5 Hz	5 Hz	2.5 Hz	2.5 Hz
No. Participants	6	2	8	3	5	3

ot all subjects responded to the vibration frequency. (Table 1) The left (L) erector spinae responded more often than the right (R) erector spinae. Both sides only responded at 2.5 Hz to the combined vibration. Chronic involuntary exercise of the muscles opposite the dominant hand could explain why the left erector spinae responded more often than the right. [3] A balanced posture with respect to the vertical acceleration could explain the lack of response in many subjects. Indicating the importance of posture: a slight flexion forward of the trunk from the upright orientation could lead the trunk to respond at 2.5 Hz as an inverted pendulum. Responding only at 2.5 Hz to a combined signal would allow an acceleration component at 5.0 Hz, the seated human's natural frequency, to apply forces to the spine. This could explain both the performance decrement noted above as well as mechanical degradation of the system. Cohen, Wasserman and Hornung's 1977 study, the basis for the current study, demonstrated that exposure to the combination of 2.5 Hz and 5 Hz resulted in increased fatigue and decreased performance. The lack of response to the 5 Hz component of the input signal is likely correlated with the fatigue and performance degradation they found.

Conclusions

Handedness has a significant effect on erector spinae response and poses the possibility of asymmetric mechanical trunk control. This study has also revealed a significant musculoskeletal control system limitation, raising questions about the ability of the human to cope with complex vibration environments, possibly affected by the posture maintained.

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ASSESSING COMBINED EXPOSURES OF WHOLE-BODY VIBRATION AND AWKWARD POSTURE

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Introduction

Simultaneous awkward posture during whole-body vibration exposure (WBV) is one of the most important risk cofactors, which can lead to musculoskeletal diseases or permanent damages. Awkward posture can be analyzed by observational investigations (Palm Trac system [1]), optical 3Dmatch analysis[2] and questionnaires. The CUELA measuring system (Computer-assisted registration and long-term analysis of musculoskeletal work loads [3]) is based on advanced movement sensor technology and is able to record the working postures continuously as angles. Thereby, the data of WBV can be combined with the postural angles simultaneously for the whole measurement. The aims of this study are (1) to introduce CUELA as a measuring technique for seated body posture while exposed to WBV and (2) to suggest an assessment method to relate non-neutral posture to WBV. Preliminary results of 10 different vehicles confirm the necessity of postural investigations and their assessement among occupational drivers.

Methods

WBV and non-neutral posture of 10 occupational drivers (male, 180±8 cm, 82±16 kg and 42±6 years old) have been investigated during their routine occupational operations. Postural angles of the seated drivers have been detected by the CUELA system. WBV measurements have been conducted in three orthogonal axes on the seat surface and at the seat mounting point. Finally, additional video taping has been used to control the alignment of the sensors and to analyze the tasks. The evaluation method of the combined work loads has been designed as follows:

1) 7 degrees of freedom (DoF), Lateral and sagital neck flexion, trunk inclination, back flexion and sagittal head inclination are detected and evaluated utilizing ISO Standards in three categories: neutral, moderate and awkward. If the observed time of non-neutral posture (the moderate and awkward) is greater than 30% of the measured time, the respective DoF is considered as non-neutral. The amount of the non-neutral DoF's compared to the 7 total measured DoF's in % has been calculated for each vehicle.

2) The vector sum of the frequency-weighted accelerations $a_{v1.4}(t)$ is used to form the following categories for vibration exposure: low ($a_{v1.4}(t) < 0.5$ m/s²), middle (0.5 m/s² $< a_{v1.4}(t) <$ 1.0 m/s²) and high ($a_{v1.4}(t) >$ 1.0 m/s²).

3) The categories of step 1 and 2 are plotted in a 3x3 matrix scheme. Based on a traffic-light principle, one can define three risk categories: low, possible and high indicating the percentage of the measured time [3]. Following the same procedure as for the postural angles, the combination of WBV and awkward posture is considered as risky, if the sum of the possible and high risk categories for each DoF exceeds 30% of the measured time. The amount of risky

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combinations compared to the total amount of DoF's in % is calculated.

Results

Figure 1 shows the results of WBV, non-neutral posture and the risk associated with their combination for 10 investigated vehicles.

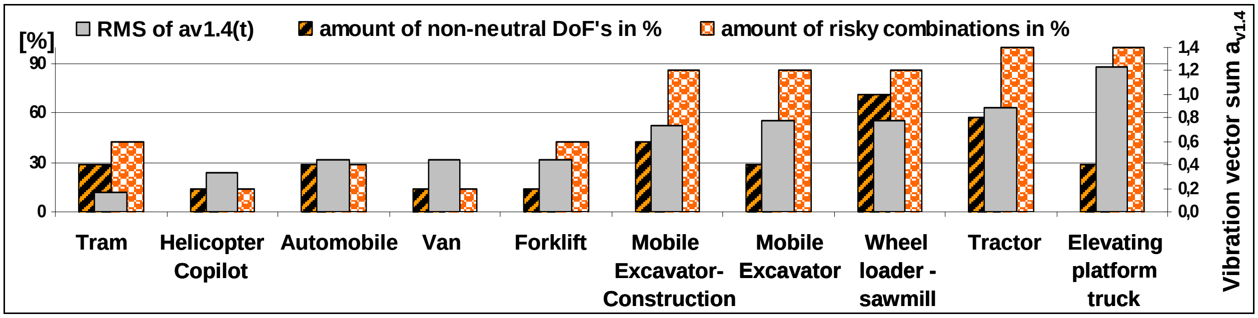

Figure 1: Exposure of WBV, posture and combined risk for 10 vehicles

The WBV ranges from 0.16 ms^{-2} < $a_{v1.4}$ < 1.16 ms^{-2} for the tram and the elevating platform truck, respectively. The highest percentage of the non-neutral posture has been measured for Wheel loader by 71%, which means that 5 of 7 DoF's are more than 30% of the measured time in non-neutral posture. The two excavators show similar values for vibration exposure, but different postural behavior. However, the combined work load shows a similar percentage, which is due to the operated tasks. The excavator on the construction site performs more tasks where non-neutral posture occurs during low vibration exposures.

Conclusion

The preliminary results of the different combined work loads, especially at similar vibration exposures indicate that the influence of the body posture needs to be considered for the WBV evaluation as well. Also epidemiological investigations are necessary to confirm these differences. In order to make assumptions about combined work loads for occupational shifts, the detailed knowledge concerning the operational tasks is needed. Furthermore, an overview of combined work loads for each task helps to find preventive actions for tasks with higher health risks.

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MUSCULAR FATIGUE AND SUBJECTIVE DISCOMFORT WHEN EXPOSED TO TRUNK ROTATION AND WHOLE-BODY VIBRATION

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Introduction

The majority of tractor-driven implements are attached at the rear. This, coupled with the requirement for forward situational awareness, means that tractor operators spend much of their task time in twisted postures. It has been suggested that co-exposure to whole-body vibration (WBV) and awkward postures increase the risk of low back pain fourfold when compared with the risk factors alone [1]. Seidel's conceptual framework of the relationship between WBV and spinal health included both posture and WBV as risk factors [2]. This is in agreement with driving studies which have shown increased discomfort with trunk rotation and speed [3]. With these factors in mind, this research aims to explore interaction effects between trunk rotation and WBV and to capture and quantify specific risks using subjective and objective measures.

Methods

Muscle fatigue and subjective discomfort was assessed in healthy subjects using surface electromyography (sEMG) [4] and a modified version of Porter's Body Map. Subjects' self assessed discomfort was recorded every 60s. sEMG was recorded bilaterally at the neck (Trapezius decendens, upper), shoulder (trapezius transversalis, middle), middle back (erector spinae, longissimus) and lower back (multifidus). EMG spectral and amplitude parameters were used as fatigue indicators. Two studies were completed, a postural rotation study and vibration study. A standard tractor cab layout, including suspension seat, steering wheel and pedals was recreated in the laboratory. For the vibration study, the rig was mounted on a 6-axis vibration simulator. Both studies followed a repeated measures design, with three conditions. For the posture study, participants were required to maintain 3 rotation levels, P0 (no rotation), P1 (110°) and P2 (170°) for 10 minutes. For the vibration study, participants were exposed to 1–20 Hz random vibration. The vibration conditions were V0 (no vibration), V1 (0.32 x; 0.23 y; and 0.39 z-axis, weighted r.m.s.) and V2 (0.73 x; 0.60 y; and 0.82 z-axis, weighted r.m.s.).

Results

In postures P1 and P2, mean power frequency (MPF) significantly decreased from the first minute T_1 to last minute T_{10} (Table 1), indicating muscular fatigue.

Table 1: Statistical significance (Wilcoxon) of changes in EMG (MPF) for posture study.

	P0, T_1 - T_{10}	P1, T_1 - T_{10}	P2, T_1 - T_{10}
Left shoulder	ns	$p < 0.05$	$p < 0.001$
Right neck	ns	$p < 0.005$	$p < 0.05$
Right middle back	ns	$p < 0.05$	$p < 0.005$

For the vibration study, EMG electrical activity (EA) decreased in V0 condition and increased in the V2 condition (Table 2), indicating muscular recovery and fatigue respectively.

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Table 2: Statistical significance (Wilcoxon) of changes in EMG (EA) for vibration study.

	V0, T_1 - T_{10}	V1, T_1 - T_{10}	V2, T_1 - T_{10}
Right shoulder	ns	$p < 0.05$ ^	$p < 0.005$ ^
Left low back	$p < 0.01$ #	ns	$p < 0.001$ ^
Right low back	$p < 0.005$ #	ns	$p < 0.05$ ^

Decrease in EMG EA, ^ Increase in EMG EA.

Subjective ratings of discomfort increased with vibration magnitude, trunk rotation and with duration of exposure (Figure 1).

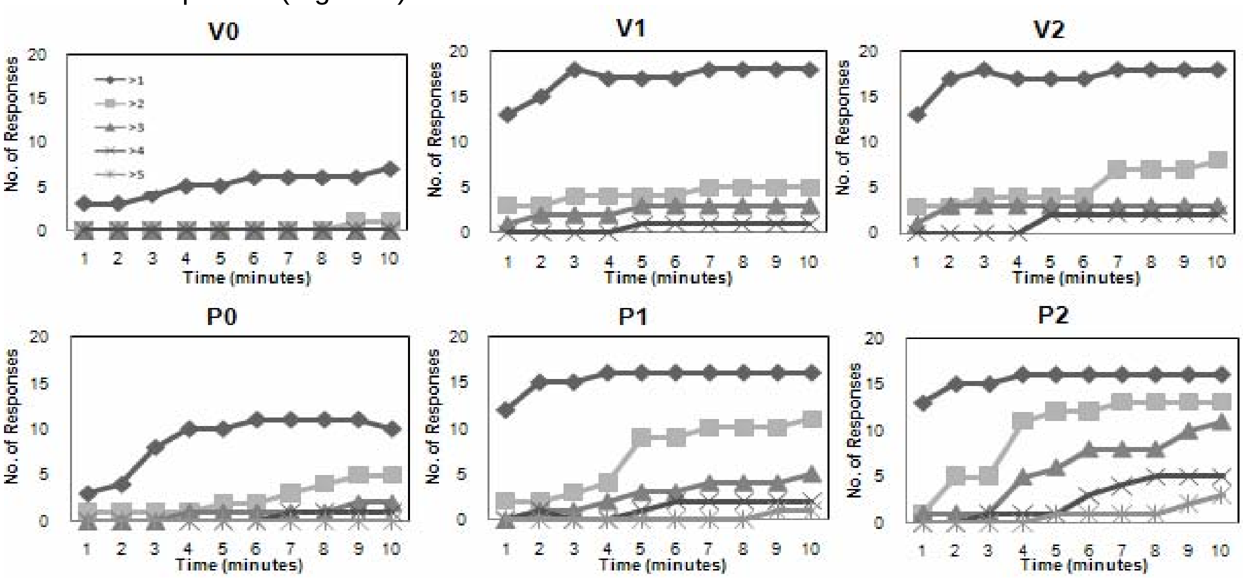

Fig. 1: Number of participants with mean discomfort scores greater than 1, 2, 3, 4 or 5 for the three vibration conditions and the three posture conditions.

Conclusions

Both subjective and objective measures of discomfort and fatigue increased when exposed to postural rotation and vibration stress. The parameters that best illustrate the muscular fatigue are different in the vibration and posture studies, and may suggest different mechanisms of fatigue from these two stressors. Further study is needed to clarify this, and the nature of the interaction effects upon the body.

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THE POSTURE-AND-FREQUENCY-WEIGHTED ACCELERATION: A NEW METHOD TO DESCRIBE THE INFLUENCE OF POSTURES DURING WHOLE-BODY VIBRATION EXPOSURE

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Introduction

Different studies show that the risk of low back pain due to the exposure of whole-body vibration increases when the trunk is twisted or bent forwards. The influence of postures is frequently discussed as an additional load factor. However, according to the Standards this effect is not regarded in the assessment of vibration stress. Drivers with awkward postures are for example drivers of container-bridge-cranes and straddle-carriers. To quantify the postures of these employees' posture measurements were made on different workplaces. Vibration measurements were also made simultaneously and were synchronized with these posture measurements. Based on the results of these measurements a proposal was made for the combination of both loads in one characteristic variable [1].

Methods

Posture measurements were made with the CUELA-system developed by the Institute for Occupational Safety and Health (BGIA) in Sankt Augustin, Germany. CUELA includes different sensors, which are fixed with a belt-system. Different angles of head and trunk were measured with a frequency of 50 Hz. At the same time measurements of whole-body vibration on the seat pad were made in three axes. The posture measurements and the vibration measurements were synchronized with an external trigger-system. Therefore, the body postures could be assigned to the corresponding whole-body vibrations with a time resolution of one second. The duration of the measurements was typically between one and two hours.

Results

The drivers of container-bridge-cranes work with a strongly forward bent upper trunk for more or less throughout their entire working time. Significant lateral flexions were not measured. The drivers of straddle-carriers predominantly sit upright when they transport container. When container are picked or set down the drivers' trunk is rotated and bent in a forward and lateral direction. Therefore, whole-body vibrations affect on both groups of drivers when their trunk is bent forwards or laterally.

Based on the frequency-weighted acceleration a mathematical algorithm was developed to combine both loads – whole-body vibrations as well as body postures – in one characteristic variable. The variable was called posture-and-frequency-weighted acceleration. It was developed from the frequency-weighted acceleration multiplied by a factor $h(\alpha,\beta)$ that depends on the strength of the forward flexion (α) and lateral flexion (β) of the upper body. Thereby it was assumed that the whole-body vibration exposure has a higher risk for low back pain when

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the trunk is bent forwards or laterally than it is upright. Furthermore it was assumed that h(α,β) should increase when bending forwards or laterally. Therefore, the posture-and-frequency-weighted acceleration $a_{h,wv}$ is defined as:

$$a_{h,wv} = h(\alpha,\beta) \times a_{wv} = \left(1 + \left(c1 \times \alpha + c2 \times \beta\right)\right) \times a_{wv}$$

The constants c1 and c2 describe the strength of posture influence on the strain of the drivers due to whole-body vibration. If the trunk is upright (α = β = 0°) the posture-and-frequency-weighted acceleration $a_{h,wv}$ and the frequency-weighted acceleration a_{wv} are equal. Otherwise, the posture-and-frequency-weighted acceleration $a_{h,wv}$ is greater than the frequency-weighted acceleration a_{wv}. This approach does not include effects of backrests or other supports for the trunk. It can therefore only be used when sitting without using such supports.

For the measurements on container-bridge-cranes and straddle-carriers also the energy-equivalent mean values were calculated once with posture weighting and without posture weighting. The values for c1 and c2 were set to a-priori values. For the drivers of the container-bridge-cranes the posture weighting caused a stronger increase of the mean value than for the drivers of the straddle-carriers.

Furthermore, first biomechanical calculations of the forces within the lumbar spine were made to determine the strength of posture influence [2,3]. Two different postures – one with an upright trunk and another with a trunk bent strongly forwards like the drivers of the container-bridge-cranes – were taken into account. The calculations showed that the mean values of the forces within the lumbar spine are higher for forward bent trunk than for upright position. These calculations were used for a first estimation of the constant c1 to describe the strength of posture weighting.

Conclusions

With the described equipment postures and whole-body vibrations can be measured simultaneously. The posture-and-frequency-weighted acceleration allows combining both loads in one variable. On the basis of further measurements typical postures can be described and mean values with and without posture weighting can be compared. With biomechanical calculations this approach should be checked and improved. Epidemiological studies could use the different mean values to look for correlations between whole-body vibrations, postures and low back pain.

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DISCOMFORT MEASURE IN MULTIPLE-AXIS WHOLE-BODY VIBRATION

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Introduction

Studies on human response to whole-body vibration agree on the complexity of defining measures for discomfort [1]. Traditionally, in single-axis WBV, a subject's discomfort is measured subjectively using verbal or paper-based techniques. Additionally, most of these studies focused on the lumber region of the spine as a major source of discomfort. In multiple-axis WBV, where the frequency and the magnitude of the acceleration are randomly changing, the accuracy of the subjective scales becomes questionable as the subjects have a hard time rating their perception. Furthermore, with the development in seat design, the relative motion in the lumbar area has been minimized, but more motion has been transferred to the neck area, which could be a new source of discomfort. In any design process, researchers normally check the situations where large relative body motion occurs and try to avoid these regions in the design.

In this work, we propose an objective discomfort function for the neck flexion-extension and lateral motion, which is useful for capturing discomfort level in multiple-axis WBV with random motion that contains large-body motion. The proposed function [2] has been tested and validated on seated subjects inside a non-vibration environment. Under the current investigation, the proposed discomfort function has also shown good results when used in comparing the relative discomfort for different control configurations.

Methods

Seven healthy subjects were tested in a whole-body environment using a ride file (60 seconds) from a heavy construction machine, the Cat D10 dozer. A six-degree-of-freedom Servotest (Sears's seating facility, Davenport, IA, USA) hydraulic motion platform was used in the testing. Eight 0.3 megapixels Vicon SV cameras were used in tracking the motion; accelerometers were attached to the head and the torso areas; and surface electromyography (EMG) of the cervical erector spinea, sternocleidomastoid, upper trapezius, biceps brachii, and triceps brachii were collected using the Delsys system. A seat with three-arm support configurations was used in this study: steering wheel (ST), seat-mounted (SM), and floor-mounted (FM). An objective discomfort measure for the neck was calculated and used to compare the discomfort level between the three configurations. The subjects were asked about their perception of each configuration.

Results

Figures (a), (b), and (c) show the discomfort level for the seven subjects, for = neck flexion-extension, and for the FM, SM, and ST configurations. The discomfort activity goes up and down during the motion with sudden peaks with maximum activity for the SM, followed by the

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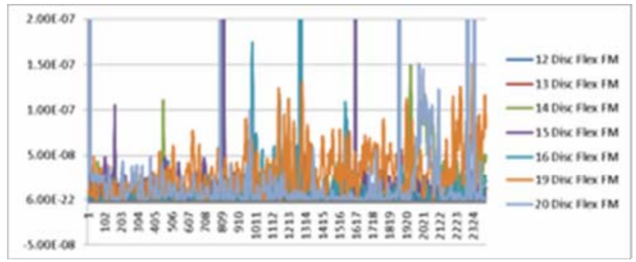
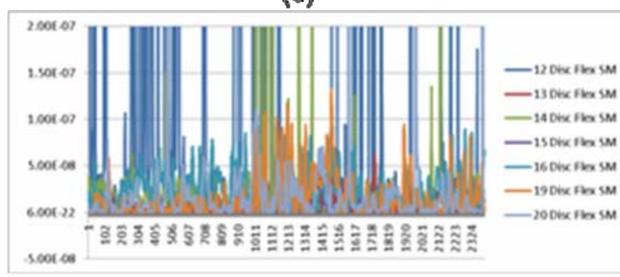
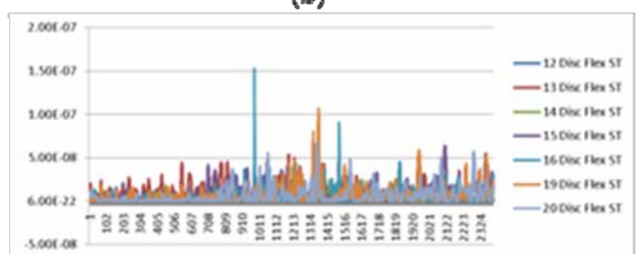
FM and ST. Similar behaviours have been shown for the neck lateral discomfort. The results show that the discomfort value increased significantly when the joint reached its extreme-uncomfortable position and that the discomfort was higher for SM and FM than for ST positions. Meanwhile, when the subjects were asked about their perceptions of vibration and which seat was better, they gave contradicting answers. The results on five muscle activities [3] have shown that SM configuration has the lowest muscle activities, followed by FM and ST.



(a)



(b)



(c)

Conclusions

While any biomechanical objective measure for discomfort should contain the motion and the muscle activation, for situations where the muscle activation is relatively low and the relative motion is large, as in the case for random large motion multiple-axis WBV, the discomfort measure may be calculated by considering the motion only.

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COMBINED EFFECTS OF LONG TERM FATIGUE AND WHOLE-BODY VIBRATION ON DISCOMFORT ONSET FOR VEHICLE OCCUPANTS

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Introduction

Long term exposure to vibration whilst driving has been associated with increased prevalence of low back pain and other musculo-skeletal disorders [1,2]. Previous studies have shown the effects of long term sitting or the effects of vibration, but few studies combine both factors. A multi-factorial model to predict overall discomfort has previously been suggested [3] but there have as yet been limited validation and verification. The model combines static factors, dynamic factors and temporal factors which combine to provide an overall indication of musculo-skeletal discomfort. This paper reports results from two laboratory trials and one field trial which serve to validate the model with quantitative data.

Methods

Study 1 – laboratory study of long term discomfort in a car seat

Study 1 was an independent measures design and used three groups of 12 subjects. Each subject was required to sit in a car seat for 90 minutes. Group V0 was exposed to no vibration; Group V1 was exposed to 80 minutes of random tri-axial vibration with a magnitude of 0.3 m/s^2 r.m.s. in each axis; Group V2 were exposed to 80 minutes of random tri-axial vibration with a magnitude of 0.6 m/s^2 r.m.s. in each axis. Groups V1 and V2 were required to remain seated with no vibration exposure for the 10 minutes after cessation of vibration.

Study 2 – laboratory study of long term discomfort in a passenger train seat

Study 2 was a repeated measures design and used one group of 12 subjects who were each exposed to vibration stimuli V0, V1 and V2. Subjects sat in a train passengers' seat for 60 minutes with 50 minutes of vibration (V1 and V2).

Study 3 – field study of long term discomfort in a car

Study 3 was a repeated measures design and used 16 subjects who were each required to travel on a 70 minutes journey by car (magnitudes 0.15, 0.16, 0.25 x-, y-, z-axes, weighted) and experience a simulation of the same journey with no motion in the same vehicle. The simulation comprised a projection of the field of view and replay of recorded sounds in the vehicle.

In each of the studies, subjects were required to complete Porter's seat discomfort questionnaire at 10-minute intervals.

Results

Results are summarised in Figure 1. For each study, there was a general trend of discomfort increasing with duration and with vibration magnitude. The crossing of V0 and V1 lines in Study

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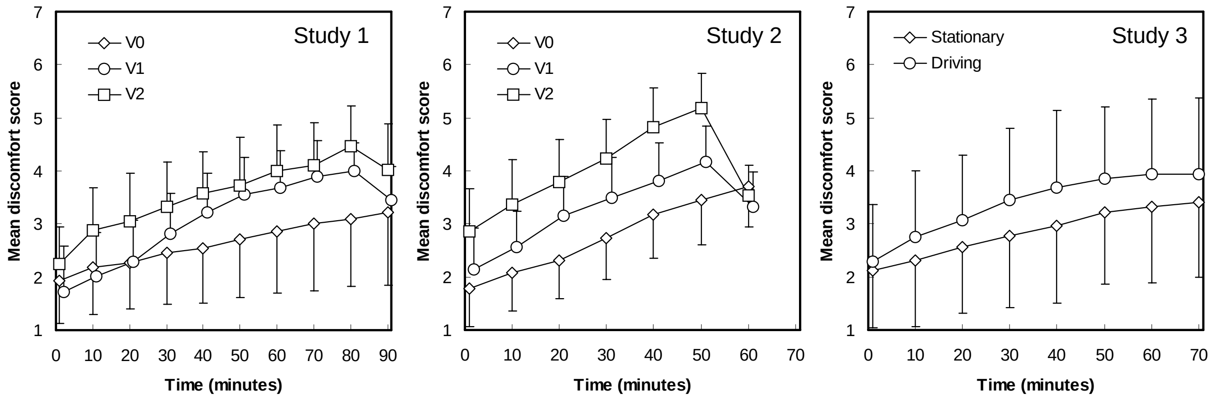

Fig. 1: Mean discomfort scores for the 3 studies (jitter added on time axis to improve clarity).

1 is likely due to the individual measures design. For the period of vibration exposure the discomfort follows a model described by $\Psi = s_s + f_t t + d_v a + i_{tv} t a$ where Ψ is the mean discomfort, s_s is a static discomfort constant, f_t is a fatigue constant, d_v is a vibration constant, i_{tv} is an interaction effect, t is the time in minutes and a is the r.s.s. acceleration. Fitted model parameters (Table 1) show that the train seat and vibration (Study 2) caused more fatigue and caused the greatest increase in discomfort due to vibration. Parameters were similar for the two studies with the car seats.

Table 1: Parameters for fitted models for the three studies.

	s_s	f_t	d_v	i_{tv}	r.m.s. error
Study 1	1.84	0.018	0.48	0.01	7%
Study 2	1.68	0.035	1.11	0.01	6%
Study 3	2.16	0.019	0.45	0.01	7%

Conclusions

The paper describes a multi-factorial model for predicting discomfort, validated through two laboratory and one field trial. The model demonstrates that only considering vibration or sitting duration alone is inadequate for prediction of discomfort, but that improvements in prediction can be obtained through consideration of static, dynamic, fatigue and interaction effects.

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COMBINED HAND-ARM AND WHOLE-BODY VIBRATION EXPOSURE – WHAT IS THE EFFECT ON MUSCULAR ACTIVITY IN THE TRAPEZIUS?

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Introduction

Prevalence of neck pain has been reported to be around 14%-48% in the industrial world [1-6]. In 2006, 2.7% of the Swedish men and 5.7% of the Swedish women reported that their work had caused neck pain. Physical risk factors that have been linked with pain in the neck and shoulders are repetitive movements, high force demands, work posture such as duration of constrained postures, as well as awkward or extreme postures, and exposure to vibration [7]. Relationships between occupations with whole-body vibration (WBV) exposure and musculoskeletal symptoms in the neck and upper limbs have also been found [8-10]. Occupational drivers in general report a high prevalence of musculoskeletal disorders. In Sweden, 21.7% of occupational drivers reported work-related symptoms and 4.1% had been on sick leave pension for more than five weeks [6]. Drivers of terrain vehicles are exposed to high levels of vibration caused by the irregular terrain that they operate in. Shocks and jolts, or short high amplitude vibrations, are a common exposure for these drivers. They are also exposed to both WBV from the seat and hand-arm vibration (HAV) from the steering devices in the vehicles.

The aim of this study was to compare the electromyographic (EMG) response in the neck in a combined HAV and WBV exposure. Additionally, possible gender differences on the effect of vibration exposure on muscle activity were evaluated.

Methods

Twelve healthy male volunteers and 10 healthy female volunteers were included in the experimental study of combined vibration exposure. The subjects had no history of musculoskeletal disorders and they were asked to avoid hard physical activity the day before the day of the experiment. All the volunteers gave their informed consent before the inclusion in the study. Surface EMG was collected from the right upper trapezius. A sinusoidal vibration with a frequency of 10Hz was used. The magnitude of the frequency-weighted acceleration was 5.0m/s2 for the HAV and 1.1m/s2 for the WBV, which corresponds to the exposure limit values established in the European vibration directive. The exposures were hand-arm vibration from the handles (HAV), whole-body vibration from the seat (WBV), HAV+WBV in phase (COMB1), HAV+WBV, 180° phase shifted (COMB2), and one period without vibration exposure (NV). Repeated measures analysis of variance (SPSS version 15.0.) was used to examine the effects of different vibration exposures on the EMG response in the neck

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Results

For the trapezius there was a higher EMGRMS for the COMB1 and COMB2 compared to the HAV and WBV separately. The WBV did not differ from the no-vibration condition. There was a similar pattern concerning the EMGMDF. The COMB1 and COMB2 had a higher EMGMDF than the other exposures with the COMB2 having the highest EMGMDF. The repeated measures analysis showed a significant effect of exposure on the amplitude and frequency of the trapezius EMG. No gender differences were found concerning the effect of combined vibration exposure.

Conclusions

This study shows that a combination of HAV and WBV exposure causes a higher muscle activity in the trapezius muscle compared to HAV and WBV exposure separately. This might help explain the high prevalence of symptoms in the neck in drivers of terrain and off-road vehicles.

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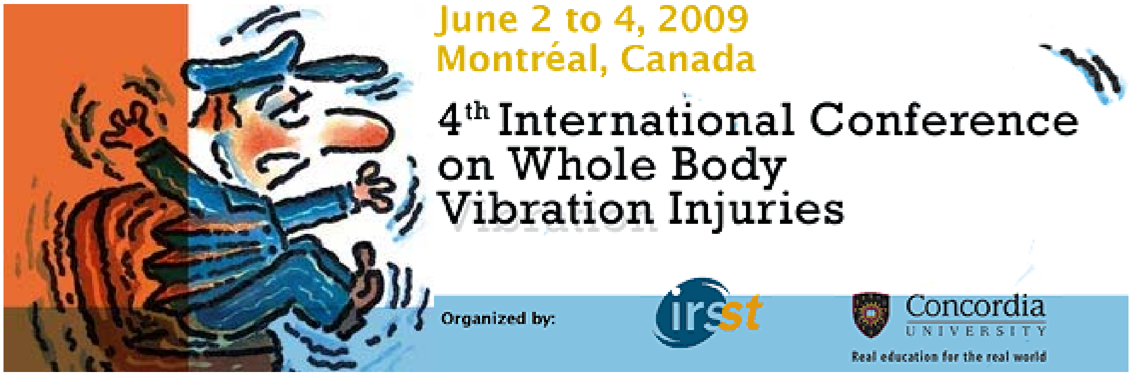

SESSION 3

BIODYNAMICS (1)

AN INVESTIGATION OF NONLINEARITY IN THE DYNAMIC RESPONSE OF THE SEATED BODY EXPOSED TO SINUSOIDAL WHOLE-BODY VIBRATION

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Introduction

Non-linear characteristics of the dynamic response of the human body exposed to whole-body vibration were reported in previous studies [e.g., 1, 2]. An experimental investigation was conducted to investigate non-linear characteristics in the movement of the seated body exposed to sinusoidal whole-body vibration. Sinusoidal input vibrations were used to investigate possible effects of muscle activities on the response, which has been hypothesised to be a cause of the non-linearity in the biodynamic responses in previous studies.

Methods

A set of three experiments was conducted to measure the dynamic responses of seated subjects exposed to vertical, fore-and-aft and lateral sinusoidal vibrations generated by an electro-dynamic shaker. No backrest was provided during exposures. Twelve male subjects were exposed to sinusoidal vibrations at the 1/3-octave band centre frequencies in the range between 5 and 25 Hz for vertical vibration and between 2 and 16 Hz for horizontal vibrations. The vibration magnitudes used were 0.25, 0.5 and 1.0 ms^{-2} r.m.s. and the duration was 5 s. The dynamic responses of the body were measured at several locations, including, the forehead, chest, first lumbar vertebra (L1), with tri-axial miniature accelerometers attached to the body surface. The acceleration was measured at the platform of the shaker in the direction of excitation also. The distortion in the acceleration waveforms was evaluated by

$$\text{distortion} = \sqrt{\sum_k (a_m(k) - a_e(k))^2 \Big/ \sum_k a_m(k)^2}\,,\ a_e(k) = A_e \sin(2\pi f \cdot k\Delta t + \phi_e) \qquad (1)$$

where $a_m(k)$ is the measured acceleration, $a_e(k)$ the estimated acceleration, k an integer index, and Δt the sampling interval of 0.001 s. A_e and ϕ_e, the estimated amplitude and phase, respectively, were determined by minimising the distortion defined by Equation (1).

Results

Figure 1 shows examples of acceleration waveforms measured at a location in the body with low and high distortions. As seen in Figure 1(b), the degree of the deviation of the measured waveform from the estimated waveform changed with time in most waveforms with high distortion, which may suggest some involvement of active control of the body caused by muscle activities. Figure 2 shows the distortions determined by Equation (1) for the measurements at the head and L1 in the excitation direction for the fore-and-aft input vibrations for a subject, as an example. For the conditions shown in the figure, the distortion of input vibration measured was less than 3%. For fore-and-aft input vibration, the distortion tended to increase with increasing vibration magnitude at all frequencies shown in the figure for the measurement at the

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head (Figure 2(a)). A similar trend was observed in the measurement at the chest, although the data are not presented. The measurement at L1, however, did not show any signs of the effect of vibration magnitude and frequency (Figure 2(b)). For vertical and lateral input vibrations, there was no clear trend in the distortion when changing vibration frequency and magnitude, although deviations from the estimated waveform were observed in many measurements.

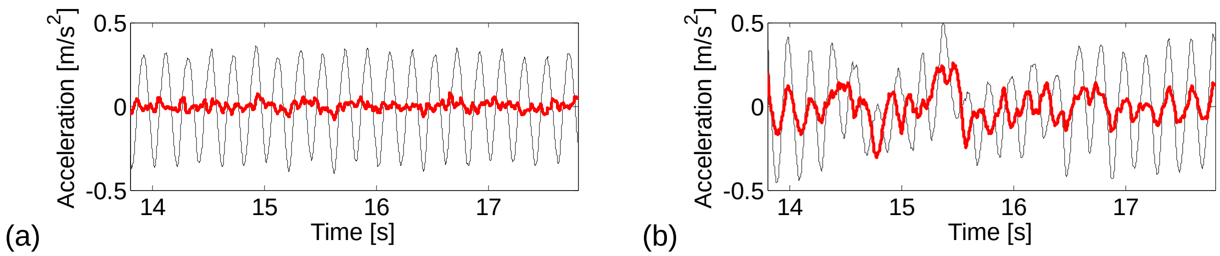

Fig.1: Examples of measured acceleration waveform (black) and its deviation from estimated waveform ($a_m(k)$-$a_e(k)$) (red, bold). (a) 11% distortion, (b) 47% distortion.

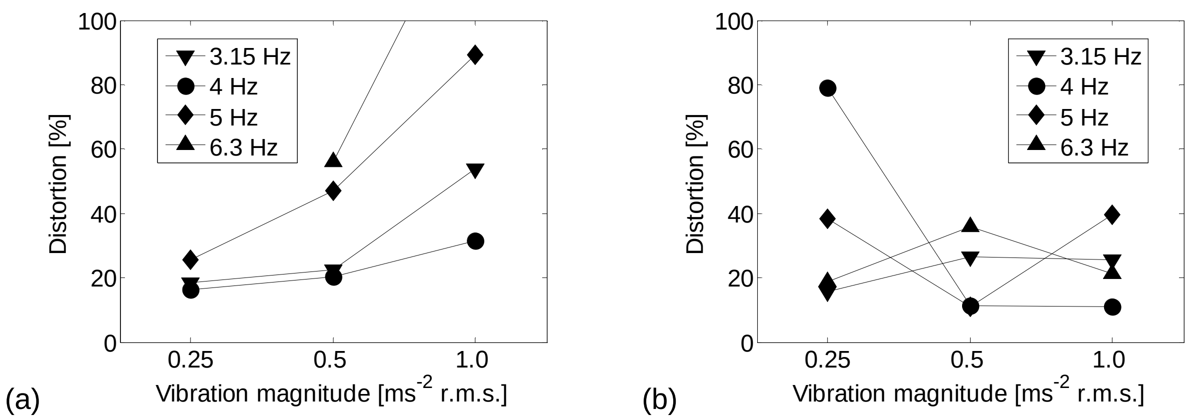

Fig. 2: Distortion in acceleration waveform measured at the head and L1 in the excitation direction for fore-and-aft vibration for a subject. (a) head, (b) L1.

Conclusions

In acceleration waveforms measured at locations in the seated body exposed to sinusoidal whole-body vibration, deviations from the sinusoidal waveform were observed. The deviations were clearer in the measurement in upper part of the body exposed to fore-and-aft vibrations.

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BIODYNAMIC RESPONSES OF THE SEATED HUMAN BODY TO SINGLE-AXIS AND DUAL-AXIS VIBRATION

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Introduction

Experimental studies of biodynamic responses of the seated human body to whole-body vibration have mostly investigated responses to single-axis excitation, especially vertical vibration [e.g., 1-3], whereas occupational exposures always involve multi-axis vibration. Since human responses to vibration are highly non-linear and cross-coupled, it is to be expected that excitation in one axis will alter the response of the body to vibration in another axis.

This study was undertaken to investigate non-linearity in the apparent masses of subjects seated without a backrest and exposed to single-axis and dual-axis vertical and fore-and-aft excitation. It was hypothesised that non-linearity would be evident when using different magnitudes of single-axis excitation in either axis and that it would also be apparent when using a fixed magnitude of vibration in one axis and varying the magnitude of vibration in the other axis.

Method

Twelve male subjects sat in a normal relaxed upright posture with their hands on their laps and with average thigh contact on a rigid seat secured to the ISVR 6-axis simulator. Subjects were exposed to random vibration (0.2 to 20 Hz) in all 15 possible combinations of four vibration magnitudes (0, 0.25, 0.5, or 1.0 ms^{-2} r.m.s.) in both the fore-and-aft and vertical directions. Uncorrelated motions were used when exciting the body in both axes simultaneously. Forces and accelerations measured on the seat surface were used to calculate the apparent mass and cross-axis apparent mass using a single-input single-output model after mass cancellation.

Results

The moduli of the fore-and-aft driving point apparent mass of an example subject during single-axis (fore-and-aft) excitation and during dual-axis (fore-and-aft and vertical) excitation are shown in Figure 1. For each of the four magnitudes of vertical excitation, the apparent mass calculated with a conventional single-input single-output model is shown for three magnitudes of fore-and-aft vibration. With only fore-and-aft excitation (top left), there is a primary peak in the range 2 to 4 Hz, with the frequency of the peak reducing with increasing magnitude of vibration.

The moduli of the vertical driving point apparent mass of the same example subject during single-axis (vertical) excitation and during dual-axis (fore-and-aft and vertical) excitation are shown in Figure 2. For each of the four magnitudes of fore-and-aft excitation, the apparent mass calculated with a conventional single-input single-output model is shown for three

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magnitudes of vertical vibration. With only vertical excitation (top left), there is a primary peak in the range 4 to 6 Hz, with the frequency of the peak reducing with increasing magnitude of vibration.

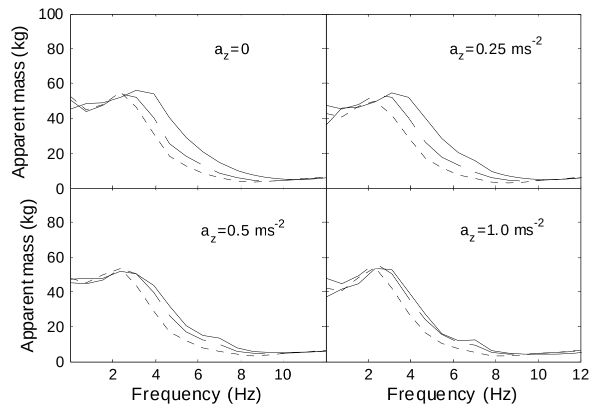

Fig.1: Fore-and-aft apparent mass.
——— a_x = 0.25 ms^{-2} r.m.s.; - - - - a_x = 0.5 ms^{-2} r.m.s.; ········ a_x = 1.0 ms^{-2} r.m.s.

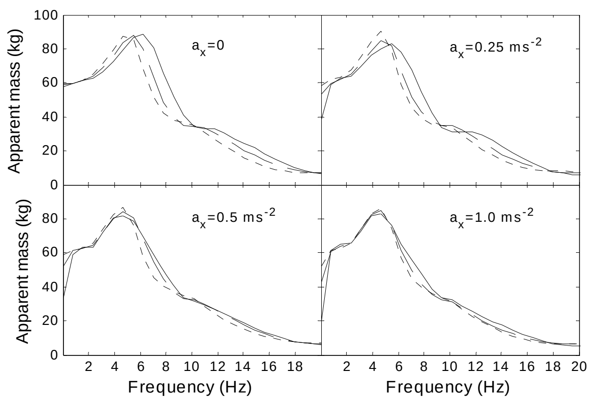

Fig.2: Vertical apparent mass.
——— a_z = 0.25 ms^{-2} r.m.s.; - - - - a_z = 0.5 ms^{-2} r.m.s.; ········ a_z = 1.0 ms^{-2} r.m.s.

Conclusions

With single-axis excitation (either fore-and-aft or vertical vibration), the principal apparent mass of a seated human body exhibits a nonlinear characteristic in which the body softens with increasing magnitude of vibration. With dual-axis excitation (combined fore-and-aft and vertical vibration), the vibration in one axis affects the apparent mass of the body measured in the other axis. The resonance frequency in the vertical apparent mass is reduced as the magnitude of fore-and-aft vibration increases, and the resonance frequency in the fore-and-aft apparent mass reduces as the magnitude of vertical vibration increases.

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APPARENT MASS AND SEAT-TO-HEAD TRANSMISSIBILITY RESPONSES OF SEATED OCCUPANT UNDER SINGLE AND DUAL AXIS HORIZONTAL VIBRATION

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Introduction

The biodynamic responses of seated occupants exposed to whole body vibration have been widely investigated in terms of apparent mass (APMS) and/or seat-to-head vibration transmissibility (STHT) considering the vibration exposures along individual axes. Only a few studies have investigated the responses to vibration applied simultaneously along the two- and three-axes, and even fewer have obtained the cross-axis responses to multiple axes vibration [1,2]. The cross-axis responses represent the coupling effects of multi-axes vibration, and could alter the total response. Moreover, the magnitudes of cross-axis forces depend upon the back and hand support conditions. While the vast majority of the studies have measured APMS responses, it has been suggested that STHT measure is more appropriate for describing higher frequency biodynamic responses and sensitivity to the postural conditions due to inclusion of the resonant oscillations of the low-inertia body substructures. Simultaneous measurements of STHT and APMS of seated occupants to single and dual axis horizontal vibration, however, have not yet been reported. This study presents the APMS and STHT measures of the seated occupants exposed to fore-aft (x), lateral (y), and combined fore-aft and lateral (x-y) axis whole-body vibration to study the coupling effects, and effects of hands support, back support and vibration magnitude on the body interactions with the seat pan and the backrest.

Methods

The experiment involved measurements of STHT and APMS responses at the buttock-pan and upper body-backrest interfaces under exposure to x, y and combined x-y axes vibration. A total of 9 healthy adult male subjects participated in the experiments conducted using a rigid seat with a vertical backrest. The seat was installed on an IMV multi-axis vibration platform with a steering column. Experiments were performed using two back support conditions (NB: no back support; and B0: a vertical back support) while sitting upright, two hands positions (HL: on lap; and HS: on steering wheel), and two magnitudes of random vibration in 0.5-20 Hz range (x, y: 0.25 and 0.4 m/s^2; x-y: 0.28 and 0.4 m/s^2). Measurements included three-axis forces at seat pan and backrest, and accelerations at the platform and subject's scalp. The data were analyzed to obtain direct and cross-axis APMS at both the interfaces, and STHT using the PulseLabShop™.

In the experiment, the three-axis force plate served as the seat pan. The body forces imparted on the backrest resulted in a canceling effect on the seat pan forces due to forces transmitted to the force plate support (Fig. 1a). This effect was far more evident in the x-axis and could be partly attributed to flexibility of the back support structure. However, such cancellations were not evident in the studies that measured forces at the bottom of the seat, and reported total

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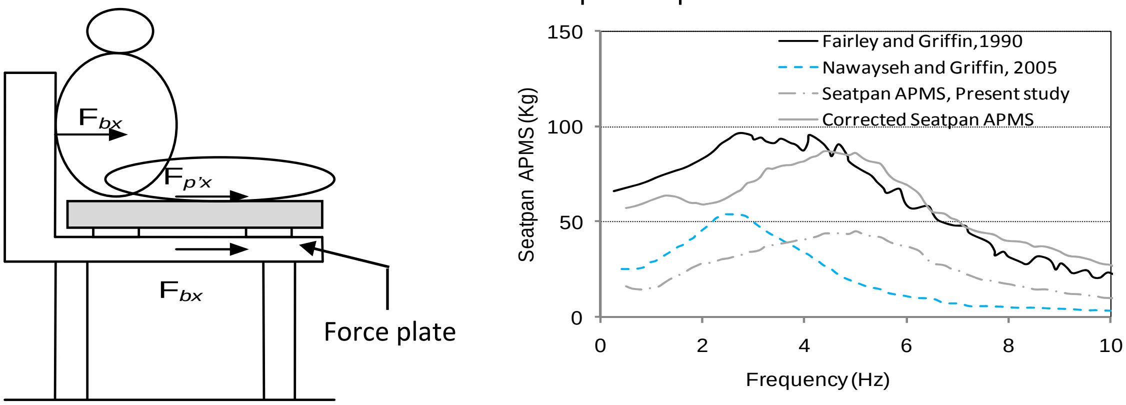
dynamics at backrest and seatpan (Fig. 1b) [3]. Apart from the inertia correction, the direct and cross-axis APMS responses measured at the seat pan were further corrected through addition of the backrest APMS to the measured seat pan response.



(a) (b)

Fig. 1: (a) Schematic of the test seat with force plate serving as the seat pan; (b) Comparisons of uncorrected and corrected measured and reported responses.

Results and Discussion

The fore-aft APMS response magnitudes were observed to be quite low as reported in [2] compared to that in [3]. The magnitudes of the corrected seatpan APMS, however, were comparable to those reported, as shown in Fig. 1(b) for B0 condition. The results revealed significant effects of hands and back support conditions on the direct and cross-axis responses. The steering wheel served as an important constraint to the upper body fore-aft movement under x-axis vibration at lower frequencies, but caused greater upper body lateral movement under y-axis vibration. The effect on fore-aft seatpan APMS was more pronounced in back unsupported postures, while responses with hands on steering wheel were comparable for both back support conditions under lateral vibration. The effect of hands position was observed to be equally pronounced on both the APMS and STHT responses with back support. Significant vertical motions were observed with both the back supported and unsupported postures, under fore-aft vibration, suggesting greater coupling between the fore-aft and vertical responses. The primary frequencies observed from direct APMS and STHT responses were quite similar under y-axis vibration but differed considerably under x-axis vibration. The direct APMS and STHT magnitudes and corresponding frequencies to dual-axis vibration were relatively lower compared to those under single axis vibration, suggesting nonlinear effect. The cross-axis STHT and APMS responses, however, were larger under dual-axis vibration. Although the magnitudes of cross components tend to be higher under dual-axis vibration, the total biodynamic responses to x- and y-axis vibration suggest only weak coupling. The responses, however, are nonlinearly dependent on the back and hand support conditions.

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AN EVALUATION OF THE METHODS FOR DERIVING A REPRESENTATIVE BIODYNAMIC RESPONSE OF THE HUMAN WHOLE-BODY SYSTEM TO VIBRATION

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Introduction

The biodynamic responses (BR) of the human whole-body system measured with subjects participating in an experiment are averaged and used to represent their mean response in many reported studies. The mean BR data reported in some of these studies are further averaged to form the reference mean response for standardization and various applications [1]. A few researchers indicated that the arithmetic averaging could introduce some systematic errors to the mean BR data [2]. However, a comprehensive examination of its suitability and limitations has not been reported. The objectives of this study are to clarify whether the conventional arithmetic averaging process could significantly misrepresent the characteristics of the original responses, and to identify the major influencing factors of the arithmetical averaging errors, and to explore appropriate procedures or methods for deriving a representative biodynamic response.

Method

This study defines the representative response as the response of a virtual subject who exhibits the average biodynamic properties (the mass, damping, stiffness, and their distributions and connections) of all subjects who participated in the experiment. Because the biodynamic properties are the basis, this baseline response is termed as the mean property-based response. Differences between mean property-based responses and the arithmetically-averaged responses are considered as the errors of the arithmetical averaging method.

There are several experimental and theoretical methods to quantify the biodynamic properties of a subject. For simplicity and the purpose of this study, a mechanical-equivalent model is used to represent the basic biodynamic properties of the subejct. A model that can simulate vertical and fore-and-aft cross-axis responses has recently been reported by Nawayseh and Griffin [3], and it is directly used in the current study. The reported model parameters for each of the twelve subjects who participated in the reported study are used to calculate both the mean property-based response (expressed as apparent mass: $M_{Mean\_property}$) and the arithmetical averaging response ($M_{Mean\_response}$). The arithmetical averaging error or the difference (ΔM) between these two types of average responses was calculated from

$$\Delta M(\omega) = | M_{Mean\_property}(\omega) - M_{Mean\_response}(\omega) | \quad (3)$$

To examine the influence of the number of subjects on the averaging effects, all possible combinations of 2, 4, 6, 8, 10, and 12 subjects among the twelve subjects are considered in the analysis. The maximum error at each frequency for each number of subjects is identified and used to assess the arithmetical averaging effects.

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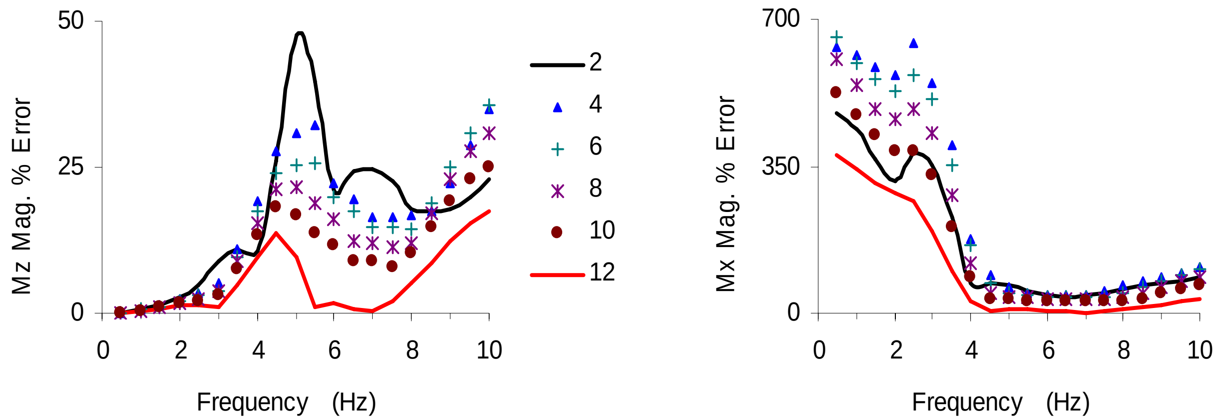
Results

The difference between the responses derived from the two approaches is correlated with the range of the peak frequencies of the subjects. As shown in Fig. 1, the maximum difference generally decreases with the increase in the number of subjects. The arithmetical averaging reduces the resonant peaks in the vertical response. Substantial percent differences are found in the fore-and-aft cross-axis response at the low frequencies (<4 Hz) where the response is small.



(a) (b)

Fig. 1: The effects of the number of subjects on the maximum percent errors: (a) in vertical response (M_z); and (b) in fore-and-aft cross-axis response (M_x).

Discussion and Conclusions

Theoretically, the reliability of the mean property-based response depends on the validity of the model used to describe the biodynamic properties of the system. Assuming the model used in this study is acceptable for representing the basic biodynamic properties of the whole-body system, this study found that the arithmetically averaged response could be more than 20% below that derived from the property-based averaging method, depending on the specific combination of subjects. The potential errors of the response-based averaging method generally depend on the range of the subjects' natural frequencies and the number of participating subjects. A practical and effective approach for controlling the potential error of the arithmetical average method is to group the subjects in terms of their body weight or stature and to include a sufficient number of subjects in each group. While more demanding than the response-based method, the property-based deriving method with a validated model can be generally used to obtain the representative response.

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EFFECTS OF THE FEET CONTACT AREA COMPLIANCE ON THE APPARENT MASS OF A STANDING PERSON

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Introduction

Several reported studies have focused on the identification of the apparent mass of standing persons exposed to whole-body vertical vibration. Thus far, this response parameter has been evaluated at the driving point by dividing the overall measured dynamic force by the measured acceleration on a rigid surface. With this approach, the contact between the feet and the vibrating platform is neglected and no information can be derived about the effect of the local pressure distribution. However, in actual condition, when vibrations are transmitted to the body, shoes are usually interposed between the feet and the vibrating surface and the contact area is not necessarily flat. Aim of our study is to identify the pressure distribution and its dynamic components on the feet when a standing person is exposed to vibration. This also allows the identification of the apparent mass distribution and of the local driving point mechanical impedance on the feet.

Methods

The measurements were carried-out using the capacitive pressure mapping system Pedar-X produced and merchandised by the German company Novel Electronics. Pressure matrices have been characterized statically as well as dynamically. The static calibration was performed to verify the effects of temperature, fraction of covered sensor surface, curvature in the contact area and tangential actions on the instrument sensitivity. The cross-talk among the neighboring sensors in the matrix was also analyzed. The dynamic characterization was performed by determining the frequency response function up to 50 Hz, together with the sensor hysteresis and the long time response stability (creep analysis).

The sensors were then used to measure the apparent mass distribution on the feet of standing persons. Tests were performed on an electro-dynamic shaker, by imposing a sweep sine vibration in the vertical direction to ten male subjects. Different surfaces were tested (flat steel, rubber, soft foams). The localized apparent mass was obtained by dividing the integrated pressure distribution on the different feet areas by the instantaneous acceleration.

Results

The static metrological characterization of the pressure mapping system showed noticeable creep and temperature effects. These, however, can be compensated or, alternatively, made negligible with proper testing conditions (i.e. short duration tests or unloads). The dynamic calibration was particularly relevant for our purposes, as the typical applications for these sensors are related to static or quasi-static inputs; in particular, the phase between sensors is almost neglected. The frequency response of the matrices showed two main issues that are a sensitivity reduction under dynamic loads and the phase delay due to both the multiplexed data

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acquisition and to the sensor physical characteristics (phase delays up to 50° in frequency passing band). Owing to the bias nature of these errors, a compensation would be possible.

Experiments have confirmed the dependence of the apparent mass on the knee angle. During test therefore, the specific posture was requested to the subject under test and monitored with a vision system. The distribution of the apparent mass on three areas of the feet (*talus-calcaneus*, *metatarsal* area and toes) was monitored with different contact area compliances. Results showed the dependence of the localized apparent mass from the contact surface stiffness. Similar results were found on the majority of the tested subject. In particular, it was found that with a more compliant contact surface the static pressure but also the equivalent mass distribution tend to become nearly uniform on the foot area. With hard contact surfaces, the apparent mass is large in the rear part of the feet (i.e. on the *talus*), as shown in Figure 1 (right-hand side - soft surface, left-hand side - rigid surface).

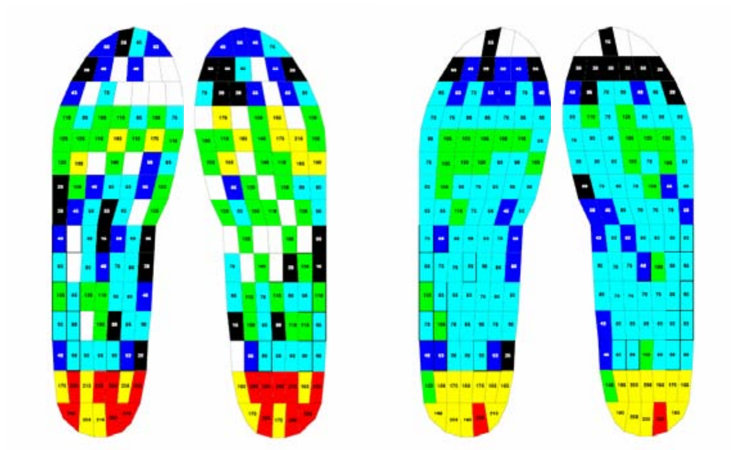

Fig. 1: A pictorial presentation of the instantaneous pressure distribution between the feet and the vibrating surface (right-hand side - soft surface, left-hand side - rigid surface)

Conclusions

The study showed the possibility of measuring the dynamic forces directly at the feet interface, despite the difficulties due to the non ideal dynamic characteristics of the sensor matrices. The possibility of measuring the static and the dynamic pressure contributions of the different foot areas allows verifying the correlation between the static pressure and local stiffness. Moreover, even minimal postural changes strongly affected the pressure distributions and could be therefore detected and correlated with the apparent mass.

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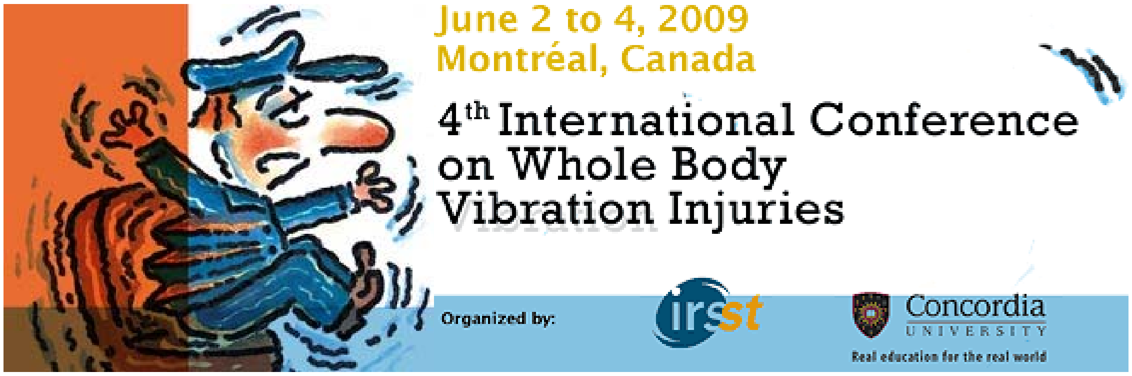

SESSION 4

BIODYNAMICS (2)

DETERMINATION OF SEAT BACK ANGLE BASED ON BIODYNAMIC RESPONSE STUDY FOR PREVENTION OF LOW BACK PAIN

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Introduction

Many occupational vehicle drivers suffer from low back pain, one of potential causes of which is long-term exposure to whole-body vibration (WBV) [1]. According to previous studies, vibration transmitted vertically to the human body are generally higher and hence has been believed to have overwhelming influence on health and safety risks compared to other two horizontal vibration components.Absorbed power is one possible indicator that represents the physical damage effects of mechanical vibration to the human body. The aim of this study was to examine and evaluate effects of seat back angles on vibration transmitted through seats to the human body via laboratory whole-body vibration (only in vertical direction) experiments based on biodynamic response parameters represented by the apparent mass (APMS) and vibration power absorption (VPA).

Methods

Twelve healthy male subjects, aged between 19-24 years, participated in the experiment. The subjects had no prior known history of musculo-skeletal disorders. Prior to the test, each subject was informed of the purpose of this study and experimental procedure. All the subjects gave their written informed consent to participate in this study. The experiment was approved by the Research Ethics Committee of Japan National Institute of Occupational Safety and Health.Subjects were exposed to vertical random vibration with a constant power spectrum density of 0.0082 $(m/s^2)^2/Hz$ at each frequency from 1 to 20 Hz. The magnitude of the vibration was 0.8 m/s^2 r.m.s. (unweighted), the exposuse time of which was 60 seconds. Back support conditions included three seat angle conditions of 90°, 100° and 120°. During the test, the subjects were seated with their hands in the lap and feet supported on the footrest rigidly fixed on the platform for each posture. Vibration generated by using IMV multi-axis shakers, was measured using an accelerometer (Type 4326A, B&K) amplified with a Nexus charge amplifier. The force at the seat pan was measured with a force plate (9281C, Kistler Inc.). Based on the acceleration A(ω) and dynamic force F(ω) data measured with a data acquisition system, APMS and VPA were calculated using the following equations:

$$APMS(\omega) = F(\omega) / A(\omega) \quad (1)$$

$$VPA = Re[j\omega \cdot APMS(\omega)] \cdot | A(\omega) / \omega|^2 \quad (2)$$

where ω is the angular velocity.

Results

Between 4 and 7 Hz, the APMS magnitude was greater for the seat angle of 90° than for the seat angle of 100°. At frequencies higher than 7 Hz, in contrast, the APMS magnitude was a bit higher for the seat angle of 100° than for the seat angle of 90°. The main peak observed at 4-5 Hz for the seat angle of 90° and 100° was not observed for the seat angle of 120°. At frequencies larger than 5.5 Hz the normalized APMS magnitude was consistently higher for the

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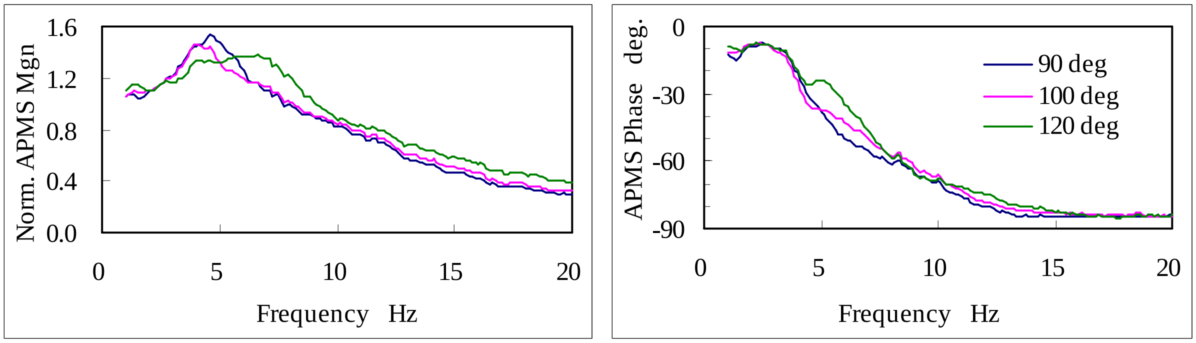
seat angle of 120° than for the seat angle of 90°. The APMS phase angle was higher particularly between 4 and 7.5 Hz for the seat angle of 120° than for any other case.



(a) Normalized mean APMS magnitude *(b) Mean APMS phase angle*

Fig. 1: Normalized mean APMS magnitude and phase angle.

The VPA peak observed at 5 Hz for the seat angle of 90° shifted a bit towards low frequency side at the seat angle of 100° and was sharpened. At the seat angle of 120°, the VPA curve was steeply decreased at frequencies between 4 and 7 Hz. Double peaks appeared at 4 Hz and at 8 Hz for the VPA at the seat angle of 120°. There were significant differences between total absorbed power (TAP) at the seatback angle of 90° and at 100° and between TAP at 90° and at 120° ($p<0.05$, Wilcoxon).

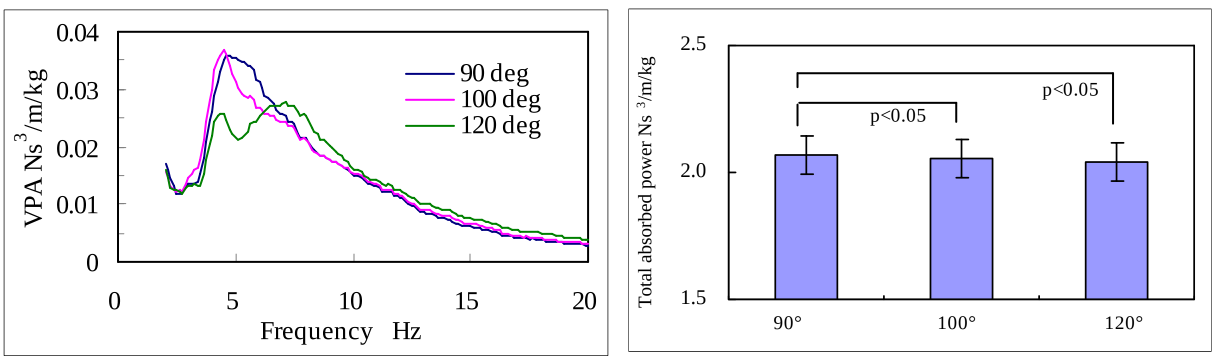


Fig. 2: Double-normalized VPA and total absorbed power

Conclusions

VPA represents vibration power transmitted and then absorbed to the body, which has been believed to relate with damage potential associated with low back pain. This is based on the idea that energy absorbed by the body causes strain and heat internal structures of the body. In this respect, our results suggest that the optimum seatback angle range, from the viewpoint of health risk on low back pain, exists between 100° and 120°.

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INFLUENCE OF SUPPORT CONDITIONS ON VERTICAL WHOLE-BODY VIBRATION TRANSMISSION PROPERTIES OF THE SEATED HUMAN BODY

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Introduction

The vibration transmission and biodynamic properties of seated human subjects exposed to whole body vibration (WBV) have been mostly characterised without the back and hand supports. A few studies have shown significant effects of the back support on the apparent mass (APMS) and vibration transmitted to the head (STHT) under vertical (Z) or fore-aft (X) excitation [1]. It has been suggested that STHT response emphasises important upper body vibration modes far more than the global APMS. Furthermore, enhancement of quality of biodynamic models requires knowledge of localised vibration responses, apart from the global APMS and STHT. A few studies have measured vibration transmitted to different locations of the upper body, which show the presence of possible modes that are not evident in APMS or STHT [2]. These studies, however, exhibit extreme variabilities among them that may be partly attributed to differences in the measurement systems and conditions. A thorough characterisation of localised vibration responses under representative seating supports is vital for enhanced understanding of the vibration modes and for deriving target functions for identification of seated body dynamic models. This experimental study presents vibration transmission to selected segments of the seated human body exposed to random excitation and analyses the influences of the back support and hands position.

Methods

The transmission of vertical WBV to different locations of the upper body along the X- and Z-axes are characterised in the laboratory using 12 healthy male subjects seated on a rigid seat with a vertical backrest and a steering-wheel hand support, and exposed to random seat vibration of 0.25, 0.5 and 1 m/s^2 RMS. Responses in terms of X and Z vibration transmission functions from the seat were measured non-invasively at different locations in the mid-sagittal plane (head, neck: C7 vertebra, thorax: T5, T12, lumborum: L3, L5) using micro-accelerometers affixed to the subjects' skin. The data were acquired for four different postures invovling different combinations of the support conditions, namely, (i) with backrest (B) or no backrest (NB); and (ii) hands resting on lap (L) or on a steering-wheel (SW). The measurement of vibration at the back posed considerable challenges when the back was supported, particularly near the T5 and T12 levels. Since the error in responses due to skin movement may be corrected only for the free-vibration condition, the back support was modified so as to prevent direct contact of the accelerometer with the backrest. The measured data were analysed to derive the vibration transmissibility responses along the X- and Z-axes at the measured locations, namely, the head, near C7, thorax (T5 and T12) and lumborum (L3 and L5) using the B&K PULSE Labshop™ spectral analyser. The measured responses were analysed to study the inter- and intra-subject variability, the influences of body mass, support conditions and excitation magnitude on the transmitted vibration. The effects of main factors (hands and back supports, excitation magnitude) on the transmitted vibration were also evaluated through ANOVA.

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Results and Discussion

The results showed significant influence of the excitation magnitude and back support on the vibration transmitted to different segments of the upper body. The decrease in primary resonance frequency in X- and Z- axis responses, with increasing vibration magnitude was clearly evident suggesting "softening" of the human body system under higher input vibration. Both the X- and Z-axes responses of the body segments further revealed lower peak magnitudes and a shifting (lowering) of the primary peak frequency with the backrest contact (Figure 1). The vibration transmitted to L3 compared well with the data reported in [2] near the primary resonance frequency (Figure 2). However, there was considerable disagreement in resonance frequency with the *in vivo* data reported by Panjabi et al. [3].

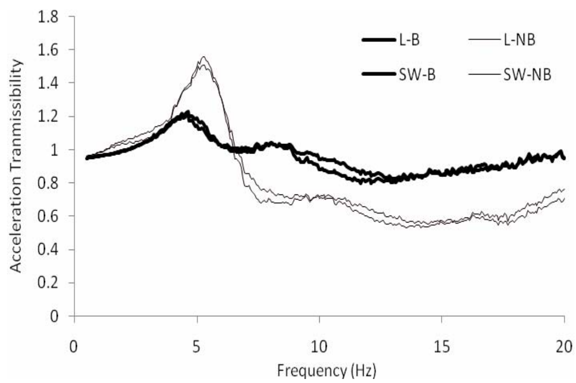

Fig. 1: Vertical acceleration transmissibility tmeasured near L3 under four different postures at 1 m/s^2 vibration magnitude.

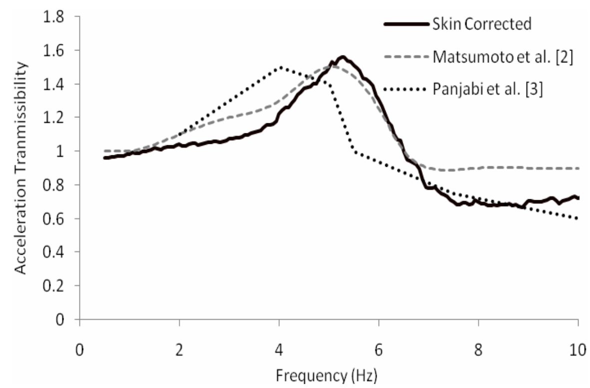

Fig. 2: Comparison of the measured vertical response near L3 in L-NB posture with data in selected studies.

Analyses of Variance (multifactorial ANOVA) also showed statistically significant effect of the excitation magnitude and backrest condition, separately on both the X- and Z-axis transmissibilities. The combined effect of the two factors, however, was observed only in T5, T12 and L3 responses, around the primary resonance frequency. The hands position did not exhibit statistically significant contributions for both back support conditions. From the transmissibility data, three characteristic frequencies could be observed in most of the vertical responses: below 3 Hz, between 4 and 6 Hz (primary resonance) and around 8 Hz. Moreover, these frequencies were strongly influenced by the backrest condition (B, NB). The results suggest strongly nonlinear effects of excitation magnitude and back support conditions. Different target functions are thus proposed for model identification corresponding to two different back support conditions.

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INVESTIGATION OF INTRA-SUBJECT VARIABILITY OF TRANSMISSIBILITY RESPONSES OF SEATED HUMAN EXPOSED TO WHOLE-BODY VIBRATION

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Introduction

Many studies have been reported about the transmissibilities of seated human exposed to whole-body vibration (WBV). The transmissibility of the human body defines biodynamic response of human between input point at which the vibration enters the body (seat, floor) and output point at which the vibration is measured on the body (head)[1]. Most of them use the mean or the median values of transmissibility as the representative value of the human response, where the responses of many subjects are measured, and the variability of the inter-subjects is also examined. However, the research about the variation of intra-subjects is hardly found. The fundamental study of the intra-subject variations is necessary for understanding the changes in the transmissibility of human exposed to WBV with the passage of time, differences in the seats, etc. Also, the vibration of the head has been measured using either bite-bar or head gear. However, a study of reproducibility and consistency of measurements obtained using both bite-bar and head gear is hardly found. The aim of this study is to investigate intra-subject variability of transmissibility responses of seated body exposed to WBV and to confirm the reproducibility through comparison of measures attained with bite-bar and head gear.

Methods

Five male healthy subjects participated in the experiment. Each subject sat on a force plate mounted on a rigid seat without backrest and with feet supported and exposed to vertical random vibration up to 20Hz. The magnitude of vibration was 0.2~0.3 m/s^2 r.m.s. and the duration was 60s. The selected 0.2~0.3 m/s^2 r.m.s. excitation is considered representative of levels experienced during vehicle driving. The subjects sat in relaxed upright posture with hands lightly resting on the thighs and looking straight-ahead [2]. The acceleration in the z-direction was measured on the seated surface using a 3-axis accelerometer. The vibration of head was measured using both bite-bar and head gear. Three 3-axis accelerometers were located on each equipment and the acceleration at center of the head was estimated using the acceleration signals from both bite-bar and head gear. An experiment was conducted under three different conditions: (a) Transmissibilities were measured under three different conditions to verify reproducibility (measurement of vibration without any change in experimental condition (basic), measurements after removal and re-installation of head gear and after subject standing up and sitting); (b) Repeated measurements on same day to investigate the intra-subject variability (measurements were repeated five times with two hour intervals); and (c) To examine variability in measurements repeated on different days. For experiments (b) and (c), the measurements were repeated 5 times and averaged. The sample standard deviation (S.D) was obtained at frequencies up to 20 Hz. The transmissibility was obtained with 0.12Hz resolution.

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Results

Figure 1 shows 5 repeated measures of vertical seat-to-head transmissibility under same conditions at the mouth level using both bite-bar and head gear. Both graphs show similar variations. However, the coherence of head gear is better than the bite-bar above 15Hz. Hence, the head gear is used in the following experiments. Figure 2 (left) shows the standard deviations of the measurements under three different experimental conditions, which suggests same extent of variations. Figure 2 (right) shows the results of intra-subject variability through comparisons basic measurements with those attained over one day and 3 days period. The values of S.D. within one day are larger than the others, especially above15Hz.

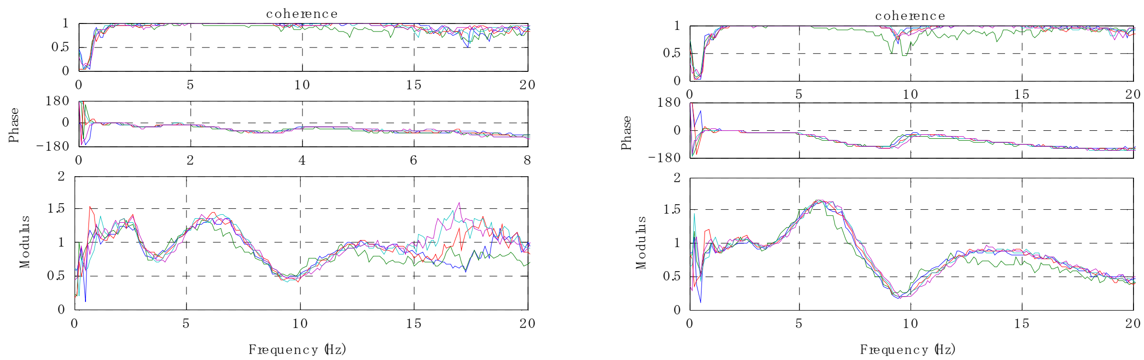

Fig.1: Variations in transmission of vertical seat-to-head vibration of a single subject repeated 5 times at the mouth level using Bite-bar (left) and Head gear (right)

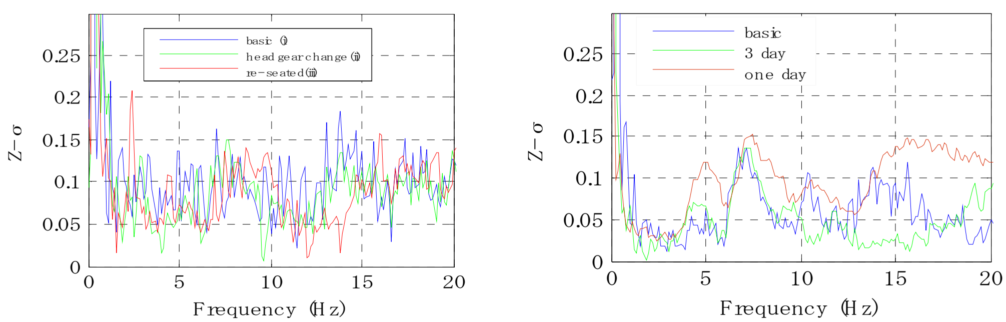

Fig.2: Standard deviation of transmissibility obtained from: experiment (a)- left ; and experiments (b) and (c) - right

Conclusions

The reproducibility and consistency of measurements are confirmed through comparisons of transmissibility under 3 different conditions. The variation over 3 days was similar to those for basic measurements, while the variation within one day appeared to be larger.

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SEAT-TO-HEAD TRANSFER FUNCTION OF SEATED MEN – DETERMINATION WITH SINGLE AND MULTI-AXIS EXCITATIONS AT DIFFERENT MAGNITUDES

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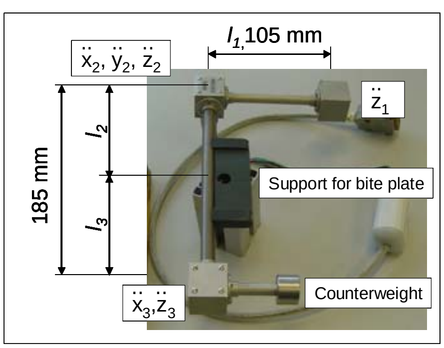
Introduction

Different methods exist to study the reasons for adverse effects of whole-body vibration on the human body. One of these methods involves consideration of how vibration is transmitted through the body. The transmissibilities through the human body reflect the biodynamic response of the body between the point at which the vibration enters the body, e.g. the seat interface, and the point at which the vibration is measured on the body, e.g. the head. Numerous studies concerning the seat-to-head transmissibilities have been published [1] and partially summarized in a standard and review papers [2,3,4]. The aim of the study was to examine the biodynamic behaviour by seat-to-head transmissibilities during one axis and three axes vibration, i.e. the resulting translational and rotational head movements in the main and cross axes without variability in the posture factor.

Methods

An experimental study was performed with 8 male subjects sitting on a rigid seat without backrest and with hands on a support (Figure 1). They were exposed to random whole-body vibration (0.25 to 30 Hz for 65 s) with unweighted root mean square (rms) values of E1=0.45 ms^{-2}, E2=0.90 ms^{-2}, and E3=1.80 ms^{-2} to vibration in X-, Y-, Z axis separately, and in all three axes. All seat-to-head transfer functions (moduli, phases, coherencies) in the main- and cross-axis were calculated. The effects of the factors 'vibration magnitude' and 'number of axes' on the maximum modulus (M_{max}) of the seat-to-head transfer functions together with its frequency(FM_{max}) were tested by statistical methods.



Top: Photography of the bite bar with the main information about the locations of accelerometers, distances between them. The hole in support can prevent relative movement between the support and the bite plate especially if the mass of the bite plate is pressed into the hole.

Right: Experimental situation is illustrated by the photography of a male subject sitting on a rigid seat

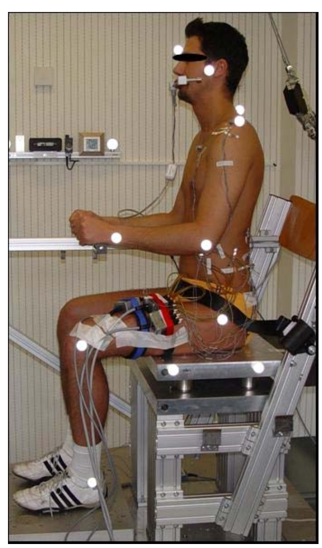


Fig. 1: Pictorial views of the siting posture and the bite bar.

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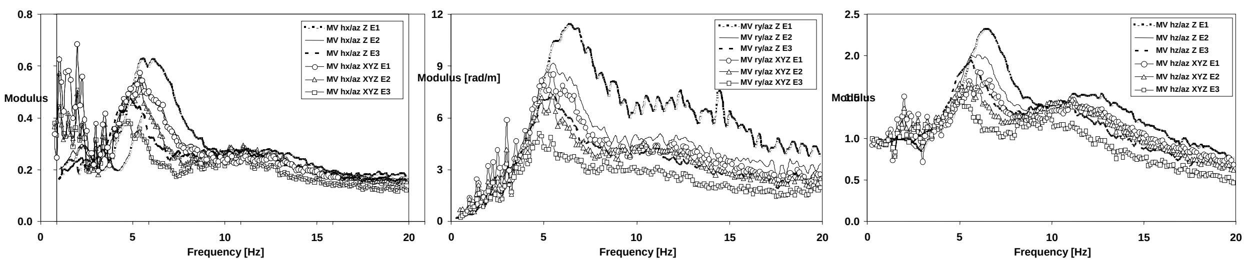
Results

In general the head movements follow constant patterns. These pattern of head movements comprise a combination of rotational and translational shares of the mean and cross-axis transmissions. The following basic composition of dominant shares is independent of the number of exposure axes. If a seat vibration in X-axis (isolated or combined) is transmitted to the head, dominant head movements were registered in x-, z- and pitch axis, seat vibration in Y-axis caused head movements in y-, roll and yaw-axis, and seat vibration in Z-axis produced head movements in z-, x- and pitch axis (Figure below). The curves showed a dependence of the moduli on the factors ‘vibration magnitude’ and ‘number of vibration axes’. These dependencies occur to a different extent in the translational vertical and horizontal as well as the associated rotational head movements.



Mean moduli of the seat–to-head transmissibility during seat vibration in Z- and XYZ-axis. Resulting head movements in x- (left) and z-direction (right) and the head movements in pitch-axis (middle)

Conclusions

Current standard [3] based on mean values of the seat-to-head transmissibilities only in Z-axis without any relations to the vibration magnitude provide limited information for the validation of biomechanical models. The examples presented indicate the existence of basic head movements resulting from a superposition of translational and rotational head accelerations. These head movements depend on the directions and axes of the seat vibration. The limited data base in the current standards [3] may even lead to wrong assumptions on the linearity/non-linearity and on the extent and location of M_{max} and FM_{max}. The results are limited to the exposure condition and posture tested. Further research is needed to enlarge the data basis, e.g. to test the influence of the factor posture.

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INFLUENCE OF TWISTED POSTURE ON SEAT-TO-HEAD TRANSMISSIBILITIES DURING EXPOSURE TO SINGLE AND DUAL-AXIS VIBRATION

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Introduction

Earthmoving machinery operators are faced with many ergonomic risk factors in their working environment. The nature of their work can expose them to unsafe magnitudes of whole-body vibration and shock, in conjunction with hazardous postures [1]. Twisted postures adopted by machinery operators have been an issue across a number of industries including underground mining [2], and construction [1]. To-date there has been little attempt to understand the biomechanical response of twisted postures adopted by machinery operators combined with vibration. In addition, many questions still exist as to how the vibration in just one axis can accurately predict the response to multi-axis vibration experienced in earthmoving machines. This paper combines two laboratory studies conducted to; firstly, validate seat-to-head transmissibilities and to determine the differences between adopting an upright versus a twisted posture during exposure to vertical vibration, and secondly, to evaluate seat-to-head transmissibilities in an upright versus twisted posture during exposure to fore-and-aft and vertical vibration, in order to develop understanding of dual-axis vibration and twisted postures.

Methods

The experiments used repeated measures designs to investigate seat-to-head transmissibilities of subjects in an upright versus a twisted posture under exposure to single axis vertical vibration (study 1) and dual-axis vibration (study 2). The main test conditions are outlined in *Table 1*.

Table 1: Outline of Study 1 and Study 2 experimental conditions and measurements.

Study 1: National Institute of Occupational Safety and Health, Japan (15 subjects)	**Study 2:** Environmental Ergonomics Research Centre, Loughborough University (21 subjects)
Twisted back and neck posture; upright posture	Twisted back and neck posture; upright posture
Vertical vibration (1 – 20 Hz, 1.0 m/s^2 r.m.s. unweighted)	Vertical and fore-and-aft vibration (1 – 20 Hz; z-1.1 m/s^2 r.m.s, x-1.4 m/s^2 r.m.s. unweighted random)
Rigid wooden seat, no backrest contact	Suspension seat with backrest contact
Bite bar (6 x accelerometers) to measure: seat-to-head transmissibilities, roll and pitch	Bite bar (6 x accelerometers) to measure: seat-to-head transmissibilities, roll pitch and yaw

Results

Comparisons between the upright and twisted posture have highlighted differences in the transmissibility of vibration to the translational and rotational axes at the head. shows the differences found between the two postures and two studies. Study 1 had greater seat-to-head transmissibilities for the upright posture in the vertical direction, but comparable results with study 2 for the twisted posture. Study 1 had a smaller peak during the twisted posture, but the remaining transmissibilities were similar. Differences between the studies could account for the discrepancies. In the rotational axes differences were observed between postures. There was significantly greater roll motion at the head at most frequencies for the twisted posture.

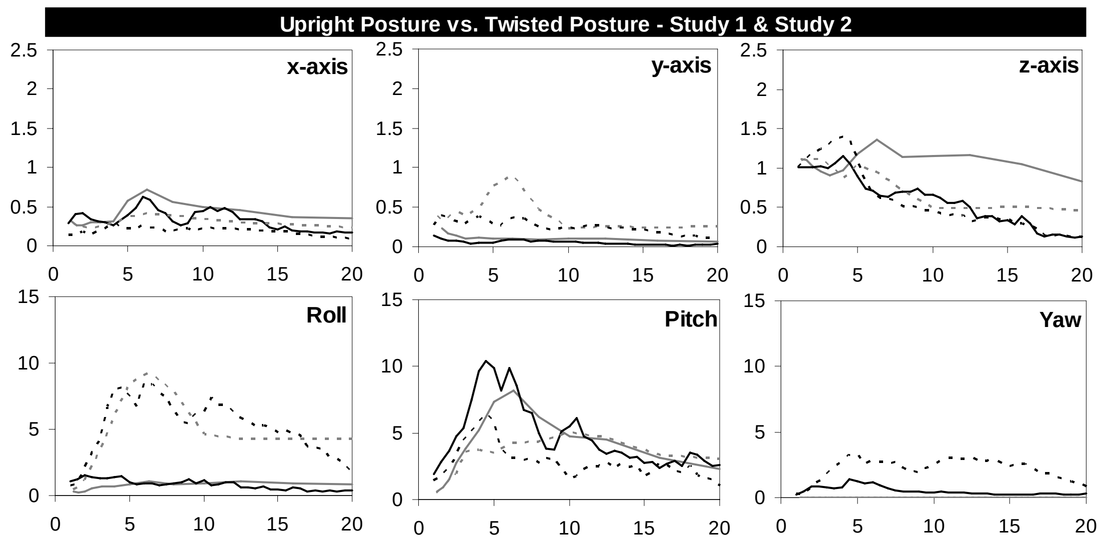

Fig. 1: Transmissibility of vertical vibration (study 1), vertical and fore-and-aft vibration (study 2) from the seat to the fore-and-aft (x), lateral (y) and vertical (z) axes at the head, with roll, pitch and yaw motion of the head. Values are presented as the median of study 1 subjects (grey lines) and study 2 subjects (black line). Solid lines denote upright posture and dashed lines the twisted posture.

Conclusions

Seat-to-head transmissibilities showed more lateral and roll motion for the twisted postures. Both motions changed from being close to zero, with no clear frequency dependence in the upright posture to a system with a clear peak around 6 to 8 Hz in the twisted posture. This demonstrates that operators necks are likely to be exposed to increased rotational movement at the head when sitting in a twisted posture during exposure to vibration.

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COMPARISON BETWEEN DIFFERENT TECHNIQUES FOR THE TRANSMISSIBILITY MEASUREMENTS

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Introduction

Vibration transmissibility along the human body is commonly measured by fixing (miniature) accelerometers to the skin. Our paper aims to compare different fixation methods the accelerometer-based measurements with two non-contact techniques, based on the image analysis and on laser Doppler vibrometers. Each of the three methods showed some peculiarity and advantages that are addressed in the paper. The accelerometer-based measurement mostly suffers from the load effect due to the transducer mass: this effect depends on the region of the body where the measurement is carried-out and also on the vibration level, which, in general, is difficult to predict. The laser Doppler system suffers from the sensitivity to lateral motions when the reflecting surface is not perpendicular to the laser beam and in general achieving a stable pointing on the human body is not as easy as on mechanical components. The image analysis is constrained by the image resolution and the sampling rate, a tradeoff between image size and frequency bandwidth has to be performed.

Methods

Tests were performed on an electro-dynamic shaker, where a swept sine motion with different vibration levels (1 to 2.5 m/s^2) was imposed on six standing and seated persons. The accelerometer-based measurement chain was setup with miniature accelerometers having different mass and shape and fixed with various methods (glued to elastic or rigid straps, glued to adhesive tape applied to the skin) to different parts of the body (both "soft regions", like the calf muscle and "stiff" where the skin is close to the bones like at the *malleolus*). The laser Doppler vibrometer (LDV) was pointed on reflective adhesive tapes applied to the skin, so as to have a negligible load effect. The LDV velocity output was numerically differentiated to obtain the acceleration signal for direct comparison with the accelerometer measurements. The vision system was based on a Marlin F131B camera (1280 x 1024 CMOS) with different optics. A fit to the purpose measuring system allowed the synchronous acquisition of the images and the acceleration. The observed areas ranged from 100x100 to 200x300 mm. Black spots painted on the skin were used as markers for the motion tracking system.

Results

Results confirmed that the accelerometer-based measurements are strongly dependent on the fixation method, especially on soft tissues. The loading effect is negligible at low frequencies and can be reduced by using the small flat pack MEMS accelerometers. The LDV-based measurement chain provided excellent results despite the difficulty of finding a good surface, almost perpendicular to the motion direction, the condition in which the system is insensitive to lateral motions. It was however found that displacements perpendicular to the laser beam could be quite easily filtered out because of the frequency content. An example of the vibration transmissibility from foot to the *malleolus* made separately with LDV and with a miniature

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accelerometer is presented in the left part of Figure 1. Owing to the adopted fixation method, (the accelerometer was glued to aluminum plate, tightened to the ankle with a strap) differences of the order of 20% were found. Conversely, the contemporary measurement with the LDV and the accelerometer led to the same results, pointing out that measurement errors mainly arise from the load effect due to the accelerometer. The vision system was found to be effective in the measurement of relative motion of close body regions. For instance, the transmissibility between a point on the *malleolus* and one on the lower part of the calf muscle is reported in the right plot in Figure 1. The intrinsic frequency limitation of the vision system (due to the displacement measurement with a constant acceleration input) is clearly pointed out by the SNR reduction above 10 Hz. This measurement method, however, has no load effect and provides a constant monitoring of the posture together with the vibration response of a whole body area.

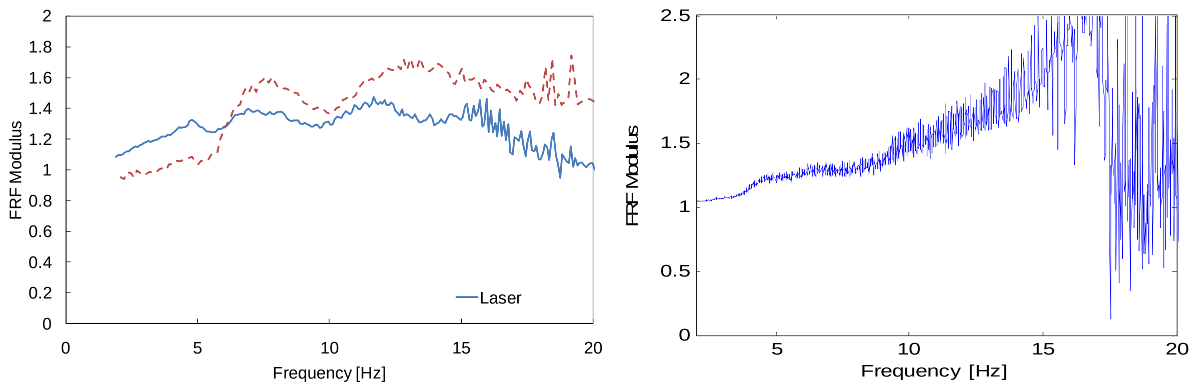

Fig. 1: FRF of different measurement systems and locations (Left – FRF of the the malleolus acceleration measured using the LDV and and a miniature accelerometer; Right – FRF between a point on the malleolus and lower part of the calf muscle)

Conclusions

Measurements obtained with the three measuring systems have been compared evidencing both the frequency range where each of them performs better in terms of accuracy and also the load error induced in various zone by the contact instrument. The limitations in terms of accuracy, frequency range and constraints on the subject during measurement was addressed. The technical implementations allowing to optimize each measuring system performances were discussed.

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SESSION 5

MODELLING

MODELLING THE VERTICAL APPARENT MASS OF THE HUMAN BODY IN DRIVING POSTURES

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Introduction

Models of the apparent mass of the human body can be used to predict the transmission of vibration through seats without exposing people to vibration. However, most models have not been developed for realistic driving postures. Recent experimental studies have measured the influence of backrest contact and backrest inclination [e.g. 1], hand position [e.g. 2,3], footrest position [e.g. 2,3], and vibration magnitude [e.g. 4] on the vertical apparent mass of the body. The aim of this study was to develop a simple generic model of the apparent mass taking into account the influence of these factors so as to assist the prediction of the vibration transmitted through seats and advance understanding of factors influencing body dynamics.

Methods

The response of a one degree-of-freedom lumped parameter model was fitted to the apparent mass of the body measured in previous studies of the effects of posture and vibration magnitude. The model consisted of a base frame, with a mass m_0 fixed at 6 kg, and a suspended single degree-of-freedom substructure consisting of mass, m_1, spring stiffness, k_1, and damping, c_1. The error between the measured and modelled apparent mass was minimised, for both individual apparent mass and median apparent mass in a group of 12 subjects, for each posture and vibration magnitude. Trends in parameters were identified as a function of the variables in each condition (backrest angle, hand position, footrest position, etc.), together with the damping ratios and damped natural frequencies.

Results

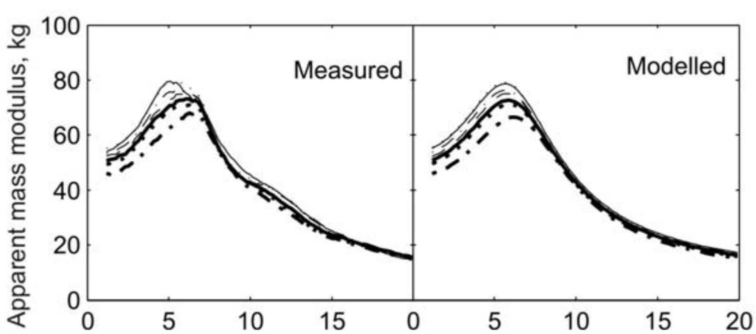

Figure 1: Effect of inclination of a rigid backrest on median vertical apparent mass of 12 subjects. Comparison of experimental data with the response of a single degree-of-freedom model —– 0°; · · · 5°; - - · - 10°; - - - - - 15°; ▬▬▬ 20°; ▪ ▪ ▪ ▪ 25°; ▬ · ▬ · 30°.

The simple one degree-of-freedom lumped parameter model was able to provide good fits to the primary resonances in the measured individual apparent masses and the median apparent masses (see Figure 1 as an example for a rigid backrest reclined from 0 to 30° in 5° steps). Parameters derived from taking the mean of the fitted individual subject parameters were similar to those derived from fitting to the median data. When subjects made contact with a rigid backrest

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there was an increase in the derived damped natural frequency of the resonance caused by a decrease in the moving mass and an increase in the stiffness. When either a foam backrest or a rigid backrest was reclined from 0 to 30°, the moving mass and the damping decreased (Figure 2). When the rigid backrest was reclined, the natural frequency increased as a result of a reduction of the moving mass. When the foam backrest was reclined there was a decrease in the natural frequency caused by a decrease in stiffness.

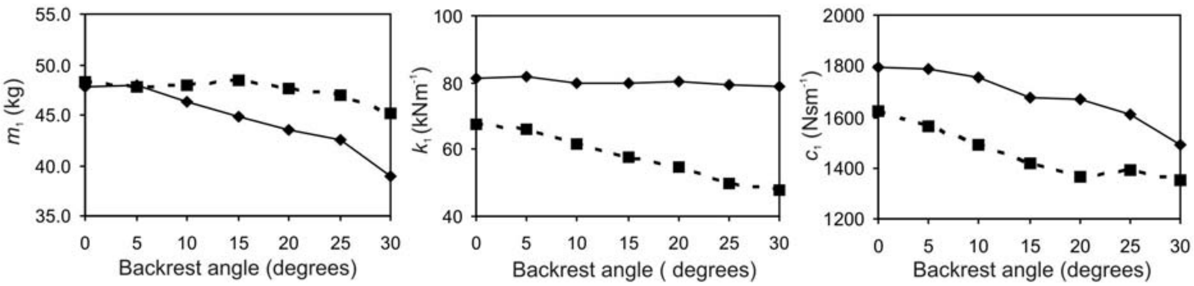

*Figure 2: Effect of inclination of rigid (—— **)** and foam (- - -) backrests on the mean of the parameters generated by fitting the model to the individual apparent masses of 12 subjects.*

Holding a steering wheel resulted in an increase in the stiffness and derived resonance frequency. When holding a steering wheel an additional resonance around 4 Hz was evident, with a tendency for this resonance to become more pronounced as the hands were movedfurther away from the body; more degrees of freedom would be required to represent this effect. As the feet moved forward, from a position where the lower-legs and the upper-legs were at 90° to a position where they were at 45°, there was an increase in the primary resonance frequency and the associated stiffness. Moving the feet forward further, to a position where the legs were outstretched, there was a decrease in the resonance frequency and in the associated stiffness.

Conclusions

A single degree-of-freedom model can provide a useful fit to the measured vertical apparent mass of the body over a wide range of postures and vibration magnitudes at frequencies less than about 20 Hz. Trends in model parameters, derived damping ratios, and damped natural frequencies have been identified. These trends allow the apparent mass response to be predicted for unmeasured conditions and may assist the development of models for the prediction of the transmissibilities of seats.

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MODELING OF SEATED HUMAN BODY WITH SPINAL COLUMN SUPPORTED BY ABDOMEN AND MUSCLE OF BACK FOR EVALUATION OF EXPOSURE TO WHOLE-BODY VIBRATION

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Introduction

It is necessary to evaluate the influence of the whole-body vibration to the spinal column. If there is a model of the human-spinal-column system that represents the vibration response in details, it is expected that mechanical loads on the intervertebral disks can be estimated in various vibration environments and is very useful. Several models represent the response of the vertebrae. They are anatomically-based complicated models. Few of them are focused on the vibration characteristics [1-3]. But In these models, it is difficult to evaluate the reliability of each parameter of the model, because various physical properties are used. Therefore the purpose of this study is a construction of a model of the seated human body that represents vibration response of the spinal column, especially the lumbar vertebrae under exposure to whole-body vibration. In addition, our goal of this model is to enable to estimate the mechanical load on the vertebrae, particularly the lumbar vertebrae.

Outline of human model

The proposed model is a two-dimensional model that has twelve degrees of freedom as shown in Figure 1. This model can represent responses of the spinal column, especially the lumbar vertebrae, to the vertical vibration input. For this purpose it consists of the head, the spinal column of which shape is S-character curve in the median plane, and some support structures such as the muscles of the back and the abdomen. The real spinal column is made by the vertebrae and the intervertebral disks. The vertebrae are modeled by regarding as rigid bodies. And some vertebrae with a little relative motion are mutually united and reconstructed to one rigid body by reference to the human anatomy and the motion of each vertebra acquired by a vibration experiment of the human body. The intervertebral disks are modeled by regarding as rotational springs and dampers. Parameters of the mass, the shape and the dimension of each vertebra are decided by some literatures and the measured body type of the subject. And stiffness and damping parameters are searched by fitting the model simulation results to the experimental measured data with respect to the apparent mass and the acceleration transmissibility from the seat surface to each vertebra and the head. In addition, the natural modes of the model compare with the result of the experimental modal analysis.

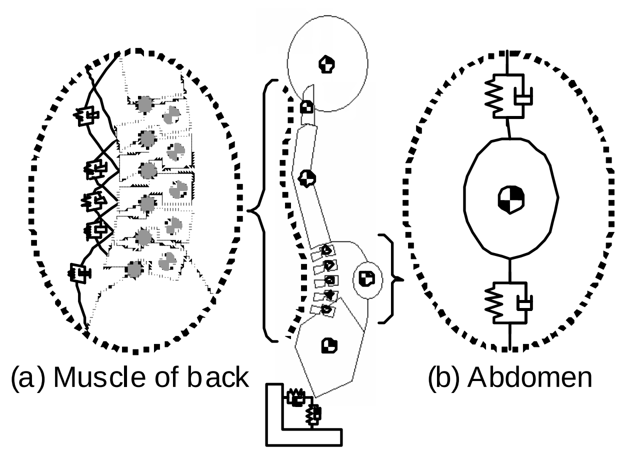

Fig. 1. Model of seated human body

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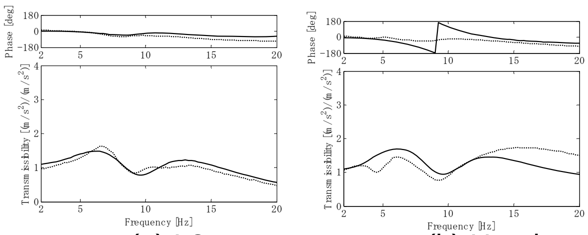
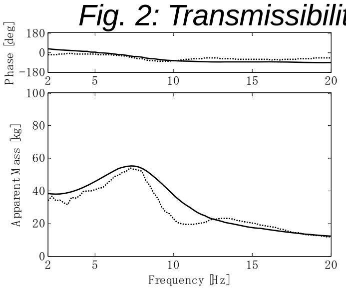
Results

Figures 2 show the transmissibilities of the third lumbar vertebra and the head obtained by the experiment and by the identification of the model. And Figure 3 shows the apparent mass. The transmissibilities and the apparent mass are realized well with a small margin of error in all frequency area; resonant frequencies are almost realized, too. Figures 4 show the second mode shape of the model and the experiment. The mode shape is well represented, too. By constructing of two models with taking away the abdomen and the muscles of the back from the proposed model, the roles of these supports are investigated by comparing these three models. With an increase in these support structures from the model with only the spinal column, the transmissibility of each part is improved. But they slightly affect the apparent mass.



(a) L3 (b) Head

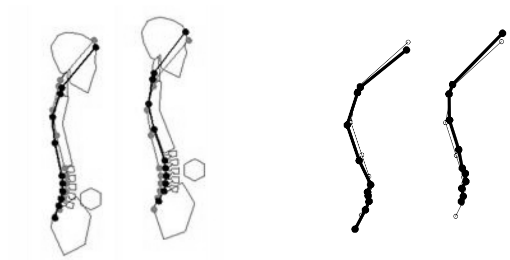
Fig. 2: Transmissibility of L3 and head



Solid line : Model

Broken line : Experiment

Fig. 3: Apparent mass



(a) Model f_d = 7.7 Hz

(b) Experiment f_d = 7.5 Hz

Deep line : Mode

Pale line : Natural position

Fig. 4: 2nd mode of model and experiment

f_d : Damped natural frequency

Conclusions

The model of the seated human body was developed, which could reproduce the vibration characteristics of the human spinal column exposed to whole-body vibration.

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BIODYNAMIC RESPONSE AND SPINAL LOAD ESTIMATION OF SEATED BODY IN VIBRATION USING FINITE ELEMENT MODELING

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Introduction

Low back pain (LBP) is a major musculoskeletal disorder with substantial human and economic costs. Prolonged exposure to whole-body vibration (WBV) is recognized as a risk factor for spine disorders. Proper injury prevention and treatment programs, however, require a sound knowledge of trunk muscle forces and spinal loads. Since these loads cannot be measured directly, biomechanical models play an indispensable role in spine pathomechanics. Earlier measurements on the force-motion biodynamic response (impedance, apparent mass) at the body-seat interface and vibration transmissibility (seat to head) have led to the development of different mechanical models [1]. Such models could simulate the overall passive response under various vibration and postural conditions and could serve as an important tool useful for vehicle seat design [2]. They are, however, not applicable for the prediction of physiological properties of seated body such as the musculo-skeletal loading during the WBV. On the contrary, anatomical models simulating human's physiological characteristics can predict activities in muscles and their dynamic effects on the spine. In this study, a nonlinear finite element model of the spine, in which the measured kinematics data are employed [3], is validated using the measured vertical apparent mass and seat-to-head transmissibility biodynamic responses [1]. Furthermore, this kinematics-driven model is used to evaluate muscle forces and spinal loads during the WBV. The results are hypothesized to demonstrate the substantial increase in spinal loads under active trunk muscle activities.

Methods

An anatomical model of the human trunk was employed in this study. The model is made of six nonlinear deformable beams representing T12-S1spinal motion segments, seven rigid elements for lumbar vertebrae (L1-L5) and head-T12 (as a single body), as well as a connector element to simulate the buttock-seat interface [3].The beams represent the overall nonlinear stiffness of T12-S1 motion segments (i.e. vertebrae, disk, facets and ligaments) at different levels with nonlinear axial compression–strain and sagittal/lateral/axial moment–rotation relations. This sagittally symmetric model also simulates trunk musculature attached to the lumbar vertebrae and thoratic cage. Throughout the vibration duration, the muscle forces are estimated using iterative kinematics-driven finite element approach [3] in which measured kinematics data are prescribed.The muscle recruitment in this musculoskeletal trunk system generates an active anatomical spine model. Furthermore, a passive (without musculature) model is considered for comparison. The input axial excitation is applied at the buttock–seat interface. White noise random vibration in the 0.5-15 Hz (magnitude=1.0 m/s^2 rms) is considered as input to the model. In the Z-axis direction, the reaction force at the buttock-seat interface and head-T12 acceleration are computed in the time domain. The force-motion transfer function (apparent mass, APMS), at the buttock-seat interface is estimated using FFT technique. Similarly, the

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vibration transmissibility from the input to head-T12 is quantified subsequently, which is considered to represent vertical seat-to-head transmissibility, STHT.

Results

Predictions of active and passive FE spine models are compared with the measured data, acquired using 12 male adults exposed to vertical WBV vibration. The simulated frequency responses in terms of both normalized APMS and STHT are compared with the measured data (Fig.1). Predictions of the active FE model show the primary resonance around 5Hz in both APMS and STHT responses. They also demonstrate a good agreement with the mean measured data over the frequency range considered. On the contrary, the results from the passive FE model lie outside the range of measured data, especially in the neighbourhood of the primary resonance. The time histories of compression and shear forces at the L5-S1 level are also compared. The compression force is larger in the active FE model compared with the passive FE model (Fig.2).

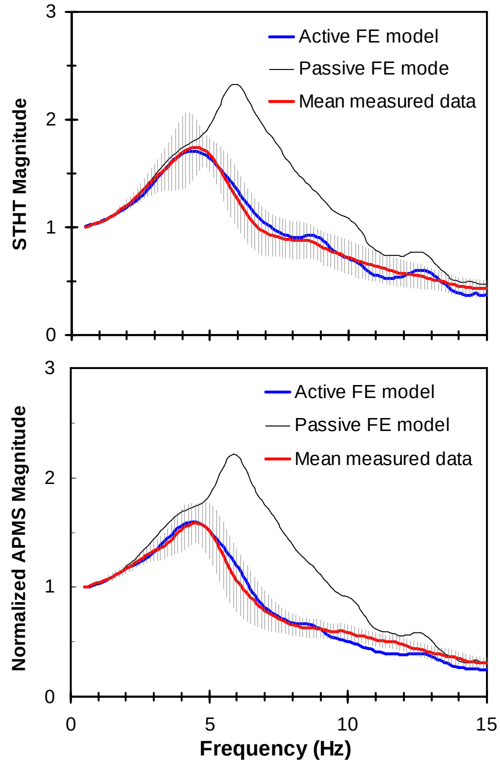

Fig. 1: Comparison of the simulated biodynamic responses with mean measured data ± standard deviation

Conclusions

Finite element-based anatomical spine models were validated using the measured biodynamic responses. Muscle recruitments, while needed to maintain trunk equilibrium and stability, substantially increased loads on the spine and hence the risk of compression failure. The relationships between the trunk muscle activity and coactivity, trunk stability and spinal loads will be investigated in future works to reveal the likely association between low-back pain and seated WBV.

Acknowledgement: This work was supported by the FQRNT-Québec and NSERC-Canada.

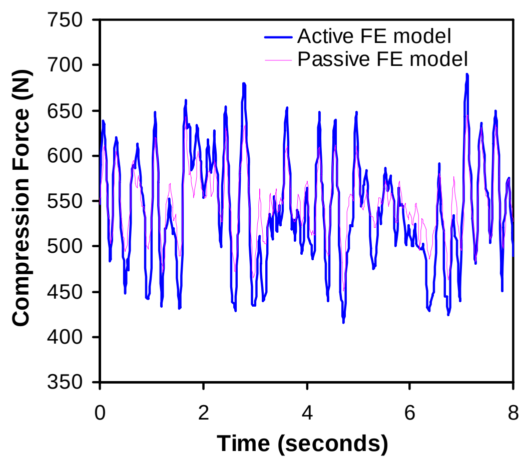

Fig.2: Estimated compression forces at the L5-S1 level

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SPINAL FORCES ESTIMATION FOR DIFFERENT OPERATING CONDITIONS AND OPERATORS

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Introduction

To protect workers against whole body vibration injuries a prediction of possible risks for specific excitations is required. This can only be done reliably on the basis of the internal forces in the lumbar spine. Due to ethical reasons measuring these quantities in vivo is almost impossible, which makes it necessary to estimate them based on measured excitations. For this estimation not only the real excitation should be considered, but also the corresponding posture due to its influence on the static and dynamic spinal forces.Results of latest experiments of spinal segments with combined compression and shear loads and flexed postures indicate a significant influence on the risk of adverse health effects. So for a reliable risk calculation not only the compression forces, but also the shear forces for the full three dimensional excitation have to be estimated. The combination of anatomy-based finite element models with in vitro data seems to be the approach best suited to establish quantitative exposure-effect relationships and to calculate the injury risk [1].

Methods

For this purpose a dynamic three dimensional finite element model of the human operator has been developed. Due to its close representation of the human anatomy, this model is capable of predicting the spinal forces within the human lumbar spine based on the three dimensional excitation at the four common contact points to the machine: seat surface, backrest surface, steering wheel and seat basis. This model has been adapted to 6 different typical postures of operators of different machines, e.g. forest machines, forklift trucks, construction machines and cranes. This is necessary not only to be able to reflect the different dynamic behaviour but also to take into account the different static forces, necessary to sustain posture. To be able to consider different individual factors a percentile classification for two different body mass indices based on a study of European workers [2] into 10 classes was performed and so for each posture 10 models with the corresponding model parameters have been created, so that one could speak of a model family.

One general problem of numerical models is the active human reaction on the vibration exposure especially at low frequencies below 2 Hz, so one of the latest enhancements of the model is a consideration of these effects on the dynamic response. Another major enhancement is the three step adaptation of the model to the excitation magnitude based on experimental results [3].

For a wide application in occupational safety and health services the use of a finite element model is much too complicated. To overcome this problem, for each finite element model of the model family the complex transfer functions from the vibrations q^j at each excitation point j to

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the spinal forces f_i have been calculated and stored in a single transfer matrix H.

$$f_i = \sum_j H^{ij} \cdot q^j$$

Based on this matrix, the spinal forces can be calculated for a real excitation by summation of the single results (product of the single excitation q^j with the corresponding element of the transfer matrix H^{ij}). For this purpose a standalone software with a graphical user interface has been developed, by means of which the user can easily estimate the spinal forces without knowledge in finite element simulations and need for special mathematical software. He simply has to choose the right model posture and anthropometry and to select the files with the excitation signals for the different excitation points.

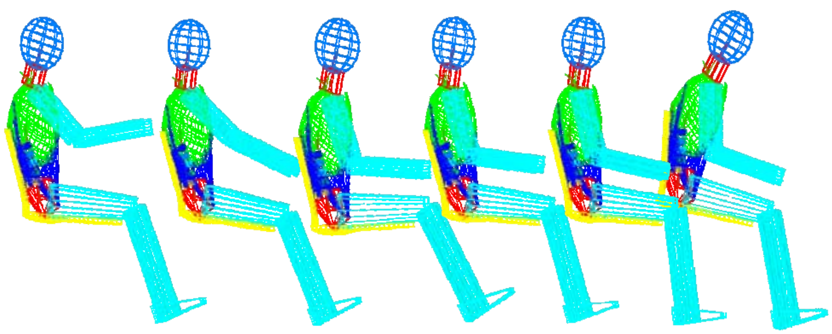

Fig. 1: Postures of the model family

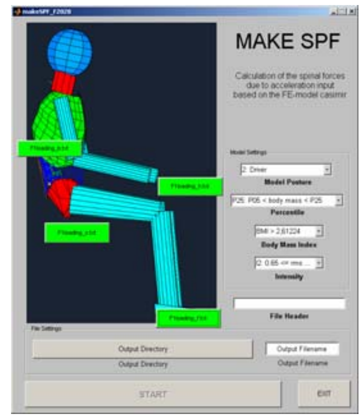

Fig. 2: Graphical user interface

Conclusions

By the combination of a finite element model with an easy to use graphical interface, the internal spinal compression and shear forces at real excitation, which are substantially necessary for risk estimations, become applicable in occupational health services. The use of three dimensional excitations and the possibility to get compression and shear forces within the lumbar spine offers new possibilities for assessing the injury risk due to horizontal and vertical whole body vibrations. But at present only the internal compression forces can be used due to the insufficient knowledge on the vibration effects in x- and y-axis and on the strength of the spine for shear loads. Future research is needed to overcome this and to quantify the exposure-effect relationship, necessary for risk calculation.

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TYPICAL VARIATIONS IN SPINAL GEOMETRY STRONGLY INFLUENCE THE MECHANICAL BEHAVIOUR OF LUMBAR SPINES – A COMBINED IN VITRO AND FINITE ELEMENT STUDY

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Introduction

Whole body vibration as well as isolated impacts may damage the lumbar spine. Effort is made to decrease this risk in the workplace. However, for further goal-oriented actions, the mechanisms by which external vibrations cause internal damages have to be understood. Moreover, the influence of individual spinal differences has to be known. It is known, that the ultimate strength of spinal specimens is well dependent on the product between endplate area and bone mineral density (BMD) [1]. To the authors knowledge such interrelations have not yet been determined referring to dynamic stiffness. The aim of this study was to determine the influence of individual geometry on spinal mechanical behaviour by means of a validated finite element (FE) model.

Methods

An established detailed FE model of a functional spinal unit (L4/L5) [2] was customised to different degrees of individualisation. Starting from a 50 % percentile model partially and completely patient specific models were developed. The individual models were based on digital computer tomography scans (CT) of lumbar spinal motion segments (L4/L5). For the partially individualised models 23 geometric parameters were measured for each functional spinal unit. The completely individualised FE models were built directly from CT data.

The spinal motion segments were harvested after consent and mechanically tested afterwards. The height of the CT slices was 0.7-1 mm and their resolution was about 0.3 mm. In-between harvesting and testing, the specimen were wrapped with wet gauze, sealed in double plastic bags and stored frozen (below -20 °C). For the mechanical testing all muscles were removed while longitudinal ligaments were kept intact. Quasistatic (0.005 Hz) and dynamic (12 Hz) force-controlled load cycles up to 2 kN where performed in the axial and anterior-posterior directions. A servo-hydraulic testrig (Bionix 858.2, MTS, MN) with an additional custom made shear-actuator was used. Based on pilot measurements it is known that the axial load provokes nuclear pressures of about 1.4 MPa. This was shown to occur in vivo during heavy lifting [3]. Loads were applied to a moving platform at the cranial side of the specimen, while the caudal side was rigidly attached to a load cell on the load frame. The two actuators of the test rig were bounded with the specimen holder by leaf springs instead of joints and sliders. This was necessary to prevent slip stick and friction problems known from joints and sliders, which can not be accepted for force controlled dynamic tests. During testing, the specimens were completely immersed in tempered physiological saline solution. Pilot tests showed that this hydration technique with the 37 °C fluid did not lead to abnormal swelling or degeneration during the testing procedure. Biological degeneration was inhibited by adding Penicillin/Streptomycin (PAA, Austria).

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For each spinal unit the relative motion of the two vertebrae were compared between the different models and with the experimental results. This was done for dynamic as well as quasistatic load cycles.

Results

The comparison between the experimental and numerical results was performed for different load cases like quasi-static compression with and without preload or dynamic shear loads with different amplitudes and different compressive preloads. In almost every load case the individualised sub-models produced better results than the old model which represented the 50th male percentile. The comparison clearly showed that accurate numerical results require a highly individualised model of the lumbar spine.

Conclusions

By simultaneously performing experiment and simulation a very reliable FE model was created which enables the assessment of the influence of individual differences on the mechanical behaviour. It was clearly shown that geometry plays a considerable role in simulating spinal behaviour. In particular disc height has a strong influence on the mechanical properties. For even better numerical results more individual parameters have to be be taken into account. A promising attempt for improving the performance of the numerical models could be the inclusion of material parameters based on the analysis of the individual bone mineral density.

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TRUNK SEATED BIODYNAMIC RESPONSE TO AXIAL IMPACT; EFFECT OF MUSCLE CO-ACTIVITY

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Introduction

Stability of the spine is an important consideration when evaluating risk of injury in sudden trunk loading. Unstable ligamentous spine is stabilized by activation and stiffness of muscles. Long latency (>200 ms) in trunk muscles' voluntary response highlights vulnerability in sudden perturbations. Reflexive muscle response with shorter latency time (>60 ms), on the other hand, tends to overshoot while attempting to compensate for deviations in desired and actual kinematics thus likely increasing the risk of back injury by causing excessive spinal loads. It has been suggested that co-activation of trunk muscles can enhance trunk stability and diminish the need for active muscle response to perturbations. This study aimed to simulate and quantify the effect of abdominal muscle co-activity during latency period on biodynamics response of trunk under whole body axial impacts. A detailed kinematics-driven finite element model of the trunk that accounts for nonlinear passive properties of the spine, dynamic characteristics of the trunk and a realistic muscle architecture [1] is subjected to axial impacts of different magnitudes. It is hypothesized that the trunk is stabilised and experiences smaller motions as a result of existing abdominal muscle coactivity. This would suggest an increase in trunk stiffness with a likely decrease in demand for subsequent reflexive response to sudden loading.

Methods

The finite element model [1] is made of six nonlinear beam elements representing the stiffness of T12-S1 lumbar motion segments, rigid elements representing lumbar vertebrae (L1-S1) and thorax-neck-head (C1-T12), concentrated mass and mass moment of inertia for segmental dynamic properties and connector elements to simulate linear/angular inter-segmental damping as well as buttocks' nonlinear stiffness and damping. For active muscle structure, a sagittally symmetric architecture consisting of 46 local (attached to lumbar vertebrae) and 10 global (attached to the thoracic cage) muscles is used. Muscles are simulated using uni-axial elements assuming a linear stiffness-force relation ($k=q\,F/L$) in which the muscle stiffness is proportional to the instantaneous muscle force, F, and inversely proportional to its current length, L, with q as a dimensionless muscle stiffness coefficient taken to be the same for all muscles [2]. The model is subjected to an axial impact at the base using a half-cycle sinusoidal acceleration input at 5 Hz. Trunk movement is computed for 100 ms (with no alterations in existing muscle activities) under two trunk postures (i.e., erect representing standing and flexed representing sitting), two levels of coactivity (i.e., 1-2-4% as well as 2-4-8% respectively in Internal Oblique IO-External Oblique EO-Rectus Abdominus RA), three levels of muscle stiffness coefficient (q=0, 5, 10) and finally two levels of input base excitation magnitudes (10 and 20 ms^{-2}).

Results

Trunk deviations from initial pre-impact equilibrium position decreased as coactivity in abdominal muscles and muscle stiffness coefficient (q) increased (Fig. 1). Trunk rotation at the T12, however, remained almost unchanged with muscle coactivity when no muscle stiffness

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was considered (q = 0). Muscle forces remained constant during perturbation for cases with q=0 but altered (increased in eccentric extensor muscles whereas decreased in concentric flexor muscles) for cases with non-zero stiffness coefficients. In contrast to extensor muscle forces and due to inertia, spinal loads reached their peak values before 100 ms. Trunk kinematics, extensor muscle forces and spinal loads increased with flexed posture and higher acceleration. Flexed posture as well as higher q and abdominal coactivity yielded a more stable trunk.

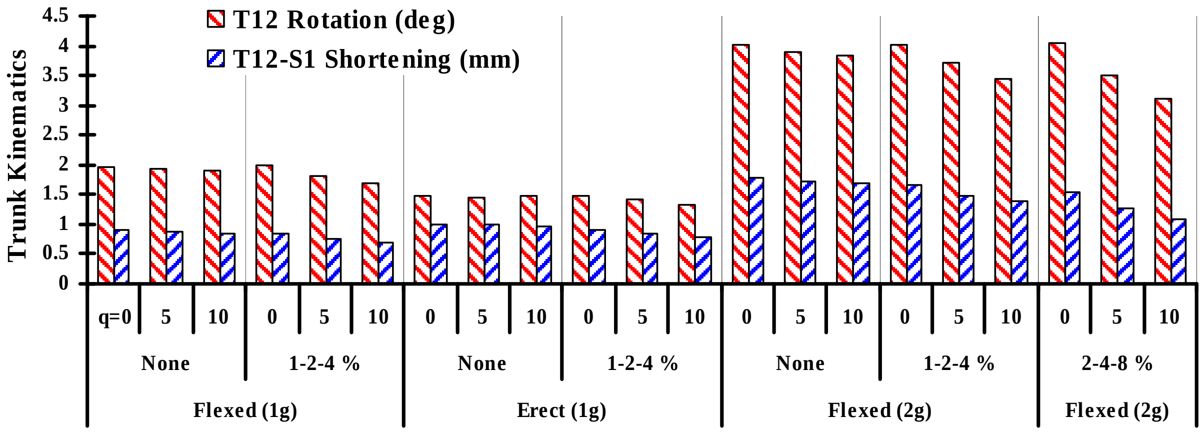

Fig. 1: Trunk rotation at the T12 and shortening of T12-S1 for different conditions

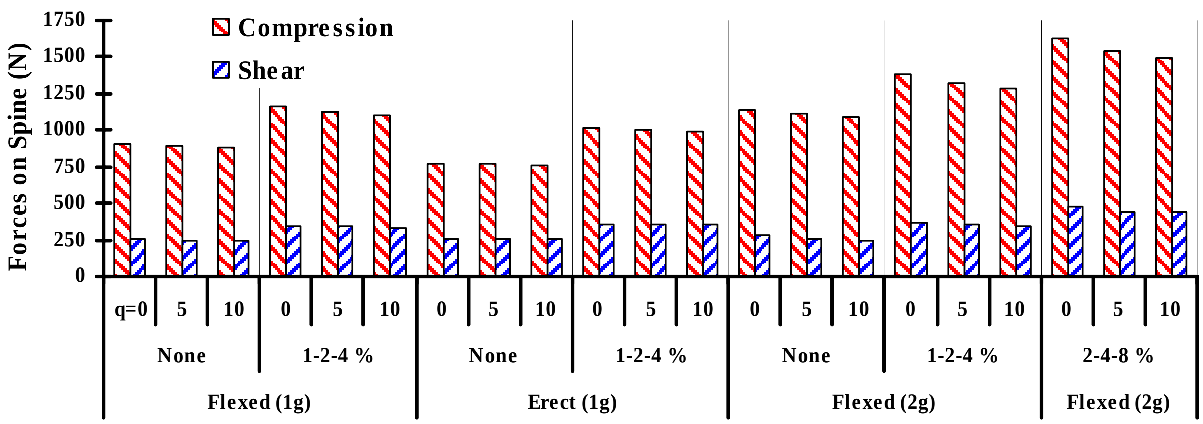

Fig. 2: Spinal forces at the L5-S1 disc for different conditions

Conclusions

Adequate dynamic stability of the spine is essential to safeguard the entire system against injuries especially in unexpected loading environments. Muscle response to perturbations remains temporarily unaltered due to time delays in reflexive and voluntary actions. Our results support the hypothesis that augmented trunk stiffness and muscle co-activity stiffen and stabilize the trunk thus reducing the need for subsequent reflexive muscle response.

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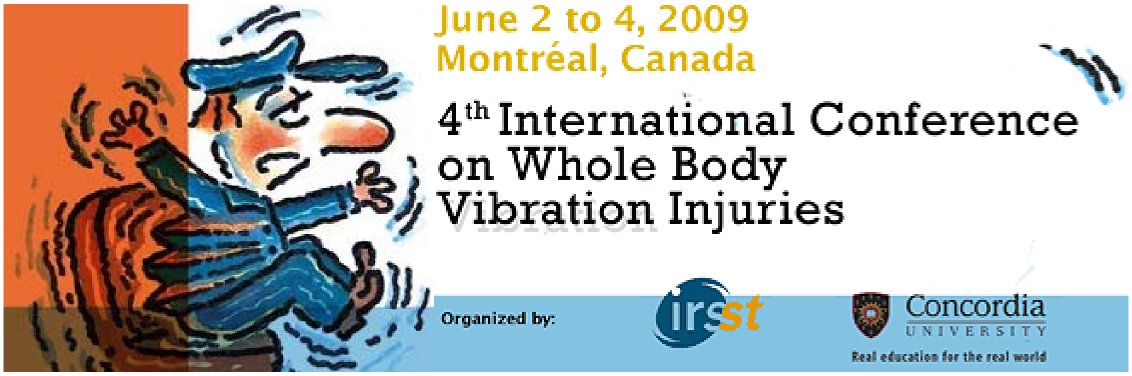

SESSION 6

POSTERS

COMPARISON OF WHOLE-BODY VIBRATION AND SHOCK MEASUREMENTS IN RAIL-BOUND AND OFF-ROAD MAINTENANCE-OF-WAY VEHICLES USED IN THE RAILROAD INDUSTRY

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Introduction

Locomotive and rail maintenance vehicle operators in the railroad industry report a high rate of back disorders (1). Among important risk factors are exposure to vibration and shocks (2;3). Railroad vehicles can be rail bound or utilized as road or off-road vehicles. The goal of this study is to compare vibration measurements of vehicles used in the railroad industry for track maintenance and construction following ISO 2631- Part1:1997 measurement standard and the new ISO 2631- Part 5:2004. The data was collected as part of injury claim investigations utilizing state of the art equipment and following international measurement guidelines.

Methods

Following international standards (i.e., ISO 2631-1:1997) the weighted root-mean-square (r.m.s.) acceleration for each measurement axis (basic vibration evaluation method), the SEAT (seat effective amplitude transmissibility), the crest factor (CF), the maximum transient vibration value (MTVV) and vibration dose value (VDV) and R factor are calculated for railroad track maintenance ("maintenance-of-way") vehicles used in the USA.

Results

The measured results of rail-bound and off-road maintenance-of-way vehicles are listed for comparison in Table 1. The r.m.s. vibration results depended in general on vehicle speed, track/surface conditions and seat properties, with the tamper and bulldozer showing the highest r.m.s. values. The measured CF, MTVV/a_w and VDV/($a_w \cdot T^{1/4}$) ratios were at or above the critical ratios in the majority of measurements (CF >9, MTVV/a_w >1.5, VDV/($a_w \cdot T^{1/4}$) >1.75) suggesting high shock content. The highest calculated shock indicator values in the rail-bound vehicles have been observed in off-road vehicles measurements with difficult terrains. Slow moving track maintenance equipment appears to be characterized by similar tri-axial basic vibration values, and high shock parameters, due to design and operational tasks.

Conclusions

These newly reported vibration measurement results of maintenance-of-way vehicles suggest that operators may have exposure under certain conditions that approach or exceed the EU 'action limit' of A(8) = 0.5 m/s^2, but also exposure to considerable shock and jolts based on the indicators, calling for additional evaluation methods under ISO2631-1(1997). The tested operator seats currently in use appear to magnify the vibration and shock exposure in the horizontal and in some cases in the vertical direction. 'R' values according to ISO 2631-5

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suggest a possibly low risk for lumbar vertebrae endplate dysfunction, although epidemiological data supporting this assumption is missing at the present time. Additional data collection under different operational conditions is needed. Improved working conditions and adequate suspension seats would be beneficial to avoid unnecessary exposure to vibration and shocks.

Table 1 : Results of rail maintenance-of-way vehicle vibration measurements

	Basic values a_w			Vector sum	SEAT			Crest Factor			MTVV/a_w			VDV/$a_w T^{1/4}$			
No	x	y	z		x	y	z	x	y	z	x	y	z	X	y	z	R
1	0.18	0.14	0.19	0.37	1.22	1.64	0.83	13.6	14.4	28.9	9.85	5.9	8.25	2.22	1.88	2.33	0.24
2	0.44	0.15	0.5	0.82	1.08	1.22	0.91	6.9	8.7	1.6	3.68	4.26	2.93	1.65	1.67	1.64	0.28
3	0.29	0.3	0.34	0.68	1.44	1.1	1.37	16.4	17	23.8	9.47	10.8	9.49	2.09	2.16	2.21	0.59
4	0.23	0.17	0.2	0.45	1.25	1.26	0.94	9	12.6	13.1	5.22	7.22	6.11	1.65	1.73	1.68	0.2
5	0.26	0.25	0.32	0.60	1.39	1.28	1.12	21.3	18.9	30.1	12.76	10.54	8.42	2.2	2.3	2.32	0.5
6	0.24	0.22	0.39	0.60	1.23	1.32	1.19	14.2	11.7	23.3	7.6	6.04	8.07	1.87	1.62	1.88	0.38
7	0.4	0.34	0.67	0.99	1.12	1.1	0.46	11.7	10.4	8.1	5.72	4.31	2.89	1.78	1.54	1.38	0.41

1) Ballast regulator, 2) Tamper ATS 6700, 3) Wheel loader Cat966F, 4) Speedswing 445E
5) Backhoe CAT420D 6) Grader JD670 7) Bulldozer BD398S

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CHARACTERIZATION AND ASSESSMENT OF CREW VIBRATION EXPOSURE ABOARD A TILT-ROTOR AIRCRAFT

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Introduction

Military propeller aircraft can expose aircrew to substantial and prolonged periods of vibration that can affect performance, comfort, and health. The purpose of this study was to characterize and assess human vibration exposure during operation of the US Air Force CV-22 Osprey tilt-rotor aircraft. The International Standard ISO 2631-1: 1997 [1] was used as the guideline for assessing comfort and health risk.

Methods

Three battery-powered vibration recorders were used to collect acceleration data at the pilot (PI) station located on the right side of the cockpit, the flight engineer (FE) station located at the center of the cockpit, and the crew chief (CC) station located on the right side of the cabin. At each station, triaxial accelerometer packs and pads were used to estimate the accelerations entering the seating system and transmitted to the occupants at the seat pan and seat back. Flight test conditions included short takeoffs, climbing in both airplane (APLN) mode (nacelle at 0 degrees) and conversion (CONV) mode (nacelle at 60 degrees), cruising in APLN mode and CONV mode, conversion and re-conversion, approach to hover, hover (at various altitudes) and landing. Each occupant used a triggering device to initiate data collection for the selected test condition when prompted by the FE. Each 20-second segment was associated with a specific flight test condition. The triaxial acceleration spectra were calculated in 0.5 Hz intervals for characterizing the vibration at each measurement site. The overall weighted accelerations were calculated between 1 and 80 Hz in accordance with [1]. For assessing comfort, the overall Vibration Total Value (*VTV)* was calculated as the vector sum of the point *VTVs* at the seat pan and seat back [1]. For assessing health, the highest weighted seat pan acceleration in any axis was used [1]. Comfort and health risk evaluation criteria of Satisfactory, Marginal, or Unsatisfactory were assigned to the various exposures based on the ISO guidelines.

Results

Figure 1 illustrates the distinct peaks associated with multiples of the propeller rotation frequency (PRF) in the unweighted PI seat pan acceleration spectra for the cruise condition in APLN and CONV modes. For most flight test conditions, the comfort evaluation was rated Marginal (fairly uncomfortable to uncomfortable based on [1]). For the health risk evaluation, it was assumed that the aircrew spent the greatest mission time in the cruise conditions, where the highest weighted acceleration at the seat pan occurred in the vertical direction at the PI station. For the health risk assessment, the allowable exposure durations were calculated for each Health Guidance Caution Zone [1]. Figure 2 illustrates the mean allowable exposure durations at the PI, FE, and CC stations during the two cruise conditions. The limiting durations for a rating of Satisfactory (determined by the lower rail of the Zones) were observed at the PI station; 2.8 hours in APLN mode, and 3.4 hours in CONV mode. Therefore, any missions

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lasting longer than about 3 hours would be considered at least Marginal for health risk.

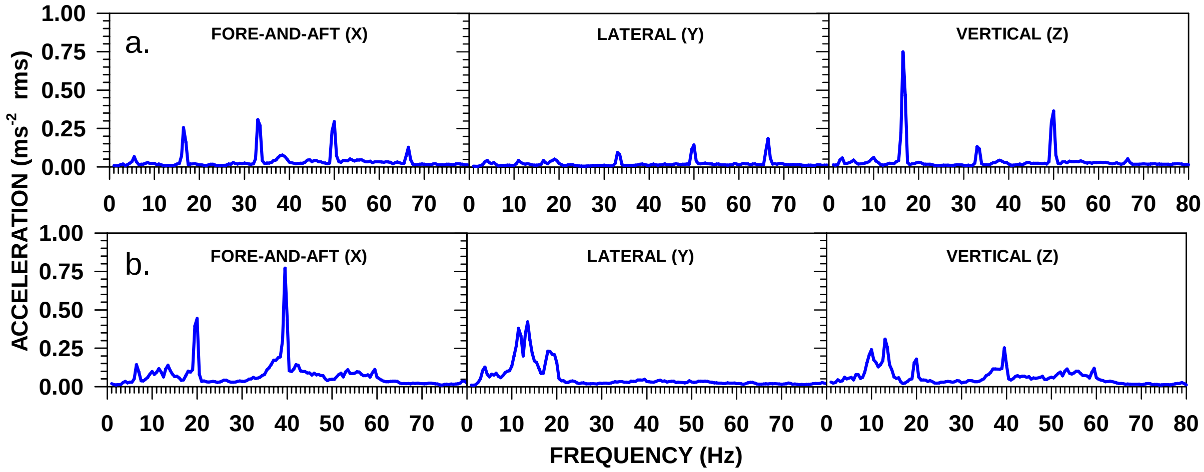

Fig. 1: PI Unweighted Seat Pan Acceleration Spectra; a. APLN Mode, b. CONV Mode

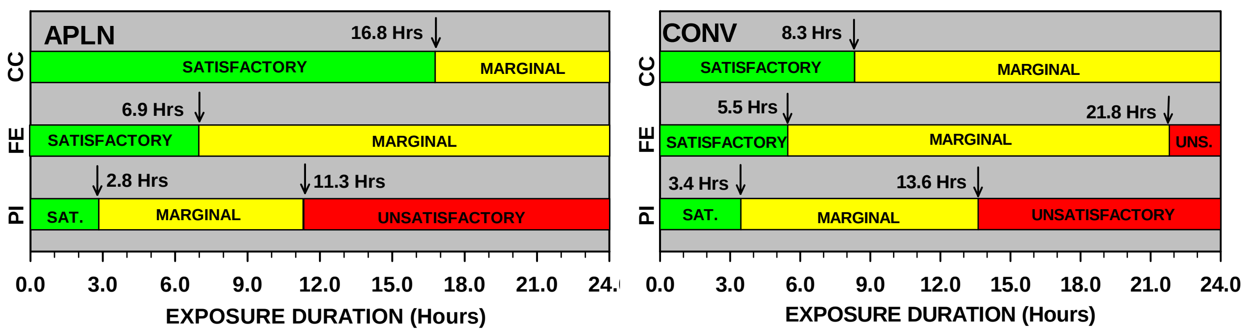

Fig. 2: Allowable Exposure Durations for APLN and CONV Modes

Conclusions

Based on the ISO 2631-1: 1997 guidelines, the Marginal ratings for comfort and health risk warrant caution with respect to CV-22 aircrew readiness and safety, particularly during longer missions. It is recommended that periodic monitoring of the aircrew be conducted by a flight surgeon focusing on discomfort, numbness, and pain in the back and lower extremities. Potential health risks should be identified using epidemiological surveys of actively deployed aircrews. Modifications of the FE and PI seating systems should be pursued for improving posture and reducing vibration.

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QUANTIFICATION OF 6-DEGREE-OF-FREEDOM WHOLE-BODY VIBRATION EXPOSURE LEVELS DURING FIVE SKIDDER FIELD OPERATING TASKS

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Introduction

The exclusion of 6-degree-of-freedom (DOF) vibration exposures at the operator-seat interface (OSI) with respect to health guidelines coupled with the instrumentation limitations associated with the collection of this data have resulted in a lack of OSI 6-DOF field exposure data. In order to obtain a more comprehensive understanding of how the human body responds to whole-body vibration (WBV) in the field, laboratory investigations which utilize realistic 6-DOF WBV exposures need to be conducted. The ultimate goal of this study was to obtain time histories of 6-DOF WBV exposure data to be used as inputs in laboratory investigations on the human biodynamic response to 6-DOF WBV. This particular paper focuses on the quantification of the 6-DOF WBV exposure levels that occured in Northern Ontario skidders during field operating tasks. Additionally, possible connections between the vibration exposures and musculoskeletal symptoms reported by the operators were explored.

Methods

WBV exposure levels at the OSI were determined for 8 male Northern Ontario skidder operators under field operating conditions with a custom made 6-DOF seat-pad transducer placed on the skidder seat beneath the operator's ischial tuberosities. Five operating conditions were observed and monitored; driving with a load (DL), driving without a load (DUL), picking up a load (PUAL), dropping off a load (DOAL), and ploughing logs. All data were band-pass filtered with lower and upper cut-off frequencies set to 0.4Hz and 40Hz respectively. ISO 2631-1:1997 [1] health and comfort weightings were applied to the filtered data using a custom Matlab™ (Mathworks Inc., MA, USA) program that utilized the Vibratools™ software package (Axiom EduTech, Ljusterö, Sweden). The weighted and unweighted running RMS average accelerations using 1-second central window averaging and 90% overlap were determined for each axis and operating condition. Vibration total values (VTV) were then calculated for the translational axes and compared to the ISO 2631-1:1997 health guidance caution zones. Translational and 6-DOF VTVs were also calculated for comfort evaluations.

Results

The greatest running RMS average accelerations typically occurred in the Y-axis and Roll (Table 1). Table 1 also shows that DUL and ploughing operating conditions had the greatest exposure levels. Based upon the translational VTVs calculated from these running RMS average accelerations, it would take on average 2.8-hours to exceed the upper limit of the ISO 2631-1:1997 health guidance caution zone while DL, and 2.3-hours while DUL or ploughing. The time to exceed the upper limit when DOAL or PUAL was quite varied, ranging from 1.6-

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hours to 35.7-hours. The operators in this study reported musculoskeletal complaints for just about every body region. Although all of the complaints were linked to some aspect of the driving tasks, the operators only attributed low-back and neck pain to vibration exposure. When considering the expected comfort ratings, the 6-DOF VTVs would be considered uncomfortable in nearly all driving conditions. Interestingly, the operators reporting low-back and neck pain were not exposed to the greatest exposure accelerations, but they were the operators who adopted the greatest lateral bending and forward flexion for the greatest percentage of time [2]. Jack et al. [3], and Village, Morrison and Leong [4] all caution that posture is a contributing factor to the WBV complaints of operators.

The dominant exposure frequencies for each driving condition were also determined. When DL and DUL the dominant weighted exposure frequencies ranged between 0.8-2.5Hz for all 6-DOF. While the dominant unweighted exposure frequencies remained in a similar frequency range as the weighted driving exposures, several trials had high dominant unweighted exposure frequencies (exceeding 25Hz) which were attenuated by the ISO 2631-1 weightings. DOAL and PUAL displayed a similar pattern of dominant weighted and unweighted exposure frequencies, but it should be noted that even the dominant weighted exposure frequencies had several trials with high dominant frequencies, higher than those found while driving. This is likely due to the fact that during these tasks, the vehicles are stationary, and the higher frequency engine vibrations become more prominent than when the vehicle is being driven.

Table 1: Average ISO 2631-1:1997 weighted and unweighted running RMS WBV exposure values

	Weighted						Unweighted					
	X	Y	Z	Roll	Pitch	Yaw	X	Y	Z	Roll	Pitch	Yaw
Driving Loaded	0.62	0.82	0.59	0.64	0.46	0.30	0.85	1.15	0.94	1.56	1.39	1.02
Driving Unloaded	0.74	0.94	0.63	0.71	0.56	0.30	0.97	1.24	0.99	1.64	1.60	1.09
Dropping off a load	0.44	0.43	0.40	0.33	0.32	0.16	0.64	0.79	0.60	1.11	1.12	0.76
Picking up a load	0.39	0.36	0.43	0.40	0.32	0.14	0.65	0.73	0.57	1.66	1.49	0.84
Ploughing	0.76	0.80	0.61	0.67	0.56	0.33	1.08	1.23	0.92	1.67	1.77	1.24

Conclusions

Northern Ontario skidder operators are exposed to high levels of whole-body vibration. These exposure levels have been associated with adverse health outcomes, including reports of low-back and neck pain, but longitudinal investigations establishing 6-DOF dose/response relationships for injury still need to be completed.

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WHOLE BODY VIBRATION DURING CAR DRIVING AND WHEN USING PUBLIC TRANSPORTATION ONLY SLIGHTLY INCREASES THE LOAD ON A SPINAL IMPLANT

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Introduction

Severe compression fractures of a vertebral body are often stabilized dorsally by an internal spinal fixation device and ventrally by a vertebral body replacement (VBR). Shortly after surgery, patients want to know whether they are allowed to drive a car or to use public transportation. The aims of the study were to measure the loads acting on a VBR for single- and multi-axis vibration of different intensity levels. The effects of a backrest on the implant loads should also be determined.

Methods

In order to measure the loads, a clinically proven implant has been modified [1]. Six load sensors and a telemetry unit were integrated into the inductively powered implant (Fig. 1). The modified implant allows the measurement of six load components. Telemeterized devices were implanted in five patients, three of them (WP1, WP2 and WP4) agreed to exposure by whole body vibration. In these patients the implants were inserted at level L1 and bone material was added to the VBR in order to enhance fusion of the adjacent segments. Patient WP2 also agreed to repeat parts of the measurements about 1 year later. The patients were videotaped during the measurements and the load-dependent signals were stored on the same videotape.

Fig. 1: Cut model of the telemeterized VBR

During the vibration measurements the patients sat on a seat fixed to a hexapod. They were exposed to random single-axis vibrations in X, Y, and Z directions as well as in multi-axis XYZ directions with frequencies between 0.3 and 30 Hz. Three intensity levels (unweighted rms values of 0.25 ms^{-2}; 0.5 ms^{-2} and 1.0 ms^{-2}) were applied. Three postures were studied: sitting freely, leaning against vertical backrest, and leaning against 25° inclined backrest. The patients placed their hands on the thighs. Each of the 36 measurement sequences per patients lasted 60 s. For the evaluation, the sequences were divided in 3 times 20 s., for which the maximum resultant force on the implant was determined. From the 3 maxima per measurement sequence

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the median value is chosen and presented. Since the absolute values of the force on the VBR vary strongly from patient to patient, the values were related to the median force value for relaxed sitting with the hands on the thighs measured several times during a session.

Results

As expected, the maximum force on the VBR increased with increasing intensity. Related to the value for sitting the maximum force increased by 84% (WP1), 17% (WP2, 1st session), 40% (WP2, 2nd session) and 28% (WP4) when the intensity level was increased from 0.25 ms^{-2} to 1.0 ms^{-2}. The maximum values in the same order were 189%, 123%, 151% and 141%. The effect of the number of axes is shown in Fig. 2. For the highest intensity level, the highest maximum forces were measured during multi-axis vibration. Leaning at the backrest during whole body vibration markedly decreased the implant loads to values below that for sitting freely without vibration exposure.

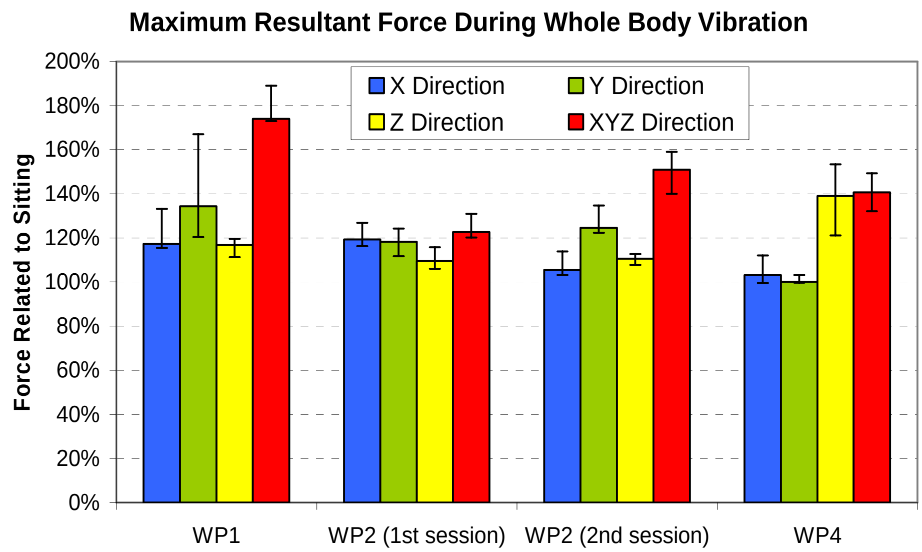

Fig.2: Effect of random single- and multi-axis vibration on related forces on VBR. The patients were sitting freely and exposed to the highest intensity level (1.0 ms^{-2}). Median and range of maximum values are shown.

Conclusions

Driving a car or using public transportation leads to lower implant loads than standing when the back leans agaist a backrest in a sitting position and can therefore be allowed already shortly after surgery. However, exposure to vibration while sitting freely may lead to implant loads which are nearly twice as high as during sitting relaxed. Similar values can be expected for standing e.g. in a bus. People with back problems should therefore travel in a sitting position with their back leaned agaist the backrest when using public transportantion.

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COMPARING THE WHOLE-BODY VIBRATION EXPOSURE HAZARD BY APPLYING THE ACTION AND LIMIT VALUES IN EC DIRECTIVE 2002/44/EC AND HAZARD GRADES IN RUSSIAN REGULATIONS

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Introduction

Risk evaluations of whole-body vibration exposure may differ depending upon the method chosen for assessing the exposure measurements [1]. Methods for risk evaluation in Russia differ from those used in the EU and the US. We intended to apply these different methods for assessing the vibration exposure in an under ground mine in Kirovsk, northwest Russia. The findings permitted a comparison of the outcomes from the two methods.

Methods

WBV exposure was measured in TORO40D large transport trucks, K14 transport locomotives and load haul dump vehicles (LHD); TORO 007D and TORO 400E. The vehicles operated in loading cycles, driving, dumping and returning. The ground qualities ranged from soft to rocky surfaces. Measurement periods ranged from 10 to 52 minutes, with 1 to 3 cycles per period, and a total of 13 measurements were taken (n=13). The measurements, data processing and analysis, and exposure assessment methods follow the guidelines of the ISO standard 2631-1 [2]. The exposure values A(8) rms are applied to the European regulations [3] and the hazard grades were defined (Table 1) as per the Russian regulations [4,5] for risk evaluation.

Table 1: Vibration exposure related to hazard classes in the Russian regulations.

Hazard class Russian standard [4, 5]	**Vibration exposure**	
	Z (m/s2)	**X, Y** (m/s2)
2	< 0,56	< 0,4
3.1	0,56 – 1.12	0,4 – 0,79
3.2	1,12 – 2,23	0,79 – 1,6
3.3	2,23 – 4,46	1,6 – 3,2
3.4	4,46 – 8,9	3,2 – 6,3
4	> 8,9	> 6,3

Results

The computed exposure values, A(8), in 3-axes are presented in Table 2 for the 4 vehicle categories. The table shows A(8) values in groups above and below the action limit value as specified in the European regulation [3]. Table 2 also shows how these risk assessments

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(above action value) correspond with the hazard grades 3,1 and 3,2 in the Russian regulations. For the K-14 vehicle, the risk assessment (below action value) corresponds to hazard grade 2.

Table 2: Vibration exposure related to hazard classes in the Directive 2002/44/EC and the Russian regulations.

Vehicle	Vibration standardised to an eight-hour reference. m/s2 Weighted values according to ISO standard, mean of subgroups				Directive 2002/44/EC Limit value: 1.15 m/s2 Action value: 0.5 m/s2 related to A(8)	Hazard categories - Russian regulations		
	A(8)rmsX	A(8)rmsY	A(8)rmsZ	Major axis		z	x	y
TORO 400D (007D) n=2	0,7	0,49	0,82	Z	Above action value	3.1	2-3.1	2
TORO 400E n=4	0,83	0,57	0,77	X	Above action value	3.1	3.1	3.1
TORO 40 n=3	0,57	0,53	1,02	Z	Above action value "close to limit value"	3.1-3.2	2	2
K-14 n=3	0,22	0,12	0,14	X	Below action value	2	2	2

Conclusions

Despite differences in the two assessment methods considered in the study, the risk and hazard grade outcomes could be considered comparable.

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QUANTIFICATION AND CHARACTERIZATION OF 6-DEGREE-OF-FREEDOM WHOLE-BODY VIBRATION EXPOSURE SPECTRA FROM THE CHASSIS OF SELECTED MOBILE MACHINES USED IN THE STEEL MAKING INDUSTRY

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Introduction

Operators of heavy machinery are often exposed to complex whole-body vibration (WBV) involving simultaneous motion along three translational and three rotational axes (6-DOF). To characterize 6-DOF WBV field exposures for machines used in a specific industry, vibration acceleration levels and spectral class data were determined for the chassis of five types of mobile equipment commonly used during steel making operations. The overall purpose of this work was to select the 'worst' machine from a vibration exposure perspective and then create representative 6-DOF field profiles of that machine for use in a laboratory study investigating the 6-DOF vibration attenuation characteristics of three different heavy equipment seats. This one year Workplace Safety and Insurance Board of Ontario funded project is being conducted to help the steel making industry and others make informed decisions based upon actual data collected under field operating conditions in order to help them choose the most appropriate seat for machine retrofitting.

Methods

Unweighted exposure spectra were determined at the chassis for 10 mobile machines used in the steel making industry (2 pot haulers, 2 loaders, 2 heavy lift transport, 2 scrappers, and 2 hoists) under field operating conditions using a 6-DOF MEMSense (MEMSense, SD, USA) transducer which was comprised of 3 accelerometers and 3 rate sensing gyros. The transducer was fixed in a rigid IP-65 rated polycarbonate case (Hammond Manufacturing, NY, USA) and the case was then fixed to the vehicle chassis using rare earth magnets. Output voltage from the MEMSense transducer was recorded using a Biometrics DataLOG data acquisition system (NEXGen Ergonomics, Montreal, Canada).

All data were collected in accordance with ISO 2631-1:1997 [1]. A custom Matlab™ (Mathworks Inc., MA, USA) program utilizing the Vibratools™ software package (Axiom EduTech, Ljusterö, Sweden) was used to determine the running RMS average accelerations with 1-second central window averaging and 90% overlap. Data were initially band-pass filtered with lower and upper cut-off frequencies set to 0.4Hz and 40Hz respectively. Based upon the mean power observed in the spectra for each of the 6-DOF's coupled with ISO 2631-1:1997 weighted accelerations obtained from a triaxial seatpad transducer [2], the worst machine from a whole-body vibration perspective was identified.

Results

Frequency peaks and running RMS acceleration values for the various machines are summarized in Table 1. Based upon the 6-DOF spectra coupled with the weighted results from

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the triaxial seatpad transducer [2], the 'worst' machines were found to be the pot haulers. Consequently, data for these machines were then further separated into driving loaded and driving unloaded conditions.

Table 1: Dominant PSD Frequencies and Running RMS Average Accelerations for Mobile Machines

Machine	Frequency (Hz) and Running RMS Acceleration (m/s^2)					
	X	Y	Z	Roll	Pitch	Yaw
Heavy Lift Transport 1	1(0.205)	3(0.226)	3(0.397)	37(1.260)	37(1.160)	37(1.700)
Heavy Lift Transport 2	4(0.264)	2(0.784)	3(0.350)	3(1.508)	34(1.179)	37(1.857)
Pot Hauler 1 – Driving Unloaded	2(0.699)	4(0.824)	2(1.088)	4(1.349)	5(1.382)	27(1.715)
Pot Hauler 1 – Driving Loaded	6(1.407)	4(1.098)	2(1.594)	4(1.647)	5(1.908)	21(1.818)
Pot Hauler 2 – Driving Unloaded	1(0.553)	1(0.711)	2(0.891)	4(1.444)	5(1.419)	31(1.872)
Pot Hauler 2 - Driving Loaded	1(0.680)	1(0.730)	2(1.113)	4(1.482)	8(1.508)	27(1.853)
Hoist 1	3(0.182)	3(0.168)	27(0.083)	27(1.515)	36(1.614)	37(1.028)
Hoist 2	4(0.296)	5(0.493)	5(0.229)	35(2.311)	34(1.290)	37(1.125)
Scrapper 1	6(0.217)	3(0.359)	4(0.157)	37(1.201)	34(1.153)	36(1.654)
Scrapper 2	2(0.385)	3(0.497)	22(0.389)	14(1.998)	28(1.767)	30(1.852)
Loader 1	1(0.781)	2(0.818)	2(0.690)	37(1.239)	16(2.010)	21(1.264)
Loader 2	1(0.469)	1(0.515)	2(0.445)	31(1.276)	32(1.771)	24(1.168)

Note: The first value is the dominant exposure frequency while the number in brackets is the running RMS average accelerations

Conclusions

In general, the spectra showed low dominant frequencies across translational axes with rotational axes exhibiting higher dominant frequencies. For the pot haulers, which carry large pots of molten slag, the high frequency peaks were only found in yaw. Interestingly, despite the fact that operators tend to drive faster when the pot is empty, the RMS accelerations were not that different for the driving loaded versus unloaded conditions. Previous research has found that WBV exposure levels increase with increases in driving speed [3,4]. The similarities between the overall exposure levels of driving conditions observed in this study could be due to the fact that most travel occurs on paved roads.

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CHARACTERIZATION OF 6-DEGREE-OF-FREEDOM WHOLE-BODY VIBRATION EXPOSURE SPECTRA DURING SKIDDER FIELD OPERATION

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Introduction

To date, studies investigating the biodynamic response of the human body to whole-body vibration (WBV) have utilized random noise, sine waves and impulses as vibration inputs. In addition, the vibration exposures present in these studies are often limited in the degrees-of-freedom (DOF) utilized. In the field, operators are exposed to complex 6-DOF WBV spectra which are not reflected in the sine wave or random white noise exposures of isolated exposure axes typically used in laboratory studies. In order to address these limitations in the biodynamic response literature, it is important to first quantify complex 6-DOF field exposure spectra and exposure levels at the operator/seat interface (OSI), facilitating their use as input parameters in laboratory investigations. To the knowledge of these authors, Parsons et al. [1] is the only study which evaluates field exposures at the OSI to this extent. However, Parsons et al.'s [1] report on standard automobiles is unlikely to be representative of industrial vehicles. This study begins to address these concerns by gathering complex 6-DOF field exposure spectra data for Northern Ontario skidders at the OSI, and characterizing those exposures into distinct spectral profiles for use as vibration inputs during investigations into the human response to WBV.

Methods

Unweighted 1/3-octave band exposure spectra were determined for 8 skidders operating in Northern Ontario under field operating conditions at the OSI with a custom made 6-DOF seat-pad transducer placed on the skidder seat beneath the operator's ischial tuberosities. All data were collected in accordance with ISO 2631-1:1997 [2]. A custom Matlab™ (Mathworks Inc., MA, USA) program utilizing the Vibratools™ software package (Axiom EduTech, Ljusterö, Sweden) was used to determine the 1/3-octave band running RMS average accelerations with 1-second central window averaging and 90% overlap. All data were initially band-pass filtered with lower and upper cut-off frequencies set to 0.4Hz and 40Hz respectively. Similar 1/3-octave band spectra were grouped together and an ensemble average for each group was calculated to create a spectral profile for each 6-DOF exposure axis during five operating conditions; driving with a load (DL), driving without a load (DUL), picking up a load (PUAL), dropping off a load (DOAL), and ploughing logs. All possible 6-DOF combinations of the spectral profiles were established, and the 6-DOF spectral combinations which occurred in the field were determined.

Results

A number of unique spectral profiles were found for each of the six exposure axes. In most instances, the profiles demonstrated distinct peaks and troughs of similar magnitude within one or two 1/3-octave bands of each other. Some profiles did not possess any apparent pattern of

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peaks and troughs, however, they did display similar underlying trends. In total, 9 distinct spectral profiles were established for the X-axis, 13 for the Y-axis, 6 for the Z-axis, 8 for roll, 7 for pitch, and 7 for yaw. Many spectral profiles occurred in a single skidder, but some profiles occurred in more than one skidder. Although individual spectral profiles would appear in a number of skidders, these profiles tended to appear under similar operating conditions, i.e. while DL, DUL and ploughing, or while DOAL and PUAL. There were however, some instances where all five operating conditions had exposures grouped into the spectral profile. This is likely do to the fact that the DOAL and PUAL conditions do include driving elements. It is interesting to note that the majority of profiles containing more dominant high frequency signal occur almost exclusively while DOAL and PUAL. This is likely the result of higher frequency engine vibration which becomes more prominent while the vehicle is stationary.

Upon determining the spectral profiles for each individual axis, the 6-DOF combinations of these profiles were obtained and the occurrence of each spectral combination in the field was investigated. Fifty-one different 6-DOF combinations were found, but each of these profile combinations were unique to individual skidders. It is important to obtain realistic field based spectral profiles which can be generalized across all Northern Ontario Skidders. This will allow lab based work using those spectral profiles to be more applicable in the field. The uniqueness of the 6-DOF spectral profiles combinations among skidders did not make the 6-DOF spectral profile combinations representative of a wide variety of skidders in the field. This resulted in the creation of 6-DOF spectral profile combinations by compiling individual axis profiles that were common to a number of skidders, and then determining which of those combinations occurred in the field. This provided fifteen 6-DOF spectral profile combinations which occurred in the field and could be generalized to a number of skidders.

Conclusions

A number of unique spectral exposure profiles were found to occur during the field operation of Northern Ontario forestry skidders. For individual axes, more than one skidder often contributed trials to the same spectral profile group. Conversely, the 6-DOF combinations of the individual exposure spectra appear to be unique to individual skidders. Therefore, the attainment of generalizable 6-DOF field spectral profile combinations for laboratory studies, at least with the current data set, requires the aforementioned compilation approach.

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INFLUENCE OF WHOLE BODY VIBRATION ON INTERVERTEBRAL DISCS AND LIGAMENTS OF HUMAN SPINE

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Introduction

Epidemiological investigations have suggested that whole body vibration (WBV) contributes significantly to injuries and functional disorders of the skeleton and of joints including spine [1]. Low back pain is a major public health problem that may restrict mobility and affect normal functions of the lumbar spine [2]. Seidel [3] emphasized the relationship of WBV expouse and spinal health risk and the significance and complexity of mechanical analysis by anatomy-based verified finite element (FE) models of human body. In this study, we will investigate the dynamic characteristics of the injured lumbar spine under whole body vibration. In addition, the facet contact forces will be analyzed, especially for the case of injured spine under WBV. The findings may be helpful to understand the WBV-related injury mechanism of human spine and provide reference to industrial product development.

Methods

The three-dimensional (3D) FE model of the spine T12-Pelvis segment in the sitting posture (Figure1) was developed based on actual geometrical data of an embalmed lumbar spine [4,5]. The model consists of cortical bone, cancellous bone, posterior bony element, nucleus, annulus, ligaments, facets and fibers. A lumped mass of 40kg was added on the top of the spine model.

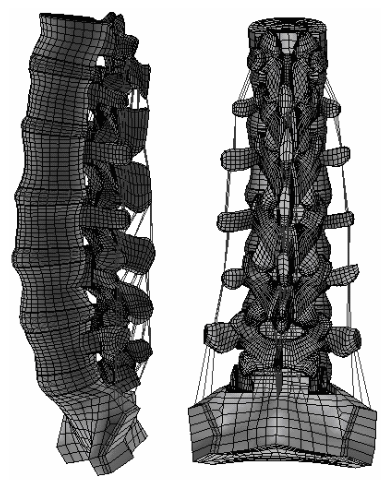

Fig. 1 : The 3D FE model of T12-Pelvis.

To investigate the effect of spinal injured components on the dynamic characterisitics of whole spine system, the denucleation and facetectomy together with the capsular ligaments at L4-L5 were employed to mimic the injury conditions of lumbar spine after surgery, as well as the severe degeneration of nucleus. By FE modal analysis, the vibration modes of T12-Pelvis was extracted and by transient FE analysis the response curves of facet contact forces of facet joints were obtained. For the transient FE analysis, a lumped mass of 40kg was added on the top of L3 vertebra to mimic the weight of human upper body and a sinusoidal compressive force was also imposed on the L3 vertebra to mimic a vibration load.

Results

Figure 2 shows the vertical displacement of all the vertebrae from T12 to S1 for the first-order vertical vibration mode of the model (for 4 cases: intact model, denucleation, facetectomy, and denucleation and facetectomy). The analytical results show that the lumbar spine segments not

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only have vertical vibration but also exhibit the anteroposterior motions (including the sagittal plane translation and flexion-extension rotation) during WBV. It can be seen that the anteroposterior displacement of L3 and L4 and their disc is maximal.

The maximum facet contact force of the denucleated model is 2.18 times of that of the intact model. Obviously, the removal of nucleus leads to high static facet contact force. The transient FE analysis shows that higher frequency cyclic compressive loads will increase the facet contact force. Compared with the cases without damping, the facet contact forces decrease due to the damping existence. However, it can be found that the peak values of the facet contact forces for the denucleated conditions are close to each other (Figure 3).

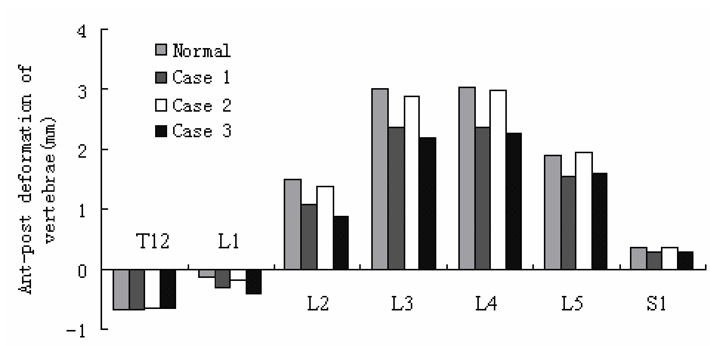

Fig. 2: The anteroposterior displacement of the first-order vertical vibration modes.

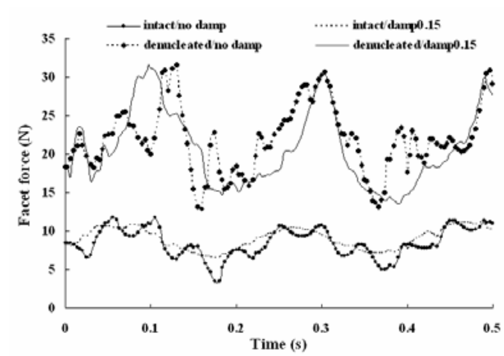

Fig. 3: The dynamic responses of facet contact forces at L4-L5 segement.

Conclusion

This study uses FE method to investigate the dynamic characteristics of the injured spine including denucleation and facetectomy. The results show that the injured cases including disc injury and ligament injury may decrease the resonant frequency of the spine system. Disc degeneration may increase not only facet contact force but also vibration amplitude of the force and might be more harmful to the facet articulation. This implies that severe disc degeneration might enlarge the burden of facet articulation and higher facet contact forces might cause higher stress and strain energy density at facet contact surfaces, specially, after the degeneration of soft tissue between facet pairs, and might also affect the remodeling of facet bone components according to Wolff's law over time, especially, under long-term WBV. This finding may aid in understanding how WBV contribute to the growth of osteophytes in facet articulation.

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INFLUENCE OF MULTI-AXIS RANDOM VIBRATION ON READING ACTIVITY

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Introduction

Recent studies on train passengers' activities by Khan and Sundstrom (2004) found that many passengers were engaged in some form of work, e.g. reading and writing, while traveling by train. A majority of the passengers reported that their activities were disturbed by vibrations or motions during their journey. Ride comfort in trains is generally measured in terms of ride indexes, like ISO 2631-1, ENV12299, etc. However these do not consider effect of vibrations on the performance of sedentary activities. Most of the studies specify importance of considering the context and seated posture when comfort is assessed in a vibrating environment. It was reported that only a few studies were found on how vibration influences train passengers' activities [Wollstrom (2000)]. Previous research work (Griffin and Hayward, 1994) has considered the effects of horizontal vibrations of seated subjects. Reading performance was found to degrade on exposure to fore-and-aft (x-axis) vibration at frequencies between 5.6 and 11 Hz (Lewis and Griffin, 1980)). In a study on Swedish trains, Khan and Sundstro¨m, 2004 reported that, although the vibration levels were found to be satisfactory based on the ISO 2631- 1, about 60% of the passengers were disturbed by vibrations or motions in the train. It was also found that two of the most common activities among the passengers are reading (80%) and writing by hand (25%). The same study reported that the choice of posture is strongly linked to the activity that is performed. Recently Sundstrom and Khan (2008) reported Influence of stationary lateral vibrations on train passengers' difficulty to read and write. It has been observed that font sizes 10, 12 and 14 in Times New Roman and Arial styles are some of the most extensively used in Newspaper and other printed material. The purpose of this study was to examine the effect of vibrations in three orthogonal directions independently, on the reading ability and to examine the influence of sitting posture (i) backrest support with text placed on lap and (ii) without back support with text placed on the table, on these font sizes.

Methodology

A vibration simulator, as a mockup of a railway vehicle, was developed in the laboratory where random vibrations independently in X, Y, and Z directions could be given. Random vibrations were applied in the frequency range (1–10 Hz) at 0.5, 1.0 and 1.5 m/s^2 rms amplitude. The influence of random vibration is investigated by giving a word chain in two different font style (Time new roman and Arial) and three different font size (10, 12 and 14) for each style. Six such word chains are given to the subjects for each condition (i.e. at 0.5, 1.0 and 1.5 m/s^2 rms amplitude in each direction) and posture. Twenty subjects were requested to make a vertical pencil mark where the words should be separated by a space character. The judgments of perceived difficulty to read were rated using 7-point discomfort judging scale.

Results, Discussions & Conclusions

The results of degree of difficulty for different vibration magnitudes for three vibration directions and three font sizes are given in Figs 1 & 2. Two thirds of the subjects reported difficulties in

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performing reading activity due to vibration and jerk. In this study, the output response had to be silent and was therefore made by manually making a mark in the text. Unfortunately, the vibrations sometimes hampered the precision of the manual marking more than the reading. Therefore this manual operation might have caused a conflict for the test subjects when rating the level of difficulty for reading. The performance of the reading task is mainly affected by the visual acuity on the retina and the cognitive decoding of individual words.

For whole body random vibration stimuli applied independently, the subjective ratings suggest that reading difficulty is significantly increased in stimulus applied in X- axis (longitudinal). However, the effect was predominant only when a seat without a backrest was used. Stimuli in lateral and vertical axes produced similar results, but the effect was less severe than that with longitudinal axis. It is also found that the degree of reading difficulty increases with vibration magnitude for all styles and font sizes. For vibration amplitudes of 0.5 m/s^2 rms commonly observed in the railway trains, it was found that Times New Roman font poses the greater level of difficulty in reading activity than the Arial font.

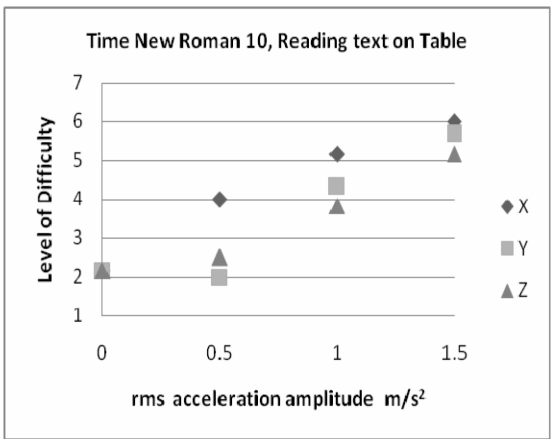

Fig.1: Effect of vibration amplitude along different axis on reading ability.

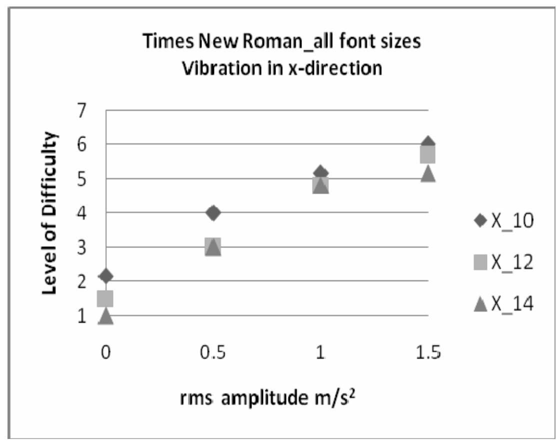

Fig. 2: Effect of vibration amplitude on reading ability of different font sizes

Acknowledgement

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THE RELATIVE CONTRIBUTION OF TWELVE AXES OF VIBRATION IN FIELD MEASUREMENTS FOR ANALYSIS ACCORDING TO ISO 2631-1

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Introduction

Typically whole-body vibration for sitting postures is measured from a seat using a tri-axial sensor. This is the standard procedure to evaluate health effects, but as there are also additional vibration sources, it might underestimate the effects. For evaluating health and discomfort the full method in ISO 2631-1 requires 12-axis measurements to be made from floor, seat and backrest. This requires equipment which is able to measure translational and rotational axes.

A sensor pad to record rotational axes of vibration has not been widely used; thus reports of 12-axis vibration data from real environments are rare. Although only seat translational axes are mandatory for the evaluation, ISO2631-1 states that additional axes should be included, if they have an effect [1]. However, there is no practical guidance on which axes to include and why. For health evaluation the standard notes the possibility to include vibration from backrest, but does not provide any health information relating to it. For discomfort the standard suggests using all twelve axes, if they appear to be relevant. Thus, because there is no information to justify using more axes and the complexity of including them, only seat translational axes are usually measured.

The standard weights each axis by using frequency weighting curves and multiplying factors primarily derived from laboratory studies using artificial stimuli. This determines the relative contribution of the axes. If field measurements show that some axes consistently provide the biggest contributions to overall discomfort according to ISO2631-1, these can be prioritised.

Methods

This study analysed results from previous publications [2] and [3] and new twelve axes field measurements to evaluate which axes have practical importance when evaluating discomfort from whole-body vibration. The new measurements by the authors were done in real working conditions comprising 1-7 repetitions of a single work phase for 3-10 minutes at one time. Seven different types of environments were measured.

A new 6-axis sensor pad was developed for the measurements. The sensor pad included the accelerometers to analyse both translational and rotational axes. Additionally the sensor pad included a memory and data processing unit, thus not requiring a separate device for data storage. The purpose of developing new equipment for 12-axis measurements was the lack of commercially viable equipment and to test more practical and cost-efficient solutions for conducting 12-axis measurements. The sensor pad was validated in a laboratory test bench.

An analysis of the relative contribution of axes and locations was made by calculating point vibration total values. The point vibration total values were used to create four different scenarios: 1) only seat translational axes were measured, 2) seat and backrest translational

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axes were measured, 3) seat, backrest and floor translational axes were measured and 4) all twelve axes were measured.

Results

The results showed that the three translational axes from the seat alone resulted in a lower overall vibration total value in almost all cases, if compared to using all twelve axes, even though the 1.4 multiplying factors were used to compensate the backrest axes. This can lead to underestimation of the subjective feeling, as the current discomfort evaluation method is directly based on the size of the overall vibration total value. However, if backrest axes were included the difference was on average less than 10 %.

In all measured environments the effect of rotational and floor axes were marginal (i.e. less than 10 % in total). This was mostly due to how the standard weights the axes. The most dominant axis for all measured machines was seat vertical. The second most important was backrest fore-aft and third seat fore-aft. The rest of the axes showed contribution of less than 6 % at best. In average roll axis showed contribution of 3,0 %, pitch axis 2,4 % and yaw axis 0,4 %. The floor axes showed average contribution of 1,2 %, 1,6 % and 5,6 % for fore-aft, lateral and vertical direction. Also vertical and lateral axis from back-rest showed only 4 % contribution.

Conclusions

The standardized method to evaluate discomfort of whole-body vibration emphasizes the dominant axes. It was found that the most dominant axes were from the seat (vertical) and backrest (fore-and-aft). Because of the standard’s method, the effect of rotational and floor axes on vibration total value were negligible. Thus, for practical purposes, only seat and backrest translational axes are needed to be measured to obtain a prediction of the discomfort for most vibration environments. However, there is still only a small body of data reporting 12-axis measurements and so it is recommended that more 12-axis data is gathered and reported so that the relative importance of the axes in further practical environments can be determined.

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EFFECTS OF WHOLE-BODY VIBRATION EXPOSURE FROM VEHICLE SEATS ON CENTER OF GRAVITY AGITATION

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Introduction

An accident of turn over / falling down of occupational vehicle drivers that happens when they walk to do some work immediately after driving a vehicle can be related to disturbance of the sense of balance. According to a previous study, vibration exposure on the head while standing has been known to cause illusion of head position and induce agitation of the body [1]. The main aim of this study was to examine effects of whole-body vibration exposure under seating position on the center of gravity (COG) agitation.

Methods

Three healthy male subjects (denoted by subject A, B, and C), aged 35, 41, and 48 years, respectively, participated in the experiment. The subjects had no experience of whole-body vibration exposure occupationally or in their leisure time activities. Prior to the test, each subject was informed of the purpose of this study and experimental procedure. All the subjects gave their written informed consent to participate in this study. The experiment was approved by the Research Ethics Committee of Japan National Institute of Occupational Safety and Health.

Vertical vibration was generated by using a single-axis shaker (Figure 1). Each subject was asked to sit on a circular seat (400 mm in diameter) secured on the platform of the shaker. The seat was braced so that the seatback angle could be 90 degrees. During the test, the subjects were seated with their hands on the lap. Vibration exposure conditions considered in this study were an expose to sinusoidal vertical vibration at 5Hz and that at 20Hz, the magnitude of which were 0.8 m/s^2 r.m.s. (unweighted). The duration time of vibration exposure was 5 minutes. As well as a normal standing condition, five-minute seating condition without vibration exposure was taken into account as control experimental conditions. Each experiment was performed on different days.

Fig. 1: Single-axis shaker

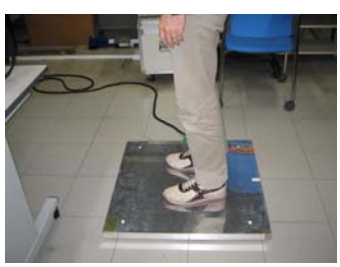

Fig. 2: Measurement of COG agitation

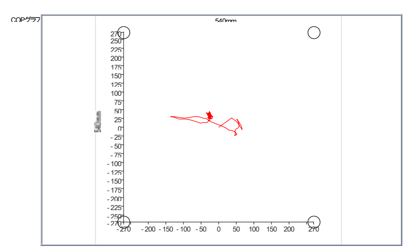

Fig. 3: Typical trajectory of COG agitation to measure LNG

COG Agitation was measured by using a force plate (Figure 2) and was then analysed with the COG measurement software (Kistler Inc.). For each experiment, COG agitation was

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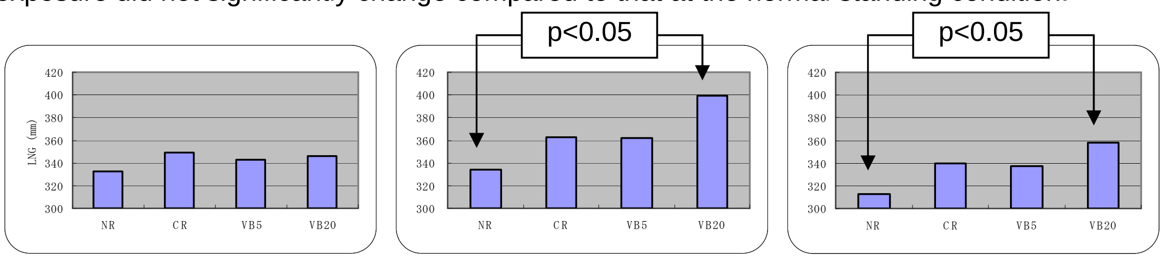
measured for 30 seconds immediately after five-minute seating with and without vibration exposure. Total length of the center of gravity displacement (LNG) was used to evaluate COG agitation (Figure 3). Each subject performed three trials for each experimental condition. Data comparison was based on average values for each condition.

Results

The LNG measured just after five-minute of seating with 20Hz of vibration exposure was observed to significantly increase for the LNG measured at the normal standing condition for subjects B and C. No subject, in contrast, showed significant differences between LNG measured at the normal standing condition and that just after five-minute seating with 5Hz of vibration exposure. The LNG obtained just after five-minute of seating without vibration exposure did not significantly change compared to that at the normal standing condition.



a. LNG for subject A *b. LNG for subject B* *c. LNG for subject C*

Fig. 4: LNG data measured for three subjects. NR: normal standing condition, CR: LNG measured after five-minute seating without vibration exposure, seated 5 minute, VB5: LNG measured after five-minute seating with 5Hz of vibration exposure, VB20: LNG measured after five-minute seating with 20Hz of vibration exposure

Conclusions

The major finding of this study was that exposure to vertical whole-body vibration at a certain frequency range can affect the COG agitation. Semicircular canals, known as detectors of movements of the human body, are located inside each ear on the head. Also resonance frequency of the human head in the vertical dirtection ranges from about 20 to 30 Hz. One posssible reason of the significant increase in LNG after five-minute seating with vibration is detrimental effects of vibration transmission to the head on semicircular canals.
Aging effects might affect the COG agitation after whole-body vibration exposure.Compared to subjects B and C, subject A showed no significant difference between LNG after seating with or without vibration exposure. Base on the well-known fact that eldder people generally show larger COG agitation, no-significant differences of LNG observed for subject A might be partly because of his younger age compared to those of the other subjects.
Further work should include data acquisition for more subjects for the same conditions to discuss the effects of vibration exposure on turn over accidents of occupational drivers. Recovery process of LNG after vibration exposure is another topic to be focused on in the near future.

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VIBRATION ALTERS SERUM MARKERS OF BONE TURNOVER IN RATS

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Introduction

Occupational exposure to whole body vibration (WBV) is associated with an increased risk of low back pain, disc compression and spinal degeneration [1]. Because exposure to WBV is often accompanied by exposure to lower frequency, higher magnitude mechanical shock, it is unclear if vibration, shock, or a combination of these two factors leads to spine degeneration and back pain [2] The goal of this study was to use a rat-tail model to determine how vibration exposure alone affects serum markers of bone mineralization and resportion. We hypothesized that exposure to vibration would increase serum markers of bone resportion and that this effect would be frequency dependent, with greater resorption occurring near the resonant frequency.

Methods

Male Sprague Dawley rats [Hla:(SD) CVF] rats (Hilltop Lab Animals, Inc, Scottdale, PA) arrived in the laboratory at 6 weeks of age. Rats were maintained in a colony room with a 12:12 reverse light:dark cycle (lights off 0700 h) and with Tekdad 2918 food and tap water available *ad libitum,* at the National Institute for Occupational Safety and Health (NIOSH) facility, which is accredited by the Association for Assessment and Accreditation of Laboratory Animal Care (AAALAC). Rats were acclimated to the facilities for 1 week before being used in experiments. All procedures were approved by the NIOSH Animal Care and Use Committee and were in compliance with the Public Health Service Policy on Humane Care and Use of Laboratory Animals and the NIH Guide for the Care and Use of Laboratory Animals.

For all exposures, rats were restrained in Broome Style restrainers. Rats were randomly assigned to a restraint group (control, n = 4), or to a vibration exposure group where the exposure frequency was 62.5 or 125 Hz (vertical sinusoidal vibration with a constant acceleration of 49 m/s squared r.m.s., n = 4/frequency). Previous work in our laboratory has demonstrated that the resonant frequency of the tail is between 125 and 250 Hz, depending upon the precise location of the measurement [3]. Rats were exposed to control or vibration conditions 4 h/day, 5 days/week for 8 weeks. After the last exposure, rats were anesthetized with pentobarbitol (100 mg/kg i.p.) and euthanized by exsanguination. Serum was isolated from blood. Serum was assayed for c-telopeptide fragments of collagen type-1 (CTX-1, rat LAPS Assay, Immunodiagnostics, Fountain Hills, AZ, USA), a marker of bone resportion, and osteocalcin, a marker of bone mineralization (Rat osteocalcin, Biomedical Technologies, Stoughten MA). Data were analyzed using one-way ANOVAs. Pairwise comparisons were made using Student's t-tests. Differences with $p < 0.05$ were considered significant.

Results

Circulating concentrations of osteocalcin were lower in control rats than in rats exposed to vibration at 125 Hz ($p < 0.05$; Figure 1A). Vibration exposure at both frequencies also resulted

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in an increase serum CTX-1 concentrations (F(2, 11) = 7.55, $p < 0.02$; Figure 1B). When we analyzed the ratio of mineralization to resorption (osteocalcin to CTX-1), we found this ratio was significantly reduced in rats exposed to vibration at both frequencies (F(2, 11) = 5.44, $p < 0.03$; Figure 1C).

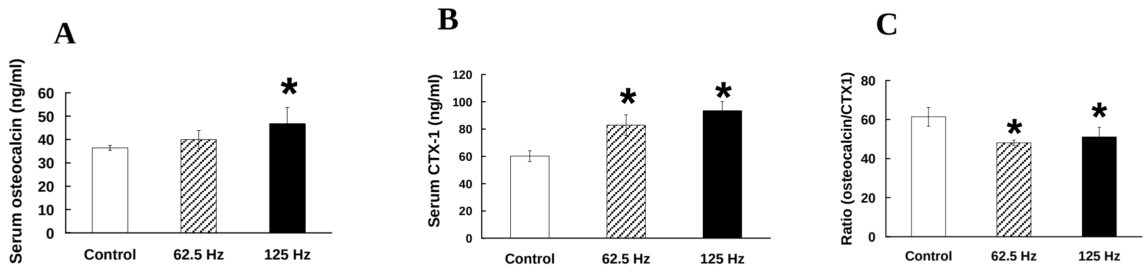

Fig. 1: Serum osteocalcin (A), CTX-1 (B) and the ratio of osteocalcin to CTX-1 in rats exposed to restraint (control) or tail vibration at 62.5 or 125 Hz for 8 weeks (different from controls, p <0.05).*

Conclusions

After 8 weeks of vibration exposure, osteocalcin was slightly increased in rats exposed to vibration at 125 Hz, indicating that vibration at this frequency stimulated osteoblast activity and bone mineralization.

- Exposure to vibration at both frequencies also resulted in an increase in CTX-1, a serum marker of bone resorption, indicating that vibration also stimulated osteoclast activity and bone resorption

- The ratio of osteocalcin/CTX1 (an index of mineralization to resorption) was significantly lower in rats exposed to vibration than in control rats, suggesting that bone remodelling was altered to favour resorption instead of mineralization.

- These findings are consistent with *in vitro* studies demonstrating that vibration induces matrix degradation that can lead to disc degeneration and pain [4].

- Exposure to higher frequency, lower magnitude vibration is capable of inducing bone resorption in the absence of mechanical shock.

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WHOLE BODY VIBRATION INJURIES WHICH ARE CAUSED BY EXTRACORPORAL VIBRATION INJURIES OF BLOOD

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Introduction

It is known that blood is fluid tissue which circulates in the cardiovascular system. Therefore an external vibration does not have a direct influence on blood. However, at present a number of medical devices are used for extracorporal operations with blood, where a direct influence of vibration on blood of the human takes place. Such vibration influence can injure blood. This injured blood can be back to the human at once or during a transfusion but already with the new injuries caused by keeping of blood in a fridge (including its transportation in the blood bags). Blood provides a vital activity of all cells of organs and tissues of the human body, so such injuries of blood can result in a deterioration of health of the human or become a cause of death. A study of of this problem thus carries an important significance.

Methods

The first step was to model the transport vibration. A helicopter was chosen as the transport media, which revealed considerable transport vibration. The tests were conducted on a dynamic test stand with six-degree of freedom (Fig. 1). A thermally insulated container with 6 packages of blood was fixed on a cabin mounted on the test stand. The packed red cells were subjected to vertical vibration acceleration of 0.4 m/s^2 and horizontal vibration of 0.5 m/s^2 at a frequency of 8 Hz over a 60 minutes duration. A visual survey and methods of the biochemical analysis were used to study the effects of vibration.

Figure 1

Results

The visual survey revealed that some clots were formed in 4 of the 6 packages, and these were not filtered. The blood provides a vital activity of all cells of organs and tissues of the human body, so injuries of blood can result in a deterioration of health of the human or become a cause of his/her death. A possibility of the extracorporal direct vibration action on blood, the injuries of blood and health is schematically shown in Fig. 2. Causality between the blood injuries and deterioration of health of a patient or a donor after the transfusion of such a blood is represented in this scheme. For example, the artificial blood circulation apparatus can cause the following injuries of blood: the mechanical injuries of the blood platelets, the partial activation of the blood platelets, the mechanical hemolysis, the anoxemia [1], and the exit of the plenty of the biologically active substances into the blood plasma, including the purine nucleotides and the

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pirimidine nucleotides [2]. Consequently, it can deteriorate the patient's health or become cause of his death. As examples, these may include: the anemia caused by the mechanical hemolysis; the thrombocytopathy; the intravascular hemolysis; the thrombosis of the veins; the hemoglobinuria; the hipoxia from the anoxemia [1], the systemic inflammatory response caused by the activation of the cascade of reactions; the complications or the death of the patients in the intraoperative period or in the early postoperative period [3]. However, the data on the complex effects of vibration and the norms on the admissible levels of vibration do not yet exist. Such a direct vibration action may also yield a positive influence on the blood. For example, it can improve the quality of purification of blood cells from various harmful substances [4].

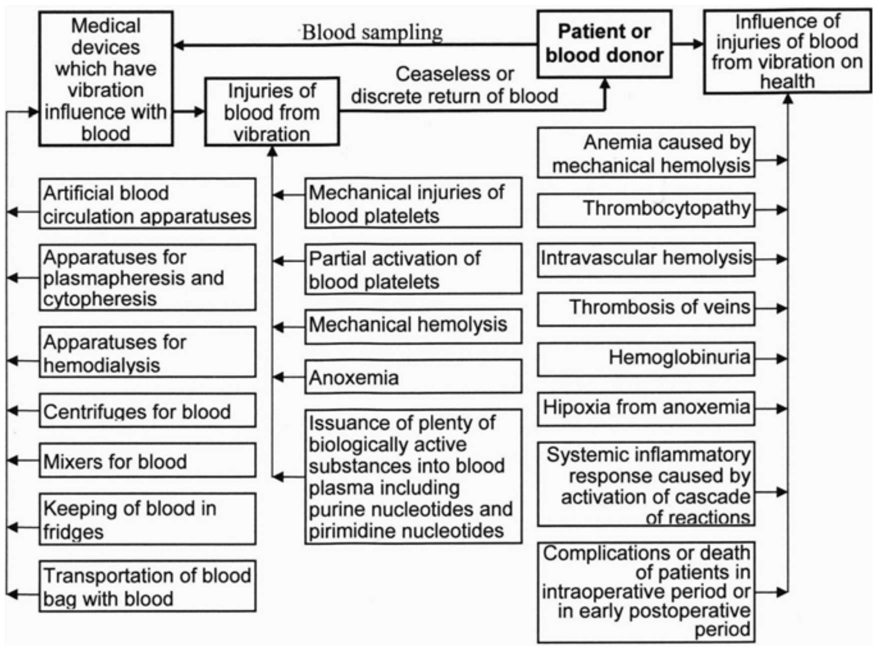

Figure 2

Conclusions

Many medical devices for some extracorporal operations with blood involve direct vibration exposure of the human blood. Such vibrating action of the blood could deteriorate the patient's health or become cause of subject’s death. However, the data on the complex effects of vibration on the blood and the norms on the admissible levels of vibration do not yet exist. Far more fundamental efforts are thus needed to understand the effects of vibration on the human blood.

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HEAD-VIBRATIONS MEASUREMENT SYSTEMS

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Introduction

Head vibrations of seated or standing persons are commonly measured at the mouth, close to the ears or at the top of the head. Head vibration measurements are strongly affected by the positioning of the transducer, since several studies [1-4] have shown that rotational motions of the head occur during the WBV exposure. In particular, the roll and pitch head motions largely affect the vibration transmissibility, as reported in 0. Furthermore, bite-plates can be hardly used during field measurements, and the biting action lead to muscles stiffening that affects the dynamic behavior of the head. The relevant effect of the measurement position, together with the possible relative motion between the skull and the accelerometer due to the presence of soft tissues, prevents the comparison between studies based on different measurement systems. To reduce the above inconveniences, an alternative measurement method based on multiple MEMS accelerometers fixed to an instrumented cap is presented.

Methods

The reliability of an instrumented silicone cap was verified through comparisons with measurements obtained with a bite bar and a laser Doppler vibrometer. Low mass bi-axial accelerometers were attached to different cap positions (above the ears, on the top of the head and on the forehead), in order to assess the possibility to determine the translational and rotational components of the motion. Preliminary experiments were performed to identify the floor noise of the measurement chain, together with the repeatability and reproducibility of the measurements. Analyses were carried out on a group of 10 persons to verify any dependency of the system performances on the physical characteristics of the subject (head dimensions and hair length). Vibrations with different characteristics (a swept sine in the frequency range 2 – 20 Hz with different amplitudes, random and impulsive) in the vertical direction were generated by an electrodynamic shaker. The acceleration stimulus was transmitted directly to the skull in recumbent position, through the feet (standing position) and through the buttocks (seated persons). The validity of the proposed method was assessed by analyzing the frequency response function between the different measurement systems.

Results

Experiments performed with the aim of identifying the metrological characteristics of the measurement chain pointed out the difficulty of measuring accelerations below 0.1 m/s^2 threshold with the MEMS accelerometers and the measurement chain. The sensitivity to electromagnetic disturbances generated by the shaker was found to be negligible. The frequency response function between the bite bar and the MEMS accelerometers attached to the cap evidenced the head rotations, identified also by the low coherence values. Rotations were also outlined by the phase of the FRF between the different transducers on the cap. The plot on the right shows the FRF between the vertical acceleration measured at the bite bar (stimulus) and at the forehead accelerometer on the cap. The left plot shows the FRF between the vertical accelerometer on the forehead and the vertical accelerometers above the ears.

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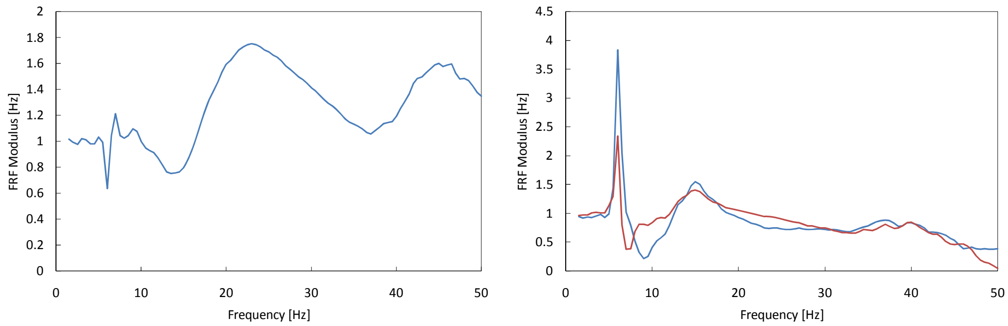

Fig. 1: Frequency responses of different measurements on the head (right - FRF between the vertical accelerations measured at the bite bar and the forehead; left - FRF between the vertical accelerations on the forehead and above the ears)

The plots show the presence of relative motions between the skin and the skull (over 20 Hz), that were also evidenced by the laser Doppler vibrometer analyses. The average accelerations and rotations of the head could be determined by combining the measurements of the transducers at different locations.

Conclusions

The proposed instrumented cap allows the measurement of the head vibration despite its small invasive characteristics. The greatest advantage with respect of the classical approach based on the bite bar is the possibility of on-field, potentially long term, measurements. The inherent frequency limitations of this measurement system, with respect to the bite bar, have been addressed, although most of the head induced vibration can be correctly measured. Moreover, the system allows the identification of the rotations of the head that could not be retrieved with the classical single point measurement.

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MULTI-MODAL SIMULATOR AT JNIOSH

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Introduction

To evaluate the effect and perceptible limits of whole body vibration, some experiments have been carried out with multi degree of freedom (DOF) shakers [1, 2]. However the real environment consists of not only the vibration but also the other stimuli, especially visual and audio. Human response to the vibration is almost certainly affected by the visual and audio information, which means it is very important to reproduce the visual and sound stimuli combined with the vibration to investigate the subjective impression of whole body vibration.

Method

At National Institute of Occupational Safety and Health in Japan (JNIOSH), a 6-DOF shaker system has been used to examine the effect of whole body vibration [1]. This shaker system was specially designed to vibrate extremely quiet. Some experiments have been carried out with this shaker system to present vibration signal only [2].
An NVH Simulator has been integrated to the shaker system to add the visual and sound stimuli, enabling multi-modal experimentation on whole body vibration. The NVH (Noise, Vibration and Harshness) Simulator was originally developed to add interactivity and more context to the evaluation of vehicle sounds by adding the visual (and optionally the vibration) stimuli [3, 4]. Some of the car manufactures started introducing the Simulator to design the sound of vehicle under the virtual driving environment.

Results

In order to get precise synchronization between the vibration, visual and sound stimuli, the NVH Simulator controls the start timing of the shaker system with trigger signal which has the possibility to add a programmable delay time. In addition, a series of scenarios were prepared. The data for these were measured in a real car on the real road with various road surfaces, e. g. smooth surface, coarse surface, and with bumps or concrete joints. The visuals in the simulation are computer generated representations of the actual events recorded. The vibration was measured on the seat in 3 directions and the sound was measured binaurally at driver's ear. The bumps on the visual scenario can be positioned so that they are synchronized with the measured vibration and the sound. To add more conditions, it is possible to create stimuli from further measured data which contains sound, vibration and vehicle performance.

Sets of stimuli can be concatenated in an arbitrary order with changeable pause between them and for voting. It is possible to choose any combination of the stimuli to be presented. This

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means that it is possible to make a test with and without visual to investigate the effect of visible information on the perception of vibration.

Following pictures show the system; left hand side, overview of the new system and right hand side, side view of the shakers with a monitor.

Conclusions

We have developed and introduced multi-modality into the vibration simulator at JNIOSH. The system can reproduce the vibration of a real vehicle with synchronized sound and visual stimuli. The introduction of this system will allow us to carry out an evaluation of whole body vibration in a representative context to investigate the subjective response to whole body vibration.

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DAMPING EFFECTIVNESS OF CUSHION FOR AGRICULTURAL TRACTORS

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Introduction:

Working life of agricultural tractors is very long and duty tractors with solid seats can still be found in operation. Interventions on existing seats need to be implemented by use of devices like cushion. In the present work, the vibration isolation effectiveness of seat cushions is investigated through measurement of vibration transmissibility. Experiments were performed on three cushions of various thickness and composition placed on a seat both on a Caterpillar and on new tractors. Accelerometers placed beneath the cushion and beneath the driver acquired the vibration signals for assessment of vibration transmissibility. Acceleration analysis were conducted for the frequency intervals ranging from 0.5 to 80 Hz (as stated in ISO 2631-1). Results show poor damping of cushions on new tractors, with a frequency variability. The considerations of ergonomics in more recent tractors designs is coupled with poor vibration isolation and damping. The situation, however, is different for very old tractors, where ergonomics considerations are absent and the cushion provide a good contribution to vibration damping.

Methods

In order to evaluate acceleration transmitted to the seated driver, three tri-axial accelerometers (PCB) were installed on the tractor floor, seat and the cushion. Three different cushions (C1, C2, C3) were assessed, which differed in type of material and thickness. Signals were recorded using Or38 (Oros) 32 channel analyzer. The measured accelerations were weighted using filters defined in ISO 2631 [1] for risk assessment evaluations. The relation:

$$T_z = \frac{a_{wC}}{a_{wS}}$$

where a_{wC} and a_{wS} are root mean square values of accelerations measured on the cushion and the seat, respectively.

Measurements were conducted on three Caterpillar tractors that mainly resulted in higher vibration exposure levels, and on three modern tractors. The measurements on all tractors were conducted on the same test track and under identical operational conditions. The measurements also employed the same drivers.

Results

Tables 1 and 2 summarize the acceleration transmissibility values between the seat and the cushion for the new and old tractors, respectively, for the three cushions used in the study. Figures 1A and 1B further depict the transmissibility responses of the cushions employed in the old and new tractors, respectively.

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Table 1: Transmissibility between seat and cushions in modern tractors.

	C1	C2	C3
New 1	1.04	1.08	1.05
New 2	1.09	1.29	1.13
New 3	1.05	1.36	1.11

Table 2: Transmissibility between seat and the cushions in old tractors.

	C1	C2	C3
Hold 1	0.74	0.75	0.82
Hold 2	0.68	0.70	0.76
Hold 3	0.71	0.62	0.72

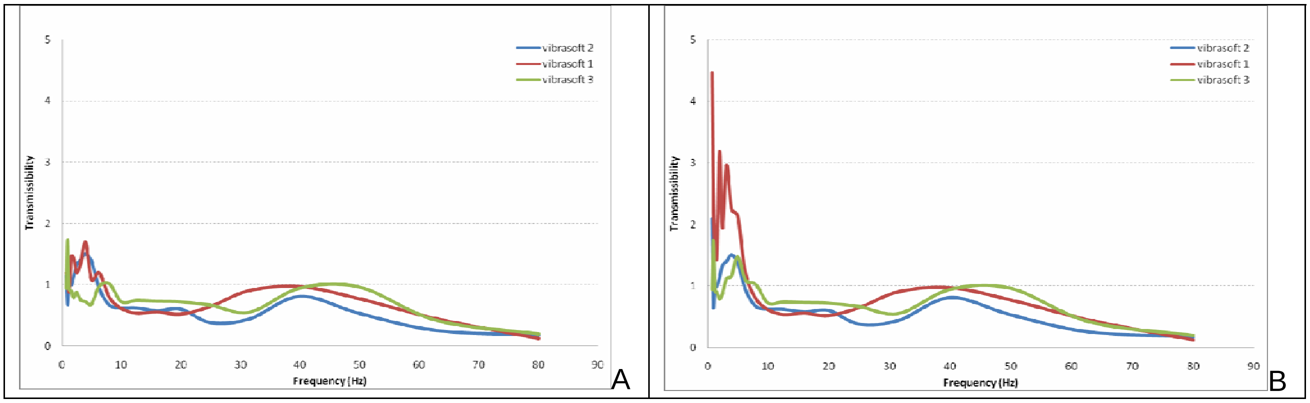

Fig. 1: Transmissibility frequency distribution for three cushion types in old (A) and new (B) tractors

Conclusions

More recent designs of tractors are equipped with seats that reduce vibration from floor to drivers, but old tractors with solid seat do not reduce vibration exposure. For this reason the use of damping cushions is desirable when workers have to operate with old vehicles, which can also improve their ergonomics properties.

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SIMULATION STUDY OF SIMULTANEOUS SHOCK AND VIBRATION CONTROL BY A FORE-AND-AFT SUSPENSION SYSTEM OF A DRIVER'S SEAT

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Introduction

Not much attention has been paid to shock and vibration control in the fore-aft direction, despite there is ample evidence of large excitation in the fore-and-aft direction in some types of earth moving machines. The aim of the present study is to undertake both vibration isolation and shock control optimisation using a simple seat suspension model of single degree-of-freedom (SDOF). The optimised parameters are the non-linear damping constants. The seat is aimed for use in wheel loaders with their typical operational cycles, e.g. driving on a rough road and site operations. The excitations are quite different in each case, ranging from low level vibration to high intensity vibration, as analysed by Fleury and Mistrot [1]. A fore-and-aft seat suspension is thus required to simultaneously attenuate both continuous vibration and shock.

The Seat Suspension Model and Representative Excitations

The model to be used in this study is based on authors' experience in seating dynamics modelling in the *x*-direction [2,3]. The SDOF model used [3] is a simplification of the complex dynamic behaviour of the seat-person system. The model; however, allows indicative prediction.

The model parameters were experimentally determined on a real driver's seat, taken as reference. Measurements indicated a non-linear influence of the end-stops on the spring force-deflection curve. Two different types of excitations were used: one represents a ride on a rough road, realised by a normalised track after ISO 5007; the other one represents the loading operation, when acceleration peak of triangular shape was observed with maximum amplitude of 0.5 $m.s^{-2}$. According to [1] the peak is representative for a wheel loader driving the bucket into a soil heap.

Methods

For simulation and optimisation, Matlab® tools were used. Numerical integration (Runge-Kutta 4th order method with a constant time step) was used for vibration response analysis. For damper optimisation purposes, a modified multidimensional unconstrained nonlinear minimization routine was used, which uses the Nelder and Mead simplex algorithm.

The objective was to minimise both RMS values of frequency weighted seat acceleration, a_{wS}, and seat relative displacement, δ_x under a stationary road excitation. For the impulse excitation, the response peak values were of interest [4], e.g. MAX($|a_S|$), and MAX($|\delta_x|$) and the ratio κ = MAX($|a_S|$)/MAX($|a_B|$), where a_B is the base excitation. The analysis of influence of driver's mass variation and excitation intensity on shock and vibration response was also evaluated.

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Results

The simulation results for the impulse excitation are depicted in Fig. 1. The ratio κ decreased from 1.84 for the reference system to 0.90 for the optimized one and the value of MAX(δ_x) decreased by 15%. For the road excitation, the acceleration transmissibility T_{ax} = RMS(a_S)/RMS(a_B) improvement is by 15 %, and the value of MAX(δ_x) decreased by 15 %, while that of RMS(δ_x) by 60 %. Similar improvement was predicted for driver's mass variation between 55 kg and 100 kg. Optimised system performed better than the reference one, when the excitation intensities were varied from 50 % to 200 % of the nominal ones.

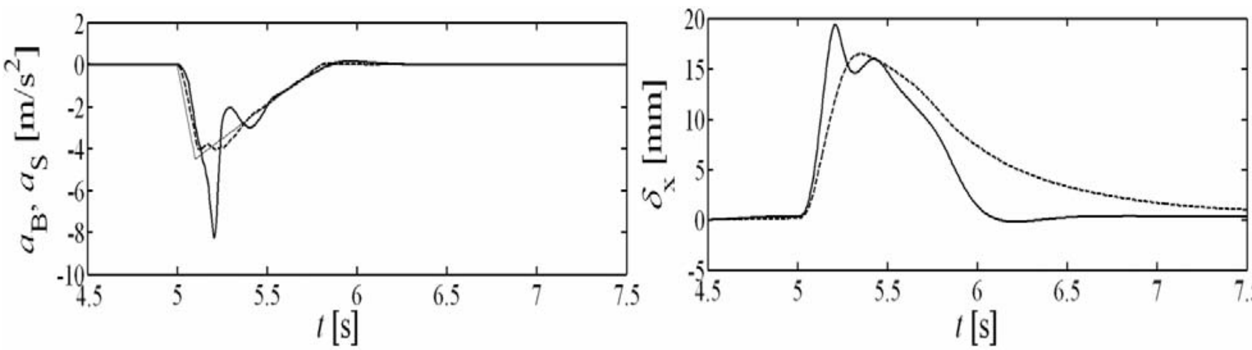

Fig. 1: Optimised suspension system responses: the impulse excitation (—), reference system performance (▬▬), optimised system performance (▬ ▬).

Conclusions

By using the optimised non-linear damper instead of the original, an improvement in the value of κ in the order of 50 % was predicted. For the stationary random road excitation the acceleration transmissibility T_{ax} improvement by 15 % was predicted. The optimised suspension system outperformed the original one under variations in excitation intensity considered (for both excitations types). No strong impacts on the end-stops were observed. The simulation predictions are of indicative nature only and have to be verified by measurement. The model used in this study cannot account for possible force exerted by driver's legs. This calls for further research in human body–compliant seat interactions in the fore-and-aft direction.

Acknowledgement

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VIBRATING PLATES: ARE WHOLE BODY VIBRATION GOOD OR NOT?

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Introduction

Vibrating plates is becoming a broadening facility in fitness gym and rehabilitation centers. As several doubts about the effectiveness of the rehabilitation effects and the compliance with the medical devices European Directive 93/42/EEC [1] have arisen. The ISPESL accordingly with the Italian Health Ministry has started a pilot study on these vibrating devices. In the present work we studied two samples of vibrating plates in order to check the attainment of performance levels declared by manufacturers and to evaluate the transmitted vibration. We measured vibration exposure of people using these devices. Preliminary results show an impressive power transferred to the user and a severe mismatch of the effective performance with respect to the characteristics declared by manufacturers. More vibrating plates will be examined in the near future, giving a more complete picture of the italian market.

Methods

The tests were carried out on two vibrating tables, the Power Plate *pro5*^{TM} (Power Plate Italia S.r.l.) and the Physio Plate (Globus Italia S.r.l.), used in two different wards of physiotherapy and motorial rehabilitation of the Orthopaedic Clinic of Policlinico Umberto I hospital of "La Sapienza" University of Rome. The position adopted by the test subjects on the footboards was upright, normally used by the hospital in treatment for osteoporosis. Two ICP triaxial accelerometers were placed under the feet of the subjects with the axes oriented in accordance with the specific directions indicated by standard ISO 2631-1:1997 [2]. Two transducers were attached to a multichannel data recorder from Racall Heim. The subsequent processings of the data were performed with a four-channel real time analyser, 01dB Harmonie with dBFA32 software for analysis of the signals. The spectral resolution of the signals recorded was no less than 801 lines for a maximum frequency of 300 Hz.

Results

Table 1 shows the summary data for the accelerations recorded under the feet of the test subjects during the execution of a treatment cycle for osteoporosis with the whole body Power Plate and Physio Plate vibrating footboards. The frequency spectra of the accelerations recorded along the z axis are shown in Figure 1. The measurements do not show a good agreement between the frequency set on the control board and the actual frequency. The measurements also show very high vibration levels transmitted to the feet of the subjects from the vibrating footboard of around, respectively W_k-weighted ,10 m/s^2 and 12 m/s^2 RMS for the Power Plate and the Physio Plate.. It should also be noted, as can be seen in Fig. 1, that the vibrating footboards not only generate the fundamental frequency at 40 Hz but also other subsequent frequencies which contribute to around 30% to the vibratory energy generated by the footboards.

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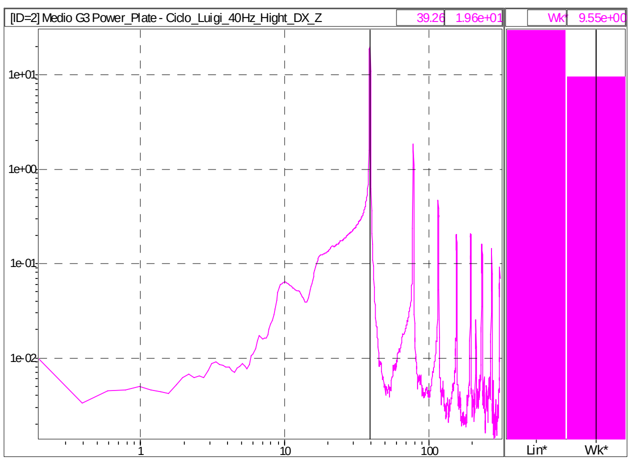
Table 1: Summary of measured accelerations under the feet of the test subject in a standing position with the Power Plate and the Physio Plate vibrating footboard

Power Plate *pro5*™ - Cycle for osteoporosis -Subject male, weight 90 kilos, transducer under right foot (DX)		Intensity at centre of frequency	Global intensity	
		Linear weighting	Linear weighting	W_k weighting
Frequency set	Actual frequency	$a_{eq,z}$ m/s^2	$a_{eq,z}$ m/s^2	$a_{w,z}$ m/s^2
40.0 Hz	39.3 Hz	19.6	**29.7**	**9.6**
Physio Plate - Cycle for osteoporosis - Subject male, weight 90 kilos, transducer under left foot (SX)				
Frequency set	Actual frequency	$a_{eq,z}$ m/s^2	$a_{eq,z}$ m/s^2	$a_{w,z}$ m/s^2
40.0 Hz	29.9 Hz	18.6	**28.8**	**12.4**



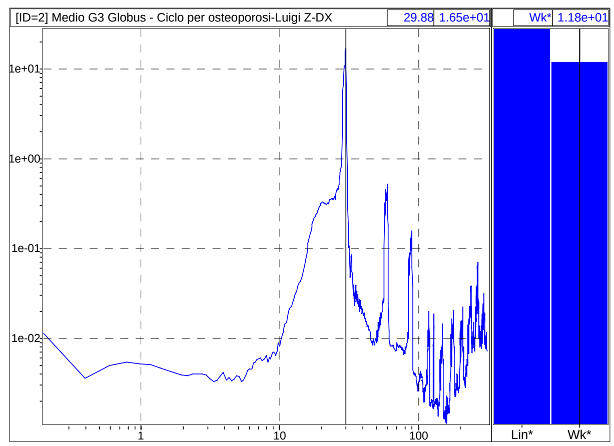


Fig. 1: Frequency spectra of the vibrations recorded respectively on the Power Plate footboard (left) and on the Physio Plate footboard (right) along the z-axis under the feet of the test subject in the conditions as set out in Table 1

Conclusions

The lack of proper information in the handbook containing the instructions for use and in the CE marking could result in a possible non-conformity of the devices to the requirements envisaged by medical devices Directive 93/42/EEC. The acceleration levels reported are very high from a hygienistic viewpoint and raise serious doubts about the device's possible acute effects on health and the effective clinical benefits for the treatment of osteoporosis.

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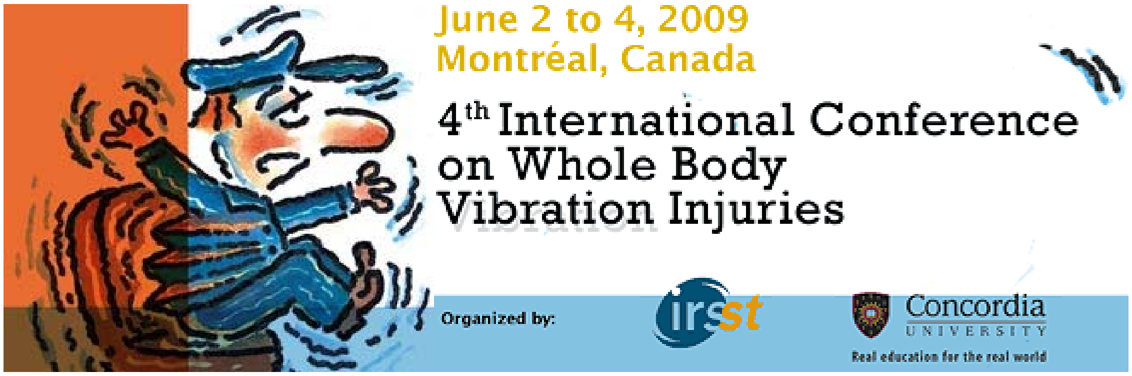

SESSION 7

EXPOSURE ASSESSMENT (1)

ASSESSMENT AND PREDICTION OF WBV EXPOSURE IN TRANSPORT TRUCK DRIVERS

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Introduction

The European Directive 2002/44/EC on the minimum Health and Safety prescriptions regarding the exposure of workers to vibrations, was implemented in Italy through the Legislative Decree 187/2005, recently amended by the Legislative Decree 81/2008. The Decrees contain legal obligations and minimum requirements for the evaluation by means of direct measurement, which is the reference method, or by assessment of vibration data banks or information provided by equipment manufacturers.

The application of the direct measurement method is not always appropriate or necessary, because of practical difficulties in identifying representative conditions for measurement, for economic reasons, because of a high degree of related uncertainty, the not insignificant execution time and also because of the scarcity of good professionals in this field. The values estimated by the last two methods cannot be applied uncritically, but must be representative of the actual working environment. In order to adapt assessed values to specific working conditions, it may be useful to adopt some statistical models. The first purpose of this study is to prepare a tool to assess WBV exposure in real working conditions. The second purpose is to determine which truck characteristics and operational variables better predicted the levels of WBV experienced.

Methods

A limited number of WBV exposures measures (24) were carried out by IVECO SpA's (FIAT Group) testing labs during a test session, in order to investigate the effect of operational variables and fittings on comfort (K-factor): the measures set was kindly put at our disposal.
WBV exposure levels were only measured in dominant axis (*z*) due to the use by IVECO of "K-factor" to test the fittings performance, exposure levels in horizontal axis (*x, y*) were not measured because they were considered less meaningful and not related to fittings modifying.
This data set has been chosen because of its interest: in fact vibrometer data has been measured in very controlled conditions (Road Roughness, Load, Speed), and in a wide range (mean=0,4510 ms^2, ranging from 0.25 to 0.75 ms^2 r.m.s., Standard Deviation =0,128).
WBV measures were taken varying the following operational variables:

- truck both fully loaded and unloaded;
- on smooth test track, (toll expressway route comparable) and on medium rough test track (provincial highway route comparable);

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- at speeds of 40 and 60 km/h on medium rough test track and of 60 and 80 km/h on smooth test track.

The two truck models used (of 15 tons of Gross Vehicle Mass) are still in production and were studied in three different fittings: traditional semielliptic spring suspension system ("K" fitting), parabolic spring suspension system ("Europa" fitting) and afterpart air spring suspension.
The two models studied had both cab and seat of an air suspended type.
The statistical method used was multiple regression analysis in order to correlate the independent variable (Road Roughness, Speed, Fitting suspensions and Load) with dependent variables (WBV exposure). Three different models of multiple regression analysis were reported, both linear and non linear type, in order to check the difference in terms of estimated parameters (Standard Error, R^2, t statistics, Analysis of Variance).

Results

Statistically significant relationships were observed by means of a multiple linear and non linear regression always with good quality of model fitting. In the best fitting model the correlation coefficient R = 0.9638 and standard error s = 0.03961. The relative influence of predictor variables was then estimated: it was similar in all three models (Road Roughness > Speed > Fitting suspensions > Load).

Conclusions

In this work we observed that from a limited sample of vibrometer measures it is possible to prepare a statistical model to assess and predict WBV exposure in truck transport drivers, so as to comply with the legal obligations that require an assess in the particular conditions of use. We believe that this method can be extended to assess the WBV exposure in other specific sector workers.

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COMPARISON OF ALTERNATIVE SHOCK CONTENT ANALYSIS OF WHOLE-BODY VIBRATION MEASUREMENTS

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Introduction

The ISO 2631-1 measurement standard recognizes that for vibrations containing shocks the basic evaluation method may underestimate the true exposure risk. A method has been recently proposed to quantify vibration containing multiple shocks in relation to lumbar vertebral endplates, that is for the most part based on military applications (ISO 2631-5:2004). However, its validity for occupational applications has been questioned (1)(2). An improved algorithm for a more appropriate risk estimate has been proposed as part of an EU 'VibRisk' project (3,4).

Methods

In addition to the 'basic vibration', the crest factor (CF), the maximum transient vibration value (MTVV) and vibration dose value (VDV) are calculated for three railroad track maintenance vehicles used in the USA following ISO 2631-1:1997. These showed that the shock content of the selected vehicles met the inclusion criteria for this study. The shock indicators were calculated following the algorithm proposed in ISO 2631-5:2004. An alternative risk assessment method in which 50 finite element models of drivers have been programmed with different postures and body-mass indices (BMI) was included in the analysis. Posture- and body-mass-index (BMI)-dependent internal compressive and shear forces of the spine were calculated.
This procedure permits the consideration of individual exposure conditions, posture and personal characteristics which are reflected by different finite element models. A Matlab-program identified the peak compressive forces in the predicted time series and calculates a risk factor according to different typical body postures and lumbar vertebrae levels.

Results

A mathematical risk estimate of lumbar vertebra endplate failure was made for operators of three in-use railroad track maintenance vehicles based on field measurements as part of occupational injury claims. The results of three typical railroad track maintenance vehicles are presented in graph 1-3 showing the calculated R (risk value) for five different typical posture examples (group 1 to 5) and according to ISO-2631-5 for each vertebrae level. (Group 1 = forklift; group 2 = front loader; group 3 = excavator; group 4 = wheel skidders; group 5 = forwarder). Calculation examples assumed an operator's age of 65y, 45y seniority, starting age of 20y, daily exposure duration of 4 h for 240 days/year.

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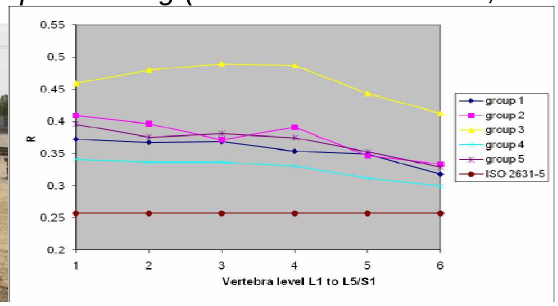
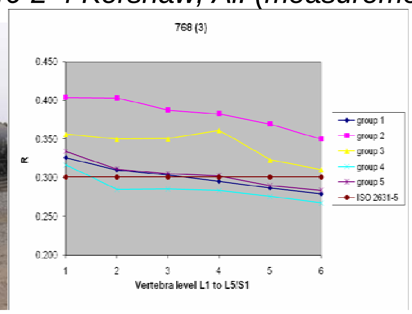
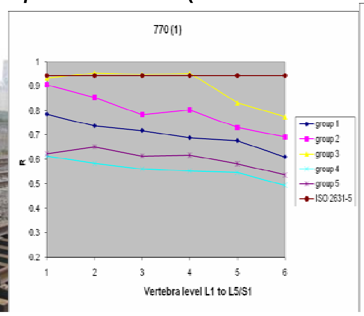
Example 1: 445-E Pettibone Speed-Swing (measurement t=55min, firm/even ground, light duty)

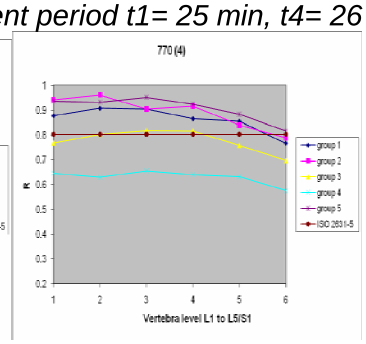


Example 2: Ballast regulator 46-2-4 Kershaw, Al. (measurement period t = 30min)



Example 3: Front loader Caterpillar 966 F (measurement period t1= 25 min, t4= 26 min)





Conclusions

The comparisons of the results of these field measurement examples suggest different risk outcomes depending on the assumed typical body postures and lumbar level. The alternative 'VibRisk' model suggests generally higher health risk particularly for low R values according to the ISO 2631-5 algorithm, which may have significant occupational health implications.

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REAL-TIME MONITORING AND ANALYSIS OF WHOLE BODY VIBRATION IN LOCOMOTIVE ENGINEERS

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Introduction

There has been considerable interest in monitoring whole body vibration in locomotive engineers. Larson, et al. (2001), Cooperrider and Gordon (2006, 2008), and Johanning et al. (2002, 2006) have all described measurements of whole body vibration in locomotive engineers according to ISO 2631-1 and ISO 2631-5. Cooperrider and Gordon (2008) have shown that voluntary occupant motions or other artifacts may have a large effect on calculated values such as VDV, and consequently, in order to obtain values that properly reflect vibration and shock exposure it is essential that these artifacts are identified and removed during the data analysis procedure. In order to deal with this issue, a data acquisition routine within LabVIEW (Version 8.6, National Instruments, Inc.) has been developed that allows for real-time data analysis in accordance with ISO2631-1 and ISO2631-5 while excluding data during the time in which the occupant is not seated and preserving the unaltered raw data for potentional further post-processing. A further advantange of the developed software is that the time required for post-processing is reduced considerably.

Methods

With this software, acceleration data are acquired at 200Hz in 0.4 second data packets. The sampled data are saved in their unaltered state for post processing and also sent to a real-time analysis routine. In the real-time analysis routine data are first passed through an 80Hz low pass, 2nd order Butterworth filter, resampled to 160 Hz in accordance with ISO 2631-5, and then saved. The data are then weighted, as specified by ISO 2631-1 using LabVIEW's vibration suite, which is also used to calculate the crest factor, RMS value, and peak value, which are subsequently used to calculate the Seat Effective Amplitude Transmissibility Factor (SEAT). The software is designed so that these quantities are calculated for the current data packet, as well as from the start of data acquisition (t0), displayed graphically, and then saved.

Routines have also been implemented that calculate a running RMS value, and the VDV, both of which are computed for the current data packet and from t0. The MTVV is derived from the running RMS calculation as described in ISO 2631-1, using a time constant of one second. Acceleration dose and spine compression dose are also computed as described in 2631-5. The above-mentioned parameters are displayed graphically and saved.

As mentioned previously, Cooperrider and Gordon (2008) have shown that including data measured on the seat when the occupant is not seated results in over approximation of WBV parameters. One method for removing these voluntary motions or other artifacts is by analyzing the frequency content of the seatpad accelerometer and comparing it to the chassis mounted accelerometer during post processing (Cooperrider and Gordon, 2008). In their method, Cooperrider and Gordon (2008) proposed excluding a minimum of 204.8 seconds of data once it has been determined that the occupant was out of the seat. Using our software with additional sensors to detect the presence of a seated occupant, one is able to exclude data from voluntary

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occupant movements within one or more short-duration (0.4s) data packets, thus minimizing the amount of data that are excluded in the analysis process. Furthermore, since the sensor is included in our LabVIEW module we are minimizing the post-processing time is further minimized by calculating WBV parameters in real-time.

Conclusions

In summary, the addition of real-time data visualization and analysis coupled with data to account for out-of-position occupants is believed to significantly reduce post-processing time and has the potential for enhancing the understanding of the WBV environment of locomotive crews without excluding any potentially relevant data. Finally, because of the selected software platform, the acquisition hardware options are completely scalable, which allows one to incorporate additional sensors or real-time video to help identify and isolate the sources of additional potential artifacts

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WHOLE BODY VIBRATION EXPOSURE AND PREDICTION OF HEALTH RISKS ASSOCIATED WITH THE OPERATION OF SURFACE HAUL TRUCKS IN OPENCAST MINES IN NORTHWEST RUSSIA

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Introduction

Operators of dumpers/surface haul trucks (SHT) in open cast mines are exposed to whole-body vibration (WBV) during work. WBV exposure is suggested to contribute to reduced health and discomfort in this group of workers. The objective of the study was to describe vibration measured at the operator-seat interface for SHTs comparing exposure values with findings in other international studies from similar work places. Health risks associated with the use of SHTs were predicted according to the criteria in ISO standard 2631-1, annex B and EC Directive 2002/44/EC.

Methods

In an open cast mine in Northwest Russia 250 workers were exposed to WBV, working 12 hour shifts, including 8 hours driving SHTs. 65 SHTs (Caterpillar and Belarussian Autoworks, 120/130 ton loading capacity) were used in the mine. 17 measurements were performed on 14 SHTs, measurement periods ranged between 13 to 58 minutes in real work cycles at the operator seat interface. The measurement, processing, analysing and exposure assessment methods follow the guidelines of the ISO standard [ISO 2631-1 1997].

Results

The mean WBV exposure values are presented in table 1 for the most severe axis, presented as acceleration r.m.s. The ISO standard recommends using vibration dose value (VDV) if the crest factor (CF) is above 9. The mean crest factor (CF) for the 14 SHTs is 12,78 SD±5,26. Thus the exposure values are also presented as VDV.

Table 1: Frequency-weighted r.m.s. acceleration and vibration dose value (VDV) for 4 types of SHTs.

Vehicle type	Number of vehicles (number of measurments)	Measurment duration (min.)	Most severe axis acceleration r.m.s (z-axis) (m/s^2)				Most severe axis vibration dose value (VDV) (z-axis) ($m/s^{-1,75}$)			
			Mean	**Min.**	**Max**	**SD**	**Mean**	**Min.**	**Max**	**SD**
Catepillar 785C	2 (2)	31-37	1,12	1,09	1,15	0,04	13,65	13,5	13,8	0,21
Belas 75 121	2 (2)	34-45	1	1,05	0,96	0,06	10,95	10,4	11,5	0,78
Belas 75 131	4 (6)	21-25	0,83	0,7	0,92	0,1	8,26	6,89	9,91	0,99
Belas 75 145	6 (7)	13-58	1,1	0,73	1,57	0,29	11,04	7,24	14,4	2,92
SHTs n=14*	14 (17)	13-58	1	0,7	1,57	0,23	10,35	6,89	14,4	2,61

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Discussion

The exposure values in table 1 are compared to other WBV measurements in SHT's. One study (1) on 9 SHTs (opencast mine, loading and transportation of ore and overburden) report acceleration r.m.s. (1,03-2,02 m/s^2) and VDV (4,4-13 $m/s^{-1,75}$). A larger study on 180 dumpers including SHTs from 2 different open mines report mean VDV 9,27 $m/s^{-1,75}$±3,98 (n=120) and mean VDV 10,81 $m/s^{-1,75}$±3,44 (n=60). The results from these studies are comparable to our findings. A study in Canada [3] on 2 types of SHTs (150 ton) report acceleration r.m.s in the most severe axis as 0,28m/s^2 SD=0,13 and 0,37m/s^2 SD=0,14. These results are much lower than in our study. Surface and work conditions may explain such differences.

Table 2: Health guidance caution zones in ISO 2631-1 (Annex B) and exposure limit values and action values in Directive 2002/44/EC.

	ISO 2631-1 Annex B			**Directive 2002/44/EC**	
	A(8) (m/s^2 r.m.s)	VDV(8) ($m/s^{1,75}$)		A(8) (m/s^2 r.m.s)	VDV(8) ($m/s^{1,75}$)
For exposure below the zone (HGCZ) health effects have not been clearly documented and/or objectively observed.	0,45	8,5	**Action value**	0,5	9,1
HGCZ - Health Guidance Caution Zone.	0,45 - 0,9	8,5 - 17			
Above the HGCZ health risks are likely.	0,9	17	**Exposure limit**	1,15	21

Risk evaluation of the vibration exposure measurement was performed according to ISO standard 2631-1 and EC Directive 2002/44/EC (table 2). The mean acceleration r.m.s. is below exposure limit value but above action value in the EC Directive 2002/44/EC. The mean acceleration r.m.s is above the health guidance caution zone (HGCZ) described in ISO 2631-1 annex B. Using VDV when CF is above 9 is recommended in ISO 2631-1. The mean VDV is below exposure limit in EC Directive 2002/44/EC. The mean VDV is within the HGCZ described in ISO 2631-1 annex B.

Conclusions

The choice of method may influence the conclusion in the risk evaluation. Also, both surface and working conditions are important factors influencing the WBV exposure. More studies are required to address the impact of these factors on the exposure on workers operating SHTs in open mines.

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LONG TERM WBV MEASUREMENTS ON VEHICLES TRAVELLING ON URBAN PATHS

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Introduction

The correlation between the drivers exposure to whole-body vibrations and the low back pain has been the focal point of many research works [1-5]. Some studies concluded that long-term WBV exposure may increase the risk of low back pain [2,3]. In other studies, a correspondence was found to exist between low back pain and physical factors such as heavy manual work and uncomfortable driving posture [4,5]. In Ref. 0 the conclusion was that there is no clear evidence of correlation between WBV exposure, postural factors and low back problems in urban vehicle drivers. The starting point for the identification of the WBV-related pathologies, though, is the reliability of the parameters used to describe the vibration. In particular, literature shows a lack of knowledge about the long term behavior of the indices suggested in the ISO 2631, which states that the duration of measurement shall be sufficient to ensure reasonable statistical precision and to ensure that the vibration is typical of the exposures which are being assessed. The standard here is quite ambiguous, as clearly evidenced by the presence of the reported studies based on observation periods of a 5 to 20 minutes. Aim of this paper is to describe the results of a long term WBV measurement campaign on cars travelling over urban paths. The study attempts to identify the variability of the WBV indices over long periods, both on the same or different urban paths, with different vehicles and drivers.

Methods

Tests were performed on five different cars of different ages driven by five people. WBVs were measured according to the ISO 2631 procedure using a specifically-designed monitoring system based on virtual instrumentation. Indices that have been analyzed are the frequency weighted acceleration levels along three mutually perpendicular axes, the total acceleration value and the ratio between MTVV and a_w. Data variability has been analyzed on different levels: 1) the same urban path has been repeated in nominally identical conditions at a fixed constant velocity by three different cars, in order to identify the "floor" measurement variability; 2) different paths (length from 10 to 20 km) have been repeat at a speed which is a variable depending on the traffic conditions; and 3) for each car, the time after which each index converged to its "final" value has been computed.

Results

Results showed that vibration strongly depends on the car speed and consequently data were analyzed on the basis of the car velocity. The vibration probability distribution analysis showed that the probability distribution functions depend on the velocity, as seen in Fig. 1. The RMS of the total acceleration was found to be in the range from 0.35 to 0.45 m/s^2. The standard deviation computed on 10 seconds buffers was between to 0.1 and 0.2 m/s^2. Both the vibration average and standard deviation depend on the car type and velocity. In a generic trip (i.e. composed by urban paths, carriageways and highway in different percentages) at least one

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hour of measurement is necessary to obtain an uncertainty on the mean of 0.01 m/s^2. It is even more interesting to notice that MTVV/a_w is always larger than 1.5 (typical values along the z axis are in the range from 3 to 5). In other words, the a_w index underestimates the vibration exposure and the additional methods (weighted instantaneous acceleration or vibration dose value).

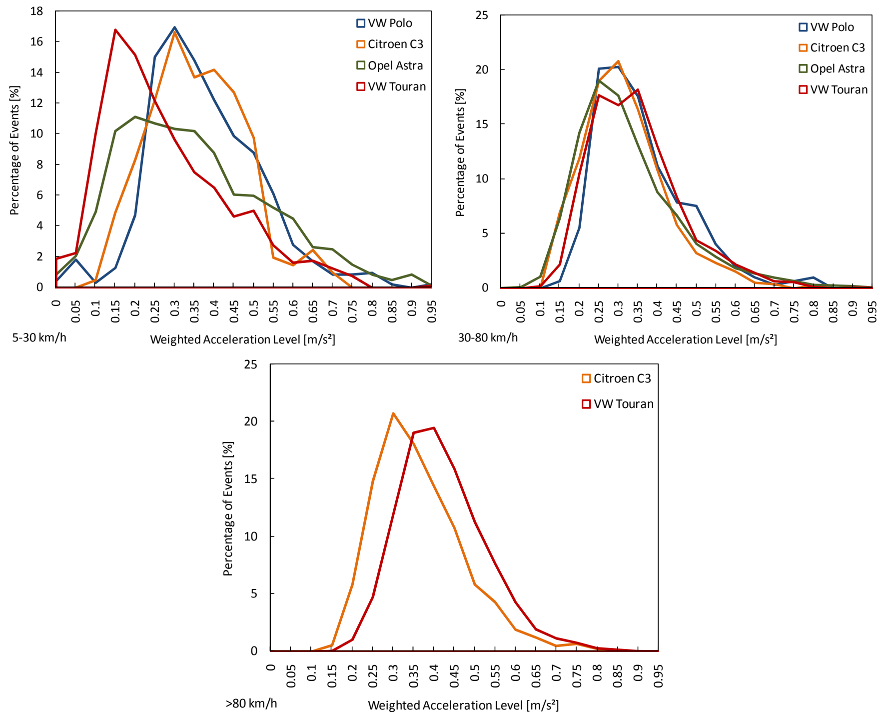

Fig. 1: Probability distributions of measured vibration

Conclusions

The long term WBV measurement on urban paths outlined that the minimum time for having an uncertainty smaller than 2.5% is close to one hour. With such a measurement time, the MTVV/a_w ratio is systematically larger than 1.5, thus indicating the unsuitability of the basic ISO 2631 criterion. This suggests that the different statements that can be found in literature about the correlation between WBV exposure, postural factors and low back problems in urban vehicle drivers can be partially endorsed to the low reliability the indexes used to describe the vibration.

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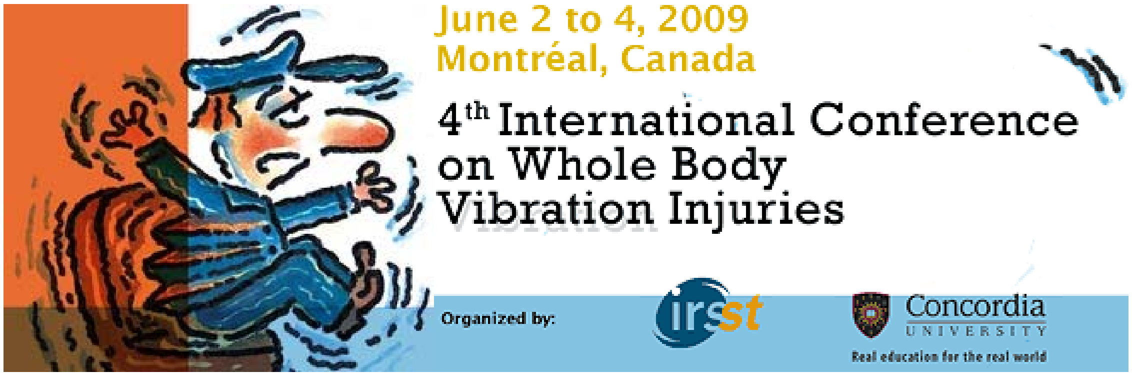

SESSION 8

GUIDANCE AND REGULATIONS

FRENCH POLICY TO FACILITATE THE APPLICATION OF THE EUROPEAN VIBRATION DIRECTIVE

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Introduction

The Vibration Directive 2002/44/EC [1] seeks to introduce minimum protection requirements for workers when they are exposed to risks arising from vibration. It has been implemented in most European countries since July 2005. According to the SUMER[1] enquiry, about 12% of French workers are exposed to whole body vibration mainly from mobile machines (10.6%). This exposure is clearly more common among men (95%) than women. The estimations for off-road machines, industrial trucks, agricultural or forestry tractors, lorries, vans and buses are respectively 130 000, 200 000, 1 million, 5.7 millions. Employers are required to assess vibration magnitudes. Very few do measurements and many even do not evaluate. The objective of this article is to provide an overview of the method adopted in France to facilitate the evaluation of whole body vibration by companies.

Methods

A practical method to assess whole body vibration dose on mobile machines without measuring was elaborated. It is based on a data bank of results collected in the field over a large number of vehicles with the assistance of the CRAM[2] (e. g. more than 600 off-road machines mainly in quarries and earthworks were studied)and on results from specific experiments carried out with different mobile plants to determine the individual parameters affecting vibration magnitude. An interactive web file on INRS site was developed so as to assist companies [2].

Results

This file proposes a five steps method for the evaluation of whole body vibration exposure without measurement. The field of application is limited to users of common mobile machines with the exception of agricultural and forestry machines.

a) Firstly the user has to answer a short questionnaire to check whether whole body vibration may be a risk in his company.
b) If this is the case, he / she will have to clarify the conditions of use for each mobile machine. Three levels of use are considered: severe (rough ground, excessive speed, poor seats..), normal or favourable. For each class of machines (off-road machines, industrial trucks, road vehicles) two questionnaires will assist him for determining the corresponding level.
c) Another important parameter to be entered is the average daily exposure duration, which corresponds to the sum of periods where the driver is actually exposed to vibration (e. g. when the fork lift truck is running).

[1] SUrveillance MEdicale des Risques
[2] Caisse Régionale d'Assurance Maladie (regional health insurance fund)

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d) Knowing the type of vehicle, condition of use, daily duration, a menu provides an estimation of daily exposure and a comparison with Directive action and limit values.

It is anticipated that action level (0,5 m/s^2) will be exceeded by operators of most off-road machines when travelling is frequent [3]. However, the limit value (1.15m/s^2) is likely to be reached only rarely, except in the case of scrapers and some conventional finishers. Workers may also be exposed above the limit value if driving fork-lift trucks for longer than eight hours a day on a rough surface or if driving trucks and lorries all day long.

Conclusions

Development of strategies or campaigns to reduce human vibration exposure requires large amounts of effort and time. Campaigns are most effective when they are maintained over several years and concentrate on specific situations. As a first step, INRS trained nine laboratories in measuring vibration and proposing solutions to reduce vibration exposure. Subsequently, INRS and these nine laboratories formed the Vibration CRAM/INRS group, which meets on a regular basis and has undertaken the following principal activities:

- Three procedures on how to take measurements were written.
- A bank of collected vibration data was developed, especially on off-road machinery.
- The vibration Directive is presented to occupational physicians across all of France.
- A guide of good practice [4] based on the corresponding European guide was published [5] and web file elaborated [3].
- For those companies which needed whole body vibration measurements, INRS and ministry of work sponsored the development of a low cost, easy to use dosimeter
- Assistance is provided to manufacturers who are interested in developing anti-vibration systems (we are presently working on pallet trucks to adapt the suspension of floor).

However there is still the necessity for research for better evaluation of risk taking into account other factors like posture.

References

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A COMPARISON OF ISO2631 HEALTH GUIDANCE FOR MACHINES IN DAILY USE

John J. Gordon[1] and Neil K. Cooperrider[2]

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Introduction

Whole Body Vibration (WBV) data were collected on five vehicles and machines in daily use in their respective industries: a semi-tractor (1997 International model 9800 with a Bostrom air suspension driver's seat); a medium duty agricultural tractor (Kubota M125X-DTC with a Grammer air suspension seat); a skid loader (2005 Bobcat S185 with an OEM non-suspension seat); an off-highway dump truck (WABCO BFA-9, 50 ton with a mechanical suspension operator's seat), and a bulldozer (Caterpillar D9 with a mechanical suspension seat). The data were processed following the ISO2631-1 [1] and ISO2631-5 [2] standards in order to contrast and compare the health guidance provided by the two WBV assessment methods.

Methods

Test data collected for this study included tri-axial seat pad accelerations; tri-axial vehicle accelerations; and for the semi-tractor and agricultural tractor, vehicle speed. All acceleration/vibration data were acquired at 400 samples per second with a data bandwidth of 100 Hz. The acquired data were processed according to the provisions of ISO2631-1 [1] to produce the basic weighted rms acceleration (aw) and the Vibration Dose Value (VDV). The provisions of ISO2631-5 [2] were followed to compute the daily equivalent static compression dose (S_{ed}).

Results

Weighted rms acceleration, VDV, and the daily equivalent static compression dose (S_{ed}) are given in Table 1. To normalize the results for comparison purposes, the vibration exposures are given for a four hour period of daily exposure. The WBV exposure on all the vehicles except the semi-tractor was relatively high. The lower boundary of the Health Guidance Caution Zone (HGCZ) of ISO2631-1[1] was exceeded for the four hour period of operation on all the vehicles except the semi-tractor. The agricultural tractor, dump truck and bulldozer had similar levels of WBV vibration while the levels were substantially higher on the skid loader.

Table 1: Whole Body Vibration Exposure at Four Hours of Daily Exposure.

Vehicle	a_{wx}	a_{wy}	a_{wz}	VDV_x	VDV_y	VDV_z	S_{ed}
	m/s^2	m/s^2	m/s^2	$m/s^{1.75}$	$m/s^{1.75}$	$m/s^{1.75}$	mPa
Semi-tractor	0.177	0.196	0.520	2.9	2.9	7.6	0.261
Ag tractor	0.667	0.646	0.576	11.9	11.4	9.8	0.611
Skid loader	1.118	0.863	1.464	18.5	15.2	26.9	1.342
Dump truck	0.491	0.540	0.834	8.5	8.8	12.8	0.641
Bulldozer	0.714	0.794	0.767	11.4	12.6	12.2	0.662

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The VDV is compared with the S_{ed} in Figure 1, where these values are shown for each vehicle for periods of daily exposure ranging from one to eight hours. Note that even for one hour of operation all the vehicles except the semi-tractor exceeded the lower boundary of the ISO2631-1 VDV health guidance value of 8.5. However, the semi-tractor values did not exceed the corresponding ISO2631-5 level of 0.5 MPa with exposure periods to 8 hours.

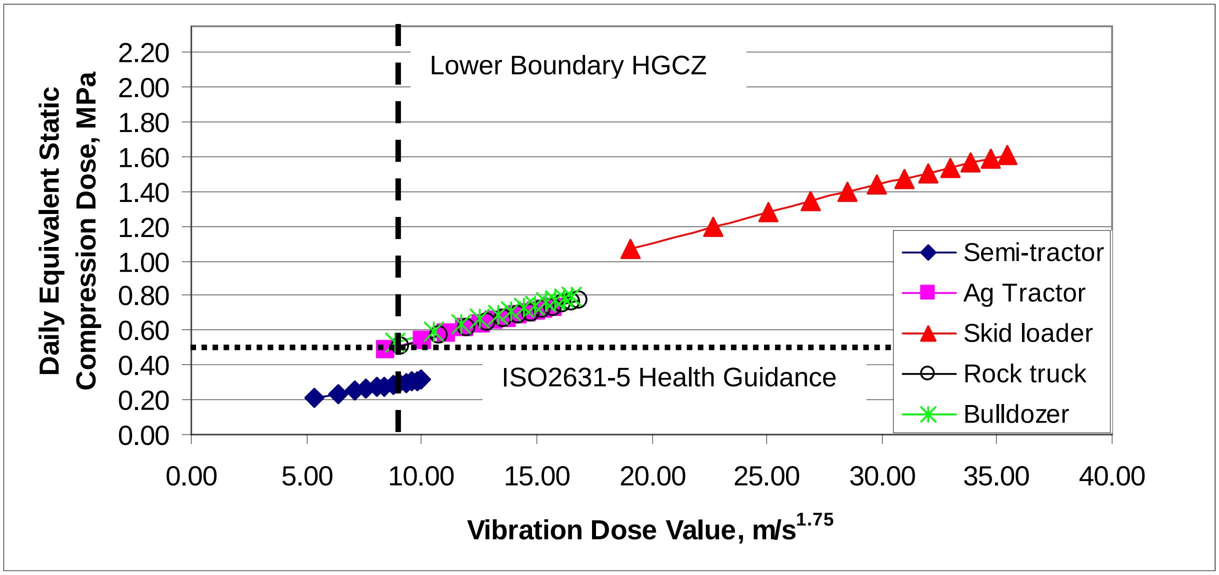

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Fig. 1: Daily Equivalent Compression Dose v. Vibration Dose Value for One to Eight Hours.

Conclusions

In all cases, the health guidance provided by the VDV analysis was more stringent than that provided by the spinal stress method. The authors reached a similar conclusion in an evaluation of locomotive WBV exposure [3]. For the semi-tractor the VDV and spinal stress health guidance relationship is comparable to that found for locomotives. For the other machines that operate on less well prepared surfaces, WBV levels are higher and the spinal stress health guidance is comparable but still less stringent then that determined for the VDV method.

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PREDITED HEALTH RISKS ASSOCIATED WITH VIBRATION EXPOSURE IN THE STEEL MAKING INDUSTRY

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Introduction

Operator exposure to whole-body vibration (WBV) was measured during the operation of four types of heavy equipment used in the steel manufacturing industry. Prolonged whole-body vibration (WBV) exposure can have damaging effects on the human body [1, 2]. Currently there is no literature specific to WBV exposure in the steel manufacturing industry in Ontario, Canada.

Methods

A total of 11 vehicles, including heavy-lift transporters (HLT, n=2), pot haulers (n=3), hoists (n=4) and loaders (n=2) were selected for study based on worker focus groups and injury statistics from one integrated steel manufacturer. Vibration was measured in accordance with the ISO 2631-1 standard [3]. Vibration exposure at the operator/seat interface was measured and recorded using a series two tri-axial accelerometer and biometrics datalogger (NexGen Ergonomic Inc., QC, CND). Data were analyzed using Vibration Analysis Toolset Software (VATS) version 2.4.3 (NexGen Ergonomics Inc., QC, CND). Health risk due to WBV exposure and mechanical shock was determined via guidance provided in ISO 2631-1 and ISO 2631-5 [3,4].

Results

Dominant frequency-weighted r.m.s accelerations occurred in the vertical (z-axis) for all vehicles tested. Moreover, the largest values recorded for each vehicle type were as follows: HLT, awz = 0.62 m/s2; pot hauler, awz = 0.90 m/s2; hoist, = awz 0.33 m/s2; loader, awz = 0.73 m/s2. Furthermore, every vehicle type and test condition resulted in crest factor values above 9; therefore, predicted health risks were based on a VDVtotal value comparison to the ISO 2631-1 Health Guidance Caution Zone (HGCZ) (Figure 1). Five of the eleven vehicles tested had VDVtotal values above the HGCZ include all three pot hauler vehicles. However, only three of the vehicles tested (when using a standard operator exposure history profile) resulted in Sed values (ISO 2631-5) that indicated probable injury risk to the lumbar spine (Figure 2). Therefore, criteria established in ISO 2631-1 led to a greater injury risk prediction than ISO 2631-5 (Figure 2). Furthermore, two of the three pot hauler operators had vibration exposure levels placing them at risk for probable injury to the lumbar spine.

Discussion and Conclusions

This research indicates that operators of vehicles commonly used in the steel manufacturing industry may be exposed to WBV levels that exceed the recommended limits set out by the ISO 2631-1 standard. Pot hauler operators appear to have the greatest risk since vibration exposure

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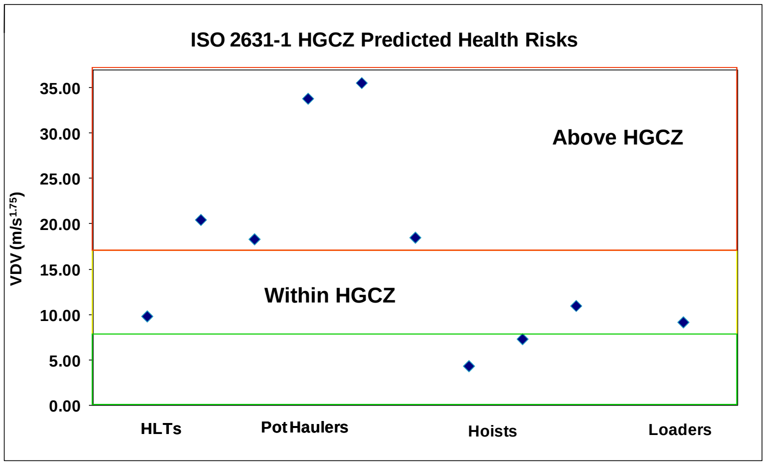

Fig. 1: Predicted injury risks according to ISO 2631-1 HGCZ criteria based on VDV_{total} value.

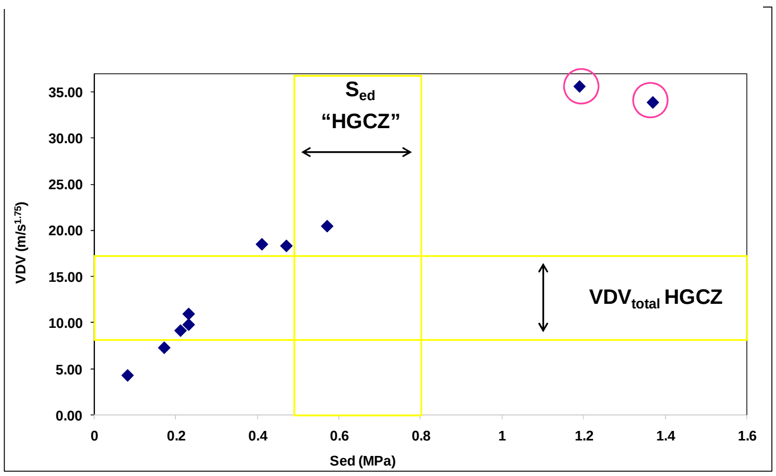

Fig. 2: Predicted injury risks according to ISO 2631-1 HGCZ criteria based on VDV_{total} value and ISO 2631-5 S_{ed} values. The two values circled indicate high injury risk according to both criteria.

at the operator/seat interface placed all three operators above the ISO 2631-1 HGCZ and two of the three operators had a high probability of injury to the lumbar spine based on ISO 2631-5 criteria. Elevated injury risk to the pot hauler operators is likely linked to high vibration shocks associated with a task called skull banging; however, futher testing is warranted.

Limitations

Caution should be applied when making definitive conclusions about health risks associated with the operation of steel manufacturing vehicles given the small sample size evaluated in this study.

Acknowledgement

Funding for this project was provided by the Workplace Safety and Insurance Board of Ontario.

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PSYCHOVIBRATION STUDIES ON ASSESSMENT OF TIME-VARIANT WHOLE-BODY VIBRATION EXPOSURE

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Introduction

The relationship between the subjective ride comfort in a vehicle seat and whole-body vibration can be modeled using frequency weightings and r.m.s. averaging as specified in ISO 2631-1.If two vibrating environments have the same frequency-weighted r.m.s. acceleration value using this method, it is assumed that the two environments would have the same degree of discomfort. In recent years, it has been found that when subjects are exposed to random whole-body vibration, even with the same frequency weighted r.m.s. acceleration signals according to the ISO 2631-1 standard which consists of different frequency spectra will elicit different degree of comfort [1]. From viewpoint of these results, it was doubtful whether frequency-weighting based on ISO 2631-1 is appropriate for such vibrations. For vibration, Miwa took a similar approach to Stevens [2] and proposed a method for assessment of multiple frequency whole-body vibration. Although Miwa [3] suggested that the total “vibration greatness” VGt (in units equivalent to sones), of a complex vibration can be estimated from the vibration greatness VGi of the components of the i^{th} center frequency of the octave band pass filters and the vibration greatness VGm of the subjective strongest component , Miwa didn’t apply his method to the real spectrum vibration in his researches.

Although Maeda et al [4] clarified the relationship between physical values (VGt) of vibration stimuli applied to the whole-body of the real spectrum steady state vibration and the perceived degree of comfort, it is doubtful whether VG method is appropriate for the time-variant whole-body vibration exposure.

The Total Vibration Greatness (TVG) is the new concept proposed in this paper. The TVG is the integrated vibration greatness (VGt) over the entire measurement period.

$$TVG = (\Sigma VG_{t})/N = (\Sigma\ (VG_{m}+0.3((\Sigma VGi)-VG_{m})))/N \text{ -------(1)}$$

In this paper, it was examined whether the TVG can apply to the real time-variant vibration.

Methods

The vibration test bench system, which reproduces the movement of a vehicle floor, was used for the experiment with the single-axis (vertical direction) four-post road simulator system, which is usually used for a car. The experiment was done on the right side of the vibration bench using floor vibration which was 5.5 minutes, 0.822 m/s2 (Wk) over the range 0.5-20 Hz with 4 male subjects (age ave21.5, SD0.5, weight ave75kg, SD7.9kg, height ave1.67m, SD0.05m) and 4 suspension seats. Subjects evaluated the degree of comfort after 5.5 minutes vibration exposure.

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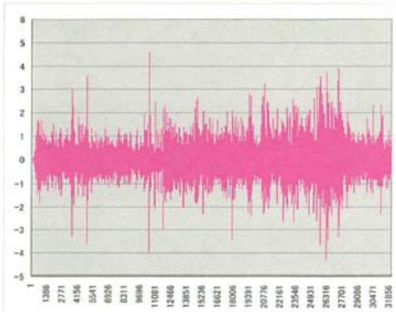

Fig.1 : Real vibration on the chassis

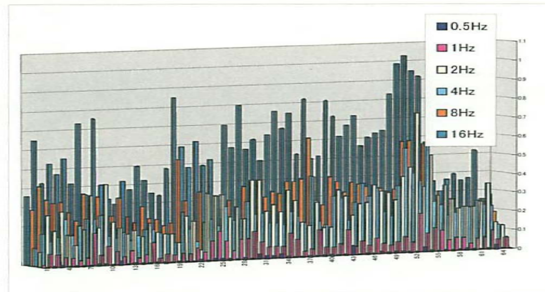

Fig. 2 : Octave-band analysis results of Fig.1 in every 5 seconds

As shown in Fig.2, the vibration contents have a different magnitude and a different spectrum such as time-variant vibration. From the Octave-Band analysis results as shown in Fig.2, VGti in each 5 seconds was calculated by Maeda's consideration [5]. And after getting all VGti, TVG is calculated by Equation (1).

Results

Table 1 shows the comparison among TVG, r.m.s. values calculated by ISO 2631-1 and the subjective judgement by each subject.

Table 1: Evaluations by TVG, r.m.s values calculated by ISO 2631-1 and subjective judgments.

	Evaluation by TGV				Evaluation (rms value): ISO-2631-1				Final judgement of 4 seats
	Seat A	Seat B	Seat C	Seat D	Seat A	Seat B	Seat C	Seat D	
Subject 1	1.18	1.23	1.17	1.16	0.69	0.68	0.67	0.65	Seat A
Subject 2	1.12	1.23	1.14	1.14	0.67	0.73	0.65	0.66	Seat A
Subject 3	1.15	1.31	1.19	1.15	0.67	0.74	0.69	0.64	Seat A
Subject 4	1.10	1.27	1.11	1.13	0.65	0.76	0.63	0.65	Seat A
Average	1.14	1.26	1.15	1.15	0.67	0.73	0.66	0.65	
Evaluation	1	4	3	2	3	4	2	1	

Conclusions

The purpose of this study was to clarify the relationship between physical values TVG(the new concept proposed here) of vibration stimuli applied to the time-variant whole-body vibration and the perceived degree of comfort. From the results obtained as shown in Table 1, it was clear that the TVG proposed in this paper could give the good prediction of comfort than the method used in ISO 2631-1.

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FREQUENCY WEIGHTINGS FOR FORE-AND-AFT VIBRATION AT THE BACK: EFFECT OF CONTACT AREA, CONTACT LOCATION, AND BODY POSTURE

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Introduction

For the evaluation of vibration with respect to health, BS 6841 [1] requires consideration of fore-and-aft vibration on the backrest of a seat in addition to the three orthogonal axes on the supporting seat surface. International Standard 2631-1 [2] requires consideration of the three axes on the seat and encourages measurements in the *x*-axis on the backrest. The EU Physical Agents (vibration) Directive [3] requires consideration of vibration on the seat but not the backrest. The relevant standards [1-2] advocate the use of the W_c frequency weighting for evaluating fore-and-aft vibration at a backrest, but do not specify the precise location for measuring vibration. This study was designed to determine equivalent comfort contours for fore-and-aft vibration of the backs of seated people over the frequency range 2 to 80 Hz, examining the effect of input location, contact area, and body posture on the derived frequency weightings.

Methods

Twelve males (mean 24.7 years) were exposed to sinusoidal fore-and-aft vibration at the back via a rigid wooden backrest (650 x 680 mm) mounted to a vibrator (Derritron VP85). The height of a stationary footrest was adjusted to produce a constant knee angle of 90 degrees. Subjective magnitudes for vibration of the back were determined with 10 backrest conditions (see Figure 1) using the method of magnitude estimation. Subjects compared pairs of motions (a reference motion and a test motion), each lasting 6 seconds and separated by 1 second, and assigned a number that represented the discomfort of the test motion, assuming the discomfort of the reference motion was ‘100’. The reference motion was fixed at 0.3 ms^{-2} r.m.s. at 10 Hz. The test motions were randomly selected from a range of frequencies (2 to 80 Hz at preferred one-third octave steps) and magnitudes (0.08 to 2.0 ms^{-2} r.m.s. in 3 dB steps). An additional experiment was performed with 10-Hz vibration to determine relative discomfort between each of the 10 backrest conditions and Condition 8 (full backrest with upright posture). The relationship between the sensation magnitude (ψ) and the vibration magnitude (φ) was determined by linear regression for each frequency using Stevens’ Power law: $\psi = k\varphi^n$, where n is the rate of change of discomfort with vibration magnitude.

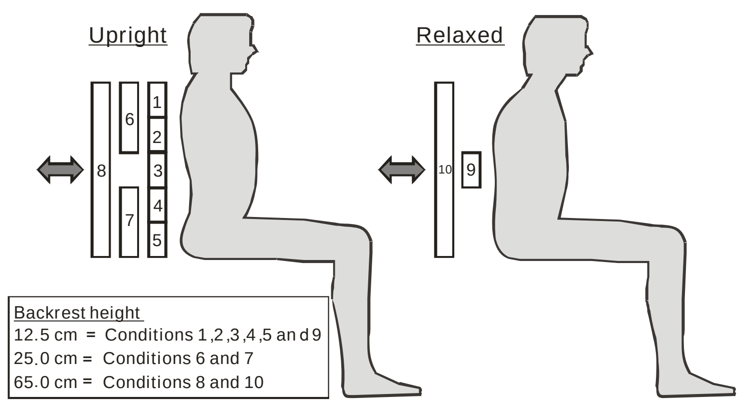

Fig. 1: Ten backrest conditions.

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Results

The equivalent comfort contours indicated decreased sensitivity to vibration acceleration as the frequency of vibration increased above 8 Hz, broadly similar to previous studies [4-5]. Contours obtained with a full backrest (Condition 8) were similar to those with contact only at the top of the back (Condition 1). Lower locations (Conditions 3, 5 and 9) had greater sensitivity. There were no obvious differences in sensitivity between upright and relaxed postures (Conditions 3 and 9). The derived frequency weightings were similar to frequency weighting W_c, but show increased sensitivity at frequencies greater than 30 Hz. The dependence of equivalent comfort contours on vibration magnitude means the frequency weightings also depend on magnitude.

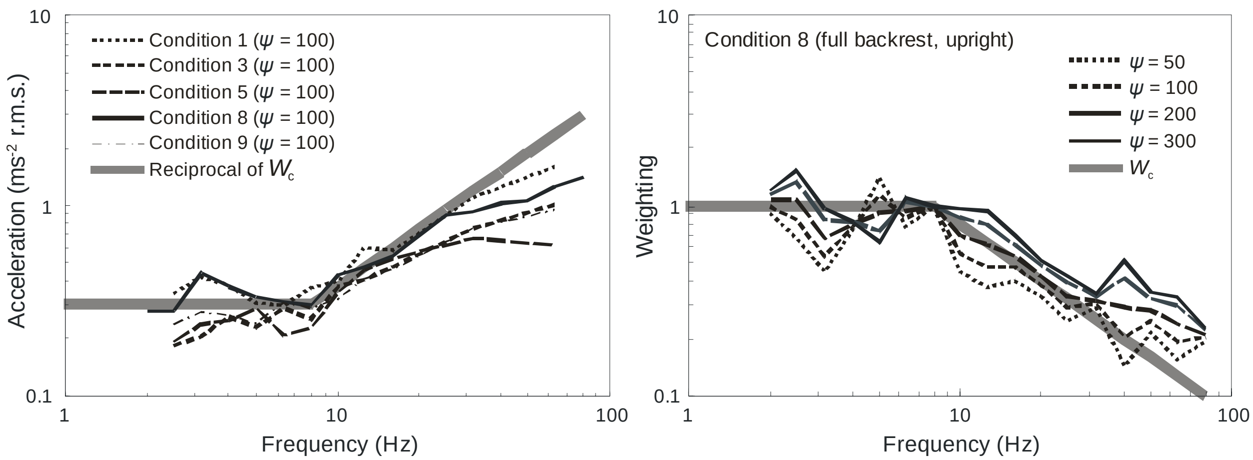

Fig. 2: Equivalent comfort contours (for Conditions 1, 3, 5, 8, and 9) and frequency weightings for Condition 8 at subjective magnitudes of 50, 100, 200 and 300.

Conclusions

Over the frequency range 2 to 80 Hz, equivalent comfort contours for the back depend on input location, with increased sensitivity at lower contact locations. Discomfort is not greatly affected by body posture. Frequency weightings corresponding to the comfort contours are reasonably consistent with the W_c weighting used in current standards [1-3] but suggest more sensitivity at frequencies greater than 30 Hz. Fore-and-aft backrest vibration can be assessed from the frequency-weighted fore-and-aft acceleration measured at the highest point of contact between the backrest and the body if the frequency weighting W_c is employed in the evaluation.

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EXAMINATION OF THE FREQUENCY-WEIGHTING CURVE FOR ACCELERATIONS MEASURED ON THE SEAT DURING HORIZONTAL WHOLE-BODY VIBRATIONS IN X- AND Y-DIRECTIONS

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Introduction

Exposure to whole-body vibration shall be assessed on the basis of frequency weighted accelerations and multiplying factors in accordance with ISO 2631-1 (1997) [1]. For the evaluation of the effect of vibration on the comfort, the weighted root mean square acceleration shall be determined for each axis of translational vibration at the surface which supports the person. For seated persons and horizontal seat surface vibration, the frequency weighting W_d should be applied with the multiplying factor k = 1. The point vibration total value a_v shall than be calculated by a root-sum-of-squares summation. Alternatively, where the comfort is affected by vibrations in more than one point an overall vibration total value a_{ov} can be determined from the root-sum-of-squares of the point vibration total values. In this case, the vibration at the feet is recommended to be assessed using the frequency weighting W_k and a multiplying factor k = 0.25. The current frequency weightings assume linearity in human response. In contrast, the newer investigations suggest a considerable dependence of the sensitivity to frequency on the vibration magnitude [2]. The study aimed at the examination of effects of sinusoidal and random whole-body vibration in x- and y-axis on the perceived intensity and comfort in order to predict the equivalent intensity and comfort contours on the basis of a_{ov} at different vibration magnitudes and to compare them with the current evaluation methods according to ISO 2631-1.

Methods

In a laboratory experiment, six male subjects were exposed to sinusoidal (0.8, 1.6, 3.15, 6.3 and 12.5 Hz) or random octave band-width white noise (mid-frequencies identical with those of sinusoidal vibration) whole-body vibration in x- or y-directions, at 6 levels of magnitude measured on the seat in the main axis (0.4, 0.8 and 1.6 m/s^2 non weighted (n.w. - M1, M2 and M3) and frequency weighted (w. - M4, M5 and M6)) with two repetitions. Every subject was exposed to these exposure conditions with a duration of about one minute at four different days. The volunteer's sensations of the vibration intensity and the vibration comfort were obtained by cross modality matching (length of a line). The subjects sat in an upright posture on a hard seat without backrest, hands on the thighs. The translational accelerations were measured on the platform and on the seat in three axes. Because of simultaneous exposure to vibration on the seat and at the feet in the experiment and owing to the instruction to judge integratively the entire vibration exposure, the judgements were assumed to be reflected more likely by a_{ov} than by a_v. Consequently, the relation between the a_{ov} calculated strictly according to ISO 2631-1 or modified without frequency weighting and the subjective judgements were determined by curve fitting to power functions and linear functions for each frequency, direction and kind of vibration signal separately in order to test the agreement with the Stevens' law.

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Results

The coefficients of determination did not vary significantly between the different curve fittings. The highest coefficients were obtained for the linear functions using the logarithmic subjective judgements normalized with respect to individual means per experimental day. Therefore, these functions were used for the prediction of subjective judgements due to an a_{ov} ranging from 0.41 to 1.65 m/s^2 n.w. (M1 to M3) and w. (M4 to M6). Subsequently, the functions were used for the calculation of the ratios of accelerations in dB, equivalent to the predicted judgements and normalized referring to the maximum of each curve. In general, the shapes of the predicted equivalent intensity and comfort contours within the range from M1 to M3 showed a significantly less steep slope compared with the current weighting curves within the range from 3.15 Hz to 12.5 Hz. Additionally, for sinusoidal vibration in x-direction at lower vibration magnitudes, an increase of normalized vibration intensity judgements was found at 3.15 Hz (Figure 1). The results concerning the magnitude levels M4, M5 and M6 confirmed the findings described above.

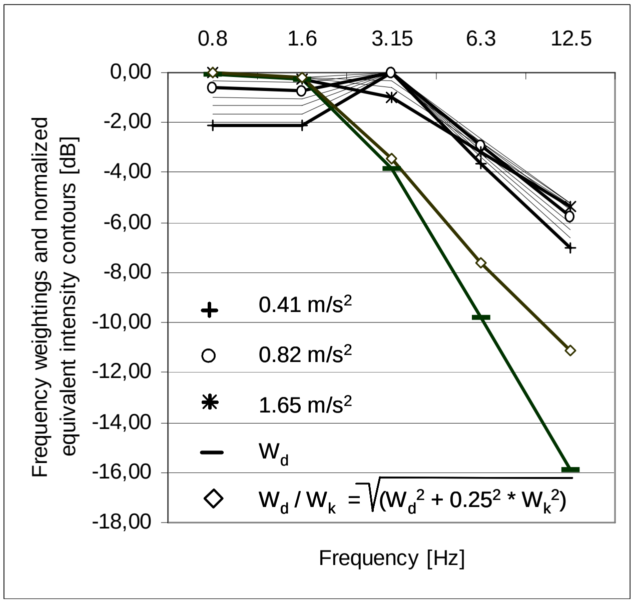

Fig.1: Frequency weightings Wd and Wd/Wk according to ISO 2631-1 and equivalent normalized intensity contours in [dB] for sinusoidal vibration in x-direction at different levels of overall vibration total value within the range from 0.41 to 1.65 m/s2 (n.w.).

Conclusions

The findings correspond to outcomes found in previous studies. They suggest that the current frequency weightings underestimate the subject's perception of vibration intensity and comfort in a frequency range from 3.15 Hz to 12.5 Hz, which is important for typical vibration frequency spectra of mobile machines at workplaces. The overall vibration total value a_{ov} might be more appropriate for reproducing the subjective judgements than the seat point vibration value a_v. Nevertheless, even a_{ov} probably underestimates the effects due to vibration in the frequency range mentioned above. Therefore, a modified weighting in this frequency range could contribute to an improved assessment of subjective evaluations due to a calculation of the daily exposure value which better reflects the human response.

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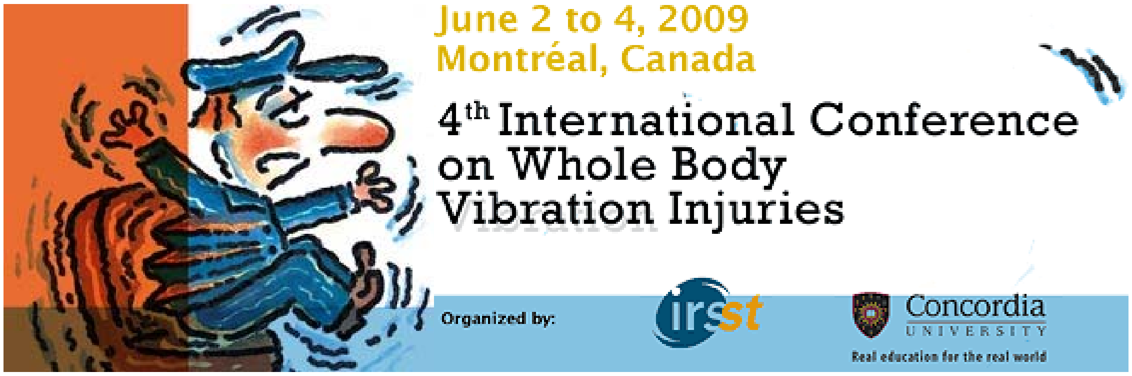

SESSION 9

SEATING

EXPLORING INTERVENTIONS TO WHOLE BODY VIBRATION EXPOSURES IN FORKLIFT OPERATORS: MECHANICAL AND AIR-RIDE SEATS

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Introduction

The goal of this study was to compare and determine whether there were differences in WBV exposures when operating a forklift with a mechanical dampening and a nearly identically designed air-ride seat. A recent review of epidemiologic research has indicated there is a relationship between working as a forklift operator and the development of low back pain [1]. In a study examining the prevalence of low back pain (LBP) and exposure to WBV among port machinery workers, it was established that forklift operators had a higher prevalence of LPB and had significantly higher WBV exposures compared to the operation of other machinery associated with port operations [2].

Methods

Using a repeated measures design, twelve experienced forklift operators used the same forklift (Model Hyster S80; NACCO Materials Handling Group, Inc; Portland, OR, USA), for a one hour period consisting of normal work activities. The forklift operators then drove over a standardized test route, consisted of a variety of outdoor paved surfaces, transitions and a smooth floor environment within a large building. Forklift operator exposure to whole-body vibration was evaluated comparing two interventions; a mechanical suspension seat and an air suspension seat. A seat pad ICP accelerometer (model 356B40; PCB Piezotronics; Depew, NY) was mounted on the driver's seat and an identically designed accelerometer was securely mounted on the floor adjacent to the base of the forklift operator's seat. A PDA-based portable WBV data acquisition system was used to collect raw (raw peak, S_{ed}) and time weighted average (A_w, Crest Factor, TWA peak) tri-axial WBV measurements.

Results

Table 1 illustrates the difference in z-axis average vibration exposures between the actual work and standardized route. Since the forklift drivers drove 7 out of 8 hours during their shift, the A_w, VDV and S_{ed} data from the actual work and standardized route were normalized to 8 hour equivalents. When comparing seat types, there were significant differences in z-axis WBV exposures with the air suspension seat consistently yielding lower exposures. The data shows that there was a significant difference in A_w and Crest Factors between the one hour of actual work and the standardized route with the standardized route having substantially higher exposures. Raw and TWA peak exposures were higher during the actual work portion.

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Table 1: WBV Mean (±SE) seat measures comparing actual work vs standardized route [n=12].

Parameter	Axis	Seat	Actual Work	Standardized Route	p-value
A_w (m/s^2)	**Z**	**Mechanical**	0.48 (± 0.07)	0.71 (± 0.10)[a]	0.0006
		Air-Ride	0.39 (± 0.07)	0.54 (± 0.08)[a]	0.0001
Crest Factor	**Z**	**Mechanical**	23.8 (± 3.5)	11.2 (± 1.5)	0.004
		Air-Ride	32.1 (± 6.3)	14.8 (± 4.9)	0.0001
VDV (m/s$^{1.75}$)	**Z**	**Mechanical**	17.6 (± 2.4)	19.0 (± 2.8)[b]	0.35
		Air-Ride	13.6 (± 1.6)	12.9 (± 1.8)[b]	0.55
TWA Peak (m/s^2)	**Z**	**Mechanical**	11.4 (± 1.9)	8.0 (± 1.0)	0.10
		Air-Ride	11.2 (± 1.7)	7.0 (± 1.5)	0.02
Raw Peak (m/s^2)	**Z**	**Mechanical**	31.0 (± 7.3)	15.7 (± 3.3)	0.09
		Air-Ride	34.8 (± 7.4)	21.3 (± 9.3)	0.02
S_{ed} (MPa)	**All**	**Mechanical**	0.69 (± 0.15)	0.43 (± 0.03)	0.09
		Air-Ride	0.53 (± 0.07)	0.48 (± 0.04)	0.29

a – significant difference between seats ($\alpha = 0.05$),
b – trending toward significant difference between seats ($\alpha = 0.05$)

Conclusions

Under both actual work and the standardized route conditions evaluated in this study the air suspension seats generally attenuated WBV exposures more than their less expensive mechanical counterparts.

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TRANSMISSIBILITY OF AGRICULTURAL TRACTORS SEATS - EFFECTIVENESS ON DRIVER WHOLE BODY VIBRATION DAMPING

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Introduction

Agricultural tractors are very different from each other in terms of structural and preservation parameters, as for mass, work age, construction and so on. Vibration transmissibility to driver's body is largely related to seat installed on tractor that will be substituted for ageing [3]. These differences lead to a variability in whole body vibration exposure, mainly considering that the life of tractors largely overcomes life of the seats. The aim of this work is to evaluate the efficiency of tractor seats in terms of both the certification tests and whole body vibration reduction to drivers. Moreover, seat producers have to define correct seat regulation considering weight and position of drivers. This research also attempts to compare ergonomics posture of subjects with different anthropometrical characteristics in medium and small tractors. It also needs to be underlined that a technical directive that defines, in ergonomic terms, a correct design of driver's position does not yet exist.

Methods

The acceleration measurements were taken in the laboratory using triaxial accelerometers installed on the seat and on its basis. These were evaluated by Oros 38 (sampling rate of 2048 Hz) under signals defined in 78/764/CEE [1] for tractors of category A and class two. Three seats with pneumatic and mechanical suspension were evaluated using subjects characterized by 59±1 kg e 98±5 kg masses increased with a maximum ballast of 5 kg. In the field measurements, a standard track was defined as per the European certification tests to evaluate transmissibility of the same seats. Thee measurements were repeated three times [4]. Seat transmissibility were assessed considering frequency range defined by risk assessment directive ISO 2631 [2]. The field measurements were carried out using the same instrumentation utilized in the laboratory. Moreover, the ergonomic properties of the seats were evaluated by means of two matrices of capacitive sensors (Novel) interposed between operator and seat, and between foot and brake pedal. The mean pressures on the seat and the brake pedal were evaluated from the measured pressure distribution over the test duration. Same ergonomic measurements were also conducted in the field on small tractors. Furthermore, these measures were recorded for operators with different weights.

Results

Table 1 illustrates the transmissibility of the selected seats measured in the field and the laboratory. The results from the field tests were evaluated from the ratio of seat acceleration to the floor acceleration (***T***) in the 0.5-80 Hz frequency range, while the laboratory results are

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expressed by ***V*** defined in 78/764/CEE, that takes into account transmissibility of the seat with respect to the platform.

Table 1: Damping values for mechanical and pneumatic seats evaluated from field and laboratory tests.

	Pneumatic	Mechanical
Laboratory (78/764/CEE) ***V***	1.00÷1.07	0.84÷1.23
Field (ISO 2631) ***T***	0.96÷0.98	1.22÷1.26

The pressure profile measured on the seat and on the brake pedal, underlined a different driver's posture behaviour between small and medium tractors. Pressure profiles revealed a decrease in seat pressure with increase in the brake pedal pressure for small tractors (Fig. 1B). This, unlike the medium tractor (Fig. 1A), highlights the action of a momentum that forced the driver to stand up. As a consequence, this resulted in a poor seat adjustment with high transmitted acceleration.
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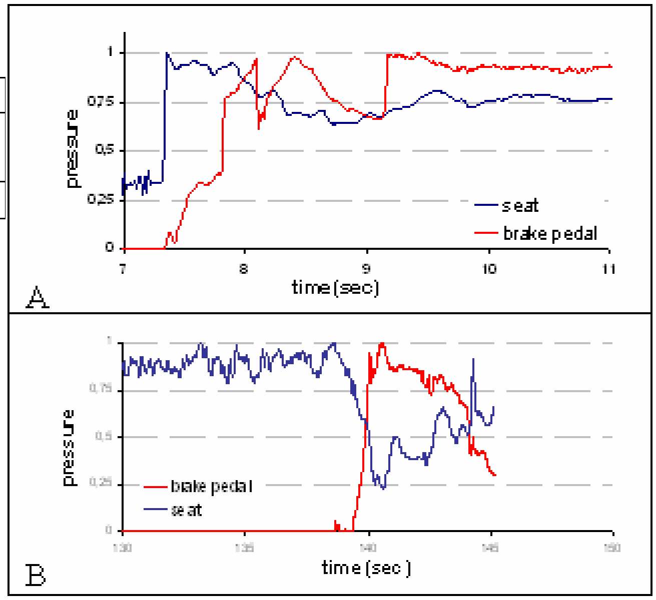

Fig. 1 : Pressure signals in medium (A) and small (B) tractors

Conclusions

Results obtained from capacitive sensor matrix demonstrate a discrepancy between driver's posture behaviour in small and medium tractors for all subjects. Indeed small tractors make subject stand up from seat in order to press the drive pedals inducing higher levels of acceleration. Seat transmissibility measured in the laboratory differed from that in the field tests (Tab. 1). This seems to indicate a damping dependency on acceleration signal. Laboratory tests. Moreover, the field measurements revealed difficulties associated with the weight-regulation of the seat suspension system since a clear indication is often lacking.

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VALIDATION OF A SUSPENSION SEAT TO REDUCE VIBRATION EXPOSURE OF SUBWAY OPERATORS

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Introduction

Subway operators have complained about discomfort caused by whole-body vibration. To reduce these vibrations, a suspension seat with extensive ergonomic features has been adapted for the small space of the operator cab. The suspension was modified from an existing suspension in order to reduce the dominant frequency of the subway vibration in the vertical direction (2.4 Hz). In order to characterize the effect of operator weight, vibration level and suspension height adjustment on the vertical (z-axis) SEAT value, the suspension seat was first tested in the laboratory with 11 subway operators on a vertical hydraulic shaker. The results of these preliminary tests have been presented in a previous paper [1]. This paper is concerned with the assessment of the suspension seat during normal subway operation.

Methods

The final version of the suspension seat prototype was validated in the subway during normal operation with 6 different operators having weight in the 5th, 50th and 95th percentile of the operator population. The measurements have been performed on the Montreal subway yellow line (between the *Longueuil-Université-de-Sherbrooke* and *Berri-Uqam* stations), where whole-body vibration values were shown to be higher in a previous study [2]. Vibrations on the floor were measured with a triaxial accelerometer (*PCB 356B41,* without the seat pad) near the operator, while the vibrations on the seat cushion were measured with an accelerometer seat pad (*B&K 4322* with three charge amplifiers *B&K 2635*). The data were recorded and analyzed with a *B&K Pulse* acquisition system. For each operator, the measurements were performed over two round trips of about 40 minutes each. The operators were asked to adjust the suspension height to their preferences at the beginning of the measurement. However, it was requested to keep a minimum of 4 cm from the limit stops to avoid end-stop impacts. The data acquisitions were halted when the subway was stopped in the stations. Then, the acceleration levels were weighted according to the ISO 2631-1 standard [3]. In addition to the vibration measurements, each operator was asked, while stopped in each station, about his perceived discomfort level [4] from previous vibration exposure.

Results

As shown in Table 1, the vertical SEAT values during these tests were between 0.86 and 0.99, lower than the actual rigid seat (1.05). As for the lab tests, the SEAT values were lower when the suspension was vertically centered, and when the vertical vibration level was higher. The seat was amplifying the vibration levels in the x and y directions. However, even after amplification, the weighted vibration levels in the y and x directions were respectively 2 and 4 times lower than the weighted acceleration in the z direction, as shown in Table 2. In addition, It was shown that in some cases, the 2.4 Hz dominant frequency was amplified by the suspension (more specifically for low weight operators and low adjustment heights of the suspension), even though the global SEAT factors were smaller than one. These amplifications of the 2.4 Hz

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component were associated to perceived discomforts in some operators. However, most of the surveyed operators preferred the new suspension seat when compared to the actual rigid seat.

Table 1: SEAT factor for the three axes

	SEAT factor		
	x axis	**y axis**	**z axis**
Operator 1	2,400	1,220	0,991
Operator 2	2,064	1,284	0,973
Operator 3	1,585	1,290	0,946
Operator 4	1,763	1,182	0,860
Operator 5	1,902	1,115	0,880
Operator 6	1,783	1,293	0,995
Average	**1,916**	**1,231**	**0,941**

Table 2. Weighted acceleration at the seat

	a_w seat cushion (m/s^2, weighted)		
	x axis	**y axis**	**z axis**
Operator 1	0,151	0,228	0,462
Operator 2	0,129	0,232	0,457
Operator 3	0,101	0,231	0,443
Operator 4	0,114	0,226	0,402
Operator 5	0,124	0,212	0,409
Operator 6	0,117	0,238	0,486
Average	**0,123**	**0,228**	**0,443**

Conclusions

A suspension seat has been adapted to the small space of the Montreal subway cab operator. The seat prototype has been extensively tested on a vertical hydraulic shaker in the lab as well as during normal subway operation. The suspension of the seat was also used as an height adjustment, and attenuated the vertical vibrations in most of the cases. The operators were also generally satisfied with the new suspension seat and its extensive ergonomic features. It has been recommended to further test the suspension seat with a larger population of subway operators during normal subway operations before implementing it on a large scale on the subway fleet.

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A DUAL-AIR BAG RIDE HEIGHT INDEPENDENT SUSPENSION SEAT DESIGN AS A SOLUTION FOR THE END-STOP IMPACTS

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Introduction

A suspension seat for city buses serves a crucial role in preserving health and safety of the drivers by providing controlled postural support and control of road-induced shock and vibration. A suspension seat is thus considered as an effective solution for mitigating the risk of whole body vibration injuries. The design of suspension seats for city buses involves many challenges, namely low frequency of dominant vertical vibration in the vicinity of wheel suspension natural frequency (near 1.6 Hz), wide variations in drivers' weight and height, vehicle interactions with discrete regularities in urban roads (pot holes and bumps). The suspension design approaches the limit of its performance due to inadequate ride height arising from variations in driver weight and height coupled with high intensity vibration due to discrete irregularities. The suspension may thus transmit high intensity vibration caused by impacts against the travel limiters. A suspension design with relative low sensitivity of its performance to height variations is thus considered desirable. This study explores such a suspension design developed by Baultar Concept. The vibration attenuation performance of the new design is evaluated as a function of the seat height and the seat load to illustrate its insensitivity to both the factors.

Methods

The proposed suspension design comprises two uncoupled air springs and two hydraulic dampers. The suspension in its lowest position is shown in Fig. 1. The lower spring is inflated by the occupant to achieve desired height, while the upper spring is inflated automatically to ensure mid-ride. The main difficulty of the design was to keep the base compact enough to achieve a minimum height of 31 cm. The vibration performance characteristics of the prototype suspension designs have been assessed in the laboratory, while the subjective and objective field evaluations are currently under-way. The laboratory assessments involved two series of measurements using the whole-body vibration simulator platform in the CONCAVE laboratories. The first series of measurements were performed under a white noise platform vibration, while the second series considered the mean vertical vibration spectrum of a city bus [1]. Each series involved measurements of transfer functions and seat effective amplitude transmissibility (SEAT) as a function of the seat load and seat height. Each series also involved multiple trials, while several ride heights were considered from the lowest position of 273 mm to the highest position of 393 mm. The measured data were analyzed to determine the acceleration transmissibility and the SEAT values.

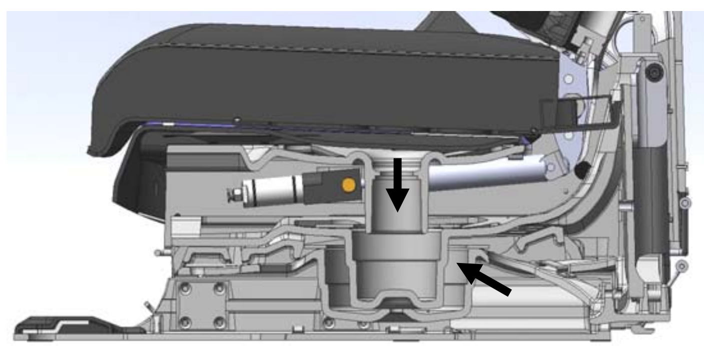

Fig 1. Suspension seat prototype; the two air springs are indentified by the arrows.

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Results

Figure 2 illustrates the transmissibility response of the suspension corresponding to 4 different right heights, while loaded with an inert mass of 58.2 kg. The results show insensitivity of the response to ride height variations, except from the extremely low position of 273 mm, where the air spring is entirely deflated. The suspension did not encounter an end-stop impact during both series of measurements, irrespective of the ride height. Considering that the city bus vibration predominate around 1.6 Hz, a low frequency suspension seat would generally lead to a high SEAT factor and frequent end stop impacts. The results further showed that the SEAT factor is also insensitive to ride height, as shown in Fig. 3, while the SEAT values remain high due to low frequency bus vibration. The natural frequency of the current prototype was measured near 2.2 Hz. A reduction in the natural frequency is being sought to enhance the SEAT performance.

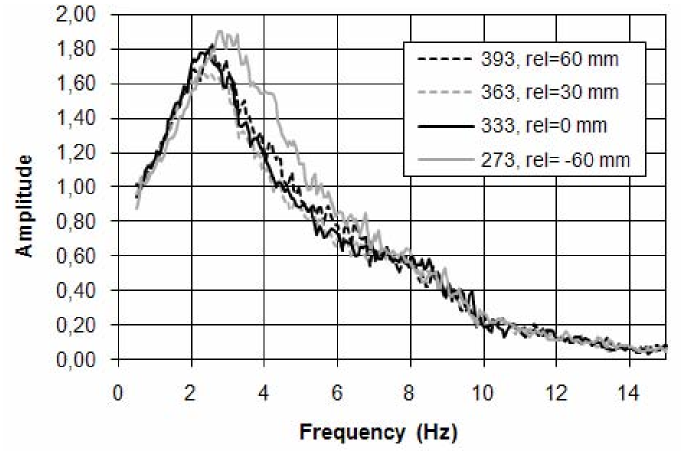

Fig. 2: Seat acceleration transmissibility as a function of the ride height.

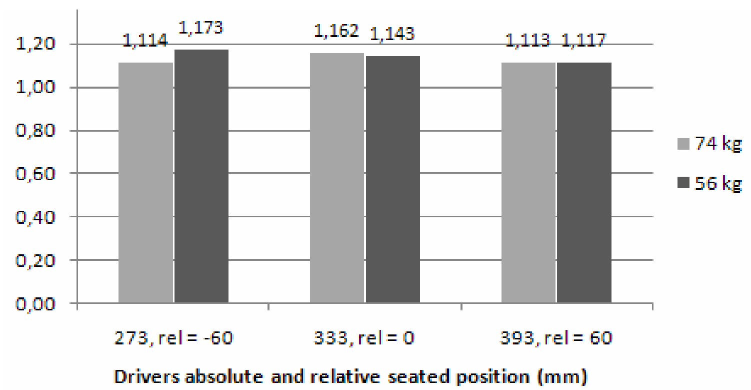

Fig. 3: S.E.A.T. factor with respect to height adjustment and mass on the seat

Conclusions

The results show that the dual air bag design concept can entirely eliminate the end-stop impacts irrespective of the ride height, which is known to vary considerably in city bus operations.

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WHOLE-BODY VIBRATORY RESPONSE STUDY USING A NONLINEAR MULTI-BODY MODEL OF SEAT OCCUPANT SYSTEM WITH VISCOELASTIC FLEXIBLE POLYURETHANE FOAM

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Introduction

Passenger dynamic comfort is one of the most important issues for automobile seating manufacturers. The support and comfort provided by the car seat has much improved over the years due to the use of polyurethane foam. The quasi-static and dynamic properties of foam significantly affect the static and dynamic comfort of an occupant. Hence, there is a need for good models of foam and seat-occupant systems through which the effects of foam properties on dynamic comfort can be directly evaluated. Based on Nishiyama's modeling effort for vehicle-seat-occupant systems and generalizing his models to incorporate nonlinear viscoelastic behavior of seating foam as well as friction at seat-occupant interface, we have developed a nonlinear seat-occupant model for planar motions. This model can be used to study the dynamic response of the occupant when subjected to various dynamic excitations, without restriction to small amplitude motions.

Methods

The seat-occupant model developed by Ippili et al. [1-2] for predicting static equilibrium position has been generalized to incorporate dynamic excitation transmitted through the seat pan. The seat foam is modeled by a set of experimentally verified viscoelastic nonlinear unidirectional springs. The force-deflection relation (or constitutive model) for each spring is modeled as:

$$\sum_{i}^{7} k_i x^i + \int_0^t \sum_j^2 a_j e^{-\alpha_j (t-\tau)} x(\tau) d\tau = f(t)$$

This model is composed as a sum of nonlinear elastic and linear viscoelastic terms. The stiffness and viscoelastic parameters in this model are obtained from quasi-static compression data using system identification techniques [1, 3] and are used in the seat-occupant model. The generalized model was used for predicting the static equilibrium position of the occupant in [1-2], and is now used to study the response of the occupant to harmonic base-excitation.

As a preliminary step, a single-degree-of-freedom foam-mass system [3], a mass block attached on top of a 3'' foam cube, is used to analytically study response to a harmonic base excitation at constant acceleration and at various compression levels. The steady state frequency-response of the system is numerically calculated by direct-time integration. In the results presented here (Figures 1 and 2), the block mass is such that the static equilibrium position simulates 50 % compression in foam. The excitation frequency is increased from 0.25 Hz to 8 Hz in steps of 0.25 Hz in the region away from resonance peak, and in steps of 0.1 Hz close to the peak.

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Results

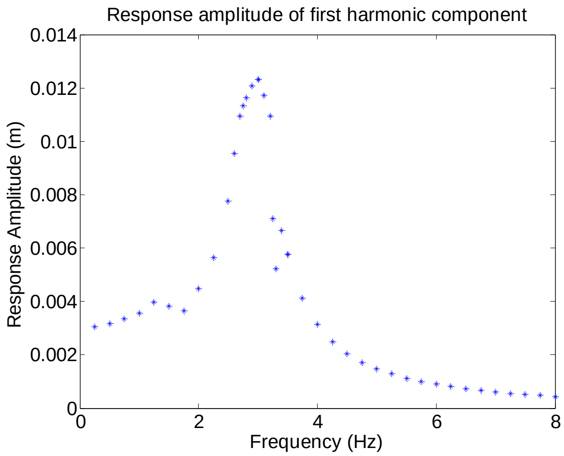

Fig. 1: Frequency response of foam-mass system at 0.2g base acceleration.

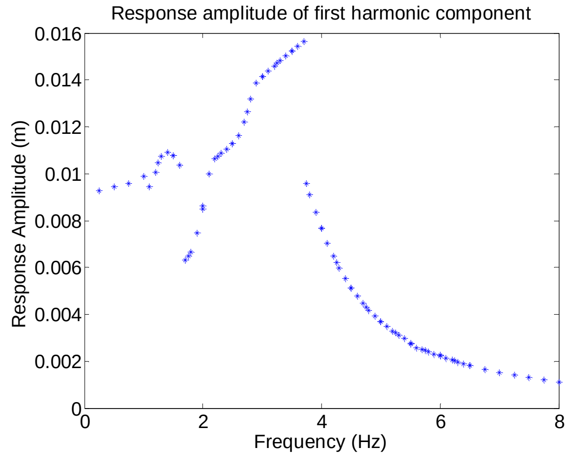

Fig. 2: Frequency response of foam-mass system at 0.5g base acceleration.

In the frequency-response curves (amplitude of first harmonic) of the foam-mass system, the primary resonance peak is observed near 3 Hz. A slight softening of response is seen in Fig. 1 for the lower base acceleration (0.2g) case. The nonlinear (softening-hardening) behavior is more clearly evident in Fig. 2 where the base acceleration is much higher (0.5g). The peak response frequency is shifted upwards and the frequency-response is much more complex. A superharmonic resonance is also seen at close to half the resonance frequency, i.e., near 1.5 Hz. This is due to the presence of even power terms in the nonlinear stiffness model of foam.

Conclusions

A nonlinear viscoelastic model of polyurethane foam with properties identified through quasi-static testing at various slow compression rates is used in a one degree-of-freedom foam-mass system, and the dynamic response is studied at various base excitation frequencies and acceleration levels. This is a step towards developing a global model of foam, as against models with different parameters for static and dynamic responses about different compression levels [3]. This methodology is now being extended to the seat-occupant models.

References

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OPTIMAL ACTIVE SEAT SUSPENSION FOR A HYBRID MODEL OF A SITTING HUMAN BODY

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Introduction

Discomfort of the driver and passenger and good handling of the car are two contradictory criteria which should be taken into consideration by the designer. In some papers concerning the human body the usual way of theoretical approaches to vibration isolation is based on simple, passive human body models and selected, a priori known, passive structures of seats. Some works concerning active human body models and their optimal vibration isolation have also already been published in [1,2]. In the present article a general procedure for the analytical construction of an optimal vibration isolation system (OVIS) for a sitting human body model (SHBM) including weighting functions describing the level of discomfort, has been proposed.

New hybrid model of a sitting human body

There are sitting human body passive biomechanical models based on the notions of impedance (1), apparent mass (2) and transmissibility functions. In the paper the driving point impedance and apparent mass were chosen as the representative of characteristics of a human body model (HBM).

$$Z(s) = \frac{F(s)}{\dot{x}(s)} \quad (1) \qquad M(s) = \frac{F(s)}{\ddot{x}(s)} \quad (2) \qquad W_b(s) = H_{fb}(s) H_b(s) \quad (3)$$

where *F(s)*, $\dot{x}(s)$, $\ddot{x}(s)$, *Z(s), M(s)* are the Laplace transforms of force, velocity, acceleration, impedance, apparent mass, and $W_b(s)$ is the frequency weighting with appropriate filters $H_{fb}(s)$ and $H_b(s)$. The weighting curve $W_b(s)$ described in the second edition of ISO2631 can serve for estimation of the discomfort of the sitting human body subjected to vibration in the 0.1–80 Hz range. In the paper a conceptually new hybrid SHBM is proposed. It is a product of impedance *Z(s)* (or apparent mass *M(s)*) and frequency weighting curve $W_b(s)$.

Analytical synthesis of OVIS for SHBM

The aim of the proposed approach is to find the OVIS for a new SHBM subjected to stationary random excitations described by their power spectral densities of acceleration. For further investigation the following criterion of synthesis was assumed:

$$J = \sigma^2_{x-x_0} + \lambda \sigma^2_{\ddot{x}} + \kappa \sigma^2_F = \min \quad (4)$$

where the components in the criterion have the following meaning: $\sigma^2_{x-x_0}$ - the variance of the relative displacement between the foundation and the seat, $\sigma^2_{\ddot{x}}$ - the variance of the acceleration of the seat, σ^2_F - the variance of the total force developed by OVIS acting on the system seat – human body. All these variances are calculated under the assumption that the excitation is described by the PSD of acceleration of excitation, which can be expressed by its factored function of complex variable *s*, $S_{\ddot{x}_0}(s) = S_0 \psi^+(s) \psi^-(s)$. The parameters λ and κ are the Lagrangian multipliers.

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Assuming that the function (5)

$$\varphi(s) = F(s)\ddot{x}_0^{-1}(s) \tag{5}$$

describes totally the OVIS, the criterion (4) can be expressed as follows

$$J = \sigma^2_{x-x_0}(L(s), W_b(s), \varphi(s), \psi(s), \lambda, \kappa) + \\ + \lambda\sigma^2_{\ddot{x}}(L(s), W_b(s), \varphi(s), \psi(s), \lambda, \kappa) + \kappa\sigma^2_F(L(s), W_b(s), \varphi(s), \psi(s), \lambda, \kappa) \tag{6}$$

where**:** *ψ(s)* - function describing the form of stationary, random acceleration excitation**,** *L(s)* - function that describes the physical properties of the isolated human body, which can be expressed by the impedance or apparent mass of HBM. As the final result of minimization of the criterion (6) the function (5) can be prescribed in the form (7)

$$\varphi(s) = f(L(s), W_b(s), \psi(s), \lambda, \kappa) \tag{7}$$

Case when the components of the criterion are expressed by the impedance

In this case the variances, components of criterion (4), are expressed by formulas (8)

$$\sigma^2_{x-x_0} = \frac{1}{j}\int_{-j\infty}^{+j\infty}\left|\frac{\varphi(s)}{sZ(s)W_b(s)} - \frac{1}{s^2}\right|^2 S_{\ddot{x}_0}(s)ds\,, \quad \sigma^2_{\ddot{x}} = \frac{1}{j}\int_{-j\infty}^{+j\infty}\left|\frac{s\varphi(s)}{Z(s)W_b(s)}\right|^2 S_{\ddot{x}_0}(s)ds\,,$$

$$\sigma^2_F = \frac{1}{j}\int_{-j\infty}^{+j\infty}|\varphi(s)|^2 S_{\ddot{x}_0}(s)ds \tag{8}$$

The final formula for *φ(s)* expressed by the impedance can be written as follows

$$\varphi(s) = \frac{1}{D^+(s)\psi^+(s)}\left[\frac{G(-s)\psi^+(s)}{D^-(s)}\right]_+ \tag{9}$$

where functions $D^+(s)$ and $D^-(-s)$ are the result of the factoring of the expression (10) and *G(s)* is expressed by the formula (11)

$$D^+(s)D^-(-s) = G(-s)G(s)\psi^+(s)(1 + \lambda s^4) + \kappa s^2 \tag{10}$$

$$G(s) = sZ^{-1}(s)W_b^{-1}(s) \tag{11}$$

Conclusions

Final formulas for $D^+(s)$, $D^-(s)$ and consequently for *φ(s)* depend on the forms of the impedance or apparent mass of HBM and the weighting function $W_b(s)$. It can be shown that the values of variances (8) and the criterion (6) are lower than for the OVIS for the system without or with any passive system of vibration isolation.

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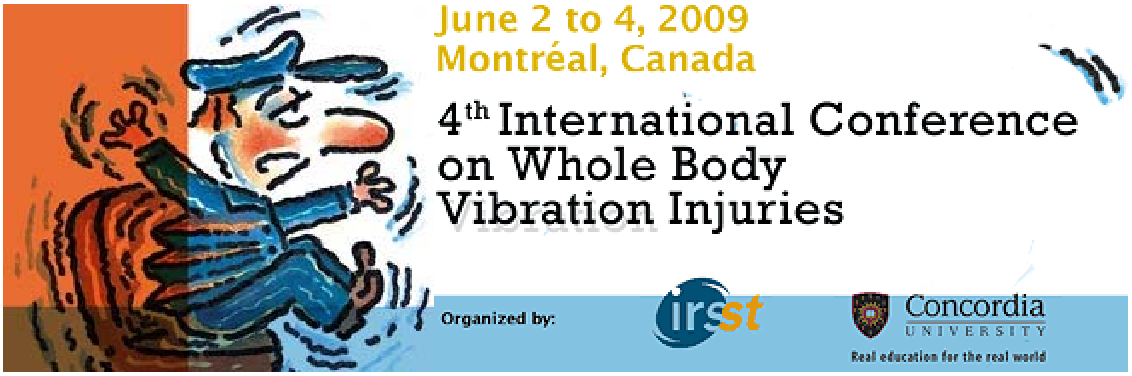

SESSION 10

EXPOSURE ASSESSMENT (2)

VIBRATION EXPOSURE OF SUPINE AND SEMISUPINE SUBJECTS

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Introduction

While travelling in a vehicle compared to semi-supine or seated postures persons may be affected more in the supine posture by the vibrations transmitted to their bodies. Patients are exposed to significantly high levels of whole-body vibrations during their transportations in an ambulance. High velocities cause high magnitude forces that pose high physiological dynamic hazards [1]. These result in discomfort and cause adverse affects on patients. The slope of the upper part of the stretcher affects the body posture which in turn alters the body's response to vibration [2]. Studies show that the presence of backrest increases the resonance frequency of the body [3]. The condition of the road surface or the road type and the speed of the vehicle may further worsen the patient's situation.

Methods

A field measurement was performed. Twelve male subjects took part in the experiment. Subjects mean age was 28.2 years, mean height 1.76 m and their mean weight was 71.83 kg. Subjects were exposed to random vibration in the field. The duration of the measurement was 4 s. Two types of roads namely smooth asphalt, AR, and cobble stone road, CSR, were chosen as the test tracks. The speed of the ambulance was either 20 or 30 km/hr. The semi-supine posture, SSP, differed from the supine, SP, one by an angle α of 38°. The accelerations on the floor were measured at two points which were the projected points P_1 and P_2 corresponding respectively to head and feet.

Results

On CSR, the acceleration level ($a_z(P_2) > a_z(P_1)$) was measured as 0.53m/s² (at 1.5Hz and when V=30km/hr). Vibration exposure of the head of the subject was signicantly higher compared to his hip. The dominant frequency range for SSP was narrower than the one for SP. The highest unweighted head acceleration in x (as indicated in ISO 2631) direction, a_x, in SSP position was 0.55m/s² (f =1.75Hz when V=30km/hr)) on CSR. The highest unweighted head a_x on AR was 0.17 m/s² at SSP. The dominant frequency range for head was same whether the ambulance travels on AS or on CSR roads. The higher discomfort stated by the subjects in SP position can be attributed to the wide range of dominant frequencies which was three times wider compared to SSP position while travelling on an CSR road.

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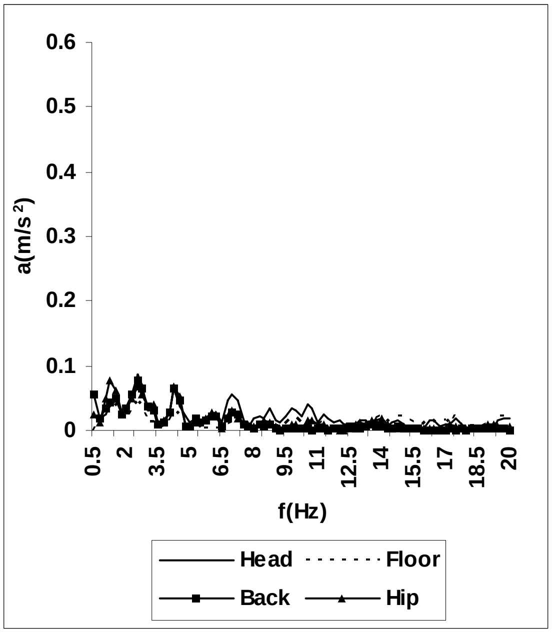

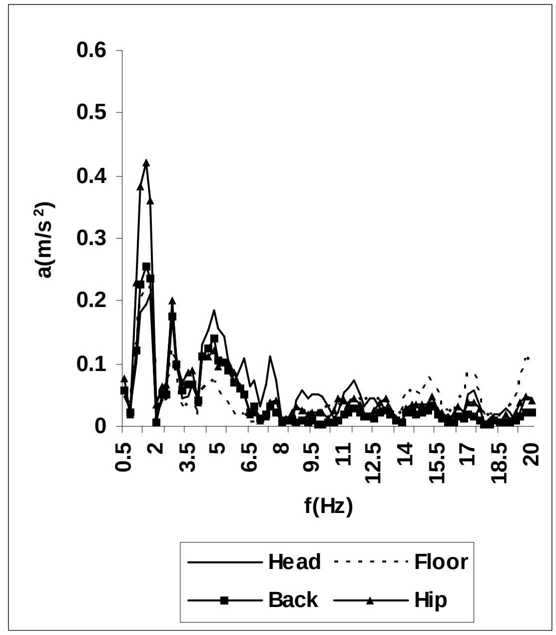

Fig. 1: Acceleration graph for $a_x$head, $a_z$floor, $a_x$back and $a_x$hip, α=38^0, AR and V=30km/hr

Fig. 2: Acceleration graph for $a_x$head, $a_z$floor, $a_z$back and $a_x$hip α=38^0, CSR and V=30km/hr

Conclusions

Vibration exposure of the subjects lying on a stretcher in an ambulance is low frequency dominant exposure. Whether the track is smooth or CSR hip is the body part affected most while travelling in an ambulance in SSP but frequency range for hip is narrower while travelling on CSR compared to smooth road.

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DETECTION OF IMPACTS AND SHOCKS IN WHOLE-BODY VIBRATION

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Introduction

The analysis of vibration exposure, and the implications for potential health effects, is influenced by the presence of mechanical shocks. The availability of instrumentation for recording long-duration acceleration time-histories, for example by data logging or by dosimeters, introduces the potential for large data files and hence tedious analysis by hand. In such circumstances it may be desirable for impacts and shocks to be distinguished from continuous or intermittent vibration by an algorithm, that is, by computer, rather than by observation. The method described here relies on the statistics of the acceleration-time history of the motion and, in particular, on the acceleration magnitude distribution during successive time segments (e.g., 1 minute intervals). It employs the predominant characteristic of an impact, or shock, namely that its peak amplitude is sustained for an extremely small fraction of the time segment.

Method

We can describe the probability that the motion will have an acceleration magnitude between α and β (see Figure 1a) in terms of the probability density distribution evaluated during a convenient time segment of the motion (e.g., 1 minute), $p(a)$ [1].

$$\Pr[\alpha < a(t) \le \beta] = \int_{\alpha}^{\beta} p(a)da = P(\beta) - P(\alpha) \qquad (1)$$

where $a(t)$ is the acceleration-time history, and $P(\alpha)$ and $P(\beta)$ are the corresponding values of the cumulative probability function (Figure 1b). The algorithm calculates the extremes of the distribution in two ways, one based on probability values (i.e., values of $P(\alpha)$ and $P(\beta)$), and the other from the *expected values* of the distribution, which are defined for integer values of *m* by:

$$E[a^m(t)] = \int_{-\infty}^{\infty} a^m(t)\,p(a)da \qquad (2)$$

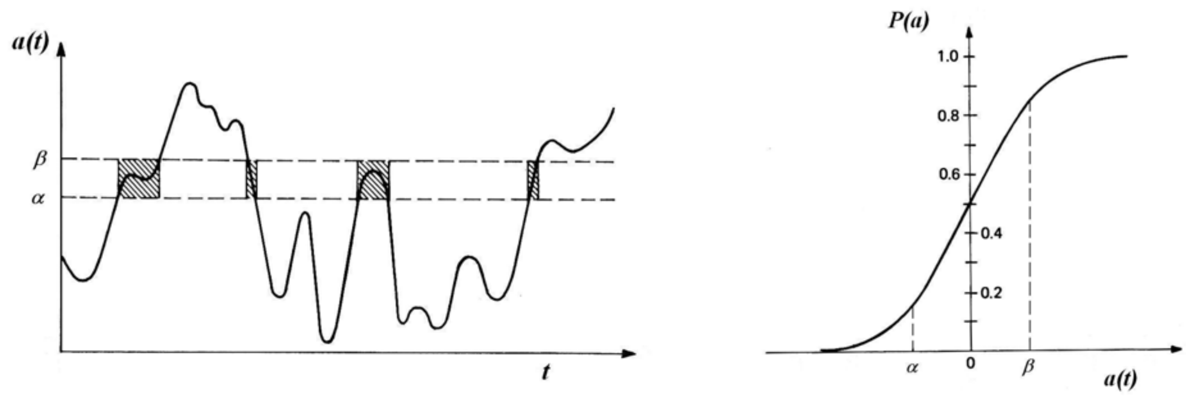

Fig. 1: (a) acceleration-time history, (b) cumulative probability distribution

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While the expected values of a distribution may be unfamiliar, they are related to the root mean square acceleration, a_{RMS}, and higher-order mean values, and are sensitive to the shape of the distribution [2]. The latter possess magnitudes that progressively approach the maximum accelerations during the motion, and reflect different cumulative probability values. For continuous random vibration (with a Gaussian distribution), the relationship between the twelfth-order root mean acceleration, a_{RMT}, derived from equation (2) with $m = 12$, and a_{RMS} is:

$$a_{RMT} / a_{RMS} = 2.16 \qquad (3)$$

and a_{RMT} corresponds to a cumulative probability of 0.97. The magnitude of this ratio and the corresponding probability will, however, change with the presence of shocks or impacts.

The second metric, the impulsiveness, retains a given probability irrespective of the shape of the distribution functions and may be defined as:

$$I_{[P(\beta)-P(\alpha)]} = \frac{|\beta - \alpha|}{2a_{RMS}} \qquad (4)$$

where α and β are now chosen to be the acceleration magnitudes that correspond to a cumulative probability of 0.97. The algorithm then consists of comparing the magnitudes of these parameters for successive time segments of the acceleration time history to detect the presence of impacts and shocks.

Results

Seat motion acceleration-time histories were obtained for tactical military vehicles operating on-the-road, and off-the-road. A selection of 30 acceleration-time histories were employed to establish "fence" values for the two metrics. For Z-axis seat motion (vertical direction) analyzed using the frequency weighting specified in ISO 2631:1997, impacts including shocks could be identified when $a_{RMT}/a_{RMS} \geq 2.5$, and $I_{(0.97)} \leq 2.6$. A subjective visual classification of 160 exposures to vibration recorded in a range of military vehicles under different operating conditions was then performed by a jury of two observers. Machine identification of the waveform signatures using these fence values for the two metrics resulted in successful identification of shocks and impacts in 94% of the acceleration-time histories.

Conclusions

The identification of shocks and impacts in seat motion appears feasible by an algorithm based on the statistics of the acceleration-time history of the motion.

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THE EFFECTS OF SEAT MOTION ARTIFACTS ON REPORTED WBV VALUES IN ISO 2631-1 (1997) AND ISO 2631-5 (2004) IN US FREIGHT LOCOMOTIVES

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Introduction

The operation of a US freight locomotive does not require continuous active control by the operator with either the hands or feet and this allows for the opportunity to frequently adjust postures and seat settings. Seat motion artifacts (SMAs) are primarily of three types; movement onto and out of the seat, operator movement on the seat cushion, and movement of the seat to adjust its position. Each of these types of SMA can induce signals that should be removed from the waveform prior to analysis. US freight locomotive crews work up to 12 hour shifts, although their vibration exposure is typically less than 8 hrs resulting in long data collection sessions. Data is typically saved in individual data files at 1 hour increments, resulting in multiple data files per crew exposure.

Methods

The SMA events are identified using any individual or combination of the following three methods; direct observation of the event by the observer, indirect observation of the event by utilizing a camcorder, or by comparing the vibration data from the seat cushion accelerometer to that of the seat base or seat support accelerometer for each axis. Once the section of the waveform has been identified, the masking filter is applied to the section. Just simply removing a section from the measured data will in general result in an abrupt jump in the residual signal. This will cause the filtering/weighting process to 'ring' and generate false larger, or smaller, amplitudes. Adding in a 'blending' signal such as a haversine curve to join the two sections is equally false and will distort the result as it has artificially included a section with no vibration. We have a section of invalid data; leaving it in or removing it without thought will potentially corrupt the results! Now the analysis process consists of applying low pass and high pass filters and a weighting filter prior to calculating the relevant measures. Calculation of these statistical measures is only concerned with the amplitude of the signal after the filtering and weighting. We also know that the original signal is continuous throughout. The solution then is to apply any filtering and weighting, including the non linear modeling in ISO 2631-5, and then remove the invalid section and concatenate the valid data to give a shorter signal.

Once the motion artifacts have been removed from the waveform of each of the data files one overall data file is created utilizing the joining function. These sections will already have been filtered/weighted so they are may be simply concatenated together. Obviously the processing software has to recognize that they are part processed and not apply the filtering or weighting again. After the initial identification the entire process is fully automated. The original acquired time signals are of course retained for any further analysis.

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Results

The factored and weighted root-mean-square acceleration values, the vibration dose values and the crest factors for the x, y and z axis were computed according to ISO 2631-1 (1997). The S_{ed} was calculated based on vibration exposure starting at 20 years of age for 240 exposure days per year for 45 years per ISO 2631-5 (2004). A comparison of the average non-modified signal results collected during revenue runs on 20 US locomotive freight engines to those that have had the SMAs removed are displayed below.

Table 1: Average Results from 20 US Freight Locomotives

	a_w (m/s^2)			Crest factor			VDV (m/s$^{1.75}$)			S_{ed}
	x	y	z	x	y	z	x	y	z	
Original	0.16	0.22	0.23	45.0	27.2	59.8	6.52	6.84	7.82	0.56
SMA Removed	0.14	0.20	0.21	28.4	13.2	27.9	3.70	4.27	5.07	0.24
% Decrease	14.2	7.8	6.3	36.8	51.5	53.3	43.2	37.6	35.2	57.9

Conclusions

The removal of SMAs significantly effects the reported vibration values concerning health as outlined in ISO 2631-1 (1997) and ISO 2631-5 (2004). Regardless the factored and weighted root-mean-square and VDV results are below the health guidance caution zone for both the original data and with the SMAs removed. The original S_{ed} results are indicative of moderate risk and the SMA removed results are indicative of low risk for 45 years of exposure.. The current standards do not address the identification or removal of SMA data from the waveform, but the results of this analysis indicate that it would be prudent to do so.

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OPTIMISING THE STANDARD METHOD TO EVALUATE DISCOMFORT FROM WHOLE BODY VIBRATION

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Introduction

Understanding how vibration affects discomfort is important when improving work and travelling experience. In most environments vibration is not high enough to cause acute health problems, but could increase chronic injury risk, cause annoyance and degrade task performance. In standard ISO 2631-1 discomfort relates strongly to health effects as the method is partially based on subjective studies. Discomfort for seated persons is evaluated by measuring vibration from floor, seat and backrest, including both translational and rotational axes.

The full twelve axis method to evaluate discomfort has not been widely used in practice or validated in a multi-axis environment. The standard guidance is not explicit, thus different interpretations are possible, especially for selecting the axes for calculating the overall vibration total value. Furthermore there are not enough studies conducted in multi-axis environments to properly suggest the right combination of axes. The standard method emphasises the axes and locations using frequency weighting curves and set of multiplying factors. The frequency weighting curves are designed to emphasise certain frequency range and the multiplying factors emphasise the relative effect of the axes and locations. The multiplying factors greatly influence the discomfort value as axes are combined using root sum of squares, which emphasise the highest value.

Methods

A multi-axis test bench at Loughborough University was used in this study. Subjects were exposed to 30 different types of stimuli, which represented vibration characteristics from measurements of real work machines. Each stimulus, lasting 15 seconds, was judged using a continuous judgement, cross-modal matching method [1]. The seat translational and rotational and the backrest translational axes were used. There was no vibration at the floor, in order to constrain the number of independent variables.

Spearman correlation (r^2) was used to find the combination of axes, which best predicted the change in discomfort. Several assessment scenarios (comprising alternative combinations of axes and locations) based on the standard were tested. The discomfort judgement of a subject to a stimulus was averaged as one value. The judgement values of all subjects were then averaged for each stimulus. The correlation was calculated for each subject individually and then for all subjects using the averaged values.

This study also analysed the effect of frequency weighting curves, multiplying factors and additional methods (i.e. VDV) for improving the correlation. The effect of frequency weighting and multiplying factors was tested by calculating the overall vibration total values of all scenarios with and without frequency weightings or multipliers respectively. The r.m.q. method was selected instead of the VDV method to test the higher power method, as it gives the same emphasis to shocks, but is directly comparable with the r.m.s. values. Additionally the

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multiplying factors were optimised for all nine measured axes. Brute force and multiple linear regression methods were used to find optimal multiplying factors for predicting discomfort.

Results

The best standard scenario, which included all measured nine axes, gave correlation of 0.850 (r^2) for the test group. Correlation between vibration and discomfort judgement was found significant for all subjects individually and combined as an averaged value. The correlation was positive and linear for all subjects. Even though there was individual differences in correlation, all subjects indicated a same tendency for each of the stimulus type.

Correlation improved using the standard frequency weighting curves. The r.m.s. method was found better than the r.m.q. method, thus there was no indication that higher emphasis to shocks would have improved correlation for the stimuli types used.

It was found that the standard's multiplying factors for all axes degraded the correlation systematically. The optimised multiplying factors showed highest correlation when seat fore-aft was multiplied by 2.7, lateral by 1.8 and vertical by 1.0, with all other axes having zero multiplying factors (i.e. not needed). This combination gave correlation of 0.950 (r^2). The optimised multiplying factors indicated that increasing the emphasis of seat horizontal axes improves correlation. The same indication has been found in at least one separate study [2]. Both optimising methods, brute force and multiple linear regression model, showed same results for the best multiplying factors. Contour map analysis showed clustering of the multiplying factors, thus several value pairs result in same correlation value.

Conclusions

The standard method for predicting discomfort from whole-body vibration was validated using a multi-axis test bench. It was concluded that the correlation improved when also the additional axes were included. The frequency weighting curves improved correlation and r.m.s. method was better than r.m.q. method. However it was evident that the standard's multiplying factors were not optimal, thus an improved set of multiplying factors for all measured axes were calculated. The results showed that seat horizontal axes should be emphasised more.

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