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Factors affecting the perception of whole-body vibration of occupational drivers: an analysis of posture and manual materials handling and musculoskeletal disorders

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Due to the high cost of conducting field measurements, questionnaires are usually preferred for the assessment of physical workloads and musculoskeletal disorders (MSDs). This study compares the physical workloads of whole-body vibration (WBV) and awkward postures by direct field measurements and self-reported data of 45 occupational drivers. Manual materials handling (MMH) and MSDs were also investigated to analyse their effect on drivers' perception. Although the measured values for WBV exposure were very similarly distributed among the drivers, the subjects' perception differed significantly. Concerning posture, subjects seemed to estimate much better when the difference in exposure was significantly large. The percentage of measured awkward trunk and head inclination were significantly higher for WBV-overestimating subjects than non-overestimators; 77 and 80% vs. 36 and 33%. Health complaints in terms of thoracic spine, cervical spine and shoulder–arm were also significantly more reported by WBV-overestimating subjects (42, 67, 50% vs. 0, 25, 13%, respectively). Although more MMH was reported by WBV-overestimating subjects, there was no statistical significance in this study.

Practitioner Summary: Self-reported exposures of occupational drivers are affected by many other cofactors, and this can result in misinterpretations. A comparison between field measurement and questionnaire was used to highlight the factors affecting the perception of drivers for whole-body vibration (WBV) exposure. Posture and musculoskeletal disorders influenced the perception of the similarly WBV-exposed drivers significantly.

Keywords: whole-body vibration; awkward posture; field measurements; questionnaires; musculoskeletal disorders

1. Introduction

According to a survey in 2010, musculoskeletal disorders (MSDs) imposed the biggest financial burden on gross value added in Germany (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin 2010). Prevention activities are therefore focused on ergonomic factors, which have a major impact on the occurrence of MSDs. Heavy physical activity, prolonged work in constrained postures and heavy manual materials handling (MMH) can cause or accelerate MSDs (Holtermann et al. 2010). Also, WBV exposure is a well-known predictor for low back pain (LBP), which is the main factor of interest, in many epidemiological studies (Bovenzi et al. 2006; Lötters et al. 2003; Punnett et al. 2005). Several recent studies investigated these predictors. Burdorf et al. (2013), for example, assessed the impact of lifting device use on low back pain and musculoskeletal injury claims among nurses. They showed a reduction in LBP prevalence and in MSD injury. In addition, Makhsous et al. (2005) introduced an improved posture by a new car seat design, while a protruded cushion supports the lumbar spine. Hereby, a significant reduction in Whole-body vibration (WBV) exposure and musculoskeletal disorders in automobile drivers was achieved.

In order to investigate the impact of predictors for MSDs, field measurements or a self-administered questionnaire are usually used to detect possible stressors. Due to the high cost of conducting field measurements, questionnaires are in most cases preferred. A comparison of different practical applications shows that the cost per successful measurement day is lowest for interviews, about 10-fold higher for observations and inclinometers, and more than 20-fold higher for electromyography and vibration monitoring (Trask et al. 2007). However, field performance is an essential method for obtaining detailed information on exposure.

While using questionnaires, several drawbacks must be taken into account. The reproducibility of self-reported exposure may depend on the time period for which subjects are asked to report retrospectively. For instance, recalled ergonomic exposures in retrospective cohort studies could serve as a relatively reliable and unbiased estimate of self-reported exposures obtained up to one year earlier, but not over a longer period (d'Errico et al. 2007). Furthermore,

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questions about working postures and the duration of awkward posture as proportions of a typical day or frequencies in times per hour seem to show very poor reproducibility (Wiktorin et al. 1996). Additionally, some factors such as musculoskeletal complaints and age seem to affect self-assessed occupational physical activities (Balogh et al. 2004). Subjects with complaints rated their exposure higher than those without, although the directly measured exposure was lower.

Only few studies compared questionnaires and direct field measurements. Physical work demands while measuring the WBV magnitude were assessed with an observational method as well as with a self-administered questionnaire (Tiemessen et al. 2008). While activities such as trunk bending, walking and standing were underestimated by drivers, the task of lifting was overestimated. In another study, both measurements and questionnaires were used to analyse work-related kneeling and squatting tasks (Ditchen et al. 2013). The correlations between measurements and self-reported data were poor-to-moderate for all examined postures. High-exposed subjects seemed to misjudge their exposure to a greater extent than low-exposed ones. However, the occurrence of knee complaints did not show any impact on the assessment behaviour.

Due to the complexity of the measurement technique, to our knowledge there is no study available comparing awkward posture by direct field measurements and self-reported data among WBV-exposed subjects. Also, the impact of awkward posture as objective data on the MSDs is still unknown.

Hence, in this study, WBV and awkward posture exposures were assessed in an exposed population (a) with representative direct measurements and (b) with the use of self-administered questionnaires. Furthermore, the occurrence of musculoskeletal complaints among drivers was investigated for exposure to WBV, awkward posture and MMH. The aims of this study were to present the differences between the subjective and objective data and also to analyse factors affecting the perception of the subjects for the same WBV exposure.

2. Subjects and methods

2.1 Study population

To compare the difference in the posture, occupations with similar vibrational exposure but great postural load discrepancies were needed. Therefore, following occupational drivers were chosen for this project.

Forty-five occupational drivers (male, mean age ± standard deviation (SD) = 42 ± 8 yr; mean height ± SD = 177 ± 7 cm; mean weight ± SD = 88 ± 13 kg) from four machinery groups (buses, locomotives, cranes and gantry cranes) volunteered to participate in this project. They were supposed to have at least 1 year of employment in the company and at least 10 years of WBV exposure experience with prolonged sitting tasks. In addition, they should not have had any musculoskeletal disease before beginning their occupational training.

All subjects were examined by two medical doctors during or outside their working shift. A self-administered questionnaire was sent to each driver one week before the medical examination. Doctors collected and checked the answered questionnaires on the day of examination. In cases of uncertainty and incompleteness, doctors sought clarification and helped drivers to fill in the questionnaire if possible.

A representative sample of drivers and operators (of four busses, two locomotives, nine cranes and six gantry cranes) from the study population was visited at the workplace for the measurement of WBV and postural exposure during routine work. Taking account of the type of vehicle and the operated tasks, measured values were adopted for the rest of subjects.

For further analysis, drivers were divided into two groups on the basis of the tasks performed: the first group (C = comfortable operating) containing bus and locomotive drivers, who move passengers or wagons by driving mostly forwards while using the backrest (11 subjects, mean age ± SD = 46 ± 7 yr; mean height ± SD = 176 ± 6 cm; mean weight ± SD = 94 ± 15 kg), and the second group (U = uncomfortable operating) containing crane and gantry crane operators, who move containers by driving forwards and backwards sitting bent forward in an elevated cabin (34 subjects, mean age ± SD = 41 ± 8 yr; mean height ± SD = 178 ± 7 cm; mean weight ± SD = 86 ± 12 kg).

All drivers were in good health and were not suffering from noteworthy physical complaints at the time of the study. All drivers and employers gave informed consent prior to participating in this study. The Ethical Committee of the Medical Faculty, RWTH Aachen University approved of the study and study design. A positive ethics committee vote was received.

2.2 Exposure assessment

2.2.1 Measurement of WBV

In accordance with DIN EN 14253: 2007 and ISO 2631-1: 1997, WBV measurements were conducted on three orthogonal axes (x: back-to chest, y: right-to-left and z: vertical direction) on the seat surface and at the seat mounting point (detected at 480 Hz). The acceleration measured at the seat mounting point was used to detect artefacts and is not discussed in the present study.

From one-third octave band frequency spectra (1 – 80 Hz) of the signal recorded in the x-axis, y-axis and z-axis, frequency-weighted RMS accelerations (a_x, a_y and a_z) were obtained by using the weighting factors of ISO 2631-1. This resulted in the frequency weighted RMS-acceleration in the three axes, a_{wx}, a_{wy} and a_{wz}. Vibration signals (detected at 480 Hz) were averaged by using the root-mean-square (RMS) method.

The vector sum of the frequency-weighted acceleration values $a_{v1.4}$ (vibration total value) is calculated with:

$$a_{v1.4} = \sqrt{1.4^2\, a_{wx}^2 + 1.4^2\, a_{wy}^2 + a_{wz}^2}. \tag{1}$$

Considering European Directive 2002/44/EC and an epidemiological study (Notbohm et al. 2009), three categories were defined for the comparison of the subjective data and the measured magnitudes of WBV:

Low vibration: $a_{v1.4} < 0.5\,\text{m/s}^2$
Noticeable vibration: $0.5\,\text{m/s}^2 \leq a_{v1.4} < 1\,\text{m/s}^2$
Critical vibration: $a_{v1.4} \geq 1\,\text{m/s}^2$.

2.2.2 *Measurement of posture*

The body posture of the drivers was detected by using the CUELA system (Raffler, Hermanns, Sayn, et al. 2010; Hermanns et al. 2008). Making use of inertial/kinematic sensor technology, the CUELA system records the detected posture continuously as an angular measurement. It can be attached to the subjects' clothing, without hindering the subjects during their work. Table 1 shows the sensor arrangement, the regions of the body, the locations of sensor attachment and the respective degrees of freedom (DOF). In addition to the measurements, video recording was used for investigating the tasks and activities of the drivers during a shift and also for monitoring the alignment of the sensors.

Further details of artefacts and filters are given elsewhere (Raffler, Hermanns, Sayn, et al. 2010; Hermanns et al. 2008). Other artefacts such as interferences of sensors with the backrest or subject's clothes were detected by video recording and were verified by subsequent observation during assessment.

In this study, two categories were defined with reference to the standards ISO 11226: 2000 and DIN EN 1005-4: 2005 for classification of the body angles of interest as neutral and non-neutral.

The main difference in the sitting posture of these two groups is highlighted by the upper body. Thus, 5 DOF are the most important factors showing the discrepancy of the postural behaviour between the two groups. Table 2 shows the description of the categories for all 5 DOF, whereas neutral is the green marked area and non-neutral the yellow and red marked area.

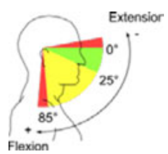
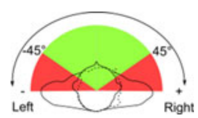
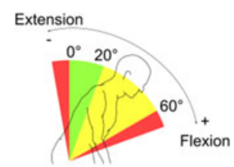
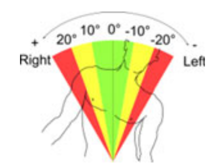
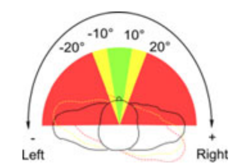
The percentage of working time spent in each category can thus be shown for each DOF. Three categories were defined as follows for comparison with the subjective data:

Low: percentage of non-neutral posture < 33%
Noticeable: 33% ≤ percentage of non-neutral posture < 66%
Critical: percentage of non-neutral posture ≥ 66%.

Table 1. CUELA posture measuring equipment with body regions for sensor attachment and degrees of freedom.

Body region	Degree of freedom
Head	Head inclination (sagittal)
	Neck torsion
Thoracic spine	Trunk inclination (lateral/sagittal)
Lumbar spine	Back torsion

Table 2. Description of the neutral and non-neutral categories for five degrees of freedom (upper body).

	Body region				
Category	Head inclination (sagittal)	Neck torsion (lateral)	Trunk inclination (sagittal)	Trunk inclination (lateral)	Back torsion (lateral)
					
Neutral	0°–25°, <0° full head support	−45°–45°	0°–20°, <0° full back support	0°–10°	−10°–10°
Non-neutral	< 0° or > 25°	< −45° or >45°	< 0° or > 20°	< −10 or > 10°	< −10 or > 10°

2.3 Subjective information about physical workloads

MMH was surveyed with dichotomous questioning (yes/no). Questions about awkward posture referred to the cervical, thoracic and lumbar regions of the spine. Questions regarding the cervical spine asked about sagittal head inclination and neck torsion, whereas questions regarding the thoracic and lumbar spine asked about trunk inclination (sagittal/lateral) and back torsion. Each body segment and body angle was illustrated in a figure, highlighting the neutral and non-neutral range of motion. Subjects were supposed to report their awkward posture (if any) in three categories: low, noticeable and critical. Moreover, WBV exposure was also surveyed on the same principle with the same three categories (low, noticeable and critical).

2.4 Medical history and functional limitations

Personal medical history was surveyed in the self-administered questionnaire with respect to health complaints by using a modified version of the Nordic Questionnaire on musculoskeletal symptoms (Kuorinka et al. 1987). The drivers were asked about the occurrence of pain in the neck, shoulder, upper and lower back region in the last 12 months or ever in their occupational lives.

Drivers who reported musculoskeletal symptoms were requested to answer additional items concerning duration, frequency, pain radiation, pain intensity and functional disability (participant hampered in daily activities), symptom-related health care use, treatment (e.g. medication or physical therapy) and sick leave due to symptoms in the previous 12 months. According to the pain scale proposed by Von Korff et al. (Korff, Jensen, and Karoly 2000), pain intensity was rated on an 11-point scale, where 0 is ‘no pain at all’ and 10 is ‘pain as bad as it could be’.

2.5 Physical examinations

In addition to the subjective MSD complaints assessed in the questionnaire, a physical examination was used to objectify complaints. This physical examination was based on the focus method (Spallek and Kuhn 2009), which is a concentrated but comprehensive instrument for the assessment of the musculoskeletal system for occupational physicians. It consists of a mixture of tests (range of motion tests, stability tests, provocation test) to give an overview of the functionality of the musculoskeletal system and focuses on the spine, the shoulder–arm region, the hand–arm region, and the knee and ankle region. In our case, it was used to evaluate functional limitations especially of the spine of the drivers in this study.

The focus method is originally a stepwise examination. The first step of the examination is the ‘screening module’ (or ‘screening’) which includes active range of motion tests (i. e. the patient shows a certain motion to the examiner), as well as ‘active’ provocation tests (going down in a squat and getting up again) and stability tests (one leg standing test), the main point of the screening being that all screening examinations are active examinations, where the examiner just evaluates visually the performance of the participant. The second module of the method (‘function module’ (or ‘function’)) mostly refers to passive (i.e. the examiner manipulates the patient) range of motion tests, but also includes provocation tests (e.g. Lasegue and Bragard test for radiculopathy/sciatica). Generally in practice, the test would be used step-wise, and in our study, both steps (screening and function module) were carried out simultaneously for all participants. For the following definition of medical outcomes, we assumed that the information value of the function module is higher than that of the screening module.

2.6 Definition of medical outcomes

On the basis of the questionnaire and the physical examinations, MSD outcomes were defined as follows:

(1) Nordic Questionnaire 12 month-positive (NQ-12 month): pain or discomfort in spinal areas (lumbar, thoracic, neck and/or shoulder–arm) in the previous 12 months
(2) Screening-positive MSD: any positive finding in terms of active functional limitations in the spinal area (lumbar, neck and shoulder–arm)
(3) Function-positive MSD: any positive finding in terms of passive functional limitations in the spinal areas (lumbar, thoracic, neck and shoulder–arm)
(4) High pain intensity LBP: LBP in the previous 12 months associated with a pain score ≥ 5 (Von Korff scale)
(5) Sick leave: sick leave because of MSD in the previous 12 months.

2.7 Data analysis and statistics

The WBV measurement data were exported to the CUELA software for body posture followed by synchronisation with body angles and video data (Hermanns et al. 2008). By means of this, simultaneous access to the vibration, posture and video data, artefacts such as shocks while sitting and standing up or no contact with the seat or any disturbances between the angle sensors and environment were disregarded.

The statistical analysis of the data was performed with IBM SPSS Statistics software (version 20 for windows).

Mean values were calculated for continuous variables as a measure of the central tendency and the SD as a measure of dispersion.

The difference between the mean values was tested with the *t*-test (for normally distributed data) and with the Mann–Whitney test for not normally distributed data, while the difference between categorical data cross-tabulated into contingency tables was chi-squared-tested.

Differences in exposure data between subjective and measured values were analysed with the Cohen's kappa coefficient. According to Landis and Koch (1977), Kappa values $K < 0$, 0–0.20, 0.21–0.40, 0.41–0.60, 0.61–0.80 and 0.81–1 were, respectively, interpreted as poor, slight, fair, moderate, substantial and almost perfect agreement.

Probability values below 0.05, 0.01 and 0.001 were, respectively, considered significant, highly significant and very highly significant in this study.

3. Results

3.1 Physical workload

3.1.1 WBV

The frequency-weighted RMS accelerations (the mean and standard deviation values) measured at the driver–seat interfaces on the machines and vehicles used by the professional drivers are presented in Table 3.

The duration of the measurements ranged from 71 min for crane operators to 109.8 min for buses and assured that the measurement was representative for the whole shift. While the *z*-axis (vertical) weighted acceleration was the dominant directional component of vibration measured in most of the machines, gantry cranes showed maxima on the *x*-axis (fore and aft). The total vibration value $a_{v1.4}$ of the weighted RMS accelerations averaged from 0.25 to 0.37 m/s^2 in locomotives and gantry cranes, respectively. A comparison of the two groups C and U in terms of the three categories (low, noticeable and critical defined for $a_{v1.4}$) does not reveal any significant difference for any vibration magnitude, thus indicating a homogenous distribution of vibration exposure among the two groups.

3.1.2 Posture

The frequency distribution of adopted body postures among machine groups is presented in Figure 1.

The different non-neutral postural behaviours between the vehicle groups were observed mostly in sagittal head and trunk inclination.

Table 3. Vibration exposure for the three orthogonal axes on the seat surface and for the total vibration value as means {standard deviation} and distribution of the measured total vibration value in three categories as the number of subjects and their percentage in the machine group (%).

			Vibration value for the measured time (m/s^2)			
Vehicle	Number	Duration of measurement (min)	a_{wx}	a_{wy}	a_{wz}	$a_{wv1.4}$
Bus	7	109.8 {7}	0.11 {0.01}	0.13 {0}	0.2 {0.01}	0.32 {0.01}
Locomotive	4	82.5 {16.9}	0.06 {0}	0.13 {0}	0.15 {0.02}	0.25 {0.02}
Crane	9	71 {13.6}	0.11 {0.04}	0.12 {0.05}	0.18 {0.12}	0.3 {0.14}
Gantry crane	25	98.7 {18.3}	0.2 {0.02}	0.1 {0.03}	0.17 {0.03}	0.37 {0.04}
Machine group		Low	Noticeable	High	*p*-value	
C	11	11 (100)	0 (0)	0 (0)	0.57	
U	34	33 (97.1)	1 (2.9)	0 (0)		

Note: *p*-values are given as results of the chi-squared test.

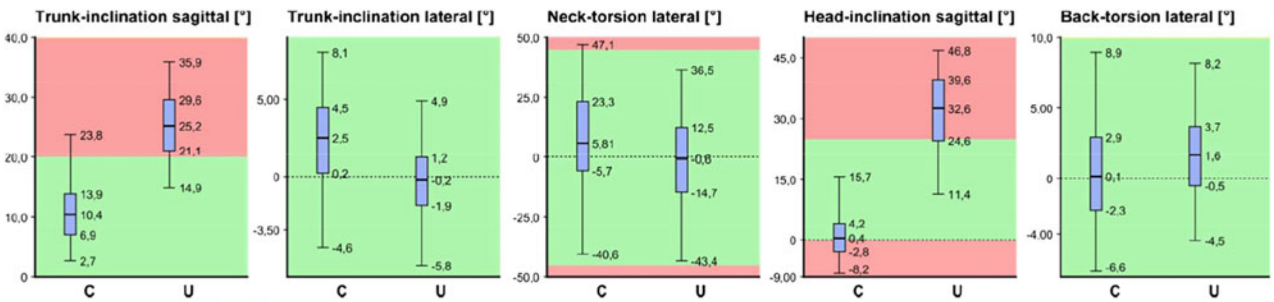


Figure 1. Distribution of the measured adopted postures among the two machine groups. Data are given as box plots indicating the 5th, 25th, 50th, 75th and 95th percentiles of body angles. Neutral ranges of angles are highlighted in green, non-neutral ranges of angles as red.

Table 4 shows the distribution of five DOF for each machine group regarding the three categories (Section 2.2.3). In terms of sagittal trunk and head inclination, much more non-neutral posture in the critical category was measured for group U than for group C (91.2% versus 0% and 76.5% versus 9.1% respectively, $p < 0.001$).

3.1.3 MMH

The MMH also reported by subjects as dichotomous variables is shown in Figure 2. The operators in group U reported more lifting/carrying (29.4%) and pulling/pushing tasks (14.7%) than the drivers in group C (9%), although a significant difference was not observed ($p > 0.05$).

3.2 MSD and medical findings

Figure 3 reports the prevalence of outcomes during last 12 months as well as positive findings from medical examinations among the drivers for each group.

Concerning the obtained data regarding complaints during the last 12 months in the questionnaire, the drivers in group U reported much more MSDs than in group C. Significant differences between the groups were seen for sick leave ($p < 0.01$) as well as for high pain intensity ($p < 0.05$).

As for functional limitations, more positive findings were found for the drivers in group U, except for complaints in the cervical spine area, where more functional limitations (active and passive) were found than in group C. However, a significant difference was only seen in the passive test (9.1% for group C versus 41.2% in group U, $p < 0.05$) in the shoulder–arm area.

3.3 Comparison between objective and subjective data

Table 5 presents the data of measured and subjective reports on WBV and posture exposure in three categories: low, noticeable and critical.

Table 4. Distribution of measured posture in the three categories: low, noticeable and critical.

		Categories for measured posture (percentage of number of subjects)			
DOF	Machine group	Low	Noticeable	Critical	*p*-value
Trunk inclination sagittal	C	11 (100)	0 (0)	0 (0)	<0.001
	U	1 (2.9)	2 (5.9)	31 (91.2)	
Trunk inclination lateral	C	11 (100)	0 (0)	0 (0)	0.57
	U	33 (97.1)	1 (2.9)	0 (0)	
Back torsion lateral	C	11 (100)	0 (0)	0 (0)	0.49
	U	30 (88.2)	3 (8.8)	1 (2.9)	
Head inclination sagittal	C	6 (54.5)	4 (36.4)	1 (9.1)	<0.001
	U	1 (2.9)	7 (20.6)	26 (76.5)	
Neck torsion lateral	C	11 (100)	0 (0)	0 (0)	0.57
	U	33 (97.1)	1 (2.9)	0 (0)	

Note: Data are given as the number of subjects and their percentage in the machine group *p*-values are given as the result of the chi-squared test.

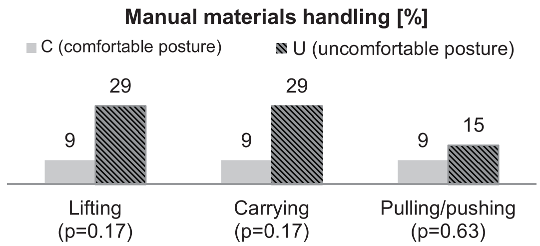


Figure 2. Self-reported data on occurrence of manual materials handling. Data are given as percentage of subjects in the machine group. p-Values are given as the result of the chi-squared test.

Almost all measured values for WBV ($a_{v1.4}$) indicate exposure below 0.5 m/s^2 (100% in group C, 97.1% in group U). By contrast, the subjective data on WBV exposure differ between the groups. While the drivers in group C only reported low and noticeable vibration exposure, 78.1% of the drivers in group U reported critical vibration exposure. In the comparison of measurement and questionnaire data, much higher level of agreement was observed for drivers in group C than in group U (45.5% and 6.3% respectively). The highest overestimation was observed for group U with 93.8%. Concerning posture, more agreements were observed for drivers in group C. While overall underestimation was observed for sagittal DOF, lateral DOF were overestimated by all drivers. Cohen's kappa values indicate poor agreements between subjective and objective data for WBV as well as awkward posture exposure. Only reported sagittal head inclination showed slight agreement with the measured data ($K = 0.27$).

In addition, the difference between self-reported data and measured exposure data regardless of the machine group was also investigated with the aid of Cohen's kappa coefficient (Table 6). For WBV exposure, there is no correlation between the measured data and questionnaire. For postural exposure data, there was slight agreement for trunk and head inclination in the sagittal direction, while there was no other agreement for lateral body angles.

3.4 *Factors affecting the perception of WBV exposure at the workplace*

Figure 4 compares the prevalence of medical outcomes, anthropometrics and physical workloads for subjects who overestimate WBV exposure (overestimators) with the outcomes and workloads of other subjects (non-overestimators).

Concerning the self-reported data on MSDs, subjects who overestimated WBV exposure claimed to have significantly more complaints than the other subjects in terms of thoracic spine, cervical spine, shoulder–arm and also sick leave ($p < 0.05$). Conversely, in terms of functional limitations of the cervical spine, other subjects

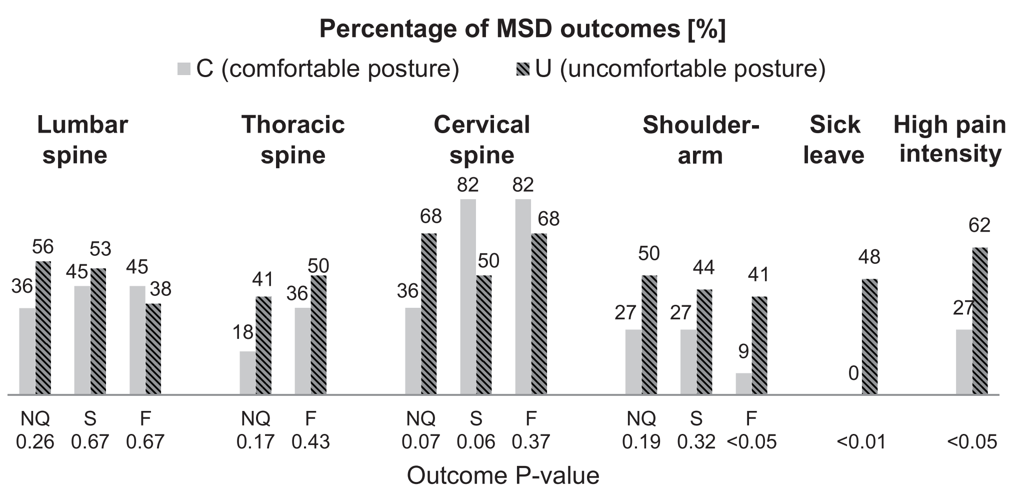


Figure 3. Medical outcomes for different body parts. Data are given as percentages of subjects (%) in each group. p-Values are given as the result of the chi-squared test. For the thoracic spine, there is no defined screening method. NQ: Nordic Questionnaire 12-month, S: Screening-positive, F: Function-positive.

Table 5. The data as a percentage for the day (measurement vs. self-reported by subjects) for whole-body vibration exposure and posture in three categories: low, noticeable and critical.

	Measurement vs. questionnaire (%)				Subjective data compared to objective data (%)			
WBV:	Machine group	Low	Noticeable	Critical	Underestimation	Overestimation	Agreement	Kappa value
	C	100 vs. 45.4	0 vs. 54.5	0 vs. 0	0.0	54.5	45.5	0.00
	U	97.1 vs. 3.1	2.9 vs. 18.7	0 vs.78.2	0.0	93.8	6.3	0.03
Posture:		Low	Noticeable	Critical	Underestimation	Overestimation	Agreement	Kappa value
Trunk inclination sagittal	C	100 vs. 90.9	0 vs. 9	0 vs. 0	0.0	9.1	90.9	0.00
	U	0 vs. 20	5.8 vs. 34.2	94.1 vs. 45.7	55.9	5.9	38.2	−0.04
Trunk inclination lateral	C	100 vs. 90.9	0 vs. 0	0 vs. 9	0.0	9.1	90.9	0.00
	U	100 vs. 74.1	0 vs. 16.1	0 vs. 9.6	0.0	23.5	76.5	−0.04
Back torsion lateral	C	100 vs. 54.5	0 vs. 27.2	0 vs. 18.1	0.0	45.5	54.5	0.00
	U	88.2 vs. 58.8	8.8 vs. 35.2	2.9 vs. 5.8	8.8	32.4	58.8	−0.03
Head inclination sagittal	C	54.5 vs. 90.9	18.1 vs. 0	27.2 vs. 9	36.4	0.0	63.6	0.27
	U	2.9 vs. 25.7	20.5 vs. 28.5	76.4 vs. 45.7	50.0	5.9	44.1	0.09
Neck torsion lateral	C	100 vs. 72.7	0 vs. 18.1	0 vs. 9	0.0	27.3	72.7	0.00
	U	94.1 vs. 54.2	5.8 vs. 22.8	0 vs. 22.8	2.9	41.2	55.9	−0.05

Note: On the right: Cohen's kappa coefficient for comparison of subjective and objective data.

Table 6. Cohen's kappa coefficient for comparison of subjective and objective data.

	Agreement test between self-reported data and measured data					
Exposure	Vibration exposure	Trunk-inclination sagittal	Trunk-inclination lateral	Back-torsion lateral	Head-inclination sagittal	Neck-torsion lateral
Kappa value	0.024	0.266	−0.032	−0.028	0.245	−0.034

showed significantly more positive findings than subjects who overestimated WBV exposure (100% versus 47.2%, $p < 0.05$).

Concerning anthropometric data of the subjects, age and height were significantly different between these two groups ($p < 0.05$). WBV-overestimators were significantly younger and taller. In addition, regarding posture, more non-neutral posture for sagittal trunk and head inclination ($p < 0.01$) was observed for WBV-overestimators. Although higher MMH was reported by the WBV-overestimators, the difference between these two groups was not significant.

4. Discussion

The distribution of measured WBV exposure was very similar among the drivers. None of the exposures exceeded the action value of 0.5 m/s^2 for an 8-h shift as defined in European Directive 2002/44/EC. In addition, the measured data for

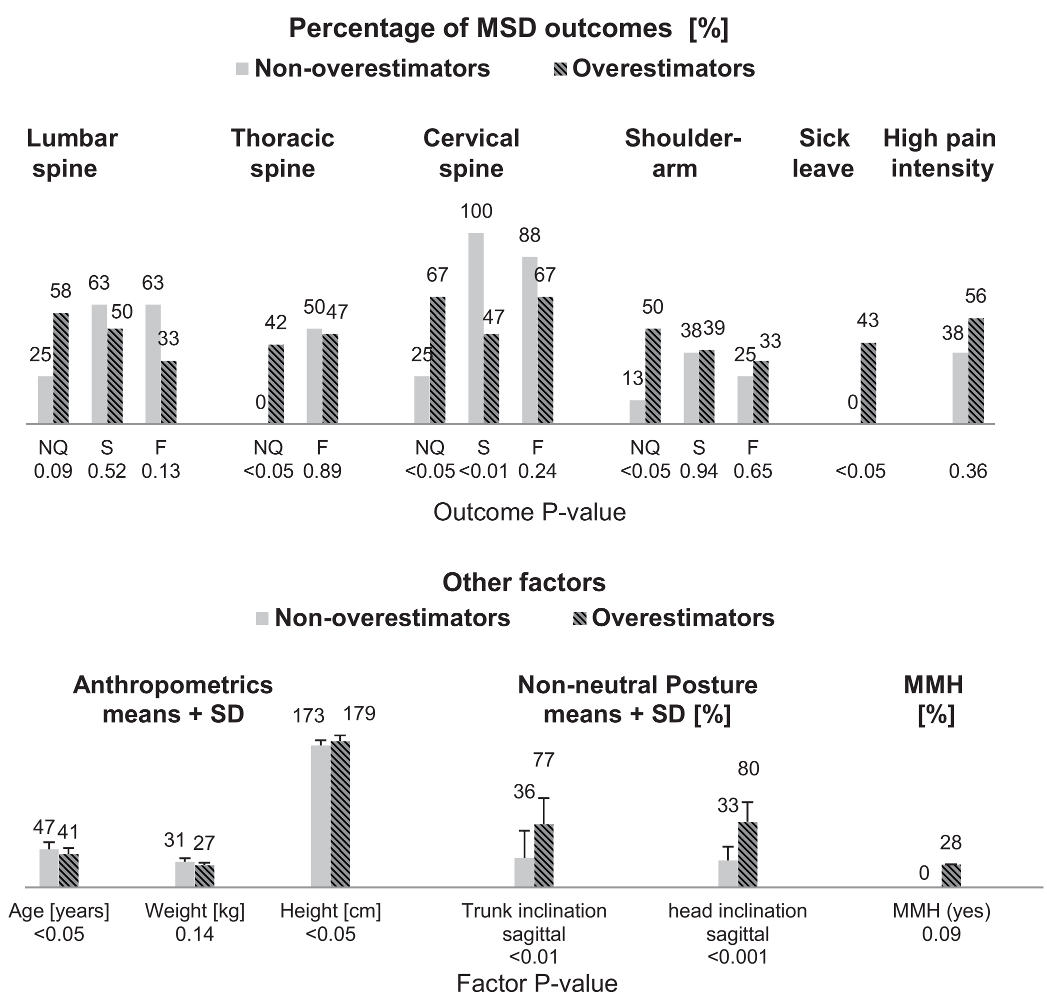


Figure 4. Distribution of outcomes and some anthropometric and posture values affecting the perception of WBV exposure. Data are given as percentages of subjects in each group. Posture data are given as mean values {standard deviation}. NQ: Nordic Questionnaire 12-month, S: Screening-positive, F: Function-positive.

vibration exposure for the vehicles are similar to those published in other reports (Bovenzi 2010; Bovenzi, Pinto, and Stacchini 2002).

Unlike WBV exposure, the measured postural workload in terms of sagittal body angles differed significantly among the machine groups. Due to the working tasks, crane and gantry crane operators are mostly forced to look downward at the containers through the cabin floor, which causes awkward posture in the sagittal direction. Bus and locomotive drivers, on the other hand, drive mostly upright, using the backrest and looking ahead at the road, which also makes the small amount of awkward sagittal head inclination negligible. These findings are comparable with those published in other reports (Raffler, Hermanns, Göres, et al. 2010).

Regarding the health complaints among the drivers of the two machine groups, significantly higher numbers of subjects in group U were affected in terms of 'sick leave because of MSD' and 'high pain intensity'. In the medical investigation, functional limitations in the shoulder arm region in group U (41.2%) were significantly higher than in group C (9.1%). In terms of NQ 12-month, a higher number of subjects showed MSDs in group U than in group C, although the difference was not statistically significant.

Concerning the subjective data on WBV exposure, there was much higher overestimation in group U than in group C (93.8% compared to 54.5%). While drivers in group C with low postural workload overestimated the WBV exposure to a moderate extent (noticeable rather than low), the operators in group U with high postural workload overestimated the WBV exposure to a much greater extent (critical rather than low). The measured vibration value only represents the exposure at the seat surface, which is weighted by the frequency of the exposure and not by the adopted posture. The subjective perception, however, considers the vibration exposure to the whole body regions. In particular, if the head is leaning forward (group U), the head vibration is expected to be larger than when the head is in a neutral position, even if the seat vibration is equal (Newell et al. 2006; Wang et al. 2006). Thus, the difference between the subjective and objective data could also be due to the adoption of wrong metrics.

In terms of the subjective and measured data on the adopted posture during work, there is more agreement in group C, in which measured postural workload was low. In group U, the self-reported data differed significantly from the measured values. While measured body angles in the sagittal direction showed high postural load in group U, over 50% of the subjects underestimated these body angles. Similar results were reported by Tiemessen, Hulshof, and Frings-Dresen (2008), whereas subjects underestimated the time spent 'bending' and 'walking + standing'.

As for the self-reported data with the measured values for both WBV and posture exposure, and regardless of the machine group, there is no agreement for WBV exposure, while slight agreement was observed for body angles in sagittal direction (Table 6). This leads to the conclusion that subjects are better able to estimate postural load when the difference in workload is significantly greater (here in the sagittal direction) than for body angles with a lower difference (here in the lateral direction). This finding for seated posture completely contradicts the results for kneeling tasks analysed by Ditchen et al. (2013). This could be due to the difference of the tasks, and thus subjects are better able to estimate the awkward posture while sitting than kneeling.

Finally, a comparison of subjects overestimating WBV exposure with the rest of the subjects reveals a number of factors affecting subjects' perception. According to self-reported MSDs, significantly more reported complaints were given by WBV-overestimating subjects for the thoracic and cervical spine and for shoulder–arm and sick leave. Regarding anthropometric data of the subjects, age and height showed an effect on the perception of WBV exposure. Thus, overestimators were significantly younger and taller.

Also, very highly significant differences were observed in non-neutral postural behaviour, whereas overestimators adopted a much more non-neutral posture (Figure 4). Regarding MMH, overestimators reported a higher workload; however, the difference in this study was not significant. These findings are comparable to the results of the study by Holtermann et al. (2010). Subjects' perception of WBV exposure proved to be affected by many concomitant factors such as MSDs and posture investigated in this study. This highlights the importance of the field measurement of physical exposure during routine work and also the need for information on individuals' state of health and of the musculoskeletal system.

5. Conclusion

This study shows the importance of direct field measurements of WBV exposure and postural workloads. Although the measured exposures of WBV according to current standards were very similar, the perceptions of subjects were significantly different. Anthropometrics (age and height), awkward posture in sagittal direction and also experienced MSDs showed to affect the perception of drivers about WBV exposure significantly. Therefore, more field measurement and also medical examinations are needed if we are to understand the effect of physical workloads such as WBV, awkward posture and MMH, especially in terms of MSDs.

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