Aus dem Institut für Arbeitsmedizin und Sozialmedizin  
(Direktor Univ.-Prof. Dr. med. Thomas Kraus)

Kombinationsexpositionen von Ganzkörper-Vibrationen und Körperhaltungen

Von der Medizinischen Fakultät  
der Rheinisch-Westfälischen Technischen Hochschule Aachen  
zur Erlangung des akademischen Grades einer Doktorin der Theoretischen Medizin genehmigte  
Dissertation

vorgelegt von

Diplom-Ingenieurin (FH)

Nastaran Raffler, geb. Shams Azad

aus Teheran (Iran)

Berichter: Frau Professorin Dr. med. Elke Ochsmann  
Frau Universitätsprofessorin Dr. rer.nat. Catherine Dißelhorst-Klug

Tag der mündlichen Prüfung: 30.03.2017

Diese Dissertation ist auf den Internetseiten der Universitätsbibliothek online verfügbar.
Die Aufsätze sind in folgenden Zeitschriften veröffentlicht:

- Industrial Health, National Institute of Occupational Safety & Health (Japan), 2010
- Ergonomics, Taylor and Francis (UK), 2015
Assessing Combined Exposures of Whole-body Vibration and Awkward Posture—Further Results from Application of a Simultaneous Field Measurement Methodology

Nastaran RAFFLER1*, Ingo HERMANNS1, Detlef SAYN3, Benno GÖRES1, Rolf ELLEGAST1 and Jörg RISSLER1

1IFA - Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung, Alte Heerstraße 111, 53757 Sankt Augustin, Germany

Received June 4, 2009 and accepted June 21, 2010

Abstract: The drivers of ten vehicles (tram, helicopter, saloon car, van, forklift, two mobile excavators, wheel loader, tractor, elevating platform truck) were studied with regard to the combined exposures of whole-body vibration and awkward posture during occupational tasks. Seven degrees of freedom (DOFs), or body angles, were recorded as a function of time by means of the CUELA measuring system (Computer-assisted registration and long-term analysis of musculoskeletal workloads) for the purpose of posture assessment. The vibrational exposure is expressed as the vector sum of the frequency-weighted accelerations in the three Cartesian coordinates; these were recorded simultaneously with the posture measurement. Based upon the percentage of working time spent under different workloads, a scheme is proposed for classification of the two exposures into three categories. In addition, a risk of adverse health effects classified as low, possible or high can be assigned to the combination of the two exposures. With regard to posture, the most severe exposure was measured for the drivers of the wheel loader and for the tractor driver, whereas the lowest exposure was measured for the helicopter pilots and van drivers. With regard to the combination of whole-body and posture exposures, the tractor driver and the elevating platform truck driver exhibited the highest workloads.

Key words: Combined exposures, Whole-body vibration, Awkward posture

Introduction

Awkward posture during whole-body vibration (WBV) exposure is one of the most important risk cofactors leading to musculoskeletal disease or permanent injury1, 2. For investigation of these two exposures, several measuring techniques and evaluation methods have been introduced for both laboratory and field measurements. Laboratory studies3 show that a greater workload and a severe decrease in performance is experienced when subjects are seated in a twisted posture with no armrest support.

In field measurements, Tiemessen et al.4 used a hand-held wireless system (Palm Trac) to observe and analyze the posture of ten drivers; the drivers’ exposure to WBV was measured simultaneously. They also compared the results from this measurement procedure to those from self-administered questionnaires for estimation of the exposures, and concluded that although the Palm Trac system was time-consuming, it was a suitable method for the obtaining of specific information on the posture and the activities being performed.

In another study, driving postures and associated postural loading upon operators of load-haul-dumping vehicles were investigated by 3D match analysis of videotaped driving5. The exposure to WBV was not evaluated simultaneously with the posture. However, a total injury risk score was proposed which produces a quantification of the combined exposures to WBV and posture.

In a previous paper, the CUELA measuring technique was introduced for measurement and analysis of combined exposure to WBV and awkward posture6, 7.

This study presents further applications of the methodology, yielding a comparative assessment of ten different driving tasks. For creation of an assessment tool by which the combined workloads may be compared, the results were presented in two different ways.

The aims of this study are (1) to compare the combined workloads of WBV and awkward exposure by means of the CUELA measuring technique for ten different vehicle drivers, and (2) to discuss the complications of measurement and evaluation of the posture exposure for seated subjects.

*To whom correspondence should be addressed.
E-mail: nastaran.raffler@dguv.de
Subjects and Methods

Subjects
The WBV and posture exposures of ten occupational drivers (male, mean age ± SD = 43 ± 6 yr; mean height ± SD = 181 ± 8 cm; mean weight ± SD = 82 ± 17 kg) were studied during their routine occupational tasks (Table 1). The subjects were required to have at least 5 yr experience of work on the vehicle concerned. All subjects were in good health and were not suffering from noteworthy physical complaints at the time of the study. The durations of measurement depended upon the tasks and operational conditions and represent a whole day shift.

Videotaping was used in addition for analysis of the tasks and activities being performed and for monitoring of sensor alignment.

Whole-body vibration
The WBV measurements were conducted in three orthogonal axes (x fore and aft, y lateral and z vertical) on the seat surface and at the seat mounting point (Fig. 1) in accordance with DIN EN 14253 and ISO 2631. The acceleration measured at the seat mounting point was used to detect artifacts and is not discussed in the present study.

Where \( \omega(x, y, z) \) represent the frequency-weighted acceleration values for each axis x, y, z at the seat surface\(^9\). The quantity \( a_{v1.4}(t) \) was selected for the vibrational exposure because it includes all three axes in a single quantity and can thus be combined with the instantaneous posture. Furthermore, \( a_{v1.4}(t) \) has also been shown in an epidemiological study\(^10\) to be suitable for quantification of vibrational exposure that may lead to low back pain. In order to assess the vibrational exposure, three categories for \( a_{v1.4}(t) \) are suggested as follows: Low \( (a_{v1.4}(t) < 0.5 \, m/s^2) \), middle \( (0.5 \, m/s^2 \leq a_{v1.4}(t) \leq 1.0 \, m/s^2) \) and high \( (a_{v1.4}(t) > 1.0 \, m/s^2) \).

Body posture
The posture of the seated drivers was detected by the CUELA system\(^6\). This system, which employs inertial/kinematic sensor technology, is attached to the subjects' clothing, and records the detected posture continuously as an angular measurement, whilst not hindering the subjects during their

![Fig. 1. Whole-body vibration measuring equipment consisting of accelerometers for seat surface and seat mounting point.](image)

<table>
<thead>
<tr>
<th>S/No</th>
<th>Vehicle data</th>
<th>Task/activity</th>
<th>Duration of measurement</th>
<th>Subject/driver data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type</td>
<td></td>
<td></td>
<td>Age (yr)</td>
</tr>
<tr>
<td>1</td>
<td>Train</td>
<td>Driving forwards, stopping, waiting while stopped</td>
<td>01:50:35</td>
<td>32</td>
</tr>
<tr>
<td>2</td>
<td>Helicopter</td>
<td>Flight manoeuvres idle, dive, auto rotation, climb, horizontal, cruise flights</td>
<td>00:54:34</td>
<td>49</td>
</tr>
<tr>
<td>3</td>
<td>Saloon car</td>
<td>Driving forwards on the highway, driving forwards in town, stopping</td>
<td>01:09:49</td>
<td>45</td>
</tr>
<tr>
<td>4</td>
<td>Van</td>
<td>Driving forwards on the highway, driving forwards in town, stopping</td>
<td>00:50:25</td>
<td>35</td>
</tr>
<tr>
<td>5</td>
<td>Forklift truck</td>
<td>Driving unladen, driving laden, engaging the fork</td>
<td>00:39:30</td>
<td>35</td>
</tr>
<tr>
<td>6</td>
<td>Mobile excavator 1</td>
<td>Excavating, driving unladen, driving laden</td>
<td>01:10:27</td>
<td>46</td>
</tr>
<tr>
<td>7</td>
<td>Mobile excavator 2</td>
<td>Sorting wood, emptying the boxes, loading conveyor</td>
<td>01:41:22</td>
<td>46</td>
</tr>
<tr>
<td>8</td>
<td>Wheel loader</td>
<td>Driving unladen, driving laden, loading, unloading</td>
<td>01:47:03</td>
<td>51</td>
</tr>
<tr>
<td>9</td>
<td>Tractor</td>
<td>Driving forwards, switching, driving backwards</td>
<td>00:38:09</td>
<td>46</td>
</tr>
<tr>
<td>10</td>
<td>Platform truck</td>
<td>Driving unladen, driving laden, loading, unloading</td>
<td>00:37:16</td>
<td>42</td>
</tr>
</tbody>
</table>
work. Figure 2 shows the sensor arrangement, the regions of the body, the locations of sensor attachment, and the respective DOFs and how they are calculated.

Movement sensors in the form of triaxial accelerometers (Analog Devices ADXL 103/203) and gyroscopes (muRata ENC-03R) record the movements directly on a flash memory card in a battery-driven logger at a sampling rate of 50 Hz. The analog output signal of each accelerometer is passed through a low-pass filter with a cut-off frequency of 10 Hz prior to digitization in order to prevent aliasing problems.

Owing to the sensitivity of the calculated angles (detected by accelerometers) to movements of low frequency and high amplitude, the signals from the gyroscopes are used to avoid these artifacts. Finally, the angle signals are low-pass filtered with cut-off frequencies which are optimized for sedentary workplaces. All body angles are initialized at the beginning of a measurement. The body posture during initialization (zero joint position) is an upright standing posture with the subject looking straight ahead. This eliminates subject-specific angle offsets and errors caused by the sensor attachment.

Overall, movement artifacts are less than \( \pm 1^\circ \) in low-vibration environments and \( \pm 4^\circ \) during shocks or rough vibrations with high amplitudes and low frequencies. Since the measurements are accompanied by videotaping of the subjects, these artifacts can also be verified by subsequent observance of the synchronized video.

With reference to the standards (ISO 11226 and DIN EN 1005-4), three categories were defined for classification of the body angles as neutral, moderate and awkward\(^{11, 12}\). For the upper body, seven degrees of freedom were specified in this study. Table 2 shows the description of the categories for all seven DOFs.

The percentage of the working time spent in each category can thus be shown for each DOF. If the observed duration of the \( i \)th DOF in the awkward category \( (t_i) \) is greater than 30\% of the measured duration \( (T) \), the DOF in question is regarded as an “awkward” DOF. The awkward DOF \( (R_{DOF}) \) is quantified by:

\[
R_{DOF} = \sum_{i=1}^{n} c_i = \begin{cases} 
0 & \text{if } \frac{t_i}{T} < 30\% \\
1 & \text{if } \frac{t_i}{T} \geq 30\% 
\end{cases}
\]

where \( c_i \) is the number of awkward DOFs, and \( 0 \leq R_{DOF} \leq 7 \).

![Fig. 2. CUELA posture measuring equipment, body regions for sensor attachment, degrees of freedom and their calculation.](image)

**Table 2. Description of the categories for seven degrees of freedom (upper body)**

<table>
<thead>
<tr>
<th>Category</th>
<th>Body region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head inclination</td>
<td>Head inclination (lateral/sagittal)</td>
</tr>
<tr>
<td>Neck flexion</td>
<td>Neck flexion (lateral/sagittal)</td>
</tr>
<tr>
<td>Thoracic spine (TS)</td>
<td>Trunk inclination (lateral/sagittal)</td>
</tr>
<tr>
<td>Lumbar spine (LS)</td>
<td>Back flexion (lateral/sagittal)</td>
</tr>
<tr>
<td>Thigh</td>
<td>Hip flexion/extension</td>
</tr>
<tr>
<td>Lower leg</td>
<td>Knee flexion/extension</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>Body region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral</td>
<td>0°–25°, 0° full head support</td>
</tr>
<tr>
<td>Moderate</td>
<td>25°–45°</td>
</tr>
<tr>
<td>Awkward</td>
<td>&lt; 0° or &gt; 85°</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>Body region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral</td>
<td>0°–25°</td>
</tr>
<tr>
<td>Moderate</td>
<td>20°–60°</td>
</tr>
<tr>
<td>Awkward</td>
<td>&lt; 0° or &gt; 25°</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>Body region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral</td>
<td>0°–10°</td>
</tr>
<tr>
<td>Moderate</td>
<td>10°–20°</td>
</tr>
<tr>
<td>Awkward</td>
<td>&lt; 0° or &gt; 10°</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>Body region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral</td>
<td>0°–20°</td>
</tr>
<tr>
<td>Moderate</td>
<td>20°–40°</td>
</tr>
<tr>
<td>Awkward</td>
<td>&lt; 0° or &gt; 40°</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>Body region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral</td>
<td>0°–10°</td>
</tr>
<tr>
<td>Moderate</td>
<td>10°–20°</td>
</tr>
<tr>
<td>Awkward</td>
<td>&lt; 0° or &gt; 20°</td>
</tr>
</tbody>
</table>
spent in the awkward posture category is assumed to be 0 in the best case, in which no awkward posture was measured for any of the seven DOFs. The maximum sum is assumed to be 700, corresponding to a worst-case measurement result of all seven DOFs in the awkward posture category. The value for the sum may therefore range from 0 to 700.

Combination of whole-body vibration and posture

For the combination of the two exposures, the categories of WBV (low, middle and high) and posture (neutral, moderate and awkward) are plotted for each DOF in a 3 × 3 matrix scheme⁹. Figure 3 shows an example for the combination of lateral trunk inclination and WBV. The percentage of time spent in the respective categories for each combined form of the exposures is plotted in the matrix (e.g. neutral and high 3.3% in Fig. 3). The result is the definition, from the matrix fields showing the percentage of measured time, of three risk categories in accordance with the “traffic-light” principle:

- “Low” risk category, encompassing neutral and moderate posture at low vibration
- “Possible” risk category, encompassing medium-level vibration with the subject in a neutral or moderate posture
- “High” risk category, encompassing awkward posture and high vibration

If the observed duration of the i-th combination (DOF and WBV) in the high risk category (νₖₖ) is greater than 30% of the measured time (T), the combination in question is considered to be a high-risk combination. The at-risk combinations (Rₖₖᵥᵥ) are quantified as follows:

\[ R_{\text{wbv-p}} = \sum c_i \quad : \quad c_i = \begin{cases} 0 & \text{if } \frac{T_{i,k}}{T} < 30\% \\ 1 & \text{if } \frac{T_{i,k}}{T} \geq 30\% \end{cases} \]

(3)

where c₁ is the number of high-risk combinations, and 0 ≤ Rₖₖᵥᵥ ≤ 7.

The percentages of this category for all seven combinations are also summed with an emphasis upon the duration of the high-risk combinations. In the best-case scenario, no combination of DOF and vibration in the high-risk category is observed; the summated value is therefore 0. For the worst case, in which all measured combinations are observed to be in the high-risk category, the summated value is 700.

Results

The WBV exposures observed for the ten vehicles are stated in Table 3. The WBV total values ranged from 0.16 m/s² for the tram driver to 1.24 m/s² for the elevator platform truck driver.

The respective percentages of the working time spent in a neutral, moderate and awkward posture for all seven DOFs studied is stated in Table 4. The combination of each DOF and WBV in terms of the measured working time is stated in Table 5. The last row in the tables indicates the sum of the percentages by time measured in an awkward posture/high risk category for all seven DOF combinations.

Rᵢᵢᵥᵥ, the awkward DOF exceeding 30% of the duration T, ranges from Rᵢᵢᵥᵥ= 0 for the van driver and helicopter co-pilot to Rᵢᵢᵥᵥ= 3 for the wheel loader driver and tractor driver (Fig. 4). Figure 4 also shows the combinations of DOF and WBV which exceeded 30% of the measured time T in high risk categories (Rᵢᵢᵥᵥᵥ). The tractor driver and elevator platform truck driver exhibit the highest values: Rᵢᵢᵥᵥᵥ = 4 and Rᵢᵢᵥᵥᵥ = 7 respectively. The smallest number was observed for the helicopter co-pilot and the van driver (Rᵢᵢᵥᵥᵥ = 0).

Figure 4 also shows the sum of all percentages of measurement time spent in an awkward posture and in the high risk category for the combinations of WBV and posture. For the awkward posture, the tractor driver and the tram driver exhibit the highest values (244 and 249 respectively). The lowest values are observed for the van driver and for the mobile excavator driver in construction work (21 and 55) respectively. The highest summated percentages of the duration spent in the high risk category are observed for the elevator platform truck driver and the tractor driver, at 298 and 300 respectively. The lowest values were measured for the helicopter co-pilot and the van driver, at 65 and 36 respectively.

---

Fig. 3. Left: CUELA evaluating software, recording each category of whole-body vibration (as aₙₖₖᵥᵥ), the vector sum of the frequency-weighted accelerations) and posture exposures (as DOF degree of freedom) simultaneously with the videotape and simulated dummy. Center: 3 × 3 matrix scheme with whole-body vibration categories on the vertical axis and posture categories on the horizontal axis. The matrix entries show the percentage of the measured duration spent in each combination of categories. Right: Three risk categories summarized from the matrix; where the working time spent in the high-risk category is greater than 30%, the combination for the given DOF is assumed to be 1, otherwise 0 in this study.

Industrial Health 2010, 48, 638–644
Table 3. Whole-body vibration data for ten investigated vehicles; $a_{w[x,y,z]}$ are the frequency-weighted, root-mean-square accelerations for the duration $T$ of the measurement; $a_{1,4}$ is the vector sum of $a_{x}$, $a_{y}$ and $a_{z}$.

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Head inclination sagittal</th>
<th>Neck flexion sagittal</th>
<th>Neck flexion lateral</th>
<th>Trunk inclination sagittal</th>
<th>Trunk inclination lateral</th>
<th>Back flexion sagittal</th>
<th>Back flexion lateral</th>
<th>Elevating platform truck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tram</td>
<td>n 77 93 60 98 84 70 87 61 89 79</td>
<td>m 1 7 0 1 7 30 7 4 10 10</td>
<td>a 22 0 40 1 9 6 35 1 11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Helicopter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobile co-pilot</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saloon car</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Van</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forklift</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobile excavator 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobile excavator 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheel loader</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tractor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elevating platform truck</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Posture data for ten vehicle drivers studied; the percentage of working time spent in each of the categories neutral (n), moderate (m) and awkward (a) is stated. $R_{DOF}$ is the quantity of the awkward degrees of freedom.

<table>
<thead>
<tr>
<th>Posture</th>
<th>Tram</th>
<th>Helicopter</th>
<th>Saloon car</th>
<th>Van</th>
<th>Forklift</th>
<th>Mobile excavator 1</th>
<th>Mobile excavator 2</th>
<th>Wheel loader</th>
<th>Tractor</th>
<th>Elevating platform truck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head inclination sagittal</td>
<td>n 77 93 60 98 84 70 87 61 89 79</td>
<td>m 1 7 0 1 7 30 7 4 10 10</td>
<td>a 22 0 40 1 9 6 35 1 11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neck flexion sagittal</td>
<td>n 3 72 72 94 77 60 35 8 64 80</td>
<td>m 0 0 0 0 0 0 0 0 0 0</td>
<td>a 97 28 28 6 23 40 65 92 36 20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neck flexion lateral</td>
<td>n 72 93 99 99 80 86 85 38 80 65</td>
<td>m 0 0 0 0 0 0 0 0 0 0</td>
<td>a 28 7 1 1 20 14 15 62 20 35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trunk inclination sagittal</td>
<td>n 99 100 100 100 100 24 85 85 92 67</td>
<td>m 0 0 0 0 0 0 0 0 0 0</td>
<td>a 1 0 0 0 0 0 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trunk inclination lateral</td>
<td>n 99 100 100 100 100 24 85 85 5 67</td>
<td>m 0 0 0 0 0 0 0 0 0 0</td>
<td>a 1 0 0 0 0 0 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Back flexion sagittal</td>
<td>n 0 0 0 0 0 94 0 0 7 0</td>
<td>m 0 75 1 87 6 99 14 93 8 4</td>
<td>a 100 25 99 13 0 1 86 0 92 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Back flexion lateral</td>
<td>n 94 98 100 100 10 98 90 70 97 70</td>
<td>m 6 2 0 0 49 2 9 30 3 19</td>
<td>a 0 0 0 0 41 0 1 0 0 11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_{DOF}$</td>
<td>2 0 2 0 1 1 2 3 3 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$\Sigma$ of percentages by time measured in awkward posture (for all 7 DOFs) 249 60 168 21 93 55 173 189 244 139
Table 5. Combination of whole-body vibration and posture; the percentage of working time spent in each of the categories low risk (L), possible risk (P) and high risk (H) is stated. $R_{\text{WBV-P}}$ is the quantity of high-risk combinations of whole-body vibration and awkward posture.

<table>
<thead>
<tr>
<th>Risk</th>
<th>Tram</th>
<th>Helicopter co-pilot</th>
<th>Saloon car</th>
<th>Van</th>
<th>Forklift</th>
<th>Mobile excavator 1</th>
<th>Mobile excavator 2</th>
<th>Wheel loader</th>
<th>Tractor</th>
<th>Elevating platform truck</th>
</tr>
</thead>
<tbody>
<tr>
<td>WBV &amp; head inclination sagittal</td>
<td>L</td>
<td>77</td>
<td>84</td>
<td>47</td>
<td>77</td>
<td>71</td>
<td>61</td>
<td>52</td>
<td>47</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>1</td>
<td>15</td>
<td>12</td>
<td>19</td>
<td>18</td>
<td>23</td>
<td>28</td>
<td>11</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>22</td>
<td>1</td>
<td>41</td>
<td>4</td>
<td>11</td>
<td>16</td>
<td>20</td>
<td>42</td>
<td>12</td>
</tr>
<tr>
<td>WBV &amp; neck flexion sagittal</td>
<td>L</td>
<td>3</td>
<td>62</td>
<td>57</td>
<td>73</td>
<td>60</td>
<td>38</td>
<td>18</td>
<td>7</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>0</td>
<td>10</td>
<td>14</td>
<td>19</td>
<td>15</td>
<td>13</td>
<td>10</td>
<td>0</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>97</td>
<td>28</td>
<td>29</td>
<td>8</td>
<td>25</td>
<td>49</td>
<td>72</td>
<td>93</td>
<td>43</td>
</tr>
<tr>
<td>WBV &amp; neck flexion lateral</td>
<td>L</td>
<td>71</td>
<td>79</td>
<td>77</td>
<td>77</td>
<td>60</td>
<td>51</td>
<td>46</td>
<td>21</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>1</td>
<td>13</td>
<td>20</td>
<td>20</td>
<td>18</td>
<td>21</td>
<td>26</td>
<td>10</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>28</td>
<td>8</td>
<td>3</td>
<td>3</td>
<td>22</td>
<td>28</td>
<td>69</td>
<td>31</td>
<td>52</td>
</tr>
<tr>
<td>WBV &amp; trunk inclination sagittal</td>
<td>L</td>
<td>98</td>
<td>84</td>
<td>77</td>
<td>78</td>
<td>77</td>
<td>61</td>
<td>56</td>
<td>62</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>1</td>
<td>15</td>
<td>21</td>
<td>20</td>
<td>20</td>
<td>24</td>
<td>29</td>
<td>22</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>15</td>
<td>15</td>
<td>16</td>
<td>95</td>
</tr>
<tr>
<td>WBV &amp; trunk inclination lateral</td>
<td>L</td>
<td>99</td>
<td>84</td>
<td>77</td>
<td>78</td>
<td>76</td>
<td>61</td>
<td>56</td>
<td>62</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>1</td>
<td>15</td>
<td>21</td>
<td>20</td>
<td>20</td>
<td>24</td>
<td>29</td>
<td>22</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>15</td>
<td>15</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>WBV &amp; back flexion sagittal</td>
<td>L</td>
<td>0</td>
<td>63</td>
<td>1</td>
<td>68</td>
<td>77</td>
<td>60</td>
<td>7</td>
<td>62</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>0</td>
<td>12</td>
<td>0</td>
<td>17</td>
<td>20</td>
<td>24</td>
<td>4</td>
<td>22</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>100</td>
<td>25</td>
<td>99</td>
<td>15</td>
<td>3</td>
<td>16</td>
<td>89</td>
<td>16</td>
<td>95</td>
</tr>
<tr>
<td>WBV &amp; back flexion lateral</td>
<td>L</td>
<td>99</td>
<td>84</td>
<td>77</td>
<td>78</td>
<td>45</td>
<td>61</td>
<td>55</td>
<td>62</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>1</td>
<td>15</td>
<td>21</td>
<td>20</td>
<td>12</td>
<td>24</td>
<td>29</td>
<td>22</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>43</td>
<td>15</td>
<td>16</td>
<td>16</td>
<td>12</td>
</tr>
</tbody>
</table>

$R_{\text{WBV-P}}$ 2 0 2 0 1 1 2 3 4 7

∑ of time percentages measured in high risk (for all 7 combinations) 248 65 178 36 111 154 255 268 300 298

Fig. 4. Summated values for the percentages of the working time spent in awkward posture and high risk category; number of awkward DOFs ($R_{\text{DOF}}$) and high-risk combinations of WBV and DOF ($R_{\text{WBV-P}}$).
Discussion

The measured vector sum \((\alpha_{1,4})\) represents the WBV values for the three orthogonal axes. An interesting observation is that most of the time, the values for the horizontal \(x\) axis are greater than those for the vertical \(z\) axis (Table 3).

The results for the awkward posture and the combination of the WBV and posture reveal two different findings. Whereas the figures for \(R_{\text{DOF}}\) and \(R_{\text{WBV, P}}\) with respect to 30% of the measured time correlate very well to the generally anticipated workloads for the vehicles studied, the summed percentages do not demonstrate an appropriate distribution of the workloads. For example, in Fig. 4, the \(R_{\text{WBV, P}}\) for the elevating platform truck driver is almost twice that of the tractor driver. However, the sum of the percentages for the high-risk category for the two drivers is virtually the same. This reflects the fact that the combined workload is evenly distributed over all DOFs in the case of elevating platform truck driver, whereas for the tractor driver fewer DOFs are associated with exposure, but for longer periods of time. In this respect, it is surprising that higher values for the summed percentages are also observed for the truck driver and the saloon car driver.

There are several explanations for the difficulties encountered during assessment of the WBV and awkward posture exposures, which have an influence on the results. The back flexion, which generally describes the curvature of the trunk, is not defined by the standards and is currently evaluated with reference to the trunk inclination defined by ISO11226\(^{[11]}\). This evaluation\(^{[11]}\) takes into account the effects of the full backrest only for the backward trunk inclination, which is then considered as neutral.

The use of the backrest cannot be measured yet by the CUELA system. It is not possible to take into account the effects of the backrest which result in high exposure in the cases of the saloon car and tram drivers. For future studies, a pressure sensor will be attached to the backrest or to the back of the subject and will yield data on the pressure on the back when the backrest is used. Furthermore, medical studies are needed for investigation of the effects of partially supported trunks in the lumbar spinal region, a situation frequently observed in the field measurements.

Also, according to ISO11226\(^{[11]}\), any extension for head and neck posture is considered awkward. Since the sensor technology reports body angles very precisely, even small movements of the head lead to extensions, which in accordance with the standards are measured and evaluated as awkward in this case. More appropriate ranges for neck flexion and head extensions are therefore needed for descriptions of moderate and awkward posture for these DOFs.

Initialization of the posture at the beginning of the measurement could also be a source of error, owing to the standing posture of the subject during initialization outside the vehicle. Depending upon the size of the vehicle, the subjects must enter it very carefully, as the sensors may otherwise be displaced. This problem can be reduced by starting the measurement after the subject has entered and exited the vehicle several times with the sensors attached. Another potential solution is initialization within the vehicle in a seated posture; owing to the limited space within the vehicles, however, this would substantially complicate the initialization procedure. In addition, an upright seated reference posture for the purpose of initialization is harder for subjects to achieve than an upright standing posture. The synchronized video data permits observation of these errors. The initializing posture of the subject is recorded on video at the beginning, in the middle and at the end of the measurement; the alignment of the sensors is therefore monitored, and errors caused by displacement of the sensors are eliminated retrospectively in the software.

In summary, this work presents a comparative assessment study of combined exposure to WBV and awkward posture in ten different driving tasks. The results facilitate future epidemiological investigations, which are required for evaluation of the health and safety implications of the different postural behaviors in association with WBV. Even at this stage, the evaluation scheme yields valuable information for prevention activities. International standards describing the postural workload in more detail are also needed.

References

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

Nastaran Raffler, Rolf Ellegast, Thomas Kraus and Elke Ochsmann

*IFA – Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung, Alte Heerstraße 111, 53757 Sankt Augustin, Germany; \(^4\)Institute and Outpatient Clinic for Occupational Medicine, University Hospital, Aachen University of Technology, Pauwelsstr. 30, D-52074 Aachen, Germany; \(^5\)Fakultät Gesundheits- und Pflegewissenschaften Westsächsische Hochschule Zwickau, Dr.-Friedrichs-Ring 2A, 08056 Zwickau, Germany

(Received 26 January 2015; accepted 4 May 2015)

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,
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 $\pm$ standard deviation (SD) = 42 $\pm$ 8 yr; mean height $\pm$ SD = 177 $\pm$ 7 cm; mean weight $\pm$ SD = 88 $\pm$ 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 $\pm$ SD = 46 $\pm$ 7 yr; mean height $\pm$ SD = 176 $\pm$ 6 cm; mean weight $\pm$ SD = 94 $\pm$ 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 $\pm$ SD = 41 $\pm$ 8 yr; mean height $\pm$ SD = 178 $\pm$ 7 cm; mean weight $\pm$ SD = 86 $\pm$ 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:

$$a_{v1.4} = \sqrt{1.4^2 a_{wx}^2 + 1.4^2 a_{wy}^2 + a_{wz}^2}.$$  (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: $a_{v1.4} \leq 0.5 \text{ m/s}^2$
- 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: $33\% \leq$ percentage of non-neutral posture $< 66\%$
- Critical: percentage of non-neutral posture $\geq 66\%$.

<table>
<thead>
<tr>
<th>Body region</th>
<th>Degree of freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>Head inclination (sagittal)</td>
</tr>
<tr>
<td></td>
<td>Neck torsion</td>
</tr>
<tr>
<td>Thoracic spine</td>
<td>Trunk inclination (lateral/sagittal)</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>Back torsion</td>
</tr>
</tbody>
</table>

Table 1: CUELA posture measuring equipment with body regions for sensor attachment and degrees of freedom.
Table 2. Description of the neutral and non-neutral categories for five degrees of freedom (upper body).

<table>
<thead>
<tr>
<th>Category</th>
<th>Head inclination (sagittal)</th>
<th>Neck torsion (lateral)</th>
<th>Trunk inclination (sagittal)</th>
<th>Trunk inclination (lateral)</th>
<th>Back torsion (lateral)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral</td>
<td>0°–25°, &lt; 0° full head support</td>
<td>−45°–45°</td>
<td>0°–20°, &lt; 0° full back support</td>
<td>0°–10°</td>
<td>−10°–10°</td>
</tr>
<tr>
<td>Non-neutral</td>
<td>&lt; 0° or &gt; 25°</td>
<td>&lt; −45° or &gt;45°</td>
<td>&lt; 0° or &gt; 20°</td>
<td>&lt; −10 or &gt; 10°</td>
<td>&lt; −10 or &gt; 10°</td>
</tr>
</tbody>
</table>
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 $\geq 5$ (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/s² 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 (%).

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Number</th>
<th>Duration of measurement (min)</th>
<th>$a_{wx}$</th>
<th>$a_{wy}$</th>
<th>$a_{wz}$</th>
<th>$a_{v1.4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus</td>
<td>7</td>
<td>109.8 {7}</td>
<td>0.11 {0.01}</td>
<td>0.13 {0}</td>
<td>0.2 {0.01}</td>
<td>0.32 {0.01}</td>
</tr>
<tr>
<td>Locomotive</td>
<td>4</td>
<td>82.5 {16.9}</td>
<td>0.06 {0}</td>
<td>0.13 {0}</td>
<td>0.15 {0.02}</td>
<td>0.25 {0.02}</td>
</tr>
<tr>
<td>Crane</td>
<td>9</td>
<td>71 {13.6}</td>
<td>0.11 {0.04}</td>
<td>0.12 {0.05}</td>
<td>0.18 {0.12}</td>
<td>0.3 {0.14}</td>
</tr>
<tr>
<td>Gantry crane</td>
<td>25</td>
<td>98.7 {18.3}</td>
<td>0.2 {0.02}</td>
<td>0.1 {0.03}</td>
<td>0.17 {0.03}</td>
<td>0.37 {0.04}</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Machine group</th>
<th>Number</th>
<th>Duration of measurement (min)</th>
<th>Low</th>
<th>Noticeable</th>
<th>High</th>
<th>$p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>11</td>
<td>11 (100)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td>U</td>
<td>34</td>
<td>33 (97.1)</td>
<td>1 (2.9)</td>
<td>0 (0)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: $p$-values are given as results of the chi-squared test.
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>
<thead>
<tr>
<th>DOF</th>
<th>Machine group</th>
<th>Categories for measured posture (percentage of number of subjects)</th>
<th>$p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>Noticeable</td>
</tr>
<tr>
<td>Trunk inclination sagittal</td>
<td>C</td>
<td>11 (100)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td>U</td>
<td>1 (2.9)</td>
<td>2 (5.9)</td>
</tr>
<tr>
<td>Trunk inclination lateral</td>
<td>C</td>
<td>11 (100)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td>U</td>
<td>33 (97.1)</td>
<td>1 (2.9)</td>
</tr>
<tr>
<td>Back torsion lateral</td>
<td>C</td>
<td>11 (100)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td>U</td>
<td>30 (88.2)</td>
<td>3 (8.8)</td>
</tr>
<tr>
<td>Head inclination sagittal</td>
<td>C</td>
<td>6 (54.5)</td>
<td>4 (36.4)</td>
</tr>
<tr>
<td></td>
<td>U</td>
<td>1 (2.9)</td>
<td>7 (20.6)</td>
</tr>
<tr>
<td>Neck torsion lateral</td>
<td>C</td>
<td>11 (100)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td>U</td>
<td>33 (97.1)</td>
<td>1 (2.9)</td>
</tr>
</tbody>
</table>

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.
Almost all measured values for WBV (a_v1.4) indicate exposure below 0.5 m/s² (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...
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.

<table>
<thead>
<tr>
<th>WBV:</th>
<th>Measurement vs. questionnaire (%)</th>
<th>Subjective data compared to objective data (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Machine group</td>
<td>Low</td>
</tr>
<tr>
<td>C</td>
<td>100 vs. 45.4</td>
<td>0 vs. 54.5</td>
</tr>
<tr>
<td>U</td>
<td>97.1 vs. 3.1</td>
<td>2.9 vs. 18.7</td>
</tr>
<tr>
<td>Posture:</td>
<td>Low</td>
<td>Noticeable</td>
</tr>
<tr>
<td>C</td>
<td>100 vs. 90.9</td>
<td>0 vs. 9</td>
</tr>
<tr>
<td>U</td>
<td>0 vs. 20</td>
<td>5.8 vs. 34.2</td>
</tr>
<tr>
<td>C</td>
<td>100 vs. 90.9</td>
<td>0 vs. 0</td>
</tr>
<tr>
<td>U</td>
<td>100 vs. 74.1</td>
<td>0 vs. 16.1</td>
</tr>
<tr>
<td>Trunk inclination sagittal</td>
<td>100 vs. 90.9</td>
<td>0 vs. 27.2</td>
</tr>
<tr>
<td>U</td>
<td>88.2 vs. 58.8</td>
<td>8.8 vs. 35.2</td>
</tr>
<tr>
<td>Back torsion lateral</td>
<td>100 vs. 54.5</td>
<td>0 vs. 25.7</td>
</tr>
<tr>
<td>Head inclination sagittal</td>
<td>54.5 vs. 90.9</td>
<td>18.1 vs. 0</td>
</tr>
<tr>
<td>C</td>
<td>100 vs. 72.7</td>
<td>0 vs. 18.1</td>
</tr>
<tr>
<td>U</td>
<td>94.1 vs. 54.2</td>
<td>5.8 vs. 22.8</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Exposure</th>
<th>Vibration exposure</th>
<th>Trunk-inclination sagittal</th>
<th>Trunk-inclination lateral</th>
<th>Back-torsion lateral</th>
<th>Head-inclination sagittal</th>
<th>Neck-torsion lateral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kappa value</td>
<td>0.024</td>
<td>0.266</td>
<td>−0.032</td>
<td>−0.028</td>
<td>0.245</td>
<td>−0.034</td>
</tr>
</tbody>
</table>

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

![Percentage of MSD outcomes](image)

![Other factors](image)

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 postural 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.
Acknowledgements

The authors wish to thank Jörg Rissler, Mark Krichels, Benno Göres, Detlef Sayn, Ingo Hermanns, and Christian Schikowsky for their contribution to this work.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research was supported by an unrestricted grant from the German Social Accident Insurance (DGUV) to the University Hospital RWTH Aachen.

References


Danksagung

Ich bedanke mich hier bei allen Menschen, die mich bei der „Suche“ mit ihren Ideen, Engagement und Zuspruch begleitet und unterstützt haben.

Mein Dank gilt als erstes meinen Betreuern Frau Prof. Ochsmann, Herrn Prof. Kraus und vor allem Herrn Dr. Rissler und Herrn Prof. Ellegast, die diese Arbeit erst möglich machten und mich bei der Bearbeitung stets durch zielführende Diskussionen und anhaltende Hilfestellungen begleitet und unterstützt haben.

Meinem Kollegen und Bürogenossen Ingo Hermanns danke ich für seinen unermüdlichen und konstruktiven Einsatz bei der Optimierung der Auswertungssoftware und vor allem auch für sein geduldiges Zuhören und Beistand.


Danke.
Erklärung § 5 Abs. 1 zur Datenaufbewahrung

Hiermit erkläre ich, dass die dieser Dissertation zu Grunde liegenden Originaldaten

*im Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung, Alte Heerstraße 111, 53757 Sankt Augustin* hinterlegt sind.
Erklärung gemäß § 5 Abs. (1) und (2), und § 11 Abs. (3) 12. der Promotionsordnung

Hiermit erkläre ich, Nastaran Raffler, an Eides statt, dass ich den wesentlichen Anteil an der Publikation:
Raffler N., Hermanns I., Sayn D., Göres B., Ellegast R., Rissler J: [Assessing Combined Exposures of Whole-body Vibration and Awkward Posture—Further Results from Application of a Simultaneous Field Measurement Methodology]; [Industrial Health]; 48, 638-644
geleistet habe.

Die Anteile an der Arbeit waren wie folgt:
N. Raffler: Durchführung sämtlicher dargestellter Experimente und Erstellung des Manuskriptes
Sayn D., Göres B.: Durchführung der technischen Messungen
Ochsmann E.: Medizinische Untersuchung der Probanden und Studiendesign und –überwachung, Korrektur der Dissertation
Kraus T.: Studiendesign und –überwachung, Korrektur der Dissertation

Aus diesem wesentlichen Anteil ergibt sich selbstverständlich die Stellung als Erstautorin.

_______________________________________
Unterschrift der Doktorandin


_______________________________________
Unterschrift des Doktorvaters

Ich schließe mich der Erklärung von Herrn Kraus/Frau Ochsmann als Koautor an

Ingo Hermanns
Sayn Detlef

Benno Göres
Rofl Ellegast

Jörg Rissler

Namen und Unterschriften aller deutschsprachigen Koautoren
Erklärung gemäß § 5 Abs. (1) und (2), und § 11 Abs. (3) und (4) 12. der Promotionsordnung

Hiermit erkläre ich, **Nastaran Raffler**, an Eides statt, dass ich den wesentlichen Anteil an der
Publikation:¹

**Raffler N.**, Ellegast R., Kraus T., Ochsmann E.: [Factors affecting the perception of whole-body vibration of occupational drivers: an analysis of posture and manual materials handling and musculoskeletal disorders]; [Ergonomics].; 59:1, 48-60

geleistet habe.⁴

Die Anteile an der Arbeit waren wie folgt:⁵

N. Raffler: Durchführung sämtlicher dargestellter Experimente und Erstellung des Manuskriptes²,⁴
Ochsmann E.: Medizinische Untersuchung der Probanden und Studiendesign und –überwachung,
Korrektur der Dissertation
Kraus T.: Studiendesign und –überwachung, Korrektur der Dissertation

Aus diesem wesentlichen Anteil ergibt sich selbstverständlich die Stellung als Erstautorin.

____________________________
Unterschrift der Doktorandin


____________________________
Unterschrift des Doktorvaters

Ich schließe mich der Erklärung von Herrn Kraus/Frau Ochsmann als Koautor an

____________________________

Rolf Ellegast Thomas Kraus

____________________________

Elke Ochsmann

Namens- und Unterschriften aller deutschsprachigen Koautoren
Lebenslauf

Persönliche Daten

Nastaran Raffler
Karl-Finkelnburg-Straße 25
53173 Bonn

Telefon: 0228-3727887
E-Mail: nastaran.raffler@dguv.de

Geburtsdatum: 9. August 1979
Geburtsort: Teheran, Iran
Staatsangehörigkeit: deutsch
Familienstand: verheiratet

Berufspraxis

seit 02/2006 wissenschaftliche Mitarbeiterin
BGIA (Berufsgenossenschaftliches Institut für Arbeitsschutz)

09/2011 - 09/2012 Elternzeit für Tochter Delina
03/2015 – 03/2016 Elternzeit für Tochter Avina

Studium

09/2001 – 05/2005 Fachhochschule Bonn-Rhein-Sieg, Rheinbach
Studienfach: Werkstofftechnik
Abschluss: Diplom-Ingenieurin (FH), 23. Mai 2005, Note: 1,7

Schulbildung

09/1999 – 06/2001 Konrad-Adenauer-Gymnasium, Bonn
Abschluss: Abitur, 18. Juni 2001, Note: 2,4
09/1997 – 07/1999 Kronberg-Gymnasium, Aschaffenburg
09/1995 – 07/1997 Regiomontanus-Gymnasium, Haßfurt
10/1986 – 04/1995 Grundschule und Gymnasium, Teheran, Iran

Auslandsaufenthalte

01/2005 – 05/2005 University of Virginia, Department of Materials Science and Engineering, Charlottesville, VA, U.S.A.
Diplomarbeit "Interface motion during transformations in alloys" in Zusammenarbeit mit der Fachhochschule Bonn-Rhein-Sieg

10/2003 – 04/2004 University of Virginia, Department of Materials Science and Engineering, Charlottesville, VA, U.S.A.
Praxissemester in Zusammenarbeit mit der Fachhochschule Bonn-Rhein-Sieg

Auszeichnungen

2001 Preis der Deutschen Physikalischen Gesellschaft (DPhG) für das beste Abitur in Physik
<table>
<thead>
<tr>
<th>Jahr</th>
<th>Autor*innen</th>
<th>Titel</th>
<th>Veröffentlichungsort</th>
</tr>
</thead>
</table>
Präsentationen

2013
Key note lecture
5th International Conference on Whole Body Vibration Injuries
Amsterdam, Netherlands, 5–7 June 2013
“Occupational posture analysis among whole-body vibration exposed crane operators”

Vortrag
5. VDI-Tagung Humanschwingungen, 28.-29. Mai 2013, Dresden
„Ungünstige Arbeitsbedingungen eines Kehrfahrzeugführers durch Kombinationsbelastungen von Ganzkörper-Vibrationen und Körperhaltungen“

2010
Vortrag
„Gefährdungsbeurteilung der Kombinationsexpositionen von Ganzkörper-Vibrationen und ungünstigen Körperhaltungen bei Bus- und Vollportalkranfahrern“

2009
Vortrag
4th International Conference on Whole Body Vibration Injuries
Montreal, Canada, 2-4 June 2009
“Assessing combined exposures of whole-body vibration and awkward posture”

Fähigkeiten

Sprachen: Persisch (Muttersprache), Deutsch (fließend), Englisch (fließend), Französisch (gut), Spanisch (Grundlagen), Arabisch (Grundlagen)

Computerkenntnisse: Microsoft Word, Excel, PowerPoint, Adobe Photoshop, WIDAAN, Image-Pro Plus, Visual Basic (Grundlagen), CAD, FEM

Bonn, den 20. August 2016