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Two way assessment of other physical work demands while measuring the whole body vibration magnitude

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Abstract

Direct observation, instead of using self-administered questionnaires might give more reliable and specific information about physical work demands at the workplace. This information is of use in a population already at risk of developing low back pain (LBP) due to whole body vibration (WBV) exposure. The aims of this study are to assess the WBV exposure in an exposed population and to assess other physical work demands in two ways, by direct observation and with the use of a self-administered questionnaire. We therefore assessed the WBV magnitude and 5 WBV-related physical work demands by using the PalmTrac system and a self-administered questionnaire in a group of drivers ($N = 10$). The main findings are 7 out of 10 drivers are exceeding the EU action value. About 50% of the drivers under-estimated the time 'bending', 60% the time 'walking + standing' and 60% over-estimated the time when 'lifting.' We concluded that 7 drivers from this group are at risk of developing LBP and substantial differences exists for the 5 physical work demands comparing the PalmTrac method with the questionnaire. Direct observational assessment in WBV measurements yields extra information. This is useful for preventive activities necessary as drivers are exceeding the EU action value.
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1. Introduction

In western countries, an estimated 4–7% of all employees are exposed to potentially harmful whole body vibration (WBV) [1,2]. Several systematic or critical reviews conclude that there is strong epidemiological evidence for a relationship between occupational exposure to WBV, low back pain (LBP) and back disorders [3–7]. Bovenzi and Hulshof [4] performed a meta-analysis of methodologically sound studies and calculated an odds ratio of 2.3 (95% CI: 1.8–2.9) for LBP in an exposed population to WBV, as compared with an unexposed population. A more recent cross-sectional study from Bovenzi et al. [8] shows an odds ratio of 0.8 (0.4–1.8) for LBP for a low-exposure (mean $<0.5\,m/s^2$) population in comparison to an unexposed control group. The Odds ratio for the high-exposure population (mean $0.92\,m/s^2$) was 2.9 (1.3–6.4).

In several European countries, it was decided to recognize and compensate LBP and certain spinal disorders as WBV-related occupational diseases, as long as they meet certain criteria [9]. After many years of debate and

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preparation, a new European Directive on the protection of workers against the risks of vibration was published in 2002 and implemented in the national legislation of the EU member states in 2005. This Directive establishes minimum requirements for the protection of workers from risks to their health and safety that arise from exposure to mechanical vibration. The Directive specifies several obligations for employers: the determination and assessment of risks, the adoption of measures for avoiding or reducing exposure, and the provision of worker information and training. Action values and exposure limits were formulated in this regard. These values, which are based on a regular 8-h working day, are 0.5 and 1.15 m/s^2, respectively, in the dominant axis. In addition to this, appropriate health surveillance for exposed workers is obliged.

In line with this European Directive, a multicentre project on the risks of occupational vibration injuries (VIBRISKS) was conducted with financing from the European Commission. The three objectives of this European multicenter study are to improve (1) knowledge of the exposure-response relationship between WBV and the development or recurrence of disorders, (2) understanding of the factors that together contribute to the development or progression of symptoms of these disorders (both with and without intervention at the workplace), and (3) understanding of the benefits of health surveillance and other intervention measures. The results of this paper are related to objective (2).

In addition to WBV exposure, LBP is also associated with other physical work demands (in this study defined as the main tasks, activities, within activities and postures while at work). Sitting in a constrained posture or performing manual material-handling tasks, for instance, are associated with a higher risk of LBP. In several studies [8,10] on the relationship between exposure to WBV and LBP, adjustment for these contributing physical work demands was made. Although self-administered questionnaires are the usual method of gathering information about physical work demands, previous research [11–15] has concluded that the use of questionnaires to assess the physical work demands does not always yield reliable results. Hansson et al. [16] suggested that direct (observational) technical measurements might be preferable.

Several observational methods have been developed for analyzing physical work demands at the workplace [17]. One of these methods is the PalmTrac (Task Recording and Analysis on Computer) system [18]. PalmTrac is a reliable, valid observational method for assessing physical work demands [19,20]. The studies from Douwes and Dull [19] and from Looze et al. [20] showed that the validity of visual observation is dependent on the dynamic characteristics of the work. A previous study by van der Beek et al. [12] determined the inter-observer reliability of the PalmTrac system. The inter-observer reliability (as measured by the percentage of agreement) of various observations varied between 85% and 95%, depending on the body region that was observed. To our knowledge, no previous studies have reported on the simultaneous measurement of WBV in field practices and the assessment of other physical work demands by an observational method.

The aims of this study are to assess the WBV exposure in an exposed population and to assess other physical work demands in two ways, by direct observation and with the use of a self-administered questionnaire. It is hypothesized that this direct observational method together with WBV measurements under actual working circumstances yields more reliable information about these physical work demands than when using the self-administered questionnaire only.

2. Methods

2.1. Population

A group of ten ($N = 10$) drivers of wheeled loaders and other types of vehicles was selected from the population of the previously mentioned VIBRISKS study. These ten drivers were selected because of three reasons: First, we expected differences in the level of WBV exposure magnitude within this group of drivers. Second, we expected differences the total time of exposure to physical work demands within this group of drivers. And third, this group of drivers are exposed to WBV for at least 40 h a week. The drivers that were included in this study worked for seven different companies and drove a variety of vehicles (see Table 1).

Table 1
Age, height, weight, and type of vehicle (specifics) for the ten randomly selected drivers

Subject	Age (years)	Height (cm)	Weight (kg)	Type of vehicle	Specifics
1	30	185	105	Lorry	(Ginaf M3232S EVS)
2	34	190	105	Wheeled loader	(Ahlmann AZ 150)
3	37	192	100	Lawn-mowing machine	(Toro Groundmaster 40,000D)
4	38	182	92	Wheeled loader	(Ahlmann AZ 150)
5	48	178	91	Double crane	(Fermec 960, 2001)
6	49	176	86	Wheeled loader	(Caterpillar 928D)
7	54	175	80	Boat	(Corvus: unique, 1997)
8	55	178	105	Wheeled loader	(Volvo 150C, 1998)
9	56	175	75	Excavator	(Leibherr Litronic A900c)
10	58	166	100	Steam roller	(Hamm 2411 D)
Mean $\pm$ SD	45 ± 11	179 ± 8	93 ± 12		

2.2. WBV measurement

WBV was measured under actual working conditions according to the requirements of the international ISO standard 2631-1 [21]. WBV was measured at the driver/seat interface using a tri-axial seat accelerometer (including DIN-microdot Cable WL 0547). The 3-axis recorded signals were amplified, converted to voltage and filtered with type 1700 (Brűel & Kjaer) 3-channel human-vibration front end, with one channel connected to a 2260-I observer modular precision sound analyzer (Brűel & Kjaer). Frequency-weighted root-mean-square (rms) accelerations (a_x, a_y, and a_z) were obtained from one-third octave band frequency spectra (1–80 Hz) of the signal recorded in the fore-and-aft direction (x-axis), horizontal direction (y-axis) and vertical direction (z-axis), using the ISO 2631-1 [21] weighting factors.

2.3. Physical work demands

The physical work demands and the tasks and activities of the drivers that are considered in this study were assessed in two different ways: (1) with a self-administered questionnaire developed by Lundström et al. [22] and (2) with the PalmTrac system [18] during observation at the workplace.

2.4. PalmTrac system

The PalmTrac system is an inexpensive, easy to learn and quick to use (direct) observational method. The Trac observational method was originally developed at the Robens Institute (University of Surrey, UK) and further adapted by the Study Center on Work and Health/ERGOcare (Academic Medical Centre, University of Amsterdam & Vrije Universiteit, Amsterdam, The Netherlands) [18].

The TRAC system was converted to PalmTrac by the Coronel Institute for Occupational and Environmental Health (AMC Amsterdam), in cooperation with EXPres (Vrije Universiteit, Amsterdam). The main adaptations were as follows: (1) enabling processing in Windows (as opposed to processing in DOS), (2) scoring of the various tasks, activities and postures with the new more user-friendly personal digital assistant (PDF) computer (as opposed to the Psion Organizer pocket computer), and (3) linking other recorded data (e.g., heart-rate frequency) with data that had been observed with PalmTrac.

Fig. 1 shows the various features of the PalmTrac system. Step 1 involves observation of the population of interest at the workplace, using a video camera. The tasks, activities, within activities, postures and extra information of the most important, representative work cycles should be assessed during this observation, along with their repetitions. Step 2 draws on the analysis of the video to arrange the tasks, activities, within activities, postures and extra information into a tree-diagram (the library). The accurate definition of each of these elements is an important aspect of the creation of this library. The elements are hierarchically structured in 6 blocks; first block will be the description of the task it self (for instance law mowing), the second block will

Fig. 1. Different steps involved in the use of the PalmTrac system.

be a description of the activities during land mowing (for instance sitting, walking and running). The 3rd block will be within activities (for instance with walking one can actually be pushing or lifting weights). The 4th block describes which body postures the within activities withheld, (for instance while walking and pushing one is rotating his hips 45°). Block 5 gives us extra info about the weight of the object which is being pushed and block 6 is an indication about the duration of the activity and the within activity. Accurate definition of the different blocks helps to ensure high intra- and inter-observer reliability. An example of this accurate definition of a task for a driver might be, transport = all activities with the goal of moving load A from place X to place Y. Step 3 involves the transfer of the library to the PDA. Step 4 consists of the actual worksite observation, and the observed data are transferred to the computer in Step 5. Step 6 involves the final editing, processing, linking and calculation of the duration, frequency and intensity of the physical demands in the assessed observations. A full description of the Trac system has been published earlier [18].

2.5. Simultaneous measurement

To ensure that the PalmTrac system and the WBV measurement would work simultaneously, the start of the measurement was synchronized. A measurement of the WBV magnitude according to the requirements of the international ISO standard 2631-1 [21] should lasts at minimum 3 min and should represent as much as possible a complete work cycle of the vehicle of interest. The WBV measurements in this study lasted between 15 and 25 min, the exact measurement time depends on the representative work cycle of the specific vehicle. Observation by PalmTrac lasted approximately 4 h. Owing to practical matters, the exact time of the PalmTrac observations will vary.

2.6. Self-administered questionnaire

Data on physical work demands were collected using the VIBRISKS Whole-Body Vibration, Initial Assessment, self-administered questionnaire [22]. This questionnaire was elaborated from an earlier version that was tested in several populations [8,23]. And was used in the baseline measurement from the VIBRISKS study. For this study, only those questions that concern physical work demands (Section 2) were included. Specifically, this concerns question 8a, 9a, 13, 16, and 15 (see Appendix A). Five physical work demands were defined according to the questions and its questionnaire items, respectively: (1) walking + standing, (2) bending over (straight or twisted), (3) sitting—while driving, (4) sitting twisted/leaning forward—while driving, and (5) lifting. The data that were gathered with the self-administered questionnaire were stored in a Microsoft Access (2002) database.

2.7. Analyses

2.7.1. WBV measurement

The WBV measurement data were exported and stored in an Excel spreadsheet, using the Noise Explorer type 7815 version 4.7 software. For further analysis, the first 2 min of the total recorded time were deleted, as it was necessary to install both the equipment and the driver properly. Zero values that might appear in the

WBV signal of the actual measurement, due to very short lost signal, were deleted and extrapolated. This was done by using the average of the values one second before and one second after the zero value, as the WBV signal was logged every second.

The vibration vector sum (total value) of the weighted rms accelerations (a_{wv}) in m/s^2 was calculated according to formula (1):

$$a_{wv} = \sqrt{1.4a_{wx}^2 + 1.4a_{wy}^2 + a_{wz}^2} \quad (1)$$

(where a_{wx} is the frequency weighted rms for the x-axis, a_{wy} is the frequency weighted rms for the y-axis, and a_{wz} is the frequency weighted rms for the z-axis). We calculated for each driver the daily rms acceleration normalized to an 8-h working day ($a(8)$). This $a(8)$ was calculated according to formula (2):

$$a(8) = \sqrt{\frac{1}{T_0}\sum a_{wv}^2 T_i}, \quad (2)$$

where T_0 is the duration of eight hours expressed in seconds, a_{wv}^2 is the squared vector sum a_{wv}, and T_i is the WBV measurement time expressed in seconds.

2.7.2. PalmTrac data

Results from the ten drivers were used for the comparison between the self-reported and the observational assessments of physical work demands. All of the questions in the self-administered questionnaire were related to an entire working day (8 h). PalmTrac data was recorded for approximately 4 h. To standardize the PalmTrac data also to an entire working day, the exact PalmTrac recording time (in min) was calculated as a proportion of 8 h (480 min). This proportion was multiplied by the total recorded time for each of the five physical work demands.

2.7.3. Self-administered questionnaire data

The self-administered questionnaire included a response item (question 16, see Section 2.6) with an ordinal (never-seldom-often) scale. The physical work demand that was defined according to this question is 'sitting twisted/leaning forward'. To make a comparison possible between the self-reported and observational assessments of physical work demands in total time, we retrospectively defined 'never' as 0 min, 'seldom' as 0–10 min, and 'often' as time in excess of 10 min.

2.7.4. Agreement between PalmTrac data and data from the self-administered questionnaire

To test the agreement between the total time revealed by the PalmTrac observation and the estimated total time (based on the self-administered questionnaire) the total times were compared. The estimation of the total time for the physical work demands in the questionnaire is based on the chosen response item. Underestimation was assumed when the total time for the physical work demands revealed by PalmTrac (for instance; 12 min) was smaller than the time from the chosen response item in the questionnaire (for instance 15–30 min). Agreement was assumed when the total time for the physical work demands revealed by PalmTrac (for instance 24 min) overlaps with the time from the chosen response item in the questionnaire (for instance 15–30 min). Overestimation was assumed when the total time for the physical work demands revealed by PalmTrac (for instance 45 min) was greater than the time from the chosen response item in the questionnaire (for instance 15–30 min).

3. Results

3.1. Drivers

Subject characteristics for the ten drivers (all male) are shown in Table 1. The average age of the group of drivers was 45 years (±11 years), the average height 179 cm (±8 cm) and the average weight 93 kg (±12 kg). The workers drove on their vehicles on average for 16.6 years (±11.3 years).

Table 2
The measured WBV magnitude (m/s^2) in x-, y-, and z-direction and the vector sum for 10 randomly selected drivers

Driver	a_x (m/s^2)	a_y (m/s^2)	a_z (m/s^2)	a_v (m/s^2)
1	0.28	0.26	0.29	0.54
2	0.60	0.62	0.53	1.15
3	0.83	0.87	0.56	1.53
4	0.76	0.69	0.49	1.31
5	0.66	0.67	0.52	1.23
6	0.65	0.90	0.43	1.38
7	0.08	0.13	0.08	0.20
8	0.75	0.78	0.69	1.45
9	0.52	0.24	0.30	0.74
10	0.37	0.25	0.34	0.63
Mean $\pm$ SD	0.55 $\pm$ 0.24	0.54 $\pm$ 0.29	0.42 $\pm$ 0.17	1.02 $\pm$ 0.46

3.2. WBV measurements

Table 2 presents the vibration magnitude (m/s^2) for the ten selected drivers in x-, y- and z-direction. The vector sum (a_v) of the WBV magnitude for the different kinds of vehicles ranged from 0.20 m/s^2 for the boat to 1.53 m/s^2 for a wheeled loader. Seven out of the ten drivers are exceeding the action value of 0.5 m/s^2 in the dominant axis assuming that the emission value during the actual measurement is maintained all workday long (8 h). The dominant axis appeared to be dependent of the vehicle driven; the x-axis is dominant for drivers 4, 9, and 10, the y-axis is dominant for drivers 2, 3, and 5–8, and the z-axis is dominant for driver 1.

3.3. Illustration of a simultaneously measurement

Fig. 2 shows an example of the added value of the simultaneous assessment of physical work demands and a WBV measurement under actual working circumstances for one specific driver (subject 6). For this 3-min period, the WBV measurement on the seat of the wheeled loader revealed frequency-weighted rms acceleration values of $a_x = 0.57\,\text{m/s}^2$, $a_y = 0.79\,\text{m/s}^2$, $a_z = 0.37\,\text{m/s}^2$, and an acceleration total value (vector sum) of $(a_v) = 1.31\,\text{m/s}^2$. Examining the example that is illustrated in Fig. 2 more closely, the dominant axis exceeds the action value of 0.5 m/s^2 for 'sitting twisted/leaning back', 'sitting' and 'sitting while driving with and without load' all during the task of 'leveling off'.

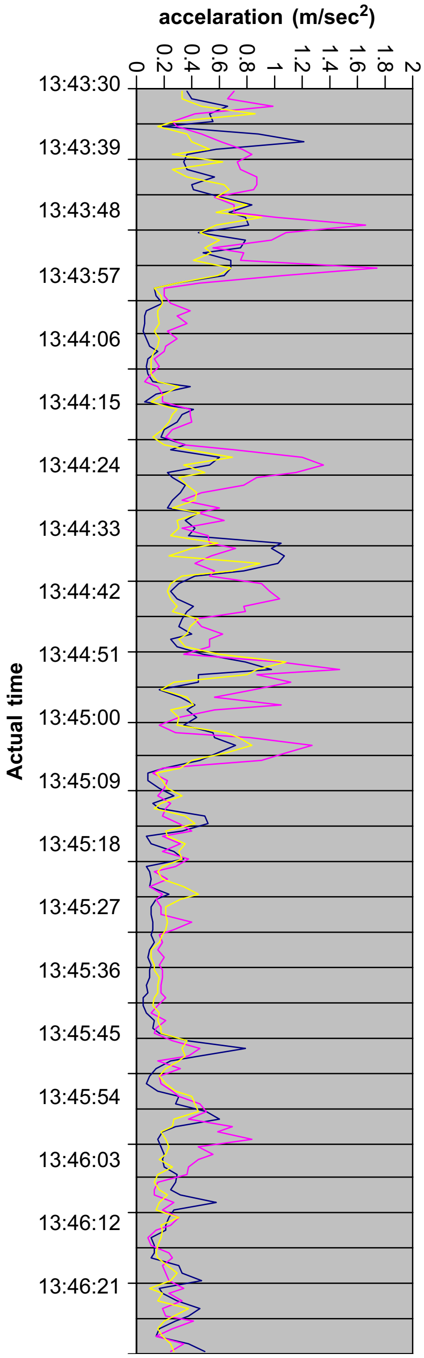
3.4. Comparison of physical work demands between PalmTrac and self-administered questionnaire

Results of the comparison in total time between the physical work demands assessed by the self-administered questionnaire and by the PalmTrac system are presented in Figs. 3–7. Each of the physical work demands is presented in a figure. Comparisons are made based on a total duration of a normal 8-h working day.

Fig. 3 shows that for 'walking + standing', 20% ($N = 2$) of the drivers reported durations that were comparable to the PalmTrac assessments; 60% ($N = 6$) underestimated the total time, and 20% ($N = 2$) overestimated the total time in which they were walking and standing during a normal working day.

Fig. 4 shows that for 'bending over (straight or twisted)', 80% ($N = 8$) of the drivers reported that they did not perform this activity during a normal working day. PalmTrac, however, showed that half ($N = 5$) of these drivers actually did bend over. Workers apparently tended to underestimate the time that they spent in a bent-over (straight or twisted) posture. The 20% ($N = 2$) of the drivers who had reported bending over (straight or twisted) overestimated the total time.

Fig. 5 shows that for the time spent in a normal sitting posture, all drivers ($N = 10$) reported durations those were comparable to the PalmTrac assessments.



Physical work Demand	m/s²		
	a_x	a_y	a_z
Sitting			
Leveling-of	0.27	0.42	0.15
Sitting	0.88	1.07	0.54
Sitting twisted/ leaning back	0.96	1.53	0.60
Sitting	0.22	0.36	0.80
Sitting (driving without load)	0.67	0.97	0.44
Sitting	0.61	0.53	0.37
Transport	0.29	0.38	0.28
Sitting	0.14	0.24	0.28
Sitting (Driving with load)	0.35	0.47	0.24
Leveling off	0.34	0.18	0.16
Sitting twisted/ leaning back	0.41	0.34	0.21
Sitting (Driving with load)			

Fig. 2. Example of a result of the simultaneous assessment of physical work demands and WBV measurement for one driver.

Fig. 6 shows that the PalmTrac data revealed that ninety percent ($N = 9$) of the drivers were ‘sitting twisted/ leaning forward’ during their normal work duties. The drivers’ self-reported estimations for this physical work demand varied: 30% ($N = 3$) of the drivers underestimated, 40% ($N = 4$) estimated it correctly and 30% ($N = 3$) overestimated.

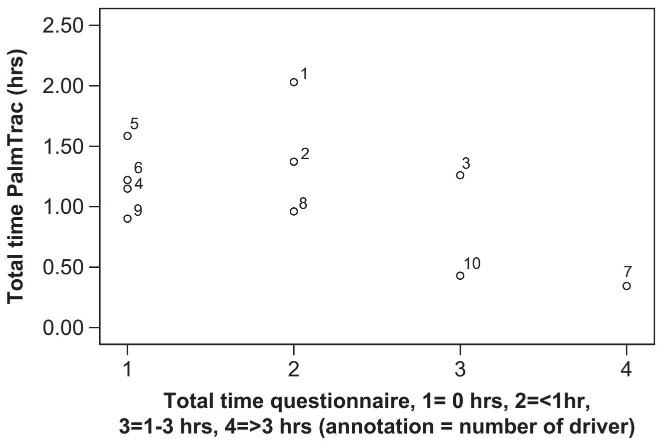


Fig. 3. Comparison of the total time on a normal working day spend on 'walking + standing' between observational (PalmTrac) and self-reported (questionnaire) assessment.

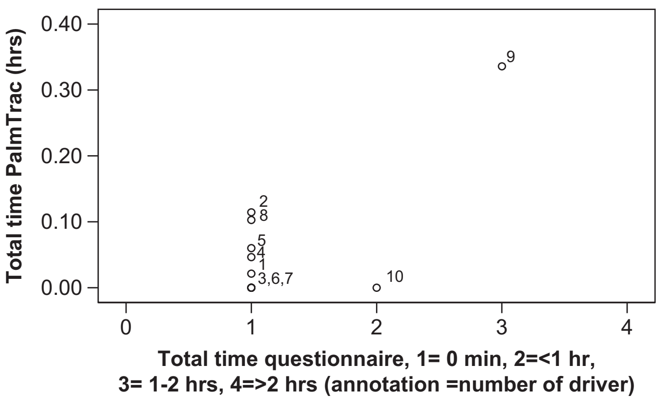


Fig. 4. Comparison of the total time on a normal working day spend on 'bending over (straight or twisted)' between observational (PalmTrac) and self-reported (questionnaire) assessment.

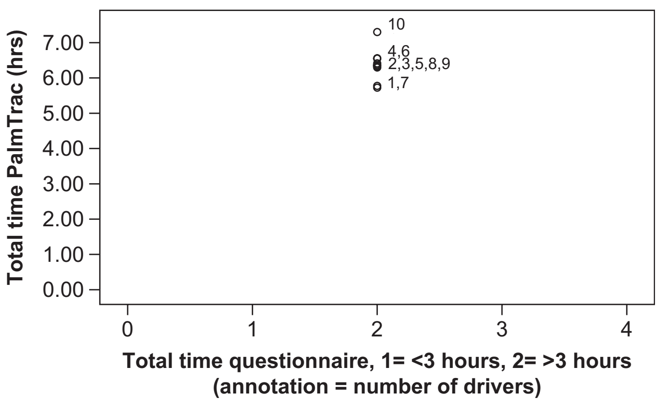


Fig. 5. Comparison of the total time on a normal working day spend on 'sitting' between observational (PalmTrac) and self-reported (questionnaire) assessment.

Fig. 7 shows that although PalmTrac registered no lifting for 90% ($N = 9$) of the drivers, half ($N = 5$) of the drivers estimated that they lift during a normal working day. There is an apparent tendency to over-estimate this physical work demand. One worker (Worker 3) did not provide a response to the question about lifting.

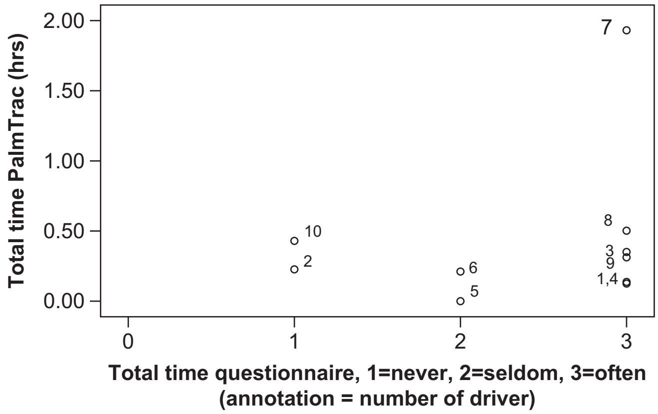


Fig. 6. Comparison of the total time on a normal working day spend on 'sitting (twisted/leaning forward)' between observational (PalmTrac) and self-reported (questionnaire) assessment.

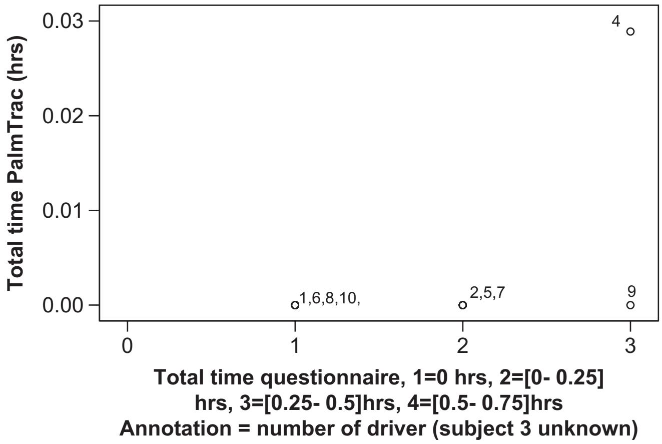


Fig. 7. Comparison of the total time on a normal working day spend on 'lifting' between observational (PalmTrac) and self-reported (questionnaire) assessment.

Table 3
The agreement between the total time of the different physical activities recorded by PalmTrac assessment and estimation by questionnaire ($N = 10$)

Physical work demand	Agreement (Time PalmTrac = Time questionnaire) (number of subjects)
Walking + standing	20% (3 and 8)
Bending over (straight or twisted)	30% (5, 8, and 10)
Sitting	100% (all subjects)
Sitting (twisted/leaning forward)	40% (3, 8, 9, and 10)
Lifting (subject 3 unknown)	40% (1, 3, 5, and 6)

As shown in Figs. 3–7, the total time estimated by the self-administered questionnaire differed substantially from the total time that was assessed by PalmTrac for the five recorded physical work demands.

Table 3 presents a summary of the agreement between the different physical activities recorded by the PalmTrac system and estimation by the self-administered questionnaire.

4. Discussion

This study showed (1) for a group drivers that 7 out of 10 drivers are exceeding the EU action value of $0.5\,m/s^2$ in the dominant axis, and it showed (2) substantial differences in the total time for assessing five specific physical work demands by using a direct observational method compared to the use of a self-administered questionnaire. 'Walking + standing' is underestimated by 60% of the drivers and 'bending' by 50% of the drivers, however 'lifting' is overestimated by 60% of the drivers. 'Sitting' is estimated correctly and for 'sitting (twisted/leaning forward)' no clear trend could be seen; 30% of the drivers underestimated, 30% of the drivers overestimated and 40% of the drivers estimated the total time correctly.

The five physical demands that are reported in this study are important in combination with WBV exposure, as they contribute to or exacerbate LBP and other musculoskeletal problems [5,24,25]. No real tendency towards under- or over-estimation was found. Over-estimation was identified for lifting. This over-estimation might have been because lifting heavy objects is one of the best-known occupational risk factors for LBP. Both anxiety for and experience with a risk factor are thought to influence self-report assessments [15]. In contrast to our finding, Burdorf and Laan [11] found an underestimation in the total time spent lifting heavy objects, while Baty et al. [26] found a total time that corresponded closely to employee estimates. On the other hand, a tendency to underestimate was identified for 'walking + standing' and 'bending over (straight or twisted)'. Similar results have also been found in other studies [11,27]. This underestimation may be explained partially by difficulties in defining tasks. Burdorf and Laan [11] found that workers were particularly likely to have difficulty providing accurate evaluations of non-neutral postures, as defined in terms of degrees of deviation. More specific postures (e.g., 'sitting'; 'sitting twisted/leaning forward' and 'bending over') are therefore more difficult to assess reliably by using questionnaires. Van der Beek and Frings-Dresen [28] concluded that these more specific postures are also more difficult to assess with observational methods (e.g., PalmTrac), in contrast to the other work demands (e.g., 'vibration exposure', 'lifting' and 'standing + walking'). The under-estimations and over-estimations of the drivers with regard to the total time of the physical work demands are of minor importance; more attention should be paid to the time that these drivers are exposed to these work demands, which contribute to the onset of LBP.

The interpretation of the findings that are reported in Table 3 and Figs. 3–7 is not straightforward. The item in the self-administered questionnaire that referred to the amount of time spent in a sitting posture during a normal working day had to be answered on an ordinal scale ('less than 1 h', '1–3 h', and 'more than 3 h'). The same applied to the item regarding the physical demand 'sitting (twisted/leaning forward)'; the response categories were arranged crudely along an ordinal scale ('never', 'seldom', 'often', see Section 2.7.3). The questionnaires thus did not require the drivers to report specific information in minutes per day. In contrast, PalmTrac provides continuous numerical data that are more precise. In order to allow direct comparisons between self-reported and observational assessments, the design of future research should be improved. One way of improving is to make sure that the response items on the self-administered questionnaire contain a continuous numerical scale. Although it is questionable if these questions with this numerical scale response items can be filled in reliable by the drivers.

Hanson et al. [16] concluded that direct technical measurements of tasks, activities, within activities and postures are preferable. Although, observation is one of the possibilities to measure these directly the results of other studies show that the validity of visual observation is dependent on the dynamics of the work. The more dynamic the work, the more difficult it is to observe valid activities and postures [18]. The work in our study, as defined in tasks, activities, within activities and postures, cannot be characterized as dynamic, given that the entire 8-h working day can be largely characterized by the combination of the five physical work demands that have been addressed in this study.

The weighted rms acceleration vibration magnitudes are comparable with studies [8,10] and databases [29,30] that performed the same kind of field measurements, although our vibration magnitudes tend to be a higher. The study from Bovenzi et al. [10] is reporting a vibration magnitude for excavators in the range of $0.20–0.52\,m/s^2$. This is conform our findings, range $0.24–0.52\,m/s^2$, though our dominant axis is found in the fore-aft direction while the study from Bovenzi et al. found the dominant axis in the vertical direction. The same study from Bovenzi et al. [10] reported a range for wheeled loaders of $0.21–0.35\,m/s^2$. The range of the wheeled loaders in this study, 0.43–0.90 m/s^2, is higher. A study by Pinto and Stacchini [31] assessed the relative uncertainty of field measurements using the same method we did, specified in the ISO 2631-1. Relative uncertainty in the WBV magnitude ranged from fourteen to 32%. For the field measurements we used different kind of vehicles working under normal working circumstances. However, choosing other vehicles of the same type might have revealed different values because of differences in operating conditions, the state and the age of the vehicle and the drivers who were operating them.

Exceeding the action value has practical implications for the employer as well as for the employee. The employee is at risk of developing LBP. The employer therefore is obliged to implement measures to decrease the WBV exposure of their drivers as specified in the new Directive. Preventive activities (to decrease the WBV magnitude under the EU action value) have to be formulated. The simultaneous measurement of the WBV magnitude and the direct observation with PalmTrac presented in Fig. 2 can actually assist in formulating these preventive activities. First, PalmTrac allows the separate analysis of vibration-exposure data from a number of work periods. According to the international ISO 2631-1 [21] standard for WBV exposure, measurement duration should be sufficient and specific to ensure that the vibration is typical of the exposure that is being assessed. Second, by simultaneously measurement the levels of WBV exposure can be identified that are associated with the tasks, activities, within activities and postures (that pose a risk for developing LBP). This enables a more detailed preventive action. In addition, simultaneous measurement provides insight into the tasks, activities, within activities and postures that are performed at the time of a minimum or maximum level in the vibration signal. If certain events happen regularly, even on an individual basis, this can be used as input for preventive activities. An example from Fig. 2 can illustrate this; the combination of 'sitting twisted/leaning forward' a known contributing risk factor for LBP [24], at time 13:43:58 together with a high exposure to WBV ($a_x = 0.96$, $a_y = 1.53$, and $a_z = 0.60$), should be avoided. This could be prevented by informing the driver not to sit in this position when driving at high speeds. And forth, based on this study, the PalmTrac system yields information about the physical work demands more in detail. With PalmTrac the exposure to physical work demands can be assessed in terms of duration and frequency more objective and in addition to the questionnaire.

Although using the PalmTrac system to assess the physical work demands seems to be an asset in WBV measurements, one have to be aware that using PalmTrac is time consuming. A study by Hoozemans et al. [32] concluded that obtaining reliable results with a method like PalmTrac requires measurements periods of at least 4 h. Measuring one driver of a vehicle in the field takes at least 4 h, while, in general, only a few work cycles (5–15 min) are already sufficient to measure WBV exposure alone. The benefits of using PalmTrac depend on the primary goal of the assessment. If the goal is to obtain extra, more specific data about physical work demands during a normal working day (for instance for formulating specific preventive activities), the PalmTrac system is apparently reliable and easy to use. Because it is time consuming, however, it is advisable to consider the relative utility of this extra information. The use of validated self-administered questionnaires would be recommended if this more specific information is not of use.

In the light of the newly introduced EU Directive for populations that are exposed to WBV, the need for development of intervention programmes is inevitable as drivers are still exceeding the action value of 0.5 m/s^2. The combined assessment technique that has been discussed in this article provides necessary information that can be used to help formulate such measures.

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Appendix A

For VIBRISKS study, only those questions that concern physical work demands (Section 2) were included. Specifically, this concerns question 8a, 9a, 13, 16, and 15 (see Table A1).

Table A1
Presentation of the specific questions in the VIBRISKS questionnaire and its response items concerning the physical work demands

Specific question in VIBRISKS questionnaire	Response item	Physical work demand
8a. If you add together all the time in an average working day that you spend walking and standing, how many hours does that make?	1 = <1 h, 2 = 1–3 h, 3 = >3 h	Walking + standing
9a. How long during an average working day do you work in a position with your trunk bended?	1 = 0 min, 2 = <1 h, 3 = 1–2 h, 4 = >2 h	Bending over (straight or twisted)
13. Does an average working day involve sitting for longer than 3 h at a time?	1 = <3 h, 2 = >3 h	Sitting
16. Do you have to drive during an average working day in a bended or twisted position?	1 = never, 2 = seldom, 3 = often	Sitting (twisted/leaning forward)
15. How long in an average working day do you have to lift loads?	1 = never, 2 = 0–15 min, 3 = 15–45 min, 4 = >45 min	Lifting (Subject 3 unknown)

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