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Occupational Exposure to Whole Body Vibration-Train Drivers

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Abstract: Whole body vibration exposure of the train drivers working for State Railway Lines is assessed by referring to ISO standard 2631 -1 and EU directive 2002/44/EC. The vibration measurements were done in the cabins of suburban and intercity train drivers. Suburban train driver performs his job usually in standing posture. Whereas intercity train driver works generally in seated (bending forward) posture and exposed to longer periods of continuous vibration, compared to suburban train drivers. The mean accelerations, a, along lateral, y, and vertical, z, directions measured on the driver seat (on the cabin floor) of the intercity (suburban) train were 1.4a_y = 0.55 (0.28) m/s^2 and a_z = 0.65 (0.23) m/s^2. Daily exposure action values suggested in EU directive are exceeded in case of intercity train drivers and their exposure falls within the health caution zone of ISO 2631-1. Intercity train drivers are therefore under the risk of having spinal disorders. A health surveillance plan requiring every five years the reassessment of the state of the spinal system of train drivers is suggested. As an early preventive measure, extended work day or more than one shift in a day is advised to be discouraged.

Key words: Whole body vibration, Train drivers, Spinal system, Complaint form

Introduction

Compared to air, water and noise pollution, problems relevant with vibration exposure are still not the primary concern of the governments. It is known that there is a relation between aggravated low back pain and exposed vibration but technical intervention programs are not as widespread as desired. The foreseen effects of Whole Body Vibration, WBV, lead to the publication of various directives and standards. Among these EU directive and ISO standard relevant with WBV seem to be the ones most sought by the concerned people. Whether by following the guide lines introduced in them improves the quality of the working life of those subjected to vibration in their work or whether their health status is conserved is subject matter of this study. For this purpose train drivers are chosen as target population. The main reason for this choice is the scarcity of the studies relevant with this group. The assessment of the health status of the train drivers will be done by

(i) Evaluating the whole body vibration exposure
(ii) Assessing the risk due to WBV exposure
(iii) Examining the applicability of the preventive measures
(iv) Referring to the current health monitoring program

Methods

Evaluation of the WBV exposure

Researchers and occupational health professionals either refer to ISO 2631-1(1997)[1)] (and) or to EU directive (2002)[2)] while trying to evaluate the WBV exposure of occupational groups. ISO standard requires the measurement results to be expressed in terms of frequency weighted (r.m.s) accelerations. The weightings suggested by the standard can now be found as embedded in all of the analyzers and vibration meters. In this study vibration exposure of suburban train drivers (posture: standing) and intercity (passenger) train drivers (posture: seated) are assessed. It has to be noted that train drivers (total no in Turkey=2,318) drive every type of train provided that they have the driving license associated with that type of train. Nevertheless besides having different working postures the vibration exposure periods of the two aforementioned drivers are also different. Suburban train dri-

vers are exposed to short periods whereas intercity train drivers are exposed to long periods of continuous vibration. This pilot study is done just to see the outcomes of the acceptance of the directive and the standard stated above. Stated otherwise local reflection of a more or less global approach will be tried to be displayed. The longest duration of the travel, by suburban train, between the starting and the terminal stations is 59 min. One tour (non-stop) of the suburban train driver is usually accepted to be 1 h 58 min of duration. The intercity train drivers drive the train at least for 2 h and 36 min. The measured vibration magnitudes at the supporting surfaces are given in Tables 1 (number of measurements, N=10) and 2 (N=5). The measurement setup consists of a tri-axial accelerometer (B&K 4322) and vibration level meter (B&K 2231). Since during the drive a suburban train driver rarely sits down and intercity train drivers generally sit (mostly in bending forward position), cabin floor and seat vibration values are given in the tables. Seat acceleration values are measured at the interface of the driver and the seat. The values having * mark in the tables indicate the dominant axis values. It has to be noted that vertical seat acceleration values are very close to lateral seat acceleration values in intercity trains. When floor accelerations of the two trains are considered z axis in intercity (mean a_z (floor) = 0.68, $1.4a_y$ (floor) = 0.48 m/s^2) and y axis in suburban train is dominating. Standard deviation, SD, values are also given in the tables. During the measurements the speed range of the intercity train and the suburban train was respectively 93–114 km/h (max. permissible limit=120 km/h) and 30–100 km/h. The acceleration values given in Tables 1 and 2 correspond to the upper limits of the train speeds. The mean seat a_v values for the suburban train and the floor a_v values for the intercity train were respectively 0.372 (min: 0.262, max: 0.482) m/s^2 and 0.843 (min: 0.494, max: 1.18) m/s^2. a_v values are calculated using Eq.10 given in ISO 2631-1:1997. The constants k_x=k_y and k_z appearing in the equation are taken as =1.4 and 1 for floor and seat. x axis indicates the direction of the travel (fore-aft direction), y axis designates side-to-side direction and z designates the vertical direction.

Assessment of the risk due to the WBV

Health caution zone concept introduced in ISO 2631 seems nowadays to be replaced by the limit values and exposure points suggested by EU directive 2002/44/EC and the associated vibration guides[3]. Nevertheless when the measured values given in Tables 1 and 2 are compared with those defining the health guidance caution zone, displayed in Figure B.1 of ISO2631-1, it can be seen that the weighted a_z (intercity train) values falls in the caution zone. Whereas suburban train driver values (considering y axis) are below the zone. But it has to be recalled that being below the zone must not be interpreted as "risk free" case for musculoskeletal system of the driver. As is well known "no effect" threshold[4] is not established yet for vibration exposure. EU directive and published guides encouraged the assessment of the risk for health to be done by comparing the daily exposure values of the worker with the daily exposure action and limit values. In Tables 3 and 4 A(8) (daily exposure) values and daily estimated Vibration Dose Values, eVDV, (using Equation B.5 given in ISO 2631-1[1]) are given for both of the trains. The crest factor for the suburban and intercity train was about 6. Daily vibration exposure in terms of A(8) and eVDV are calculated following the procedure described in EU guide[3].

As can be seen in the tables daily exposure values for suburban train drivers are not above the limit action values (i.e., A(8)=0.5 m/s^2 or VDV=9.1 m/s$^{1.75}$) but in case

Table 1. Weighted acceleration values (m/s^2)
(Suburban train-cabin floor)

	1.4 a_x	1.4 a_y	a_z	a_v
Min	0.01	0.18	0.13	0.23
Max	0.08	0.36	0.32	0.49
Mean	0.05	0.28*	0.23	0.36
SD	0.02	0.06	0.07	0.09

Table 2. Weighted acceleration values (m/s^2)
(Intercity train-driver seat)

	1.4 a_x	1.4 a_y	a_z	a_v
Min	0.37	0.42	0.59	0.85
Max	0.46	0.72	0.72	1.12
Mean	0.41	0.55	0.65*	0.95
SD	0.03	0.12	0.05	0.11

Table 3. Daily exposures—Suburban train
(Total daily exposure=6 h)

	x axis	y axis	z axis	Daily vibration exposure
A(8) (m/s^2)	0.1	0.3	0.2	0.3
eVDV (m/s$^{1.75}$)	1.7	8.8	7.6	8.8

Table 4. Daily exposures—Intercity train
(Total daily exposure=5 h)

	x axis	y axis	z axis	Daily vibration exposure
A(8) (m/s^2)	0.31	0.45	0.52	0.52
eVDV (m/s$^{1.75}$)	9.6	14.1	15.9	15.9

of intercity train drivers the limit values are exceeded. It has to be noted that even though the values in Tables 3 and 4 are calculated for working hours ≤ 40 h in a week (which is the usual case) it is not however unusual for the drivers to have working hours exceeding this limit and approaching to a value of ~75 h/wk.

Another way of expressing the exposure levels of the train drivers can be done by referring to exposure points, P_E calculated[3] from

$$P_E = \left(\frac{ka_w}{0.5}\right)^2 \frac{T}{8} 100 \text{ (T = exposure time in hours)} \quad (1)$$

The P_E values calculated from Eq.1 for suburban and intercity train drivers are respectively 22 points (range: 10–39 points) and 106 points (range: 87–130 points) when dominant axis values are considered. The intercity train driver's exposure points can be much more higher than 100 points if following the note of ISO 2631-1(i.e., if no dominant axis of vibration exists, vector sum, a_v, can be used in health risk evaluations) a_v values are considered. These results show that some preventive measures have to be taken in case of intercity train drivers and from now on their health surveillance reports should contain information about the condition of their spinal system.

Preventative Measures

Among the preventive measures suggested by EU directive, the ones corresponding to technical intervention, i.e., maintenance of the track and the interfaces and their renewal, is done periodically by the transport line. As the speed of the train increases the vibration magnitudes increase. Reducing the train speed can decrease the vibration exposure of the persons in the train but this will result in an increase in the travel time. Neither the railway line nor the passengers will like it. The speed limitations are based generally on the characteristics of the track and the train type not on the peak transmissibility ratio (= $a_{z\ seat}/a_{z\ floor}$) of the seat of the driver. In transport sector priority is always given to the fulfilment of the task and to the shortness of the travel time not to the wellbeing of the driver. The enthusiasm of the train drivers in doing their jobs is so great that they in general do not complain about their situations. Anyhow an ergonomically planned intervention (including the redesign of the working space and renewal of the driver seat) is needed in the driver cabins of both of the trains considered in this study.

The train drivers, in general, do not work more than 8 h/d and they are not allowed to drive more than 300 km in one day. At least 16 h of rest is respected between two consecutive tasks. The suburban train operators take their rest every 80 or 100 km. All the train drivers work 5 d in a week. They have 4 wk (=30 d) of vacation in a year. Except the special periods (like national or religious holidays) this schedule is regularly applied. Even though the level of the vibration exposure of the intercity train driver dictates a reduction in the driving hours of the driver it will not be easy to put this into action. Reduction in hours will automatically lead to a decrease in the additional income (due to the extra working hours) of the drivers and therefore will not be appreciated by them. The absence of the causal link between WBV and back ailments render it difficult to treat WBV with utmost caution. Efforts however should be spent to make the aggravating role of WBV to be well known by the drivers.

Health Surveillance

Assessment of the health effects of WBV is usually done either by medical interview or by questionnaires identical or similar to Nordic Questionnaire on musculoskeletal symptoms. In this study a questionnaire similar to Nordic Questionnaire[5] is used and the suburban drivers are interviewed in order to find out their spinal complaints associated with (waist, back), (neck, shoulder), (hip, knee, ankle, feet) and (hand, wrist). Out of 12 male suburban train driver (mean age: 41, range: 27–50 yr; range of employment years: 10–28 yr), 6 had Low Back Pain, LBP, 4 had neck-shoulder complaints. Episodes of the complaints were every day. Even in this minor group, it can be seen that, neck-shoulder problems must be treated as equally contributing, as LBP, in decreasing the quality of the work life of the drivers[6–8]. They had no opportunity for any kind of sport or exercise. They are actually "out of shape" and exposed to vibration daily. In the questionnaire there were also questions asking whether or not the complaints associated with low back and neck-shoulder affect their normal activities and cause any job away day (i.e., absenteeism). Only two of the drivers claimed that their normal activities are affected due to their complaints but none miss a job day. The drivers as well as other rail road workers currently pass a medical examination every year (in accordance with HSE's[9] suggestion). The so called general health examination covers the control of the eyes, ears, heart, lungs, liver, and nervous system of the driver and involves biochemical analysis of blood samples taken from them. In addition to these they have to pass the psycho technique test. On the onset of the job they pass the same examinations. Unless a self-reported complaint is submitted by the driver to the doctor the periodic health examination of the train drivers do not include diagnosis of musculoskeletal disorders, MSD. Questionnaire survey about MSD is not a custom and is not done till now. Formats of the baseline health and annual health examinations are identical. There is therefore neither individual nor group data relevant with the acclaimed vibration induced musculoskeletal disorders.

Discussion

The absence of "enough evidence to outline an exposure-response relationship between exposure to seated WBV and lower back disorders"[10] seems to render difficult the acceptance of vibration exposure as a serious problem both by the employers and the employees. When what has been put forward in the researches performed till now is reviewed, one can reach to a conclusion that WBV is contributively effective in the development of spinal disorders. Waddell[11] have emphasised the fact that the evidence of the link between the physical demands of work (WBV included) and LBP does not necessarily imply a causative effect. Battié[12] also have found no causal link between the lifetime occupational driving and lumbar disc generation. This does not mean that the effect of WBV on muscles tendons and neural changes at the cellular level can be ignored. In fact the blood analysis of 9 male passengers travelling in the intercity train ($a_{z\,max}$ (on the coach floor) = 0.24 m/s^2 at f = 1.25 Hz when v_{train}=114 km/h) showed changes in their CPK, Creatinin, Lactic acid, Cortisol and ESR values. At the beginning and end of a 5 h of travel (=2.5 h of travel +1 h rest +2.5 h of travel) blood samples of 10 cc were taken from each of the nine volunteer passengers. The biochemical analysis showed that after a total of 5 h of travel CPK, Creatinin and lactic acid values increased whereas cortisol and ESR values decreased (Table 5)[13]. These results can be interpreted not only as an indication of the fatigue of the passenger's muscles but also as an indication of the increased vulnerability of their spine to postural loads. It is however to be noted that the observed muscle fatigue of the passengers was not due solely to WBV but instead to the combined effect of prolonged sitting and WBV.

Even though some of the countries in Europe considered Vibration Induced Spinal Disorders, VISD, as an occupational disease most of the countries in the world do not recognize VISD as a disease. Like Turkey they have directives or standards identical or very similar to EU directive and ISO standards but VISD is not included in the list of occupational diseases. There is however general agreement that WBV is associated with an elevated risk of lumbar syndrome[14, 15]. The willingness of the train drivers in accepting extra working hours, on the other hand, shows that publication of the directives, standards and associated guideline leaflets is not enough for the recognition of the health risks associated with vibration. One of the tasks of those working on the assessment of occupation based musculoskeletal disorders appears to be therefore to encourage the performance of as many follow-up studies as possible. The pilot research presented in this study has displayed the fact that "train drivers" can be chosen as target population. A follow-up study for an adequate assessment of the temporal changes in the spinal disorders of the train drivers has to be of long duration. Starting with the new train drivers it is advised to gather information, on the status of the spinal system of the driver, every year (together with the routine medical examination of the train drivers) and reassess it, at least, every 5 yr. Bovenzi *et al.*[16] in their work on tractor drivers have shown that in the first 4 yr the prevalence odd ratio for back pain did not change with respect to WBV dose, whereas thereafter a linear relationship was observed. The slope after 10 yr was much steeper compared to 4–10 yr range. Provided that the pre-placement medical examination of the train drivers involves films (or MRI or CT) of the spine (films of upper and lower extremities included) a period of 5 yr[17] (5 yr can be stretched up to 10 yr if the age of the new employee < 25 yr[18]) can be thought to be enough for the diagnosis of the first symptoms of the back ailments. This primary period can be considered as action onset period. It is a vibration dominant period because technical interventions are not yet planned. As is well known the planning of the work station specific measures is usually triggered by the onset of the worker complaints. This period coincides also with the period during which occupational health professionals gather data relevant with the driving style, sitting postures and other cabin activities of the train drivers[19]. Within 5 to 10 yr i.e., during the secondary period, the temporal changes in the spinal disorders can be expected to occur. This period can also be regarded as the awareness (of the seriousness of VISD problems) period both for the employer and the employee. During this period technical intervention and health monitoring programmes will be in action and outcomes will be watched. It has to be noted that this posture dominant period coincides with 30–40 yr of age which is considered to be most crucial for developing lumbar degenerations due to vibration[20]. In the tertiary period of 10–20 yr (starting with the tenth year) occupational health professionals or doctors may require changes in the jobs of some drivers. The data gathered, up to this period (combined with the base health line data), can be assumed to be adequate for the display of the individual specific (also of

Table 5. Mean values of blood parameters
(train passengers, total exposure time=5 h)

	Before travel	After travel	% Change
CPK (U/ml)	5.43	7.05	30
Creatinin (mg/dl)	0.83	0.87	5
Lactic Acid (mg/dl)	11.36	13.54	19
Cortisol (μg/dl)	15.67	12.41	21
ESR (mm/h)	5.25	8.13	55

the group when normalized with respect to the confounding factors) temporal changes of the spinal disorders. It goes without saying that unforeseen confounding factors can be taken into consideration if the routine annual medical examinations is supported with questionnaire surveys about the out of work life of the train drivers and periodical observations of occupational health professionals. Even if the driver changes job, the health surveillance has to continue, up to the end of his working days. The proposed surveillance plan can be found costly and demanding a lot of time of the health and safety engineers but it is believed that in the long run it will be beneficial both for the employee and employer. In addition thus accumulated data will render possible, in the future, the publication of evidence based standards.

Conclusions

Train drivers are suggested as target population for the assessment of the combined effect of WBV and posture on the temporal changes of spinal disorders. For every driver besides the routine general health examination done annually, health data including the medical status of the upper and lower extremity is proposed to be gathered also annually. Complaint forms (taking into consideration the hereditary aspect) can be required to be filled by the drivers prior to the medical examination (Appendix A). A lifetime long follow-up study requiring every five year the updating of the assessment of the state of spinal system is suggested. Feedback relevant with the details of the out of work life of the drivers, obtained from questionnaire surveys done at least every 5 yr, is also recommended. In correlation with published vibration guides vibration exposure data as well as observation notes of the occupational health professionals are expected to be updated (provided that a base data already exists) whenever a change is introduced into the system either mechanically or ergonomically or whenever a worker complaint is submitted to the State Railway Line.

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Appendix A: Complaint form for professional drivers.

	Waist	Back	Neck-Shoulder	Hip-Knees-Legs-Feet	Arms-Wrists-Hands
Do either of your parents have complaints relevant to these regions?	Yes No	Yes No	Yes No	Yes No	Yes No
For how many years have your parents had these complaints? A) less than 1 yr B) 1–5 yr C) 5–10 yr D) more than 10 yr	A B C D	A B C D	A B C D	A B C D	A B C D
Do you have any complaint relevant to these regions?	Yes No	Yes No	Yes No	Yes No	Yes No
For how many years? A) less than 1 yr B) 1–5 yr C) 5–10 yr D) more than 10 yr	A B C D	A B C D	A B C D	A B C D	A B C D
Have you had any accident associated with these regions?	Yes No	Yes No	Yes No	Yes No	Yes No
Have you been treated in the hospital relevant with these regions?	Yes No	Yes No	Yes No	Yes No	Yes No
Have you changed your job because of your complaints?	Yes No	Yes No	Yes No	Yes No	Yes No
For how many days in the last year have you had this complaint? A) 0 B) 1–7 d C) 8–30 d D) 30–180 d E) 180–365 d	A B C D E	A B C D E	A B C D E	A B C D E	A B C D E
For how many days in the last year have your normal daily activities been affected? A) 0 B) 1–7 d C) 8–30 d D) 30–180 d E) 180–365 d	A B C D E	A B C D E	A B C D E	A B C D E	A B C D E
For how many days in the last year were you off work due to this problem? A) 0 B) 1–7 d C) 8–30 d D) 30–180 d E) 180–365 d	A B C D E	A B C D E	A B C D E	A B C D E	A B C D E
In the last year, have you received treatment because of your complaint? A) No treatment B) drug C) physical therapy D) surgery	A B C D	A B C D	A B C D	A B C D	A B C D
Have you had any complaint in the last week relevant to these regions?	Yes No	Yes No	Yes No	Yes No	Yes No