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WHOLE BODY VIBRATION STUDY OF FULLY LOADED AND NON- LOADED LORRY BASED ON ISO 2631-5(2004)

Ahmad Fuad Mohd Noor[1], Ismail Abdul Rahman[2],Musli Nizam Yahya[1], Mohd Imran Ghazali[1], Nor Azali Azmir[1], Raemy Md Zein[2], Noorul Azreen Azis[2] and Hari Krishnan Tamil Selvan[2]
[1]Noise and Vibration Analysis Research, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia Parit Raja, Batu Pahat Johor, Malaysia
[2]Ergonomics Excellence Centre, NIOSH Southern Regional Office, Jalan Persiaran Teknologi, Taman Teknologi Johor, Malaysia
E-Mail: admnoor91@gmail.com

ABSTRACT

Whole-body vibration (WBV) is the vibration energy transmitted from a workplace machine or vehicles to a person's body. The path of this vibration can be either through a seat or by standing on a vibrating surface which can cause health injuries or disorder. This high daily exposure increase the risk of long term health effect, particularly low back back pain (LBP) injury. Due to poorly and limitation on previous international standard on transient shocks which recognize the transient shocks to be dangerous to the lumbar spine, the ISO 2631-5 (2004) was produced as the only current standard that can be used to analyze shocks properly. Thus, proper research on WBV towards LBP problems was done. The determined of vibration exposure levels of lorry drivers using ISO 2631-5 (2004) standard according to route and type of lorry for loading and unloading activities. The future of vibration difference between type of lorry and route was shown in order to find the subjective correction by qualitative and quantitative analysis. Data collected by Larson Davis Vibration Meter (HVM 100) was and Tri-Axial Seat Pad Accelerometer was analyzed by BLAZE program. The value of daily equivalent static compression dose, S_{ed} and the R factor gain by calculation. Then, IBM Statistical Package for Social Science (SPSS) used to analyze the Modified Nordic Questionnaire. Found that, there are high risk of health adverse toward lumbar spine according to the value of S_{ed}. The different level of exposure for R factor was according to year's exposure. Different year's exposure related to different level of health risk by value of start working age. Thus, several ways of minimizing the exposure such as frequent health monitoring, employer provide training and job rotation as well as with installation the vibration dampers on equipment was also useful. On other hand, new guidelines of vibration exposure level suitable for off-road lorry drivers in Malaysia can be produced for future studies.

Keywords: whole-body vibration, low back pain, ISO 2631-5 (2004).

INTRODUCTION

WBV occurs when a human is supported by a surface that is shaking and the vibration affects body parts remove from the site of exposure (Mansfield, 2004). The exposure of WBV principally occurs in vehicles and wheeled working machines (Tamrin *et al.* 2007). Work-related musculoskeletal disorder, especially low back pain, cause substantial economic losses to individuals as well as to the community (Alperovitch-najenson *et al.* 2010). The work-related musculoskeletal symptoms were greatest in the low back (60%), neck (44%), and shoulders (37%). Missed work due to musculoskeletal symptoms was most prevalent in the low back (8%), ankle/feet (3%), wrist/hands (3%), and shoulders (2%). Physician visits due to musculoskeletal symptoms were highest for the low back (25%), neck (20%), upper back (13%) and shoulders (12%) (Kittusamy & Buchholz, 2004).

As we known, the exposure of WBV highly contribute to LBP problems (Kumar, 2004)(Bovenzi & Hulshof, 1999). LBP is among the most common health problems in the world. Lifetime prevalence has been estimated to be 60% - 80% for industrialized countries, having a large impact on health care utilization and on sickness absence and disability figures and cost (Hulshof, Van Der Laan, Braam, & Verbeek, 2002). The specified condition of the spine mostly related with herniated disc, degenerative disc disease, spondylolisthesis, spinal stenosis and osteoarthritis. The condition of lumbar spine while driving has been associated with the LBP problems (De Carvalho & Callaghan, 2012).

Basically, the intervertebral disc and paraspinal ligaments and muscles (soft tissues) can be at risk injury in multiple mechanical shock environments (ISO 2631-5, 2004). The ISO 2631-5(2004) provides guidance for the assessment of health effect in the lumbar spine relating to long-term exposure to WBV containing multiple shocks (Monaghan & Twest, 2004). Besides that, it defines a method of quantifying WBV containing multiple shocks (such as bumpy rides) in relation to human health (Granlund & Brandt, n.d.).

Figure-1. The example of off-road lorry.

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Table-1. The detail of lorry according to route.

Route 1							
Model	Number of lorry	Phase	% Time for each phase	Duration of measurement	Trips	Length (m)	Age of lorry
HINO	6	Unloaded Travel Loaded Travel	37.5 62.5	8 minutes	6/hours	800	10-15 years
FUSO	7						
Route 2							
Model	Number of lorry	Phase	% Time for each phase	Duration of measurement	Trips	Length (m)	Age of lorry
HINO	7	Unloaded Travel Loaded Travel	40.6 59.4	16 minutes	4/hours	1200	10-15 years
FUSO	14						

Thus, the study needs to be conducted in systematic ways to fulfill the requirement and achieve good outcome. The main focus for the study was to determine the exposure levels for the off-road driver using the ISO 2631-5 (2004) standards according to the normal working hours. The measurement of exposure levels were collected from difference type of lorry and route. Those off-road lorry drivers will undergo normal activities of loading and unloading. The activities were categorized according to the type of lorry and route taken. The vibration exposure data collected was evaluated due to the vibration significant different based on the type of lorry and the route taken on the subjective correlation using questionnaire analysis. The prevalence of LBP analyzed directly according to the qualitative and quantitative analysis from both data measurements.

METHOD

The subject for this research was involved off-road lorry driver with average daily 8 hours working per day. There are 34 participants involved in the study. The driver must be good in health and were interviewed using the modified WBV questionnaire in Malay version adapted from Standardized Nordic Questionnaire for the musculoskeletal symptoms analysis (Kuorinka *et al.* 1987). The questionnaire was divided into five categories ;(i) personal identification,(ii) working information,(ii) bus condition,(v) worker health; and (iv) back pain problems. The drivers undergo interview session for five minutes in order to collect the statistical data based on questionnaire. Basically the lorries are used for the mining activities that performing haul and dump process. The example of off-road lorry can be referring in Figure-1 with the detail of lorry according to route shown in Table-1.

Procedure

The data measurement tools were Tri-Axial seat accelerometer and Spectral human vibration meter analyzer (HVM 100). The weighting-frequency and the direction axes of seat-pad accelerometer according to ISO 2631-1 (1997). The measurement took placed during standard working periods which undergo loading and unloading activities. The time taken for each lorry to complete a cyclical nature of haul and dump activities can be refer as percentage of time per duration of measurement. The measures for the cyclical nature of loading and unloading activities were considered representative of exposures for the shift (Mayton, Jobes, & Miller, 2009). Thus, cyclical nature for each road was according to duration of measurement in Table-1. The measurement should at least three minutes with at least three repeat measures taken (Mansfield, 2004). Drivers could complete different numbers of trips at route 1 and 2 due to different length of roadway itself. The data collected analyze by using BLAZE software and SPSS software.

Analysis

The collected data of vibration exposure by HVM 100 will be transferred and analyzed by using the BLAZE software. The software will provide the results of such the peak acceleration value. Thus, static compressive dose (S_{ed}) which has been developed through biomechanical modeling in order to capture the linear relationship between peak acceleration and input shocks to responses in the spine (Blood, Ploger, Yost, Ching, & Johnson, 2010). The detail of S_{ed} can be referring in equation (1).

$$S_{ed} = \left[\sum_{k=x,y,z}(m_k D_{kd})^6\right]^{\frac{1}{6}} \quad (1)$$

The value of $m_k$are constant for the vertical and horizontal directions with value according of m_x= 0.015 MPa/(m/s^2), m_y = 0.015 MPa/(m/s^2), m_z = 0.015 MPa/(m/s^2). The formula to calculate the value of D_{kd} can refer to equation (2).

$$D_{kd} = D_k\left[\frac{t_d}{t_m}\right]^{\frac{1}{6}} \quad (2)$$

Where, t_d = duration of daily exposure, t_m= period over which D_k has been measured. The formula of D_k can be refer to equation (3) below.

$$D_k = [\sum A_{ik}^6]^{\frac{1}{6}} \tag{3}$$

This information was then used to determine the daily equivalent static compression dose, S_{ed} which is used to compute a risk factor, R factor. In general, a factor R can be defined for use in the assessment of the adverse health related effects related to the human response acceleration dose. The R should be calculated sequentially taking into increased of age and reduced of strength as the exposure time increase. The equation R factor is shown in equation (4).

Where,
N = Number of exposure days per year;
I = the year counter;
n = number of years of exposure;
c = 0.25 MPa (driving posture);
S_{ui} = 6.75 – 0.066 (b + i);
b = the age at which the exposure starts;

According to ISO 2631-5 (2004) provide the assessment of adverse health effects on drivers. For the assessment of S_{ed} was related to health effect at lifetime exposure with detail below;

- S_{ed} below 0.5 MPa: low probability of an adverse health effect.
- S_{ed} above 0.8 MPa: high probability of an adverse health effect.

For the assessment of *R* factor was related to health effect at n years of exposure with detail below;

- *R* below 0.8: low probability of an adverse health effect.
- *R* above 1.2: high probability of an adverse health effect.

The data collected from the questionnaire analyze by IBM Statistical Package for Social Science (SPSS). This statistical analysis was used to determine the relation of WBV toward the absence of LBP among lorry drivers. The testing of correlation was applied in order to know the relationship between two variables numerically. The null hypothesis for the study can be rejected or not depend on the strength of correlation which was the value of *p*-value and *a*-value. The strength of *a*-value was by the significant correlation as below.

- Moderate-weak < 0.5
- strong-very strong ≥ 0.6

The decision making on correlation testing of null hypothesis was when the significant value of *p*-value ≤ 0.05.

RESULT AND DISCUSSION

The Table-2 shows results from the WBV exposure from loading and unloading activities according to the different route 1 and 2. The data obtained the value of daily equivalent static compression dose, S_{ed} are possibilities of high health effect due to WBV exposure. At route 1, lorry type of F29 FUSO contributes highest value of S_{ed} equal to 1.519 MPa under unloading activities. The F923 FUSO contributed highest value of S_{ed} for loading activities which equal to 1.372 MPa. The different vibration produce by the machine itself can be differentiate according to several external influence factors such as speed (Ismail, Nuawi, Kamaruddin, & Bakar, 2010)(Park, Fukuda, Kim, & Maeda, 2013), route condition (Granlund & Brandt, n.d.) and condition of machine (Mayton *et al.* 2009). The range of vibration exposure of FUSO for loading activities was 1.115 MPa to 1.378 MPa and unloading activities with range of 1.316 MPa to 1.519 MPa. For HINO, the range value of exposure for loading activities was 1.083 MPa to 1.325 MPa and unloading activities from 1.231 MPa to 1.495 MPa which slightly lower that FUSO.

At route 2, WBV exposure slightly higher than exposure at route 1. The length of the roadway at route 2 was longer than roadway at route 1. Meant that, increasing length of roadway will increase in term of vibration intensity toward driver for each routine. It generally takes several years for health changes caused by whole-body vibration to occur. It is therefore important that exposure measurements became the representative of the whole exposure period (ISO 2631-1, 1997). HINO 122h contribute highest value of S_{ed} by value of 1.582 MPa also for the unloading activities and for loading activities the highest contribution of vibration exposure by FUSO 616 with S_{ed} of 1.453 MPa. The range S_{ed} vibration value for loading activities was 1.007 MPa to 1.437 MPa and for unloading activities from 1.144 MPa to 1.623 MPa. The detail of influence factor that can cause of different value for each route such as speed shown in Table-3. The static compression dose is generally increasing with speed. Drivers, who make some 30 trips daily on this road, cannot drive more than 10 km/h before the limit value exceeded (Granlund & Brandt, n.d.). Besides that, the lower value of loading compared to the unloading due to decreasing speed cause by load. The speed of fully loaded truck is able to be reduced, especially when travelling uphill, which may reduce WBV amplitude (Wolfgang & Burgess-Limerick, 2014). The speed of driving had great effect on the magnitude of the vibration exposure. Decrease vehicle mass and increased driving speeds associated with unloaded travel contribute to the high vibration acceleration (Kumar, 2004).

Other than influence of speed towards various data distribution based on analysis previous, the condition of roadway also can give huge impact on higher value of S_{ed}. Basically, Majority of shocks (jars/jolts) occurred at the loader, dump, and the wash out just below the entrance to the pit road, and the corner approaching the loader that the trucks took at a fairly high speed. Drivers entered this turn with no loaded (truck empty of material) and were travelling downhill (Mayton *et al.* 2009). For the rough

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roads if the driver is exposed more than 30 to 35 minutes he will feel uncomfortable (Katu, Desavale, & Kanai, 2003). More than that, the effect of roadway condition on vertical accelerations experienced by haul truck drivers is potentially large. It is likely that roadway maintenance will be an effective control measure to reduce WBV exposure of haul truck drivers (Wolfgang & Burgess-Limerick, 2014).

Basically, the analysis of *R* factor take into account the number of years and days per year of exposure and factors in the vertebrae bone ultimate strength that depends on the age of the operator at the time of exposure. Related to bone density, which normally reduced with age (Alem, 2005). Addition with increasing intensity at vertical acceleration also can contribute to the high risk of health adverse effect on lumbar spine. For example, the road roughness, vertical acceleration of vehicles cause passenger to experience discomfort, when a vehicle is being drive over the road, the oscillations of its spring have frequencies which has not only depend on the road impulses or bumps are encountered but also on the relation between the spring stiffness and the mass of the spring part of vehicle (Katu *et al.* 2003). This phenomenon excessively risk toward LBP problems.

The assessment of *R* factor for route 1 shows that the FUSO F923 drivers suffered high intensity on vibration exposure which directly to the lumbar spine with the value of 1.189 under unloading activity. While 1.172 value of *R* factor vibration intensity during loading activity. Knowing that the amount of weight and where the load was placed could affect the level of vibration and some of operators who performed this job had indicated that they had back pain and discomfort when travelling over entire work cycle (Salmoni, Cann, Gillin, & Eger, 2008). This value vibration exposure experience by drivers could be influence by factor of age start and years of exposure. The range of vibration intensity for the *R factor* assessment was from 0.611 to 1.189 for and 0.611 to 1.172 for loading and unloading activities respectively.

Meanwhile, at route 2, the highest intensity of WBV experience by drivers was from FUSO 616 with value of 1.369 also during unloading activity while the value during unloading activity was equal to 1.381. The range of vibration intensity at route 2 was from 0.550 to 1.369 and 0.523 to 1.381 for unloading and loading activities. Based on the result, the driver has exceeded the higher value of exposure which equal to 0.8 although has not reach the age of 65. According to the (ISO 2631-5, 2004), when a person who starts being exposed at the age of 20 years (b=20) will reach R=0.8 at the age of 65 (n=45) if daily is equal to 0.5 MPa. The same person will reach R=1.2 at the age of 65 if the daily dose S_{ed} is equal to 0.8 MPa. This shows that external factor has contributed huge influence towards the increasing assessment value for the daily dose S_{ed} and also for the assessment of *R* factor.

Table-2. Assessment of WBV exposure according to ISO 2631-5 (2004).

Route 1						
FUSO						
Model	Age start	Years exposure	S_{ed} (Mpa)		*R Factor*	
			loading	unloading	Loading	unloading
F923	20	11	1.372	1.425	1.172	1.189
F10	20	2	1.291	1.329	0.761	0.760
F661	19	1	1.312	1.329	0.670	0.628
F626	24	1	1.155	1.360	0.707	0.663
F29	19	3	1.338	1.519	0.894	0.920
F511	23	4	1.248	1.316	0.902	0.873
HINO						
H19	27	10	1.325	1.367	1.014	0.941
H860	22	6	1.083	1.306	0.871	0.861
FZ9	24	1	1.231	1.231	0.934	0.913
951	28	10	1.246	1.259	0.831	0.815
308	26	1	1.244	1.259	0.611	0.611
126	41	6	1.299	1.427	1.003	1.022
F7	19	10	1.289	1.495	0.688	0.684

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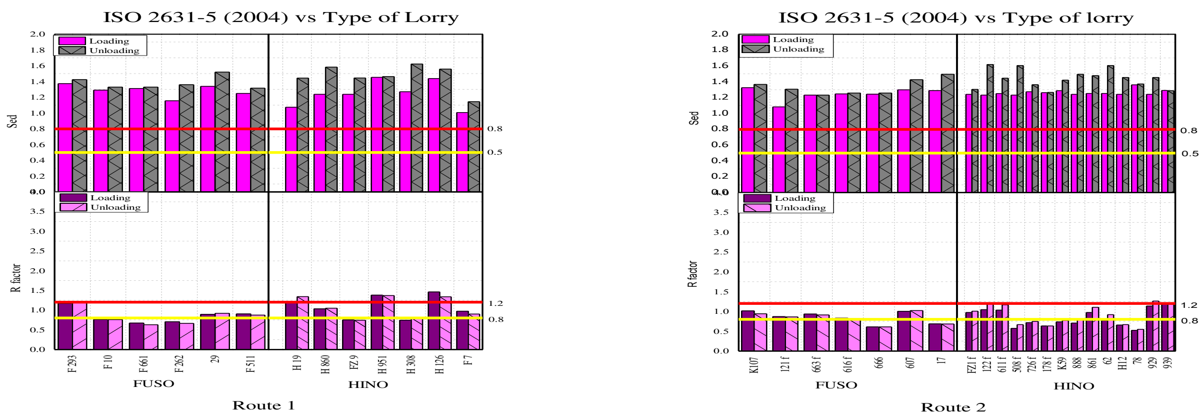
Route 2						
FUSO						
Model	Age start	Years exposure	S_{ed} (Mpa)		*R Factor*	
			loading	unloading	Loading	unloading
K107	20	7	1.074	1.444	1.188	1.342
121	25	5	1.238	1.582	1.034	1.049
663	22	6	1.238	1.445	0.750	0.745
616	20	4	1.453	1.462	1.381	1.369
666	30	0.4	1.269	1.623	0.742	0.800
607	35	3	1.437	1.557	1.461	1.338
17	21	0.9	1.007	1.144	0.973	0.901
HINO						
FZ1	19	8	1.241	1.305	0.974	1.005
122h	34	4	1.232	1.619	1.046	1.188
612h	39	3	1.250	1.446	1.035	1.166
508h	30	0.3	1.232	1.606	0.572	0.666
726h	20	2	1.274	1.364	0.716	0.749
178h	27	0.6	1.262	1.266	0.632	0.633
K59h	40	0.4	1.286	1.421	0.737	0.769
888h	17	2.3	1.241	1.495	0.705	0.789
861	28	5	1.253	1.478	0.974	1.107
62	16	4	1.252	1.606	0.769	0.918
H12	20	0.9	1.241	1.454	0.654	0.669
78	25	0.2	1.361	1.373	0.523	0.550
929	25	10	1.242	1.454	1.138	1.262
939	26	10	1.291	1.286	1.215	1.179

Table-3. Speed of lorry according to route.

Route 1				Route 2			
Loading		Unloading		Loading		Unloading	
Max speed (km/h)	Average speed (km/h)	Max speed (km/h)	Average speed (km/h)	Max speed (km/h)	Average speed (km/h)	Max speed (km/h)	Average speed (km/h)
17.6	12.1	20.1	15.7	15.8	12.7	13.7	11.3



(i)

Figure-2. (i) Exposure level at route 1 and (ii) Exposure level at route 2.

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The statistical analysis focuses on the subjective correlation from the questionnaire questions. Thus, two main statistical objectives have been highlighted as Table-4 below.

Table-4. The research statistical objective.

No	Statistical Objective (SO)
1	The effect of WBV on human body part
2	The contributing factor for LBP problems

Thus, to obtain the results for the SO1 (statistical objective 1) and SO_2 data from sample of population, 35 and 34 sample are able to perform the correlation analysis. The maximum age drivers who participate in this research were 42 with average of late 20's. Basically, the drivers experience at least two months of driving and average of four to five months. The future detail of demographic result of participants involved can be referred at to Table-5. For the SO1, the most effected body part from the WBV vibration was the low back pain problems. If there were absence of LBP problems since last 12 months, it can be ensure that the drivers will suffer pain for last 7 days with value of *p*-value equal to 0.912**. This shows that z-axis was the dominant axis for the transmission of WBV (Salmoni *et al.* 2008). The others effect of WBV on human body can shows in Table 6 below.

Table-5. The demographic results of participants.

Question	Min	Max	Mean	Std. Deviation
Age	20	42	28.91	6.14
Weight	47	89	62.38	12.40
Height	130	176	157.88	12.90
Years working as a lorry's driver	.20	11.00	4.406	3.52
The duration of driving a single trip	8.00	8.00	8.00	0
The length time to complete a single trip	8.00	12.00	10.59	1.94
The total lorry trips per day	32	48	37.65	7.76
The duration of rest taken before the next trip	1	1	1	0

Table-6. The statistical data for SO1.

SO1	*p*-value	
	Last 7 days	Last 12 months
Low back	0.774**	0.881**
Upper back	0.388*	0.501**
elbows	0.497**	0.583**
Wrists/hand	0.415*	0.594**
knees	0.444**	0.482**
Suffering LBP right after driving	0.392*	0.638**

**significant $p < 0.01$;*significant $p < 0.05$

The results for SO1 already obtained, and there was contributing factor for LBP to happen in term of statistical approached. Based on the analysis done, the results show that the main factor that can cause the LBP was the year's exposure of WBV towards drivers itself. The value of *p*-value equal to 0.415* which correlation was the moderate evidence. WBV absorbed by the human body increase with an increase in the duration and magnitude of the vibration exposure by the driver (Ismail *et al.* 2010). There is evidence that long-term exposure to WBV containing multiple shocks can lead to adverse effects on the lumbar spine (ISO 2631-5, 2004). The others factors for SO_2 also can be refer to Table-7 below.

Table-7. The statistical data for SO_2.

SO2	*p*-value
Year's exposure	0.415**
Age of drivers	0.368*
^Total lorry per day	0.883**
^time to complete single trips per minutes	-1.000**

**significant $p < 0.01$;*significant $p < 0.05$; ^correlate to each other

The factor of age was compiled with analysis of R factor because different ages are related to varies bone density of the vertebrae and will be reduced parallel with age (ISO 2631-5, 2004). If the drivers are exposed at early age and continuously until late 60's, for sure will adverse for health problems especially LBP. From the analysis obtained, if the total lorry per day increase, the exposure of WBV toward driver will go higher. The alarming fact is, that even after as few as three daily trips on this stretch, the health risk is high (Granlund & Brandt, n.d.). In addition, time complete single trips negatively relation with total lorry per day with *p*-value -1.000**. If the total lorry per day increases, the time taken to complete single trip must be reduced in order to avoid the continuous WBV exposure. This is caused of increasing duration, vibration intensity, and vibration dose and assumed to increase the risk, while periods of rest can reduce the risk.

CONCLUSIONS

The study was about the exposure of whole-body vibration (WBV) among the off-road lorry driver with the guide of ISO 2631-5 (2004). Adverse effects on the lumbar spine are the dominating health risks of long-term exposure to vibration containing multiple shocks. The assessment of LBP problems based on the WBV can be represented by the Daily equivalent static compression dose, S_{ed} and the R factor. There are some limitations for this research, such as weather, unfixed point of haul and dump, different number of lorry at each route. For the example, the loading activity there has no exact weight but the different between loading and unloading activities can be justified by the absence of load (soil or rock) without in term of specified weight. The results obtained show that there were high intensity of exposure toward human body. At higher magnitudes, vibration constitutes a health risk, and occupations with the high vibration exposures have been linked with high incidences of LBP. Thus, additional effort should be made in order to minimize the exposure. In addition, in this highly risk industry the vibration exposures should be reduced. One method of reducing exposure is to design seats such that they isolate the occupant from the vibration. Recommend of retrofitting the truck with new suspension systems also useful. The detail and good care must be taken into the specification and adjustment of suspension seats to ensure that occupants are not exposed to end-stop impacts that might introduce an even more serious risk. Thus, future studies are needed in order to provide more clear and strong evidence that complied under normal working situation.

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REFERENCES

[1] Alem, N. (2005). Application of the new ISO 2631-5 to health hazard assessment of repeated shocks in U.S. Army vehicles. Industrial Health, 43(3), 403–412.

[2] Alperovitch-najenson, D., Santo, Y., Masharawi, Y., Katz-leurer, M., Ushvaev, D., & Kalichman, L. (2010). Low Back Pain among Professional Bus Drivers : Ergonomic and Occupational-Psychosocial Risk Factors, 12(January).

[3] Blood, R. P., Ploger, J. D., Yost, M. G., Ching, R. P., & Johnson, P. W. (2010). Whole body vibration exposures in metropolitan bus drivers: A comparison of three seats. Journal of Sound and Vibration, 329(1), 109–120.

[4] Bovenzi, M., & Hulshof, C. T. (1999). An updated review of epidemiologic studies on the relationship between exposure to whole-body vibration and low back pain (1986-1997). Int.Arch.Occup.Environ.Health, 72(0340-0131 SB - IM), 351–365.

[5] De Carvalho, D. E., & Callaghan, J. P. (2012). Influence of automobile seat lumbar support prominence on spine and pelvic postures: A radiological investigation. Applied Ergonomics, 43(5), 876–882.

[6] Granlund, J., & Brandt, A. (n.d.). Bus Drivers' Exposure to Mechanical Shocks Due To Speed Bumps, (8), 1–10.

[7] Hulshof, C. T. J., Van Der Laan, G., Braam, I. T. J., & Verbeek, J. H. a. M. (2002). The Fate of Mrs Robinson: Criteria for Recognition of Whole-Body Vibration Injury as an Occupational Disease. Journal of Sound and Vibration, 253(1), 185–194.

[8] Ismail, A. R., Nuawi, M. Z., Kamaruddin, N. F., & Bakar, R. A. (2010). Comparative assessment of the whole-body vibration exposure under different car speed based on Malaysian road profile. Journal of Applied Sciences, 10(14), 1428–1434.

[9] ISO 2631-1. (1997). Mechanical vibration and shock. Evaluation of human exposure to whole-body vibration. Part 1.

[10] ISO 2631-5. (2004). Mechanical vibration and shock-Evaluation of human exposure to whole-body vibration-Part 5: Method for evaluation of vibration containing multiple shocks. ISO 2631-5 (2004).

[11] Katu, U. S., Desavale, R. G., & Kanai, R. a. (2003). Effect of Vehicle Vibration on Human Body – RIT Experience. NaCoMM, 1–9.

[12] Kittusamy, N. K., & Buchholz, B. (2004). Whole-body vibration and postural stress among operators of construction equipment: A literature review. Journal of Safety Research, 35(3), 255–261.

[13] Kumar, S. (2004). Vibration in operating heavy haul trucks in overburden mining. Applied Ergonomics, 35(6), 509–520.

[14] Kuorinka, I., Jonsson, B., Kilbom, a, Vinterberg, H., Biering-Sørensen, F., Andersson, G., & Jørgensen, K. (1987). Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. Applied Ergonomics, 18(3), 233–237.

[15] Mansfield, N. J. (2004). Human response to vibration. CRC Press.

[16] Mayton, A. G., Jobes, C. C., & Miller, R. E. (2009). Comparison of whole-body vibration exposures on older and newer haulage trucks at an aggregate stone quarry operation. 2008 ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, DETC 2008, August 3, 2008 - August 6, 2008, 5, 685–690.

[17] Monaghan, S. J., & Twest, D. C. Van. (2004). whole-body vibration – review of Australian and International standards and the future Whole-Body Vibration History of WBV Evolution of WBV Standards, (November), 609–614.

[18] Park, M., Fukuda, T., Kim, T., & Maeda, S. (2013). Health Risk Evaluation of Whole-Body Vibration by ISO 2631-5 and ISO 2631-1 for Operators of Agricultural Tractors and Recreational Vehicles. Industrial Health, advpub, 364–370.

[19] Salmoni, A. W., Cann, A. P., Gillin, E. K., & Eger, T. R. (2008). Case studies in whole-body vibration assessment in the transportation industry-Challenges in the field. International Journal of Industrial Ergonomics, 38(9-10), 783–791.

[20] Tamrin, S. B. M., Yokoyama, K., Jalaludin, J., Aziz, N. A., Jemoin, N., Nordin, R., Abdullah, M. (2007). The Association between risk factors and low back pain among commercial vehicle drivers in peninsular Malaysia: a preliminary result. Industrial Health, 45(2), 268–278.

[21] Wolfgang, R., & Burgess-Limerick, R. (2014). Whole-body vibration exposure of haul truck drivers at a surface coal mine. Applied Ergonomics, 45(6), 1700–1704.