

Mechanical Function Analysis of Whole-Body Vibration (WBV) Exposure and Musculoskeletal Disability Index Among Malaysian Train Drivers

Farah Nurdiyana Yazid^a, Alia Farhana Mahyuddin^a, Fairus Muhamad Darus^a, Ayuni Nabilah Alias^b,
 Aida Soraya Shamsuddin^c & Nurulain Mustafa Udin^{a*}

^a*School of Chemistry and Environment, Faculty of Applied Sciences,
 Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia*

^b*Department of Resource Management and Consumer Studies, Faculty of Human Ecology,
 Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia*

^c*Institute for Environment and Development (LESTARI),
 Universiti Kebangsaan Malaysia, Selangor, Malaysia*

*Corresponding author: nurulainmustafa@uitm.edu.my

Received 16 January 2026, Received in revised form 20 June 2026
 Accepted 20 July 2026, Available online 30 September 2026

ABSTRACT

Train drivers are exposed to prolonged sitting and whole-body vibration (WBV) during train operation, which may increase the risk of musculoskeletal disorders. This study assesses the WBV exposure levels and estimated the prevalence of neck pain and low back pain (LBP) among train drivers. WBV exposure was evaluated for six train drivers using $A(8)$ and vibration dose value (VDV (8)) in accordance with ISO 2631-1:1997 and EU Directive 2002/44/EC. A cross-sectional survey involving 51 train drivers was conducted using socio-demographic and occupational questionnaires, as well as the Standardised Nordic Questionnaire, the Neck Disability Index (NDI), and the Oswestry Disability Index (ODI). The mean $A(8)$ and VDV (8) values (1.174 m/s^2 and $35.0 \text{ m/s}^{1.75}$, respectively) exceeded the Exposure Action Value and Exposure Limit Value. A high prevalence of LBP (78.4%), as well as upper and lower neck pain (49.0% and 47.1%, respectively) was observed. Respondents reported functional limitations related to neck pain, while 64.7% of drivers had moderate to severe disability associated with prolonged sitting and ergonomic strain. These findings highlight the need for effective control measures to reduce WBV exposure and mitigate the impact on musculoskeletal health among train drivers.

Keywords: Whole-Body Vibration (WBV); mechanical function; system elements; musculoskeletal disability

INTRODUCTION

Whole-body vibration (WBV) is a mechanical stimulus that is transmitted through the body via a vibrating surface. It normally occurs when vehicles or machinery are used by persons sitting or standing. WBV exposure is a chronic occupational risk in the transportation (particularly railway) industry. WBV affects approximately 285 million workers worldwide. Train operators are particularly affected because they face vibration exposure from their seats, backrests, and operating platforms (International Labour Organisation 2023).

Rail transportation forms the backbone of Malaysia's national mobility system. In 2022, a total of 148 million

passengers were recorded, showing a significant surge of 134% relative to the previous year (Ministry of Transport Malaysia, 2023). Train operators face increased pressure from rising demand, working longer and more frequent shifts that result in amplified WBV exposure. Exposure of the human body to frequencies close to the natural resonance frequency, particularly those between five and seven hertz, may be especially detrimental to the spine and musculoskeletal system (Singh et al. 2019; Karmakar 2023).

Lower back pain (LBP) is one of the most prevalent musculoskeletal disorders (MSDs) reported among occupational drivers. It leads to rigidity, poor mobility, and reduced quality of life (Ali et al. 2019). Neck pain is a

prevalent condition that has been linked to high social and economic costs because of reduced work productivity and increased healthcare expenditure (Kazeminasab et al. 2022). Many studies on the occurrence of LBP and neck pain among drivers exposed to WBV have shown high prevalence rates in various countries, including Malaysia (Mad Isa et al. 2018; Maduagwu et al. 2021).

There are several research on this subject conducted internationally, but limited local data exist on train drivers. These workers typically spend long hours in a sedentary sitting position, which, when coupled with WBV, can hasten lumbar disc degeneration and LBP symptoms (Arma et al. 2019; Zhang, 2022). Standards such as ISO 2631 Part 1 (1997) and Directive 2002/44/EC from the European Union are referred to for WBV exposure limits. Still, adequate compliance with and surveillance of these standards are absent in most instances.

This study attempts to analyse the relationship between work-related factors and the occurrence and prevalence of LBP among Malaysian train operators. The outcomes will contribute to the development of effective work practices, healthier working conditions, and the well-being of transportation workers.

METHODOLOGY

PARTICIPANTS

The research was conducted in one of the selected railways in Malaysia; the journey was undertaken between the Kuala Lumpur Sentral Station and the Klang Station in Selangor and vice versa. The chosen route is a traditional Malaysian railroad system, and its tracks are in different states with different conditions. The train line has 15 intermediate stations and high-frequency services, which makes it an appropriate means of determining the exposure of WBV among the train drivers. WBV data were collected three times during each round trip, covering multiple segments of the route. Measurements were taken on weekdays during normal operating hours to reflect actual working conditions.

The study population consisted of full-time train drivers employed within the Malaysian public rail transportation sector. All participants were male, aged 18 years and above, having at least one year of experience in their current role. Only drivers who operated fixed, full-time routes exceeding 110 kilometres daily were included. Those with a history of MSDs unrelated to work, previous back or spinal surgeries, bone deformities, or other medical conditions that could affect study outcomes were excluded. Participation was voluntary, and only complete responses were included in the final analysis.

EXPERIMENT DESIGN AND PROCEDURE

WBV levels were measured using the SVANTEK SV106D Human Vibration Meter (Figure 1), a tri-axial device compliant with ISO 2631-1 standards. A triaxial seat-type disk accelerometer (SV38V) (Figure 2) was installed on the driver's seat pan to record acceleration in the longitudinal (x), lateral (y), and vertical (z) axes. Data collected included root mean square (RMS) acceleration, vibration dose value (VDV), and daily exposure levels represented by A (8) and VDV (8). These values were calculated according to standardised formulae, and the exposure levels were compared with internationally known threshold limits according to ISO 2631-1:1997 and EU Directive 2002/44/EC (Table 1). Compliance and potential health risk assessments were conducted using both action values and limit values.



FIGURE 1. SVANTEK SV106D Human Vibration Meter



FIGURE 2. SV38V Triaxial Seat-Type Disk Accelerometer

TABLE 1. Exposure Action Values (EAV) and Exposure Limit Values (ELV) for A (8) and VDV (8) Based on Standards

Standards		A (8) (m/s ²)	VDV (8) (m/s ^{1.75})
ISO 2631-1:1997	EAV	0.43	8.5
	ELV	0.86	17.0
EU Directive 2002/44/EC	EAV	0.5	9.1
	ELV	1.15	21.0

Subjects in this study completed self-administered questionnaires to measure the occurrence and degree of LBP. The instrument contained five components: socio-demographic data, occupational exposure, Standardised Nordic Questionnaire (SNQ), Neck Disability Index (NDI), and Oswestry Disability Index (ODI). Musculoskeletal discomfort within several areas of the body, such as the lower back, was determined by the SNQ and rated on a 4-point Likert scale. The end scores were broken down into four levels of intervention: low, medium, high, and very high, based on discomfort intensity and frequency. The ODI was also used to quantify the disability level due to LBP, with drivers being classified into different categories based on their functional limitation, ranging from minimal to bed-bound restriction. Equation 1 summarises the calculation of the ODI score:

$$\text{ODI (\%)} = \frac{\sum \text{ of Respondents score}}{\text{No. of section answered} \times 5} \times 100 \quad (1)$$

The NDI was used to assess the impact of neck pain on respondents' quality of life. The NDI consists of ten sections, each targeting a specific daily activity potentially affected by neck discomfort. Participants responded to each item using a 6-point Likert scale ranging from 0 (no disability) to 5 (maximum disability). The total score was computed by summing the individual item scores, then doubling the total to yield a percentage score out of 100. All data were analysed using IBM SPSS Statistics Version 29.0. Descriptive statistics were used to summarise participants' characteristics, WBV exposure levels, and LBP symptoms.

RESULTS AND DISCUSSION

WBV EXPOSURE BASED ON A (8) AND VDV (8)

WBV exposure was assessed using the A (8) and VDV (8) metrics, which capture continuous and impulsive vibration profiles, respectively, as outlined in ISO 2631-1:1997 and the EU Directive 2002/44/EC.

A (8) EXPOSURE LEVELS

A (8) provides a measure of continuous vibration exposure by incorporating both the amplitude and duration of the vibration signal (Wallis, 2022). Table 2 shows the highest A (8) value, which was recorded in Train 1, with 1.174 m/s² (SD = 0.129), followed by Train 2 at 1.153 m/s² (SD = 0.131), and Train 4 at 1.148 m/s² (SD = 0.132). The remaining trains exhibited slightly lower A (8) values: Train 3 (1.147 m/s², SD = 0.130), Train 6 (1.136 m/s², SD = 0.145), and Train 5 (1.116 m/s², SD = 0.136).

All values exceeded the EAV recommended by both ISO 2631-1:1997 and the EU Directive 2002/44/EC, which stipulate an A (8) threshold of 0.5 m/s². Comparatively, Kowalczyk and Opala (2024) reported a maximum A (8) value of 1.376 m/s² among metro train operators, which also exceeded regulatory limits. The relatively higher WBV levels observed in this study may be attributed to the operational characteristics of the trains, which typically cover longer distances with fewer stops than metro systems. Additionally, the track conditions and lower damping performance of the suspension systems could further contribute to higher vibration amplitudes. In contrast, WBV exposure among heavy equipment vehicle operators was reported to be substantially lower, with a maximum A (8) of 0.55 m/s² (De La Hoz-Torres et al. 2022). The outcomes might result from vehicles generally having advanced suspension technology intended to dampen vibrations from the road surface.

VDV (8) EXPOSURE LEVELS

VDV (8) is sensitive to transient shocks and peak accelerations over the working day and is more sensitive in environments that have varying levels of vibration, such as moving trains (Gracey 2024). Trains 4, 5, and 6 showed the highest VDV (8) values, 35.0 m/s^{1.75} (SD = 4.7). Train 3, with 34.1 m/s^{1.75} (SD = 4.6), came next, followed by Train 2, with 26.9 m/s^{1.75} (SD = 3.6), and finally Train 1, with 26.5 m/s^{1.75} (SD = 3.5). These VDV (8) values were significantly higher than those reported previously in metro train systems, where Kowalczyk and Opala (2024) reported a maximum VDV (8) of only 1.456 m/s^{1.75}, well below the EAV and ELV as defined by ISO and EU directives. A rapid escalation in these trains is probably associated with unpredictable railway servicing and their twin role in commodity transport, situations that result in persistent variations of trembling and shock phenomena. Besides, the top VDV (8) value of 12.78 m/s^{1.75} for drivers of heavy machinery was significantly lower than the value reported in the present study (De La Hoz-Torres et al. 2022). This is due to the fact that the VDV levels in trains are higher

owing to increased mass, high operating speed, and geometry of the tracks, which contribute to higher vibration transmission into the body of the vehicle to the driver.

COMPLIANCE WITH ISO AND EU STANDARDS

Vibration exposure levels documented in this investigation were above the benchmarks specified in both ISO 2631-1:1997 and EU Directive 2002/44/EC for A (8) and VDV (8). ISO sets A (8) limits at 0.43 m/s² (EAV) and 0.86 m/s² (ELV), while for VDV (8), limits are 8.5 m/s^{1.75} (EAV) and 17 m/s^{1.75} (ELV) (Orelaja et al. 2019). The European Union specifies EAV and ELV thresholds for A (8) as 0.50 m/s² and 1.15 m/s², respectively, and for VDV (8), the boundaries are 9.1 m/s^{1.75} (EAV) and 21 m/s^{1.75} (ELV) (Orelaja et al. 2019).

Without exception, the measurements went above both the EAV and ELV and landed within or beyond the

boundaries of the Health Guidance Caution Zone (HGCZ). Train drivers are regularly subjected to WBV levels that surpass safe thresholds, a situation that raises the likelihood of long-term health issues such as LBP and MSDs (De La Hoz-Torres et al. 2022; Neto & Gomes, 2018). Even though crossing the EAV threshold does not inevitably lead to immediate outcomes, sustained exposure above the ELV level is much more severe. This emphasises the pressing requirement for proactive steps, such as mechanical improvements or management protocols, to minimise WBV and ensure driver wellness at work (Azrah et al. 2016; Lynsey 2023; Newton 2024). Former studies have correlated such exposures with spinal symptoms, LBP, and MSDs (Zanatta et al. 2019; De La Hoz-Torres et al. 2022). The evidence demonstrates an immediate requirement for anticipatory strategies to minimise WBV exposure risks for locomotive engineers.

TABLE 2. A (8) (m/s²) and VDV (8) (m/s^{1.75}) among Train Drivers (N = 6)

Train No.	Axis	Weighted RMS, aw (m/s ²)	A (8) (m/s ²)	VDV (m/s ^{1.75})				Total VDV, VDV _s (m/s ^{1.75})	VDV (8) (m/s ^{1.75})
1	x	0.776	1.174 (SD = 0.129)	15.7	15.5	15.1	21.6	26.5 (SD = 3.5)	
	y	0.707		15.7	15.5	15.1	21.6		
	z	0.527		15.8	15.6	15.1	15.5		
2	x	0.766	1.153 (SD = 0.131)	15.4	15.6	15.9	21.9	26.9 (SD = 3.6)	
	y	0.693		15.4	15.6	15.9	21.9		
	z	0.512		15.5	15.7	15.9	15.7		
3	x	0.762	1.147 (SD = 0.130)	20.3	19.0	20.3	27.8	34.1 (SD = 4.6)	
	y	0.960		20.3	19.0	20.3	27.8		
	z	0.509		20.3	19.0	20.3	19.9		
4	x	0.766	1.148 (SD = 0.132)	20.3	20.4	20.4	28.5	35.0 (SD = 4.7)	
	y	0.688		20.3	20.4	20.4	28.5		
	z	0.509		20.3	20.4	20.4	20.4		
5	x	0.749	1.116 (SD = 0.136)	20.3	20.4	20.4	28.5	35.0 (SD = 4.7)	
	y	0.670		20.3	20.4	20.4	28.5		
	z	0.485		20.3	20.4	20.4	20.4		
6	x	0.771	1.136 (SD = 0.145)	20.3	20.4	20.4	28.5	35.0 (SD = 4.7)	
	y	0.678		20.3	20.4	20.4	28.5		
	z	0.486		20.3	20.4	20.4	20.4		

SOCIO-DEMOGRAPHIC CHARACTERISTICS

A total of 51 train drivers participated in the study, with the majority being Malay (94.1%) and having a mean age of 45.4 ± 9.4 years (Table 3). Most were aged 36 years and above (82.4%) and had over 11 years of work experience (86.3%). A high percentage of drivers were overweight (56.9%) or obese (23.5%). Accordingly, obesity was

significantly associated with increased LBP prevalence (Siddiqui et al. 2022; Su et al. 2018). Additionally, 25.5% had hypertension and 5.9% had diabetes, both of which are known to exacerbate musculoskeletal symptoms (Suri et al. 2023; Mack, 2022; Pozzobon et al. 2019; Shahid et al. 2021; Lucha-López et al. 2023). Nearly half of the drivers (49.0%) were smokers, and studies have linked tobacco use to increased chronic pain and inflammation.

Long work hours, limited rest (92.2% worked ≥ 6 days/week, 84.3% had ≤ 1 hour rest), and shift work (56.9%) further contributed to LBP risk (Wang et al. 2017; Awaad et al. 2022; Boivin et al. 2021; Fan et al. 2022; Angier, 2023). 15.7% driving more than eight hours per day or per journey, and only 15.7% engaging in pre-work stretching or exercise. These findings highlight occupational, physiological, and lifestyle risk factors that possibly contribute to the prevalence of LBP among train drivers.

PREVALENCE AND DISTRIBUTION OF MUSCULOSKELETAL SYMPTOMS

Based on Figure 3, musculoskeletal pain was most prevalent in the lower back (78.4%) and upper back (56.8%) among train drivers. However, exceeding rates reported in other studies, such as those in Saudi Arabia (44.1%), are associated with poor driving posture (Althuwaybi et al. 2022). These issues are likely due to prolonged sitting, poor seat ergonomics, and exposure to

WBV. Hip (56.9%) and buttock pain (35.3%) were also common, potentially linked to prolonged sitting, compromised pelvic stability, and piriformis syndrome (Joseph et al. 2020; Hicks et al. 2023; Cleveland Clinic, 2022). Additionally, 39.2% reported bilateral foot pain, possibly from vertical (z-axis) vibration impacting posture and spinal health (Setuain et al. 2019). Neck pain was also significant, with 81.9% reporting symptoms, particularly in the upper (49%) and lower (47.1%) neck, often associated with static posture and seat misalignment (Kasemsan et al. 2021; Zhou et al. 2024). Upper limb discomfort was reported in the left (45.1%) and right (27.4%) upper arms, frequently radiating from the neck (Zengi et al. 2024). Shoulder pain affected 37.3% (left) and 35.3% (right) of drivers and was closely related to neck discomfort and impaired quality of life (Jimoh et al. 2023). These findings demand the need for ergonomic redesign and musculoskeletal health interventions to protect train drivers from chronic pain and injury.

TABLE 3. Self-Reported Lower Back Pain (LBP) Symptoms among Respondents (N=51)

Variables	Frequency (N = 51)	Percentage (%)
Race		
Malay	48	94.1
Indian	3	5.9
Age (years)	45.4 $\pm$ 9.4	
≤ 35 years	9	17.6
≥ 36 years	42	82.4
BMI		
Underweight (< 18.5)	2	3.9
Normal (18.5 – 24.9)	8	15.7
Overweight (25.0 – 29.9)	29	56.9
Obesity (≥ 30.0)	12	23.5
Smoking		
Yes	25	49.0
No	26	51.0
Working Experience as Train Drivers		
≤ 10 years	7	13.7
≥ 11 years	44	86.3
Working Days (Every week)		
≤ 5 days	4	7.8
≥ 6 days	47	92.2
Driving Duration (Every day)		
≤ 8 hours	43	84.3
≥ 9 hours	8	15.7
Driving Duration (Every journey)		
≤ 7 hours	42	82.4

continue...

...cont.

≥ 8 hours	9	17.6
Work Shift		
Yes	29	56.9
No	22	43.1
Rest Duration		
≤ 1 hour	43	84.3
≥ 1 hour 30 minutes	8	15.7

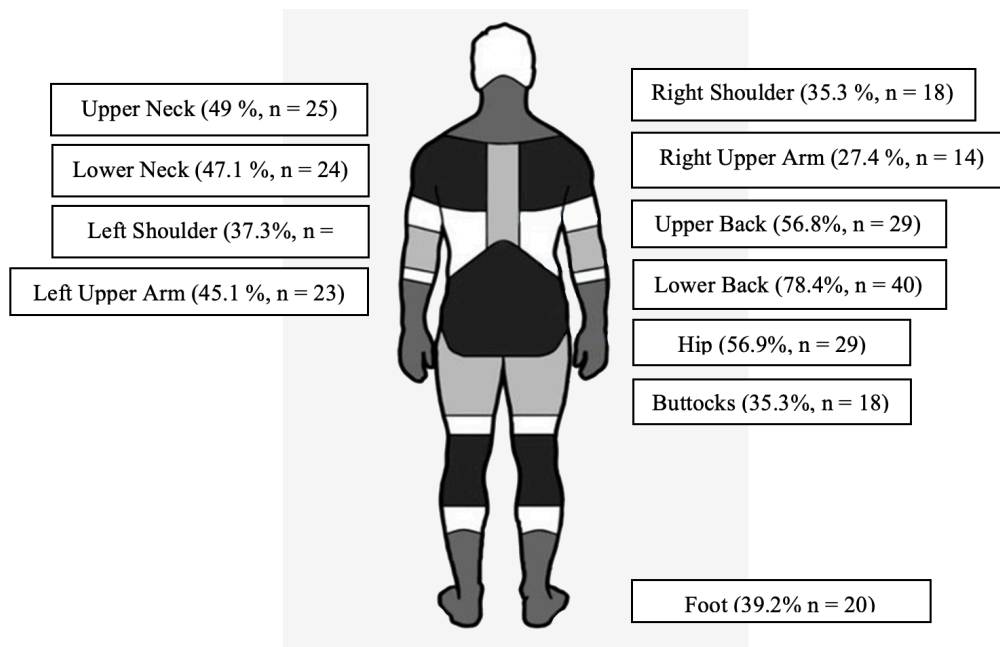


FIGURE 3. Percentage of discomfort for specific body parts related to lower back pain among train drivers (N=51)

OSWESTRY DISABILITY INDEX (ODI)

Table 4 shows the ODI findings, with pain intensity, lifting, and standing identified as the most affected functions among train drivers. Nearly 39% reported moderate to severe pain, including some with disabling symptoms. Prolonged static sitting was a contributing factor associated with reduced physical activity and work performance (Dorrian et al. 2022; Halek et al. 2024). Over 25% experienced moderate to severe lifting difficulties, consistent with studies showing increased spinal load and altered muscle activation in individuals with LBP during lifting tasks (Bernard et al. 2020; Phan et al. 2022). Standing was also affected, with 23.5% reporting moderate to severe limitations, likely linked to spinal fatigue and impaired postural transitions after prolonged sitting (Pickard et al. 2022; Fan, 2018).

Overall, 45.1% of drivers had moderate disability and 19.6% had severe disability (Table 4.6), reflecting a notable impact on quality of life (Alfalogy et al. 2023). Comparable LBP prevalence has been reported in Sri Lanka (50.2%) and Malaysia (79.3%) (Senarath et al. 2021; Hasrina et al.

2021). Most participants in this study had over 11 years of experience, suggesting prolonged ergonomic exposure, in line with findings from Bangladesh, where long-serving drivers showed a 41.2% LBP rate (Nabi et al. 2023). These findings highlight the need for ergonomic improvements to reduce disability and support occupational health.

NECK DISABILITY INDEX (NDI)

Table 5 presents the NDI results, which assess the impact of neck pain on daily activities among train drivers. This was mostly reflected in the driving domain, with mild disability of 54.9%, moderate disability of 15.7%, and severe disability of 5.9%. This supports the results reported by Agarwal et al. (2024), who determined that 31.4% of drivers cited neck pain as negatively affecting their ability to drive. Long-duration driving may impair cervical range of motion and body position sense, influencing driving skills (Alshahrani et al. 2024). About 47.1% of the participants demonstrated light reading struggles, while 9.6% had moderate reading limitations. Such problems might stem from sustained cervical stress or poor postural

alignment (Kashif et al. 2023). In addition, 58.8% of drivers documented mild work-related functional limitations, and 3.9% of drivers documented moderate limitations. Neck pain is usually associated with reduced work performance,

high dependency on healthcare, and general poor job functionality, which highlights the necessity of urgently improving ergonomics in this profession (Raza et al. 2024; Van Gorp et al. 2024).

TABLE 4. Oswestry Disability Index (ODI) among train drivers (N = 51)

Sections	Frequency (%), N=51				
	0 (No Restriction)	1 (Minimal Restriction)	2 (Moderate Restriction)	3 (Severe Restriction)	4 (Crippling)
Pain Intensity	6 (11.8)	24 (47.1)	19 (37.3)	1 (1.9)	1 (1.9)
Personal Care	33 (64.7)	6 (11.8)	5 (9.8)	6 (11.8)	1 (1.9)
Lifting	19 (37.3)	19 (37.3)	3 (5.9)	7 (13.7)	3 (5.9)
Walking	35 (68.6)	7 (13.7)	5 (9.8)	4 (7.8)	-
Sitting	26 (51.0)	9 (17.6)	11 (21.6)	4 (7.8)	1 (1.9)
Standing	20 (39.2)	19 (37.3)	3 (5.9)	6 (11.8)	3 (5.9)
Sleeping	28 (54.9)	18 (35.3)	1 (1.9)	3 (5.9)	1 (1.9)
Social Life	30 (58.8)	6 (11.8)	8 (15.7)	6 (11.8)	1 (1.9)
Traveling	29 (56.9)	14 (27.5)	6 (11.8)	1 (1.9)	1 (1.9)
Employment	20 (39.2)	16 (31.4)	13 (25.5)	2 (3.9)	-

TABLE 5. Neck Disability Index (NDI) among train drivers (N=51)

Components	Frequency (%), N=51				
	0 (No Disability)	1 (Mild Disability)	2 (Moderate Disability)	3 (Severe Disability)	4 (Complete Disability)
Pain Intensity	20 (39.2)	16 (31.4)	13 (25.5)	2 (3.9)	-
Personal Care	33 (64.7)	6 (11.8)	5 (9.8)	6 (11.8)	1 (2.0)
Lifting	19 (37.3)	18 (35.3)	4 (7.6)	7 (13.7)	3 (5.9)
Reading	17 (33.3)	24 (47.1)	10 (19.6)	-	-
Headaches	18 (35.3)	17 (33.3)	13 (25.5)	3 (5.9)	-
Concentration	23 (45.1)	11 (21.6)	17 (33.3)	-	-
Work	19 (37.3)	30 (58.8)	2 (3.9)	-	-
Driving	12 (23.5)	28 (54.9)	8 (15.7)	3 (5.9)	-
Sleeping	28 (54.9)	18 (35.3)	1 (2.0)	3 (5.9)	1 (2.0)
Recreation	30 (58.8)	6 (11.8)	6 (11.8)	8 (15.7)	1 (2.0)

ASSOCIATION BETWEEN WHOLE-BODY VIBRATION (WBV) EXPOSURE AND MUSCULOSKELETAL DISABILITY INDICES

Table 6 shows the Spearman's correlation analysis between whole-body vibration (WBV) exposure parameters, A (8) (m/s^2) and VDV (8) ($\text{m/s}^{1.75}$), and musculoskeletal disability outcomes measured using the Oswestry Disability Index (ODI) and the Neck Disability Index (NDI). The result presents weak negative correlations

between A (8) and both ODI ($r = -0.116, p = 0.827$) and NDI ($r = -0.200, p = 0.704$), and indicates no statistically significant associations. This suggest that within the measured exposure range, the daily vibration exposure magnitude presented by A (8) was not a dominant factor contributing to lower back and neck disability among the respondents.

In contrast, positive correlations was found between VDV (8) with both ODI ($r = 0.524, p = 0.286$) and NDI ($r = 0.319, p = 0.538$). Although the relationships were not

statistically significant, the moderate positive correlation demonstrated between VDV (8) and ODI suggest a potential tendency for cumulative vibration exposure to be associated with increased lower back disability. The VDV(8) which accounts for vibration peaks and cumulative effects, may be a more sensitive variable than A (8) in reflecting WBV-related musculoskeletal loading.

In this study, no statistically significant correlations were observed between WBV exposure variables and musculoskeletal disability indices, which may be attributed to the limited sample size which restricts statistical power. Nevertheless, the observed trends for VDV (8) imply the importance of considering cumulative vibration metrics in the assessments of WBV exposure and its potential implications for musculoskeletal health.

Based on the observed exposure levels and potential musculoskeletal risks in this study, several practical recommendations for reducing WBV exposure among train drivers are proposed. For engineering controls, active seats that alter vibrations can be installed and standardized across

all commuter trains to reduce transmission to drivers' bodies due to their good suspension, shock absorption, and posture support (Peng et al. 2022). Adjustable lumbar support and improved seat cushions may further enhance comfort and reduce localized vibration. Track maintenance and installation of tuned mass dampers (TMD) can minimize vibrations and reduce wear on trains and infrastructure (Li et al. 2025). For administrative controls, drivers are encouraged to exercise before shifts to strengthen muscles, and work schedules could include shorter shifts, regular breaks, or job rotation to reduce cumulative WBV exposure. Educating drivers about WBV, its sources, effects, and preventive measures can improve compliance with engineering controls, including proper seating posture, hand positioning, and optimal use of equipment. PPE such as padded gloves can reduce vibration transmission to hands. Regular health surveillance with confidential records is recommended, and professional guidance should be followed to mitigate vibration-related risks.

TABLE 6. Correlation between whole-body vibration (WBV) exposure and musculoskeletal disability indices

WBV exposure variables	Musculoskeletal Disability Indices	<i>r</i>	<i>p-value</i>
A(8) (m/s ²)	Oswestry Disability Index (ODI)	-0.116	0.827
	Neck Disability Index (NDI)	-0.200	0.704
VDV (8) (m/s ^{1.75})	Oswestry Disability Index (ODI)	0.524	0.286
	Neck Disability Index (NDI)	0.319	0.538

CONCLUSION

Monitoring of WBV in train drivers was successfully conducted in this study. The outcomes revealed that the A (8) values were within the range of 1.116 to 1.174 m/s², while the VDV (8) values were in the range of 26.5 to 35.0 m/s^{1.75} across all six trains. These results suggest that there is a high risk of exposure, which requires immediate protective action. Besides, this study indicated that musculoskeletal symptoms were prevalent among respondents. 78.4% of train drivers presented with LBP symptoms, while 64.7% showed moderate to severe activity restrictions based on ODI scores. Additionally, neck pain was common, as 49% and 47.1% of the participants complained of lower and upper neck pain, respectively. Driving and reading were the most impacted activities according to NDI results, where 76.5% and 54.9% of drivers reported functional impairments in these tasks. No statistically significant correlations were observed between WBV exposure variables and musculoskeletal disability indices. Overall, this study highlight the effect of long-term WBV exposure on mechanical system components with human operators, the necessity to ergonomically redesign the process, and to implement

vibration and preventive measures to protect human health and maximise operational performance.

ACKNOWLEDGEMENT

The authors would like to express gratitude to School of Chemistry and Environment, Faculty of Applied Sciences, Universiti Teknologi MARA, Shah Alam, Malaysia for supporting this project.

DECLARATION OF COMPETING INTEREST

None.

REFERENCES

- Alfalogy, E., Mahfouz, S., Elmedany, S., Hariri, N. & Fallatah, S. 2023. Chronic low back pain: Prevalence, impact on quality of life, and predictors of future disability. *Cureus* 15(9): e45760. <https://doi.org/10.7759/cureus.45760>

- Public Health England. 2019. *Musculoskeletal health: A 5-year strategic framework for prevention across the lifecourse*. Public Health England. https://assets.publishing.service.gov.uk/media/5d0b44eded915d0939f84803/Musculoskeletal_Health_5_year_strategy.pdf
- Atallah, A.A., Althuwaybi, S.E., Faydh, J.A., Alsherbi, R.K., Alsufyani, M. & Aljuaid, H. 2022. Prevalence of lower back pain and its relationship with driving postures among drivers in Taif, Saudi Arabia. *Journal of Pharmacy and Bioallied Sciences* 14(Suppl. 1): S433–S438. https://doi.org/10.4103/jpbs.jpbs_882_21
- Angier, F. 2023. Driver fatigue. *UK FISA*, 10 October. <https://ukfisa.com/News-Events/News/driver-fatigue>
- Arma, M., Septadina, I.S. & Legiran. 2019. Factors affecting low back pain (LBP) among public transportation drivers. *Majalah Kedokteran Sriwijaya* 51(4): 206–215. <https://doi.org/10.36706/mks.v51i4.10240>
- Awaad, A.E.-S., El-Bestar, S., El-Gilany, A.-H., Al-Wehedy, A. & El-Hadidy, S.S. 2022. Presenteeism and associated factors among railway train drivers. *F1000Research* 11: 470. <https://doi.org/10.12688/f1000research.111999.2>
- Azrah, K., Mirzaei, R., Safari, Z. & Khavanin, A. 2016. Evaluation of exposure of metro passengers to whole-body vibration and recurrent shocks according to ISO 2631-1 standard. *Journal of Research & Health* 6(4): 380–389. <https://doi.org/10.7508/jrh.2016.04.002>
- Liew, B.X.W., De Nunzio, A.M., Srivastava, S. & Falla, D. 2020. Influence of low back pain and its remission on motor abundance in a low-load lifting task. *Scientific Reports* 10(1): 17831. <https://doi.org/10.1038/s41598-020-74707-4>
- Boivin, D.B., Boudreau, P. & Kosmadopoulos, A. 2022. Disturbance of the circadian system in shift work and its health impact. *Journal of Biological Rhythms* 37(1): 3–28. <https://doi.org/10.1177/07487304211064218>
- Cleveland Clinic. 2022. Piriformis syndrome: Symptoms, causes and treatment. *Cleveland Clinic*, 20 July. <https://my.clevelandclinic.org/health/diseases/23495-piriformis-syndrome>
- de la Hoz-Torres, M.L., Aguilar, A.J., Ruiz, D.P. & Martínez-Aires, M.D. 2022. Whole body vibration exposure transmitted to drivers of heavy equipment vehicles: A comparative case according to the short- and long-term exposure assessment methodologies defined in ISO 2631-1 and ISO 2631-5. *International Journal of Environmental Research and Public Health* 19(9): 5206. <https://doi.org/10.3390/ijerph19095206>
- Dorrian, J., Chapman, J., Bowditch, L., Balfe, N. & Naweed, A. 2022. A survey of train driver schedules, sleep, well-being, and driving performance in Australia and New Zealand. *Scientific Reports* 12(1): 3956. <https://doi.org/10.1038/s41598-022-07627-0>
- Fan, C., Huang, S., Lin, S., Xu, D., Peng, Y. & Yi, S. 2022. Types, risk factors, consequences, and detection methods of train driver fatigue and distraction. *Computational Intelligence and Neuroscience* 2022: 8328077. <https://doi.org/10.1155/2022/8328077>
- Gracey, B. 2024. Vibration dose terms and definitions. *Acoustic Glossary*. <https://www.acoustic-glossary.co.uk/vibration-dose.htm>
- Halek, R.B.A., Dev, A., Chew, K.H. & Hannan, M.A. 2024. Conceptual analysis of lower back pain resulting from awkward sitting posture in driver vehicle seat—Systematic review and surveys. *Open Journal of Safety Science and Technology* 14(3): 75–85. <https://doi.org/10.4236/ojsst.2024.143006>
- Abd. Rahman, S.H., Rasdi, I., Karrupiah, K. & Abdullah, A.M. 2021. Risk factors of musculoskeletal symptoms among healthcare workers in a public hospital. *Malaysian Journal of Medicine and Health Sciences* 17(SUPP8): 80–88. [https://medic.upm.edu.my/upload/dokumen/2021112318530112\)_2021_0526.pdf](https://medic.upm.edu.my/upload/dokumen/2021112318530112)_2021_0526.pdf)
- Hicks, B.L., Lam, J.C. & Varacallo, M. 2023. Piriformis syndrome. In *StatPearls*. StatPearls Publishing. <https://www.ncbi.nlm.nih.gov/books/NBK448172/>
- Jimoh, A.K., Jimoh, J.T. & Akinola, T.O. 2023. Musculoskeletal pain and health-related quality of life of occupational drivers in Southwest Nigeria. *West African Journal of Medicine* 40(2): 196–202. <https://pubmed.ncbi.nlm.nih.gov/36861374/>
- Joseph, L., Standen, M., Paungmali, A., Kuisma, R., Silitertpisan, P. & Pirunsan, U. 2020. Prevalence of musculoskeletal pain among professional drivers: A systematic review. *Journal of Occupational Health* 62(1): e12150. <https://doi.org/10.1002/1348-9585.12150>
- Singh, K.J., Palei, S.K. & Karmakar, N.C. 2024. Role of contributing factors on health risks of whole-body vibration exposure of heavy equipment and vehicle operators: A critical review. *Journal of Vibration and Control* 30(11–12): 2338–2355. <https://doi.org/10.1177/10775463231185627>
- Kasemsan, A., Joseph, L., Paungmali, A., Silitertpisan, P. & Pirunsan, U. 2021. Prevalence of musculoskeletal pain and associated disability among professional bus drivers: A cross-sectional study. *International Archives of Occupational and Environmental Health* 94(6): 1263–1270. <https://doi.org/10.1007/s00420-021-01683-1>
- Kazeminasab, S., Nejadghaderi, S.A., Amiri, P., Pourfathi, H., Araj-Khodaei, M., Sullman, M.J.M., Kolahi, A.A. & Safiri, S. 2022. Neck pain: Global epidemiology, trends and risk factors. *BMC Musculoskeletal Disorders* 23(1): 26. <https://doi.org/10.1186/s12891-021-04957-4>

- Kowalczyk, K. & Opala, M. 2024. Commuter experience: An assessment of metro-train comfort amidst operational vibroacoustic conditions. *Applied Sciences* 14(14): 6137. <https://doi.org/10.3390/app14146137>
- Li, P., Li, B., Bai, Y. & He, Z. 2025. Study on the railway bridge vibration reduction characteristic and train driving safety evaluation under debris flow impact. *SSRN*. <https://doi.org/10.2139/ssrn.5100259>
- Lucha-López, M.O., Hidalgo-García, C., Monti-Ballano, S., Márquez-Gonzalvo, S., Ferrández-Laliena, L., Müller-Thyssen-Uriarte, J. & Lucha-López, A.C. 2023. Body mass index and its influence on chronic low back pain in the Spanish population: A secondary analysis from the European Health Survey (2020). *Biomedicine* 11(8): 2175. <https://doi.org/10.3390/biomedicine11082175>
- Lynsey. 2023. HAVS exposure limits—EAV, ELV and what they mean. *HAVSPro*, 21 August. <https://www.havspro.com/havs-exposure-limits-eav-elv-and-what-they-mean/>
- Mack. 2022. Can pain cause high blood pressure? *Midwest Pain Clinics*, 9 November. <https://midwestpainclinics.com/can-pain-cause-high-blood-pressure/>
- Maduagwu, S.M., Galadima, N.M., Umeonwuka, C.I., Ishaku, C.M., Akanbi, O.O., Jaiyeola, O.A. & Nwanne, C.A. 2022. Work-related musculoskeletal disorders among occupational drivers in Mubi, Nigeria. *International Journal of Occupational Safety and Ergonomics* 28(1): 572–580. <https://doi.org/10.1080/10803548.2020.1834233>
- Mad Isa, N.S., Mohd Razali, M. & Sahani, M. 2018. Musculoskeletal discomfort and its associated risk factors among train drivers. *Malaysian Journal of Public Health Medicine Special Volume* (1): 98–106.
- Ministry of Transport Malaysia. 2023. *Malaysian transportation statistics 2022*. <https://www.mot.gov.my/en/media/annual-report/yearly-statistic>
- Nabi, M.H., Hawlader, M.D.H., Naz, F., Siddiquea, S.R., Hasan, M., Hossian, M. & Dalal, K. 2023. Low back pain among professional bus drivers: A cross-sectional study from Bangladesh. *BMC Public Health* 23: 1172. <https://doi.org/10.1186/s12889-023-16018-7>
- Neto, M.F. & Gomes, H.M. 2018. Análise de níveis de vibração em usuários de trens urbanos. *Estudos Tecnológicos em Engenharia* 12(2): 24–44. <https://doi.org/10.4013/ete.2018.122.02>
- Newton, E. 2024. Why fleet owners must prioritize reducing exposure to whole-body vibration in vehicles. *Field Technologies Online*, 9 January. <https://www.fieldtechnologiesonline.com/doc/why-fleet-owners-must-prioritize-reducing-exposure-to-whole-body-vibration-in-vehicles-0001>
- Orelaja, O.A., Wang, X., Ibrahim, D.S. & Sharif, U. 2019. Evaluation of health risk level of hand-arm and whole-body vibrations on the technical operators and equipment in a tobacco-producing company in Nigeria. *Journal of Healthcare Engineering* 2019: 5723830. <https://doi.org/10.1155/2019/5723830>
- Peng, Y., Zhou, J., Fan, C., Wu, Z., Zhou, W., Sun, D., Lin, Y., Xu, D. & Xu, Q. 2022. A review of passenger ride comfort in railway: Assessment and improvement method. *Transportation Safety and Environment* 4(2): tdac016. <https://doi.org/10.1093/tse/tdac016>
- Phan, T.C., Pranata, A., Farragher, J., Bryant, A., Nguyen, H.T. & Chai, R. 2022. Machine learning derived lifting techniques and pain self-efficacy in people with chronic low back pain. *Sensors* 22(17): 6694. <https://doi.org/10.3390/s22176694>
- Pozzobon, D., Ferreira, P.H., Dario, A.B., Almeida, L., Vesentini, G., Harmer, A.R. & Ferreira, M.L. 2019. Is there an association between diabetes and neck and back pain? A systematic review with meta-analyses. *PLoS ONE* 14(2): e0212030. <https://doi.org/10.1371/journal.pone.0212030>
- Shahid, S., Akhter, Z., Sukaina, M., Sohail, F. & Nasir, F. 2021. Association of diabetes with lower back pain: A narrative review. *Cureus* 13(6): e15776. <https://doi.org/10.7759/cureus.15776>
- Singh, A., Nawayseh, N., Singh, L.P., Singh, S. & Singh, H. 2019. Investigation of compressive stress on lumbar spine due to whole body vibration exposure in rotary tillage operation. *International Journal of Automotive and Mechanical Engineering* 16(2): 6684–6696. <https://doi.org/10.15282/ijame.16.2.2019.16.0503>
- Senarath, M.K.I.D., Thalwaththe, S.T.R.D. & Tennakoon, S.U.B. 2021. Prevalence of selected musculoskeletal disorders among the students of Faculty of Allied Health Sciences, University of Peradeniya. *Journal of Musculoskeletal Disorders and Treatment* 7(2): 097. <https://doi.org/10.23937/2572-3243.1510097>
- Setuain, I., Bikandi, E., Amú Ruiz, F.A., Urtasun, F. & Izquierdo, M. 2019. Horizontal jumping biomechanics among elite female handball players with and without anterior cruciate ligament reconstruction: An ISU based study. *BMC Sports Science, Medicine and Rehabilitation* 11: 30. <https://doi.org/10.1186/s13102-019-0142-8>
- Suri, P., Elgaeva, E.E., Williams, F.M.K., Freidin, M.B., Zaytseva, O.O., Aulchenko, Y.S. & Tsepilov, Y.A. 2023. Evidence of causal effects of blood pressure on back pain and back pain on type II diabetes provided by a bidirectional Mendelian randomisation study. *The Spine Journal* 23(8): 1161–1171. <https://doi.org/10.1016/j.spinee.2023.04.001>
- Wallis, C. 2022. Understanding whole-body vibration (WBV). *Pulsar Instruments*, 12 January. <https://pulsarinstruments.com/news/whole-body-vibration-faq/>

- Wang, M., Yu, J., Liu, N., Liu, Z., Wei, X., Yan, F. & Yu, S. 2017. Low back pain among taxi drivers: A cross-sectional study. *Occupational Medicine* 67(4): 290–295. <https://doi.org/10.1093/occmed/kqx041>
- Zanatta, M., Amaral, F.G. & Vidor, G. 2019. The role of whole-body vibration in back pain: A cross-sectional study with agricultural pilots. *International Journal of Industrial Ergonomics* 74: 102872. <https://doi.org/10.1016/j.ergon.2019.102872>
- Zengi, H., Safran, E.E. & Şevgin, Ö. 2024. The effect of home exercises with kinesiotaping on pain, functionality, and work performance in bus drivers with non-specific neck pain. *Journal of Back and Musculoskeletal Rehabilitation* 37(6): 1617–1630. <https://doi.org/10.3233/BMR-240001>
- Zhang, C. & Guo, L.-X. 2022. Effect of whole-body vibration at different frequencies on the lumbar spine: A finite element study based on a whole human body model. *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine* 236(12): 1752–1761. <https://doi.org/10.1177/09544119221135688>
- Zhou, Y., Reddy, C. & Zhang, X. 2024. The deflection of fatigued neck. *Proceedings of the National Academy of Sciences* 121(34): e2401874121. <https://doi.org/10.1073/pnas.2401874121>