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Structural equation modelling of lower back pain due to whole-body vibration exposure in the construction industry

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Whole-body vibration (WBV) exposure is a health hazard among workers, causing lower back pain (LBP) in the construction industry. This study examines key factors affecting LBP due to WBV exposure using exploratory factor analysis and structural equation modelling. The results confirm five key factors (equipment, job related, organizational, personal, social context) with their 17 associated items. The organizational factor is found the most important, as it influences the other four factors. The results also show that appropriate seat type, specific training programme, job rotation, workers' satisfaction and workers' physical condition are crucial in reducing LBP due to WBV exposure. Moreover, provision of new machines without proper training and good working condition might not help reduce LBP due to WBV exposure. The results help the construction companies to better understand key factors affecting LBP due to WBV exposure, and to plan for a better health improvement programme.

Keywords: exploratory factor analysis; lower back pain; structural equation modelling; whole-body vibration exposure

1. Introduction

The construction industry plays an important role in both developed and developing countries [1]. The nature of the industry is unique, when compared with other industries. Viability, design, plan, execution, decommission, demolition and clearance are several phases in the construction industry [2]. Activities of the industry mostly take place outdoors, without consideration for the safety and health of the workers [3]. Around 40% of the construction workers face, at least, one accident during their working life [4]. According to Ringen and Stafford [5], major causes of injuries are lifting, awkward posture, repetitive motion and vibration. These, in turn, lead to damage of the lower back, shoulder, knee, hip and wrist. It is found that around 60% of construction workers retire because of permanent disability [6].

Health hazards in the construction industry have both acute and chronic effects. Ladder work, roof work, lifting, carrying or moving heavy tools and electric shocks cause acute health effects, while noise, heat, solar radiation and vibratory tools cause chronic health effects [7]. Vitharana et al. [7] and Donati et al. [8] mentioned that there should be a systematic study on chronic effects of health hazards due to vibration, as around 40% of the workforce is exposed to whole-body vibration (WBV).

According to Smith and Leggat [9], WBV is the vibration transmitted to the entire body of a person via a vibration source. Around 7% of all workers are regularly exposed to WBV in Europe, Canada and the USA [9]. Exposure to WBV for a short term can cause an increase in heart rate, hyperventilation, headache, loss of balance, motion sickness, muscle fatigue, effects of speech and effects of vision [9]. Nevertheless, long-term exposure to WBV can cause degenerative disorders of the spine, spine disc disease and failure, lower back pain (LBP) and disorders of the gastrointestinal system [9]. If the magnitude, duration and severity of shock or jolts of WBV are high, the risks are great [10]. Disorders of muscles, nerves, bone, joints and the circulatory system caused by hand-transmitted vibration occur when vibration frequency is in the range of 8–1000 Hz [11]. To explain: frequency up to 5 Hz causes motion sickness, alerting effects and malfunctions; 5–10 Hz causes LBP, chest pain, abdomen pain and communication problems; 10–20 Hz causes intense pain, bladder pain and communication problems; and more than 20 Hz degrades manual and visual controls and actions [12]. The high vibration level increases risk of having LBP, as well as musculoskeletal disorders [13]. Smith and Leggat [9] agreed that LBP is a common symptom of WBV exposure. In the United Kingdom, more than 400,000 cases of LBP are attributable to occupational WBV [9].

Palmer et al. [14] showed that the construction industry is the largest industry contributing to WBV exposure. Construction workers are usually exposed to WBV through the use of heavy equipment. The exposure level of WBV is very high among those heavy equipment operators,

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including soil roller, excavator, motor grader, skid-steer loader and dozer operators [15]. Waters et al. [16] mentioned that heavy equipment operators are at higher risk of developing LBP in comparison with those who are not working with heavy equipment. Boshuizen et al. [17] stated that 68% of workers in the construction industry suffer from LBP regularly, and the prevalence of LBP is 25% higher among the workers who are exposed to WBV. Ueno et al. [18] mentioned that LBP is the primary cause of occupational sick leave for 4 days or more in the construction industry in Japan. Guo et al. [19] agreed that LBP is a major cause of morbidity and lost production for US construction workers.

These research studies provide an insight into LBP disorders. However, it is important to understand causal relationships among key factors affecting LBP due to WBV exposure, so that construction companies can effectively plan for LBP improvement. This article, therefore, aims at identifying key factors affecting LBP disorders due to WBV exposure, and investigating the causal relationships among those key factors, utilizing a structural equation modelling (SEM) technique. It is expected that construction companies use the study results to better understand the key factors, as well as their relationships, and to effectively plan for LBP improvement.

2. Methodology

Research steps of this study are as shown in Figure 1. Based on a number of LBP-related and WBV exposure-related literature sources, 17 items affecting LBP due to WBV exposures are identified. These items are used in questionnaire survey development to gather data necessary for the statistical analyses. The questionnaire survey is distributed to large-sized construction companies, dealing mainly with road work construction in Sri Lanka. Data collected are performed with data screening processes, including normality and outlier tests. The screened data are then analysed with exploratory factor analysis (EFA) to extract the 17 items into a number of key factors affecting LBP due to WBV exposure. The SEM is finally developed, based on the key factors achieved in the EFA, to examine relationships among those key factors. Research output is finally achieved.

3. Items affecting LBP due to WBV exposure

A number of research studies have been conducted in the area of LBP due to WBV exposure. Chaudhary et al. [20], e.g., examined key factors affecting LBP due to WBV exposure in the Indian mining industry, and concluded that job-associated, machine-related and personal

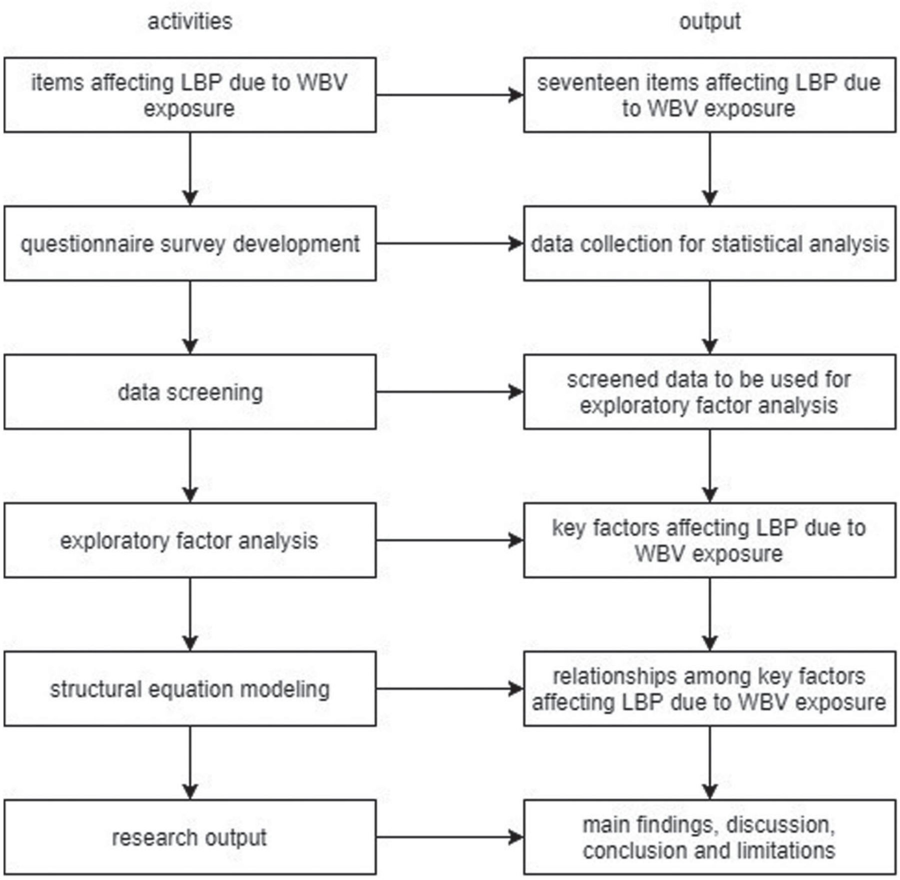

Figure 1. Research steps of the study.
Note: LBP = lower back pain; WBV = whole-body vibration.

Table 1. Items affecting LBP due to WBV exposure.

Item	Code	Reference
Age of the machine	AOM	[10,13,25,26]
Age of the worker	AOW	[8,15,22,25,27–29]
Exercise	EXR	[8,29,30]
Education	EDU	[13,28–30]
Job rotation	JOR	[8,27,31]
Job satisfaction	JOS	[8,13,21,29]
Night shift	NSF	[25,26,32]
Safety and health budget	SBT	[13,28,33]
Seat type	STP	[8,10,13,15,27,30]
Smoking	SMK	[8,13,20,29,30]
Soil type	SOT	[10,30,34]
Training programme	TPM	[8,10,25,27,28]
WBV exposure	VEX	[8,10,25,27,30,34]
WBV standard	VST	[8,10,22,27,28]
Weight of the worker	WGT	[8,13,25,27,29]
Working experience	WEP	[10,25,26]
Working hours	WHO	[8,10,26,28,32]

Note: AOM = age of the machine; AOW = age of the worker; EDU = education; EXR = exercise; JOR = job rotation; JOS = job satisfaction; LBP = lower back pain; NSF = night shift; SBT = safety and health budget; SMK = smoking; SOT = soil type; STP = seat type; TPM = training programme; VEX = WBV exposure; VST = WBV standard; WBV = whole-body vibration; WEP = working experience; WGT = weight of the worker; WHO = working hours.

factors are key factors affecting LBP. Ramond-Roquin et al. [21], on the other hand, considered the biomechanical, organizational, personal and psychological factors as having influences on LBP in France in the male general working population. Beeck and Hermans [22] emphasized machine-related, non-work-related, organizational, personal, physical, psychological and social context factors as having major effects on LBP due to WBV exposure among drivers in Europe. The study results suggest education, job rotation, training programmes and vibration limits as a prevention strategy for LBP occurrence [22].

Alghadir and Anwer [23] mentioned that workers who work more than 8 h/day experienced a 51.2% chance of having LBP. Receiving a specific LBP training and having a job rotation, on the other hand, reduce chances of having LBP due to WBV exposure [8,10,20,22]. Lahiri et al. [24] added that workers who receive specific LBP training have a 50% reduced chance of having LBP, compared with those who have not received such training.

In this study, a total of 17 items are extracted as presented in Table 1. These are used in questionnaire survey development to collect data for the analyses.

4. Questionnaire survey and data collection

A questionnaire survey was developed based on the 17 items affecting LBP due to WBV exposure. Soil roller operators were selected as the target respondent, as they are mainly exposed to a high WBV level (in the range of 2.19–4.69 $m \cdot s^{-2}$), which is higher than the acceptable value of 2.00 $m \cdot s^{-2}$ based on Standard No. ISO 2631-1:1997 [35], the international standard for mechanical vibration and shock evaluation of human exposure to WBV [34,36]. Project managers and project engineers are also included in the survey to elicit various perceptions of LBP due to WBV exposure in the construction industry.

The survey comprises two parts. The first part gathers the demographic information of the respondents. The second part covers 17 statements explaining items affecting LBP due to WBV exposure. The respondents are asked to rate their agreement on each statement using a 5-point Likert scale, ranging from *1 = strongly disagree* to *5 = strongly agree*. An example of a questionnaire survey is shown in Appendix 1.

Site observations and interviews were also conducted to gather information relating to real practices such as soil type, current machine condition and seat type used with soil rollers.

A total of 149 questionnaire surveys were distributed to 35 construction sites around Sri Lanka, with 100% return, as the surveys are filled and returned immediately after completion. Based on the 149 data sets, around 70% of them are soil roller operators. Almost all of the respondents are aged between 25 and 45 years. Half of the soil roller operators work more than 8 h/day. Moreover, most of the operators have a moderate education background, while respondents in a management position have at least a higher education background with at least 5-year working experience in construction companies. Further, almost all of the respondents receive at least site safety and personal protective equipment usage training.

5. Data screening

According to Abdulwahab et al. [37], quality of the data is important for a better output of an acceptable analysis. In this study, data collected from the questionnaire survey are tested with two major data screening analyses, including normality and outlier tests, to ensure appropriateness of the data for further analyses.

5.1. *Normality test*

The most important assumption of research work is assuming normal distribution of the data [37]. Skewness and kurtosis are two key measures of normality test. Skewness is a measure of symmetry, while kurtosis is a parameter that describes the shape of a random variable's probability distribution [38]. According to Abdulwahab et al. [37], skewness and kurtosis values in the range of ±2.00 and ±7.00, respectively, are considered normally distributed.

Table 2. Skewness and kurtosis values of the 17 items.

Item	Skewness value	Kurtosis value
AOM	−1.00	0.52
AOW	−0.11	−1.36
EXR	−0.85	−0.41
EDU	0.14	−1.20
JOR	−0.84	−0.38
JOS	−0.40	−1.25
NSF	0.15	−1.43
SBT	−1.16	0.83
STP	−1.18	2.07
SMK	0.55	−0.83
SOT	−1.07	0.65
TPM	−1.29	2.86
WGT	0.49	−1.24
VEX	−0.97	0.24
VST	−1.46	3.96
WEP	−1.13	1.56
WHO	−1.04	0.54

Note: AOM = age of the machine; AOW = age of the worker; EDU = education; EXR = exercise; JOR = job rotation; JOS = job satisfaction; NSF = night shift; SBT = safety and health budget; SMK = smoking; SOT = soil type; STP = seat type; TPM = training programme; VEX = WBV exposure; VST = WBV standard; WEP = working experience; WGT = weight of the worker; WHO = working hours.

The 149 data sets are analysed with the normality test, and the results show skewness and kurtosis values in the acceptable ranges, thus confirming normal distribution of the data (see Table 2).

Table 3. Mean and 5% trimmed *M* values of the 17 items.

Item	*M*	5% trimmed *M*
AOM	3.72	3.76
AOW	3.22	3.21
EXR	3.41	3.45
EDU	3.05	3.02
JOR	3.58	3.59
JOS	3.30	3.29
NSF	3.11	3.09
SBT	3.62	3.66
STP	4.07	4.14
SMK	2.74	2.71
SOT	3.77	3.79
TPM	3.93	3.97
WGT	2.80	2.76
VEX	3.77	3.79
VST	3.91	3.96
WEP	3.83	3.86
WHO	3.86	3.91

Note: AOM = age of the machine; AOW = age of the worker; EDU = education; EXR = exercise; JOR = job rotation; JOS = job satisfaction; NSF = night shift; SBT = safety and health budget; SMK = smoking; SOT = soil type; STP = seat type; TPM = training programme; VEX = WBV exposure; VST = WBV standard; WEP = working experience; WGT = weight of the worker; WHO = working hours.

Table 4. Potential outliers from the box plot analysis.

Data set number	Frequency of potential outlier
67	4
61	3
63	3
81	3
1	1
46	1
140	1

Note: One data set contains scores of the 17 items.

5.2. *Outlier test*

The outlier test is an additional step of the data screening process [37]. It reports unusual data values that occurred in observational studies [37]. In this study, the 5% trimmed mean, z score and box plot are performed to detect outliers [39]. A difference between mean and 5% trimmed mean greater than 0.2 and a z score of higher than 3.29 are potential outliers [40,41]. The results show no items with large mean differences and z scores over the stated limit (see Table 3).

The box plot, on the other hand, shows four data sets with potential outliers, including data numbers 61, 63, 67 and 81, respectively (see Table 4). As a result, these four data sets are removed, resulting in 145 data sets remaining for EFA analyses.

6. Exploratory factor analysis

EFA is one of the most commonly reported quantitative methodologies in social sciences [42]. It examines all pairwise relationships between individual variables, and seeks to extract latent factors from measured variables [42]. In this study, SPSS version 20 is used to perform the EFA.

There are different methods used in the EFA, including the principal component, principle axis factoring, alpha factoring, image factoring, unweighted least square and generalized least square methods [42]. In this study, the principal component analysis method is used to extract key factors affecting LBP due to WBV exposure, as it groups together variables that are highly correlated [43]. The varimax rotation method is also used, together with a factor loading of 0.3, to make the results easy to interpret [40,42].

The EFA is performed to extract the 17 items, within the 145 data sets, into a number of key factors affecting LBP due to WBV exposure. The first run groups the 17 items into four factors. Factor 1 is accounted for by four items, explaining mainly equipment characteristics, and is called the equipment factor (EQF). Factor 2 is related to organizational context, and is called the organization factor (ORF). Factor 3 consists of three items, explaining mainly the social-related content. It is therefore called the social context factor (SCF). Factor 4 is associated with six items, explaining about employee and job-related issues.

Closer examination reveals the potential to further extract Factor 4 to confirm the groupings of these six items.

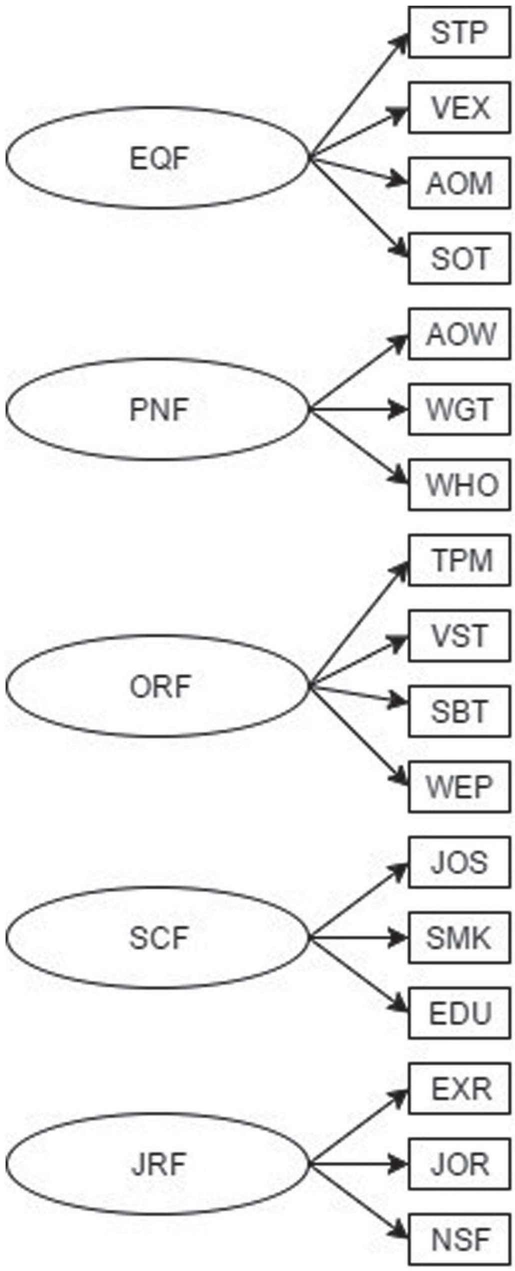

Figure 2. The conceptual model of LBP due to WBV exposure.
Note: AOM = age of the machine; AOW = age of the worker; EDU = education; EQF = equipment factor; EXR = exercise; JOR = job rotation; JOS = job satisfaction; JRF = job-related factor; LBP = lower back pain; NSF = night shift; ORF = organizational factor; PNF = personal factor; SBT = safety and health budget; SMK = smoking; SCF = social context factor; SOT = soil type; STP = seat type; TPM = training programme; VEX = WBV exposure; VST = WBV standard; WBV = whole-body vibration; WEP = working experience; WGT = weight of the worker; WHO = working hours.

Table 5. Five factors extracted from 17 items.

	Factor loading of the five factors extracted				
Item	EQF	ORF	SCF	PNF	JRF
STP	0.68				
VEX	0.60				
AOM	0.59				
SOT	0.34				
TPM		0.63			
VST		0.63			
SBT		0.58			
WEP		0.45			
JOS			0.57		
SMK			0.55		
EDU			0.54		
AOW				0.73	
WGT				0.71	
WHO				0.67	
EXR					0.76
JOR					0.74
NSF					0.39

Note: AOM = age of the machine; AOW = age of the worker; EDU = education; EQF = equipment factor; EXR = exercise; JOR = job rotation; JOS = job satisfaction; JRF = job-related factor; NSF = night shift; ORF = organizational factor; PNF = personal factor; SBT = safety and health budget; SMK = smoking; SCF = social context factor; SOT = soil type; STP = seat type; TPM = training programme; VEX = WBV exposure; VST = WBV standard; WEP = working experience; WGT = weight of the worker; WHO = working hours.

The principal component and varimax rotation methods together with a factor loading of 0.3 are used, and the results extract the six items into two groups, three items under the personal factor (PNF) and another three items under the job-related factor (JRF).

In summary, five factors affecting LBP due to WBV exposure are extracted from the EFA, and form a conceptual model of LBP due to WBV exposure, as shown in Figure 2 and Table 5.

To further confirm the extracted factors with their associated items, the reliability test is performed. Based on Zandvakili et al. [44], Cronbach's α of at least 0.4 is considered reliable. The results show that the five factors have α values higher than 0.4, with a maximum value of 0.6, thus increasing confidence in the contribution of 17 items to their respective factors.

To further explore the relationships among the five key factors affecting LBP due to WBV exposure, the SEM is performed.

7. Structural equation modelling

SEM is used in this study to examine relationships among key factors affecting LBP due to WBV exposure. It consists of measurement and structural models [45]. The measurement model represents a set of measured variables (considered 'item' in this study) as multiple indicators of latent variables [46]. The structural model, on the other hand, describes relations of dependency between the factors. According to McDonald and Ho [46], the structural model represents an operation of causality.

In a measurement model, non-directed paths are used to represent the correlated disturbances (unexplained variations), while directed paths are used in the structural model to indicate direct effect interventions [46]. A non-directed path is usually drawn as a double-headed arrow, while a single-headed arrow is used for a directed path representation.

In this study, Analysis of Moment Structures (AMOS) version 21 is used to perform the SEM. The overall fit of the model is assessed using a number of fit indices, including χ^2 to the degree of freedom (CMIN/*df*), root mean square error of approximation (RMSEA) and comparative fit index (CFI) [47].The CMIN/*df*, also called normal χ^2, is the χ^2 fit index divided by the degree of freedom. RMSEA is the discrepancy per degree of freedom and CFI is an index that compares the existing model fit with a null model, which are assumed indicator variables [48].

In this study, CMIN/*df* of lower than 3.88, RMSEA of less than 0.08 and CFI close to 1 are used to assess model fit [42,48]. Model adjustment can be performed to increase the model fit using modification indices (MI) provided in the model output. According to Hox and Bechger [49], path coefficients with high MI values should be added to improve the model fit. Paths with low coefficients, on the other hand, should be removed from the model.

7.1. The measurement model

The conceptual model of LBP due to WBV exposure (see Figure 2) is performed with the measurement model to confirm correlations of the five key factors. The results show that correlations between the ORF and the JRF, and between the ORF and the SCF, are removed due to their low correlation coefficients. The MI results, on the other hand, suggest the age of the machine (AOM) and seat type (STP) items, and the WBV standard (VST) and job rotation (JOR) items, to be correlated.

After the modifications, the model is run and the best fit measurement model is achieved (see Figure 3 and Table 6). It is found that the age of the worker (AOW), education (EDU), WBV exposure (VEX) and VST items have high effects on LBP due to their high loadings on their respective factors (0.74, 0.71, 0.64 and 0.52, respectively).The EQF and the PNF have the strongest correlation with a correlation coefficient of 0.85. This is consistent with, e.g., Donati [50] that seat adjustment for different body weight is crucial to reduce LBP due to WBV exposure. Older workers also need a better seat to reduce LBP due to WBV exposure [51]. The PNF and the SCF are also found to have a strong correlation (correlation coefficient = 0.68). According to Beeck and Hermans [22], time pressure causes low job satisfaction and leads to higher chances of having LBP due to WBV exposure.

7.2. The structural model

To further explore directions of relationships between the five key factors affecting LBP due to WBV exposure, the structural model is performed. In this study, a total of eight paths are hypothesized based on a number of construction-related research studies:

- the ORF $\rightarrow$ PNF and the ORF $\rightarrow$ EQF: Griffin [52] mentioned that the WBV standard recommends working hours of less than 8 h/day to reduce LBP and Jailer et al. [53] stated that experienced workers can effectively use outdated equipment without having LBP problems;
- the PNF $\rightarrow$ EQF, the PNF $\rightarrow$ JRF and the PNF $\rightarrow$ SCF: Okunribido et al. [54] commented that workers who exercise regularly experience less chance of having LBP, Donati et al. [8] stated that appropriate working hours help prevent LBP problems and Uehata [55], on the other hand, mentioned that long working hours cause stress, leading to smoking and LBP problems [18];
- the SCF $\rightarrow$ EQF: Jailer et al. [53] mentioned that a proper educational programme assists workers to work with heavy equipment safely;
- the JRF $\rightarrow$ EQF and the JRF $\rightarrow$ SCF: having job rotation increases job satisfaction and reduces by around half the chances of having LBP due to WBV exposure [56,57].

These eight hypothesized directions are tested in the structural model. The model is run, and the MI values suggest a number of correlations to be added to increase model fit. These include the correlation between working experience (WEP) and VEX items, between VST and AOM items and between VST and weight of the worker (WGT) items. After the modifications, the best fit structural model, or the final model of key factors affecting LBP due to WBV exposure, is achieved as shown in Figure 4 and Table 6.

7.3. Discussion

The final model of key factors affecting LBP due to WBV exposure reveals a number of direct and indirect relationships (see Table 7). It is found that some factors have strong relationships with each other, while some factors influence the other factors indirectly through the intermediaries. The ORF, e.g., influences the EQF, both directly and indirectly, through the implementation of the PNF. This factor, nevertheless, has no direct, but an indirect, effect on the JRF and the SCF through the PNF.

The results show that the ORF is the most important, as it influences all four other factors, both directly

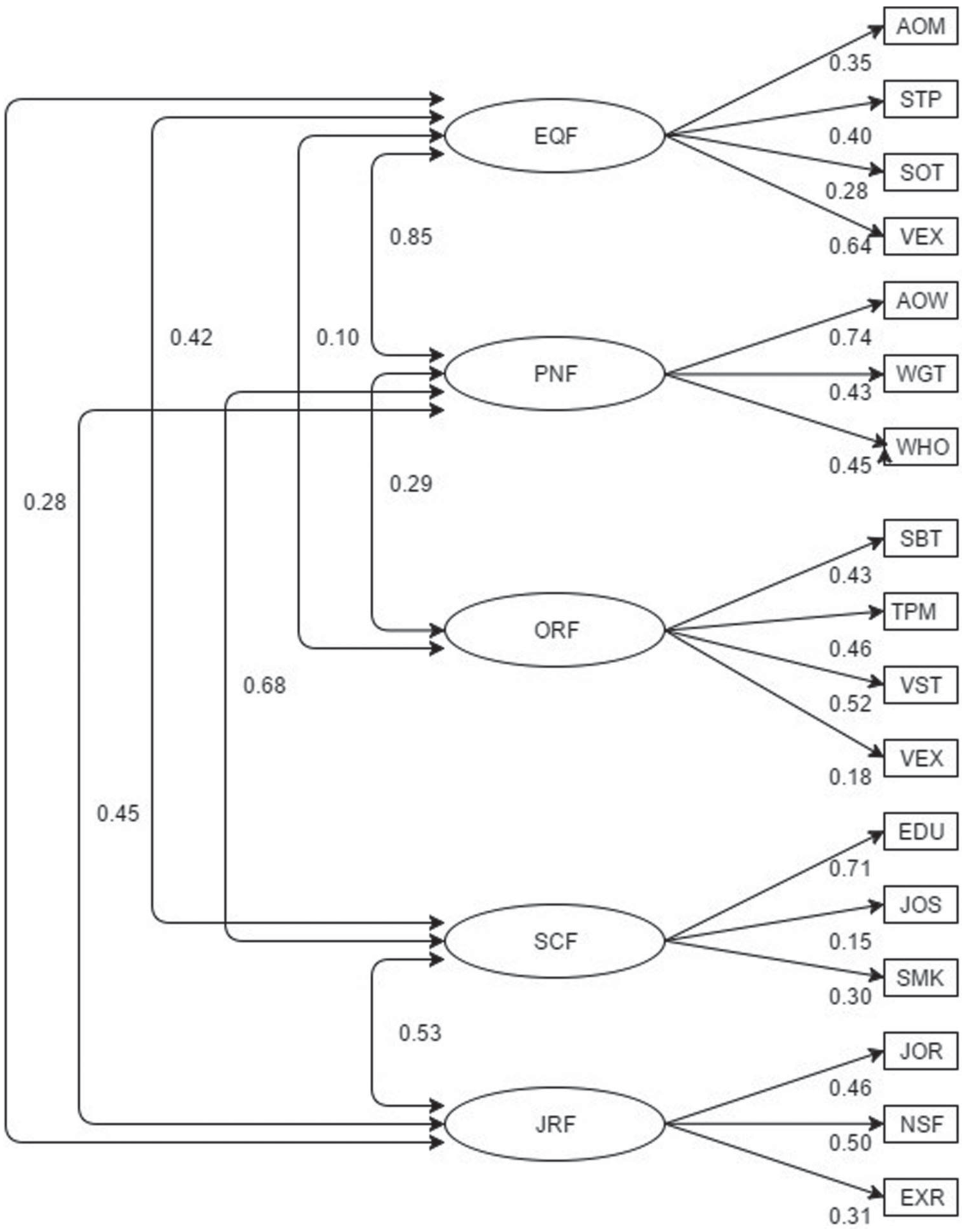

Figure 3. Best fit measurement model.
Note: AOM = age of the machine; AOW = age of the worker; EDU = education; EQF = equipment factor; EXR = exercise; JOR = job rotation; JOS = job satisfaction; JRF = job-related factor; NSF = night shift; ORF = organizational factor; PNF = personal factor; SBT = safety and health budget; SMK = smoking; SCF = social context factor; SOT = soil type; STP = seat type; TPM = training programme; VEX = WBV exposure; VST = WBV standard; WEP = working experience; WGT = weight of the worker; WHO = working hours.

and indirectly. This is consistent with, e.g., Gervais [58] that appropriate WBV standards and training programmes (items in the ORF) assist in preventing LBP disorders in the construction industry. This factor has direct effects on the PNF and the EQF, with path coefficients of 0.22 and –0.20, respectively. When the ORF goes up by one standard deviation, the PNF goes up by 0.22 while the EQF decreases by 0.20. With a good WBV standard (an item in the ORF), appropriate working hours (an item in the PNF) is considered one of the important issues to reduce long-term health problems, including LBP [52]. Langer et al. [38], on the other hand, mentioned that workers who receive a specific WBV training programme (an item in the ORF) can effectively utilize the existing heavy equipment (an item in the EQF) without having LBP problems.

The ORF also affects the EQF, the SCF and the JRF indirectly through the implementation of the PNF. Adequate provision of a safety and health-related budget (an item in the ORF), e.g., results in more workers hired for and performing heavy equipment tasks, thus reducing

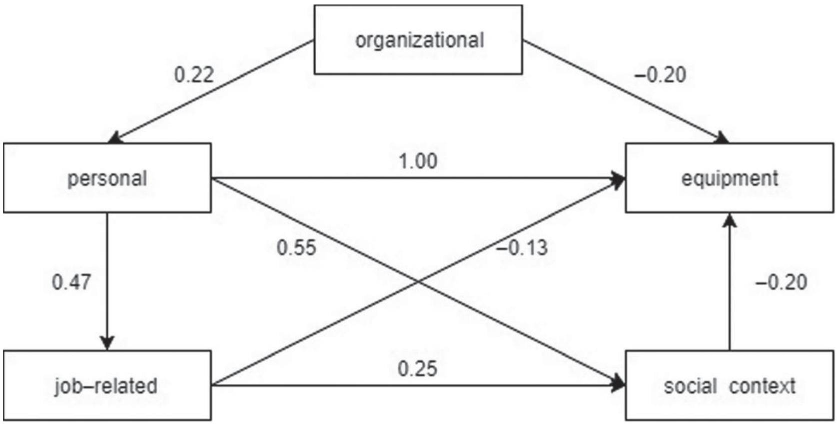

Figure 4. Final model of key factors affecting lower back pain due to whole-body vibration exposure.

Table 6. Fit index results.

Fit index	Acceptable level	Best fit measurement model	Best fit structural model
CMIN/*df*	≤3.88	1.14	1.07
RMSEA	<0.08	0.03	0.02
CFI	>0.90	0.92	0.96

Note: CFI = comparative fit index; CMIN/*df* = χ^2 to the degree of freedom; RMSEA = root mean square error of approximation.

working hours (an item in the PNF). This in turn increases job satisfaction (an item in the SCF) and reduces WBV exposure (an item in the EQF) [22,52,59].

The results also show that the PNF has the strongest relationship with the EQF, with a path coefficient of 1.00. This is consistent with, e.g., Donati [50] that body weight adjustment (an item in the PNF) of the seat (an item the EQF) is crucial to reduce LBP of the construction workers. Hutchinson [28] also mentioned that younger workers should be assigned to work on sites with heavy clay soil types, as they have higher vibration levels.

The JRF is found to have a positive relationship with the SCF and a negative relationship with the EQF. Having a job rotation (an item in the JRF), e.g., increases job satisfaction (an item in the SCF), resulting in a positive relationship between the JRF and the SCF [57]. On the other hand, workers who exercise regularly (an item in the JRF) are found to be healthier, and are able to work with outdated machines (an item in the EQF) with less pain [22]. This explains a negative relationship between the JRF and the EQF.

8. Conclusion and limitations

WBV exposure among soil roller operators causes long-term health effects, especially LBP disorders. This study investigates key factors affecting LBP due to WBV exposure in the Sri Lankan construction industry. The EFA results confirm five key factors, including the EQF, JRF, ORF, PNF and SCF, with their 17 associated items. The SEM results reveal direct and indirect relationships among the five key factors, and concluded that the ORF is the most important as it directly and indirectly influences the other four factors.

It is clear that the implementation of items in the ORF requires support and commitment from the management level. This is consistent with the interview results that a specific WBV standard is needed, and that it must be well maintained to reduce the reimbursement cost due to LBP. Provision of an adequate safety and health-related budget can also generate more WBV-related training programmes. This in turn enhances knowledge of the workers, leading to proper use of heavy equipment.

A strong relationship between the PNF and the EQF is also found. Physical conditions of workers, such as weight and age, must be considered before assigning them to

Table 7. Direct and indirect relationships of key factors affecting LBP due to WBV exposure.

Factor	Correlation coefficient
PNF	$0.22 \times \text{ORF}$
JRF	$(0.47 \times \text{PNF}) + (0.10 \times \text{PNF} \times \text{ORF})$
EQF	$(1.00 \times \text{PNF}) + (-0.20 \times \text{ORF}) + (-0.20 \times \text{SCF}) + (-0.13 \times \text{JRF}) + (0.22 \times \text{PNF} \times \text{ORF})$
SCF	$(0.55 \times \text{PNF}) + (0.25 \times \text{JRF}) + (0.12 \times \text{PNF} \times \text{ORF}) + (0.12 \times \text{JRF} \times \text{PNF})$

Note: EQF = equipment factor; JRF = job-related factor; LBP = lower back pain; ORF = organizational factor; PNF = personal factor; SCF = social context factor; WBV = whole-body vibration.

heavy equipment tasks. The results also show that the EQF is influenced by the other four factors. This implies that provision of a new machine or better seat type without a proper working strategy and personal consideration might not help reduce LBP problems due to WBV exposure.

This study contributes to the construction industry in several ways. Relationships among key factors affecting LBP due to WBV exposure are examined, thus enhancing the understanding of LBP and WBV exposure, leading to a better work plan. Items associated with LBP due to WBV exposure in this study are both qualitative and quantitative. This reflects real practices in the construction industry. Managers must also hold a major responsibility in providing adequate safety and health budgets to support a WBV-related plan, motivating workers to work safely. This will help reduce LBP due to WBV exposure in the long term.

There are limitations in this study. Data used in the study are from soil roller operators and managers in the Sri Lankan construction industry. The use of the study results in other developing countries or developed countries might need some adjustments. Some items, such as posture, gender and weather conditions, are not included in the study and could be examined in future studies.

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Appendix 1. Please rate your agreement on each item by considering the chances of having LBP

1	2	3		4		5
Strongly disagree	***Disagree***	***Neither agree nor disagree***		***Agree***		***Strongly agree***

Statement	**Scale**				
Use of new machine reduces chance of having LBP due to WBV exposure	1	2	3	4	5
Young workers have chances of having LBP due to WBV exposure	1	2	3	4	5
Having regular exercise reduces chance of having LBP due to WBV exposure	1	2	3	4	5
Workers with high education background have less chance of having LBP due to WBV exposure	1	2	3	4	5
Having job rotation reduces chance of having LBP due to WBV exposure	1	2	3	4	5
High job satisfaction reduces chance of having LBP due to WBV exposure	1	2	3	4	5
No night shift work reduces chance of having LBP due to WBV exposure	1	2	3	4	5
Adequate safety and health budget provision reduces chance of having LBP due to WBV exposure	1	2	3	4	5
Better seat types of a soil roller reduces chance of having LBP due to WBV exposure	1	2	3	4	5
Non-smoking workers have less chance of having LBP due to WBV exposure	1	2	3	4	5

Note: LBP = lower back pain; WBV = whole-body vibration.