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The Consequences of Mechanical Vibration Exposure on the Lower Back of Bus Drivers: A Systematic Review

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Abstract: Professional drivers are exposed to whole-body vibration while driving, which contributes to an increased risk of developing physical problems, such as pain in the lower back. This article aims to review the effects of vibration exposure on bus drivers. Searches were performed on the PubMed, Embase, Web of Science, and Scopus databases. Only full articles of observational and experimental studies that investigated the effects of vibration on bus drivers with consequences in the lumbar region published in English were included. Data on driver demographics, study design, objectives, bus model, seat model, length of exposure to vibration, and outcomes were extracted. Two studies were classified as evidence level III-2 and three studies as level III-3. The methodological quality of the publications presented one with a moderate and four with a serious risk of bias. In all the publications, pain in the lumbar spine was reported. In conclusion, the results of this systematic review suggest that bus drivers are exposed to mechanical vibration in their work routine, and this might be considered a risk factor for the development of pain in the lumbar spine, bearing in mind that the exposure is for long periods.

Keywords: bus drivers; vibration exposure; lumbar spine; lower back

1. Introduction

Public transport is one of the world's most popular systems of transportation [1], playing an important role in commuting passengers across the world [2], with buses being one of the most used option [1]. Professional drivers often face severe adverse conditions, such as traffic congestion, continuous time pressure, excessive physical demands, and so on, which could challenge their health condition, leading to work-related musculoskeletal disorders [3,4]. The physical risk factors contributing to these musculoskeletal disorders include prolonged sitting, exposure to whole-body vibration (WBV), static or awkward postures, continuous movements, excessive forces, lack of recovery between movements, and repetitive actions [3].

According to Azenan et al. (2018) [2], bus drivers are exposed to high-intensity vibrations during their work routine, and the vibrations are considered to be etiologic agents or risk factors of occupational tasks [5]. Increased duration and intensity of the vibrations are assumed to increase risks [6]. As such, ISO 2631 of the International Organization for Standardization (ISO) [7] established standards related to human exposure to WBV. Several factors can contribute to the intensity of the vibration the driver may be exposed to, including the type and design of the vehicle [7], the engine, the seat [7], the speed at which the vehicle is moving, the body posture adopted [8], the road, and environmental issues. This intensity of vibration can be measured on three orthogonal axes, x-forward and backward, y-lateral, and z-vertical [2].

When driving a bus, the driver's seat receives or is exposed to vibration, and then that vibration is transmitted through the whole body of the driver. According to Blood et al. (2015) [9] and Bovenzi et al. (2009) [6], professional drivers of buses and trucks regularly spend long hours (usually 8 h a day) in heavy vehicles, being continuously exposed to WBV, without the possibility of stretching their body while driving. Bovenzi and Hulshof (1999) [10] suggested that vibration exposure while sitting can affect the spine due to mechanical overload and excessive muscle fatigue. Fatigue among professional drivers could be associated with the vibration transmitted to the body of the individuals [11]. It is important to emphasize that drivers carrying out a specific activity in a sitting position for a long time with constant exposure to vibration can, over the years, suffer consequences in their bodies, especially in the lower back [8,12,13]. In this sense, physical work has been suggested as an important predictor of LBP [14].

Thus, professional drivers constitute an occupational group that presents a high risk of developing physical issues, such as low-back pain (LBP) or lower-back pain [15,16], herniated disc, and early degeneration of the spine [14,17]. Worldwide, 37% of LBP is attributed to occupational risk factors [18]. LBP is responsible for 21% of all indemnifiable work accidents and 33% of costs in health services [19]. The exposure to occupational vibration is one of the most common causes for lower back disorders [2,20,21], due to it being a potential stressor which can lead to the development of postural stress as a result of muscular effort and long exposure time, consequently also affecting personal, psychological, and social aspects of drivers [11,14,22]. Furthermore, according to Bovenzi and Hulshof (1999) [10], there is evidence that in occupations with exposure to WBV, LBP is the major cause of sick leave and the development of occupational illnesses.

In this context, LBP has been associated with WBV, overwork, wrong working posture, repetitive tasks, misallocation of resting and working times, lack of education about correct working posture, and job stress that can favor musculoskeletal diseases [23,24].

According to those mentioned, there is evidence for the relationship between exposure to vibration and LBP; however, little is known about the effects of vibration on bus drivers in relation to LBP. Thus, this systematic review aims to verify the effects of WBV on bus drivers and highlight the possible consequences related to LBP resulting from mechanical vibration.

2. Methods

This systematic review was based on the guidelines of the preferred report items for systematic reviews and meta-analyses (PRISMA) [25] and was registered on the international prospective register of systematic reviews (PROSPERO: CRD42020203294).

2.1. Search Strategy

This systematic review aimed to answer the following question: Can a vehicle's vibration develop pain in the lumbar spine of a driver? The PICO search strategy (P = population, I = intervention, C = comparison, and O = outcomes) was used to define the four major components of the research question [26] as follows: P = bus drivers, I = vibration, C = road vehicle, and O = low-back pain. The literature search was conducted on June 22, 2020, using the PubMed, Embase, Web of Science, and Scopus electronic databases. The search expressions ((“bus driver”) AND (“pain”) OR (“low-back pain”) OR (“lower back”) AND (“vibration”)) were used in the search.

2.2. Eligibility Criteria

Inclusion Criteria: only full articles of observational and experimental studies that investigated the effects of vibration on bus drivers with consequences for the lower back published in English were included. No publication date restrictions were defined.

2.3. Exclusion Criteria

Any filters used in the search that have not been mentioned above, replies, editorials, letters, abstracts, comments, or brief communications were excluded.

2.4. Study Selection and Data Extraction

The references found in the databases were exported to EndNote X9 and duplicates were removed. The current systematic review was conducted following four steps. The records were identified through database search and reference screening (identification). Two reviewers (DSC, AC) independently examined the titles and abstracts of the studies, excluding any irrelevant studies (screening). All relevant articles were included following the analysis of all relevant full texts for eligibility (eligibility). Any disagreement was resolved by a third reviewer (MG). The same researchers were responsible for extracting data from the included studies. Data related to study information (author and year), driver data, study design, objectives, bus model, seat model, exposure time load, and results were extracted.

2.5. Level of Evidence (LE)

The LE of each article was classified according to the National Health and Medical Research Council (NHMRC) 2003–2009 [27], and the hierarchy of evidence was used to classify the studies included in this systematic review, which consists of six levels: (I) LE I—systematic review; (II) LE II—randomized controlled trial; (III) LE III-1—pseudorandomized controlled trial; (IV) LE III-2—comparative study with concurrent controls: nonrandomized experimental trial, cohort study, case-control study, interrupted time series without a parallel control group; (V) LE III-3—comparative study without concurrent controls: historical control, two or more single-arm study, interrupted time series without a parallel control group; and (VI) LE IV—cases series with either post-test or pretest/post-test outcomes.

2.6. Risk of Bias in the Included Studies

The risk of bias was assessed using the ACROBAT-NRSI instrument (a Cochrane risk assessment tool for nonrandomized studies), which compares the health effects of two or more interventions. ACROBAT-NRSI is divided into seven domains of having preintervention, at intervention, and postintervention criteria, with each item classified as low, moderate, serious, or critical for bias, the necessity to inform when no information is present [28].

3. Results

A total of 177 publications were identified through the database search (PubMed, Embase, Web of Science, and Scopus), and one article was included through other sources.

Thirty-eight duplicate articles were excluded, leaving 140 articles for screening. During screening, 116 publications were excluded because they were not related to the subject of the current review, and 24 were considered for eligibility. After analysis, a further 19 articles were excluded. Finally, 5 articles were included in this systematic review. A flowchart according to PRISMA is presented to highlight the steps for selecting the full articles analyzed in the current systematic review (Figure 1).

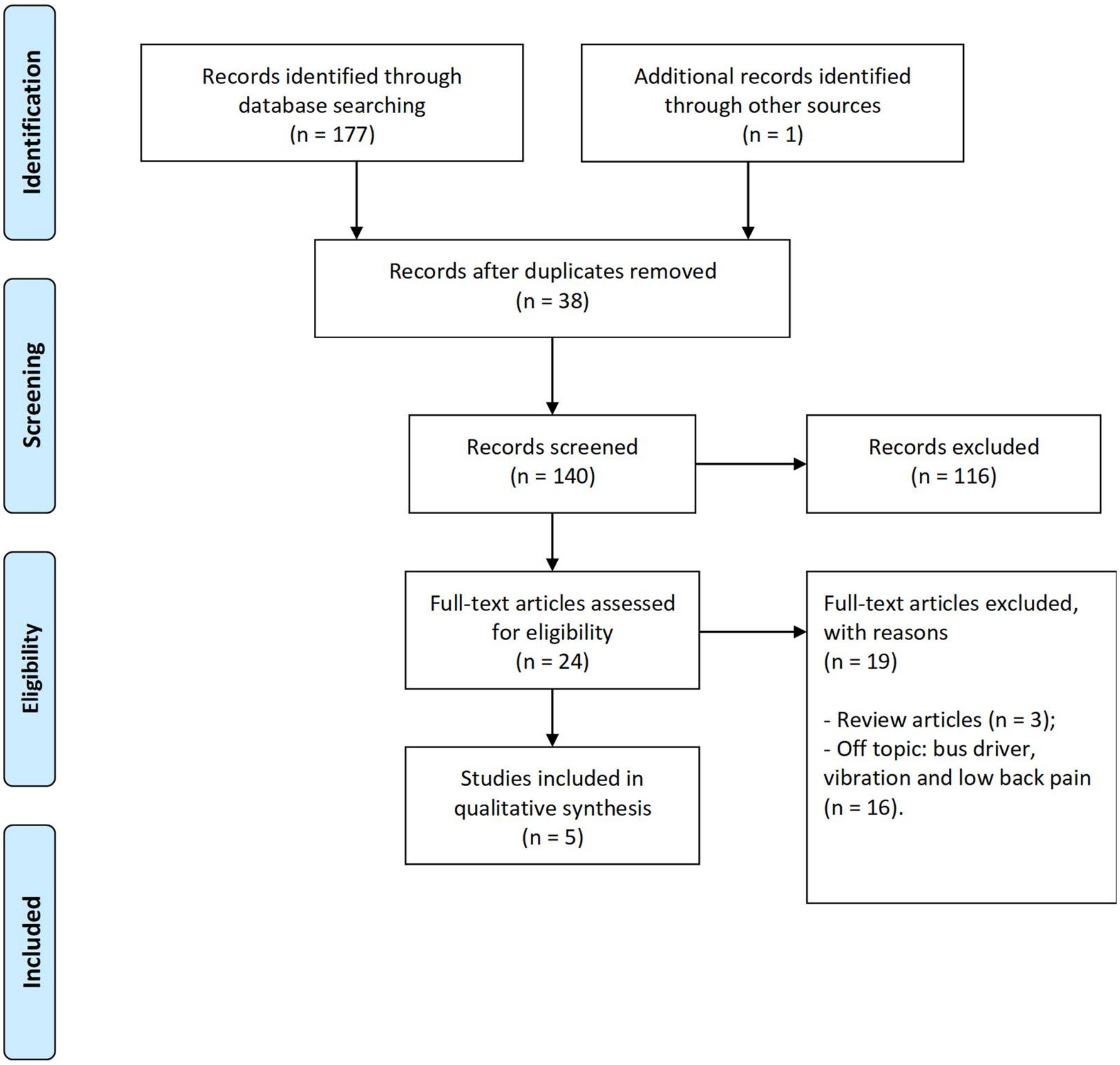

Figure 1. PRISMA flow diagram of the literature selection process.

Table 1 presents the characteristics of each study related to the type of publication, demographics, aims, results, and level of evidence of the selected publications. Among the five studies included, there were two experimental studies [29,30] with a III-2 level of evidence and three cross-sectional studies [2,31,32] with a III-3 level of evidence. The number of individuals in the included publications ranged from 7 to 760 participants of both sexes (men and women). The aims in the three studies [29,31,32] were focused on the prevalence of LBP, and two [2,30] focused on the level of exposure to vibration. The results showed that four studies reported an association between vibration and LBP [2,29,30,32] and one study did not report this association [31].

The variables evaluated in the studies were WBV, bus model, seat model, vibration measurement, and exposure time. The reported bus models varied between old buses, new buses, low-floor buses, and high-floor buses. The different models also varied according to the year of manufacture. Two studies reported the seat model and three studies did not. Considering the evaluation of the intensity of mechanical vibration, the studies fixed an accelerometer to the seat. Four studies [2,29,31,32] used a triaxial accelerometer and one study [30] used an ICP accelerometer. The time of exposure to mechanical vibration varied from 6 to 8 h (Table 2).

Regarding the risk of bias, four publications [29–32] were identified as having a serious risk of bias (RoB), and one study [2] presented moderate RoB, according to our analysis based on the ACROBAT-NRSI instrument. These results are shown in Figure 2.

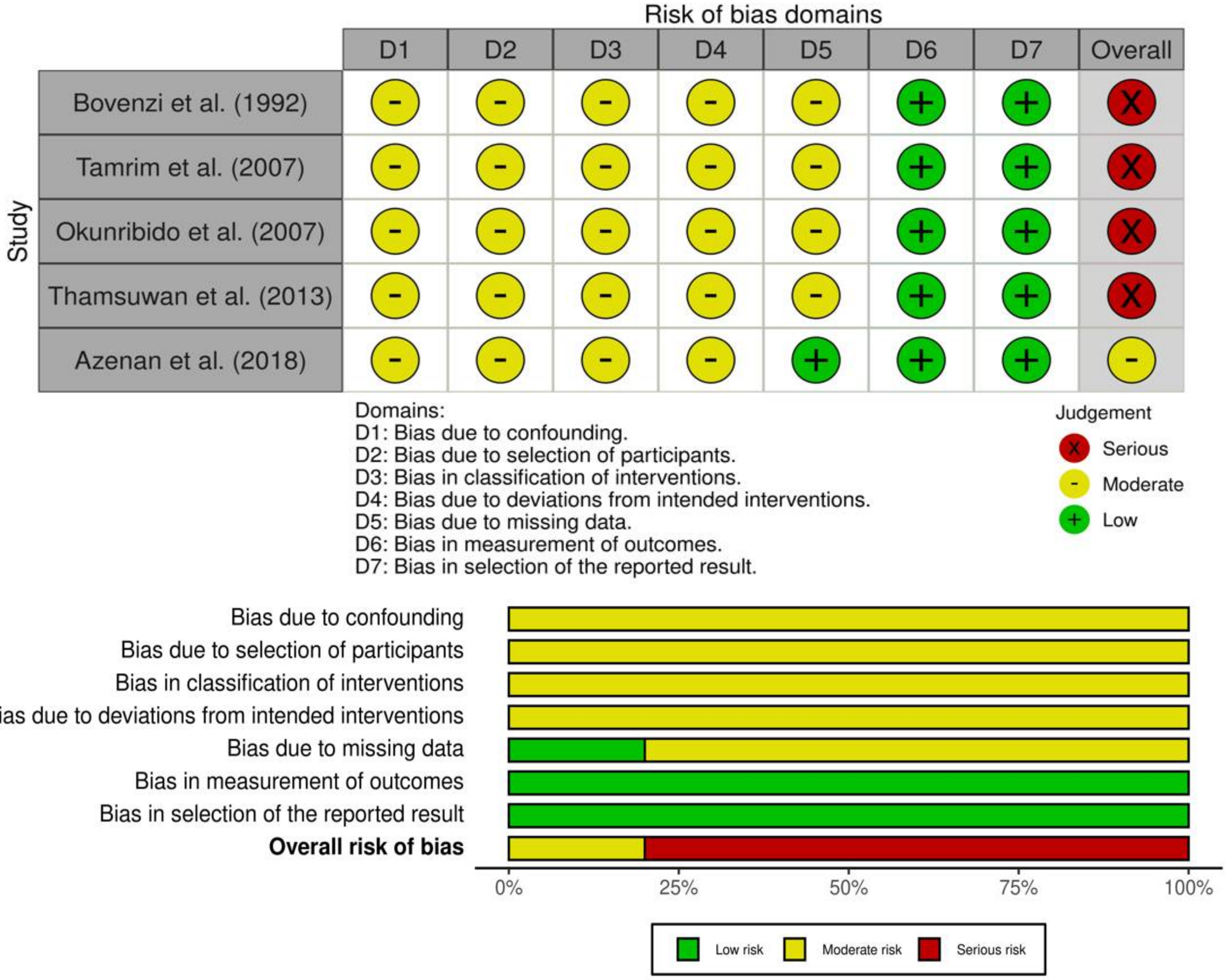

Figure 2. ACROBAT-NRSI risk of bias.

Table 1. Characteristics of the included studies and the level of evidence.

Study	Study Design	Demographics	Aim	Results	LE
Bovenzi et al., 1992	Experimental study	234 drivers (male) Age: 41.2 years 125 control workers Age: 44.5 years	To analyze the prevalence of severe types of LBP among bus drivers employed in a municipal public transport company.	The findings also indicated that among bus drivers, lumbar symptoms occurred at levels of exposure to WBV below the health exposure limits proposed by the International Standard ISO 2631/1.	III-2
Tamrin et al., 2007	Cross-section of a cohort study	760 drivers (male) from 11 bus companies	To determine the prevalence of musculoskeletal disorders, including LBP, and reveal the physical and psychological risk factors.	This study revealed no significant association between WBV exercise and LBP and demonstrated that the risk factors for developing LBP do not depend on just one factor (physical and psychological).	III-3
Okunribido et al., 2007	Cross-sectional study	61 drivers (58 men and 3 women), Age: 19 to 64 years Body mass: between 58.6–129.0 kg (mean 84.9 kg, SD 15.72) Height: between 154.9 and 192.0 cm in height	To investigate the typical exposures of urban bus drivers to the demands of posture when driving, manual material handling and vibration, as well as the prevalence and nature of LBP.	City bus drivers spend about 60% of their daily work time driving, often with the torso straight or unsupported, perform occasional and light manual material handling, and experience discomforting shock/jerking vibration events. Transient and mild LBP (not likely to interfere with work or customary levels of activity) was found to be prevalent among the drivers, and a need for ergonomic evaluation of the drivers' seats was suggested.	III-3
Thamsuwan et al., 2013	Experimental study	Low floor: 15 drivers (13 men and 2 women) Mean age: 42.3; Mean body mass: 93.7 kg; Mean height: 176.8 cm; Mean BMI: 30.0 kg/m^2. High floor: 12 drivers (8 men and 4 women) Mean age: 42.8; Mean body mass: 94.2 kg; Mean height: 169.9 cm; Mean BMI: 32.5 kg/m^2	To determine if there are differences in performance between the two buses on the road and the traffic conditions that are encountered during normal operation.	WBV exposures were significantly different between road types, both on high-floor and low-floor buses. The WBV exposures on the high-floor bus were slightly smaller than the low-floor bus exposures when driving on smooth highways and city streets. In contrast, on the high-floor bus, the WBV exposures were substantially larger than the low-floor bus exposures when driving on the bumpy road segment.	III-2

Table 1. *Cont.*

Study	Study Design	Demographics	Aim	Results	LE
Azenan et al., 2018	Cross-sectional study	12 drivers (5 bus drivers from Putrajaya Sentral and 7 bus drivers from Larkin Central	To identify the level of WBV among bus drivers and assess whether exposure to vibration has already exceeded the exposure limit based on ISO 2631/1.	Upper back pain and LBP were identified as significant effects of vibration. The results showed a positive, strong, and significant relationship between daily exposure to vibration and upper and lower back pain. The Larkin Central drivers were exposed to significantly higher vibration that exceeds the exposure limit when compared to those at Putrajaya Sentral.	III-3

Legend: BMI—body mass index, ISO—International Organization for Standardization, WBV—whole-body vibration; LBP—low-back pain; SD—standard deviation; LE—level of evidence.

Table 2. Characteristics of mechanical vibration exposure.

Study	Variables Measured by WBV	BUS MODEL	Seat Model	Vibration Measurement	Exposure Time
Bovenzi et al., 1992	Standardized questionnaire on musculoskeletal symptoms	3 old buses: Fiat 409 DSU, Fiat 410 P, Fiat 418 AL (1968–1973) 3 new buses: Inbus U-210 FTN, Iveco U-F1, Iveco Turbocity-U (1987–1990)	Not reported	Bruel & Kjaer triaxial seat accelerometer (B&K 4322, Denmark), compatible with ISO 2631-1. The average magnitude of vertical vibration of the entire body measured was 0.4 m/s^2.	For vibration analysis: each measured vibration lasted from 15 to 20 min. Daily exposure value: 6 h and 10 min.
Tamrin et al., 2007	LBP and work factor, postural analysis, mood state.	Not reported	Not reported	Maestro human vibration meter (01DB-Metravib®, Lyon, France) with a triaxial accelerometer (0.4–1000 Hz), compatible with ISO 2631-1. Movements analyzed during travel: (1) forward bending, (2) inclined, (3) sitting straight, and (4) twisted.	Each driver drove a different bus and made different routes on different days. For vibration analysis: The total duration of 25 min with an interval of 1 s for data recording. The action level for 25 min was 2.18 m/s^2 and the r.ms—exposure limit—for 25 min was 5.02 m/s^2. Daily exposure value: 8 h.

Table 2. *Cont.*

Study	Variables Measured by WBV	BUS MODEL	Seat Model	Vibration Measurement	Exposure Time
Okunribido et al., 2007	Self-evaluation: questionnaires about LBP experience when driving (sitting), posture, and manual material handling.	One-story Volvo B10BLE Wright Renown; one-story Volvo B10BLE Alexander ALX300; articulated single-deck Volvo B7LA Wright Eclipse; Leyland Olympian Alexander R two-story; Volvo B7TL Alexander ALX400 double-decker; Mercedes 709D Alexander AM minibus; Volvo B10 M Plaxton Premiere 3.5; Volvo B6, and Coach Plaxton Paramount.	Mercedes 709D Alexander AM minibus = 23 Beaver seats. The other types of seats were not informed.	Liberty Mutual 2.0 full body vibration meter using a triaxial seat accelerometer, which was placed in the seat below the driver's ischial tuberosities when seated and connected to a portable field computer packaged in a robust instrument.	Service route driving throughout at least one complete round trip. Observation times varied between 1 h 21 min and 1 h 44 min. Daily exposure value: 7 h 36 min.
Thamsuwan et al., 2013	Different types of highways	Low floor: model D40LF; New Flyer; Winnipeg, Manitoba 12.2 m in length (7 years) High floor: model D4500; Motor Coach Industries Inc; Winnipeg, Manitoba 13.9 m in length (5 years)	Model Q91; USSC; Exton, PA	Four-channel data recorder (model DA-20; Rion Co., Ltd.; Tokyo, Japan). Gross unweighted triaxial WBV measurements were collected at 1280 Hz per channel using a seat cushion ICP accelerometer (model 356B40; PCB Piezotronics; Depew, NY, USA) mounted on the driver's seat. In addition, once a second, a global positioning system (model DG-100; GlobalSat; Chino, CA, USA) collected GPS data to record location and speed.	Different drivers had to operate each bus. All participants drove on the same standardized test route, which took about 75 min to complete. Daily exposure value: 8 h.
Azenan et al., 2018	Modified Nordic questionnaire (screening for musculoskeletal disorders and pain)	Not reported	Not reported	Human vibration meter instruments (HVM100 Larson Davis) and a triaxial seat cushion accelerometer. Each HVM 100 record = up to 4 min.	Vibration measurement time: Putrajaya Sentral was 36 min and Larkin Central 40 min. Daily exposure value: 8 h.

Legend: WBV—whole-body vibration; ISO—International Organization for Standardization, LBP—low-back pain.

4. Discussion

This systematic review aimed to assess exposure to mechanical vibration and its association with lumbar symptoms of bus drivers in different situations. It was possible to observe the influence of vibration on LBP in bus drivers through factors such as several levels of exposure to vibration, long hours and routine exposure to vibration, inadequate posture used by drivers when driving, psychological factors related to work, and the various types of roads that bus drivers use during their journeys. It is important to highlight that LBP was reported in four of the five studies.

All the selected publications followed the recommendations of the ISO 2631 standard, which regulates human exposure to WBV, and performed vibration measurements. Different levels of vibration were described in the publications of the current systematic review. Nevertheless, the levels of exposure to vibration reported by Okunribido et al. (2007) [32]; Azenan et al. (2018) [2]; and Thamsuwan et al. (2013) [30] were considered high, considering the ISO 2631 standards. In this context, Bovenzi and Zadini (1992) [29] reported that higher total doses of vibration are strongly related to all types of lumbar symptoms and disc protrusion.

Additionally, considering that the level of exposure to vibration varies depending on the place and the company, Okunribido et al. (2007) [32] suggested that there may be exposure to uncomfortable levels of vibratory stress in bus drivers, whereby the vibration received by the bus driver can promote effects on the lumbar spine, with there being a high risk and a relationship between the vibration and exposure of these drivers. Bovenzi and Zadini (1992) [29] reported that exposure to vibration is a significant indicator of low-back problems among bus drivers. Accordingly, Azenan et al. (2018) [2] stated that there was a positive, strong, and significant relationship between daily exposure to vibration and upper and lower back pain. However, Tamrin et al. (2007) [31] did not report a significant association between exposure to WBV and LBP. Therefore, it is not yet possible to define whether LBP would be directly associated with exposure to vibration. Bovenzi and Zadini (1992) [29] suggested that the high risk for low-back problems is related to driving a bus and that there is an increase in the prevalence of most lumbar complaints with an increase in the total dose of vibration. Thus, vibration would be a factor that can significantly affect drivers. Other factors, such as conditions and type of road, can also influence lumbar symptoms, together with vibration. Thamsuwan et al. (2013) [30] reported that the vibration exposures were significantly different between the types of roads, often due to their conditions and imperfections, along the route, which may affect the drivers and increase how they feel the vibration. In this sense, Thamsuwan et al. (2013) [30]; Tamrin et al. (2007) [31]; and Okunribido et al. (2007) [32] studied the vibration on different roads consisting of smooth road, bumpy road, city street, and speed bumps, and whether the area was urban, suburban, agrarian, residential, or industrial. It was verified that the parameters of WBV were higher on the road with speed bumps and lower on the smooth road, even though different types of buses and seats were used in the studies.

As previously mentioned, posture at work is also a factor that can negatively influence the daily life of bus drivers [33] including lumbar symptoms [8,19]. Corroborating this statement, Bovenzi and Zadini (1992) [29] B and Tamrin et al. (2007) [31] reported that frequent inappropriate postures were significantly related to certain types of lumbar symptoms. Blood et al. (2015) [9] also observed a significant effect on the results between posture and exposure to WBV, given the posture acquired by the bus driver, reflecting in how they feel the vibration and possibly causing negative results. Therefore, Azenan et al. (2018) [2] suggested that inappropriate postures, together with vibration, would amplify exposure to WBV. Therefore, it is important to consider that although posture alone may or may not affect the lower back, the addition of vibration can help trigger lower back symptoms.

Psychological factors are poorly reported in the studies and may have a direct or indirect relationship with mechanical vibration and other factors for lumbar symptoms. Tamrin et al. (2007) [31] reported a significant association between negative moods and

LBP caused by a high level of stress, since bus drivers must meet schedules, provide good service to passengers, adhere to safe driving practices, and withstand peak traffic conditions. In other studies, Alperovitch-Najenson et al. (2010) [34] stated that stressful and psychosocial ergonomic factors, as well as a lack of a sports activity, are associated with LBP in professional urban bus drivers. Similarly, Pope et al. (2002) [19] suggested that psychosocial factors can influence disability and LBP.

Among the included publications, Bovenzi and Zadini (1992) [29]; Tamrin et al. (2007) [31]; Okunribido et al. (2007) [32]; and Azenan et al. (2018) [2] used questionnaires to assess the drivers' routine. Among the factors reported as the cause of LBP, it was suggested that fatigue can be caused by the mechanical vibration received throughout the daily work routine. Tamrin et al. (2007) [31] reported a significant relationship between fatigue and LBP, as did Tiemessen et al. (2007) [15], who found that exposure to vibration can induce fatigue and depletion of the paravertebral muscles of the lumbar region. In addition and agreement, Bovenzi and Zadini (1992) [29] performed electromyographic measurements of the back muscles during the vertical vibration felt by the drivers, and observed that the increased muscle tension increases the load on the vertebral bodies and discs, causing fatigue and pain. Moreover, it was reported that vibration-induced muscle fatigue has a conditioning effect, resulting in increased susceptibility of the spine to injury.

Bovenzi and Zadini (1992) [29] concluded that there is a significant indicator of lumbar problems between exposure to WBV and bus drivers, which corroborates the studies by Bovenzi and Hulshof (1998) [10] and Tiemessen et al. (2007) [15]. Azenan et al. (2018) [2] and Jonsson et al. (2015) [7] described several causes of LBP, such as speed, vehicle design, and environmental conditions. Thamsuwan et al. (2013) [30] and Tamrin et al. (2007) [31] reported that the body posture of the driver was also one of the causes that influenced the transmissibility of the vibration. Sinczuk-Walczak et al. (2015) [13] reported that evidenced nervous system disorders indicate the need to undertake preventive measures tailored for bus drivers. Simões et al. (2019) [35] described worse health, mainly common mental disorders, was associated with self-assessed work precariousness as reported by bus drivers and conductors. LBP has been also found in taxi drivers (prevalence of 27.9%) through self-reported LBP in the past 12 months. Yosef et al. (2019) [36] interviewed 400 truck drivers to assess the magnitude of LBP in these individuals and a prevalence of 65% was found. Ghasemi et al. (2020) [37] studied the impact of rest breaks and stretching exercises on commercial truck drivers, and reported that these individuals presented a reduction in LBP and disability due to the use of supplementary exercises during break periods.

Regarding the limitations of this systematic review, different methods were used for the evaluation of mechanical vibration exposition, only four databases were used, only publications in English were considered, and different types of vehicles and designs were observed. Furthermore, control groups were not included in the five studies, and X-rays of the lumbar spine were not assessed. Consequently, according to the overall RoB judgment, the articles included in this review were, in general, at a serious risk of bias.

The strength of this systematic review is related to the finding that being a bus driver could be a risk factor to the development of pain in the lumbar spine. In addition, it is important for companies to support drivers by establishing partnerships with health agencies focused on medicine, psychology, nutrition, physiotherapy, and other services to aid drivers. Furthermore, for prevention, the companies could (i) perform weekly follow-ups with bus drivers to prevent lumbar spine impact; (ii) provide proper bus maintenance; and (iii) limit the length of vibration exposure time to minimize the impact on bus drivers. Moreover, this information on bus drivers may be important to policies involving drivers in agriculture and forestry, on diggers, in road construction, or on military vehicles.

5. Conclusions

The findings of the current systematic review suggest that the exposure of bus drivers to vibration in the work routine may be considered a risk factor to the development of pain in the lumbar spine. It is suggested that posture, psychological factors, the conditions and road, and the exposure to vibration may be related to LBP in bus drivers. For better understanding of the effects of mechanical vibration exposure during the daily work routine of bus drivers that might lead to LBP, more studies with better methodological quality are necessary.

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