TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 68, Issue IV, November, 2025

VIBRATIONS: A SILENT RISK IN WORK-RELATED MUSCULOSKELETAL DISORDERS

Daniel Onuț BADEA, Doru Costin DARABONT, Oana Roxana CHIVU, Şener KARABULUT, Alina TRIFU, Raluca Maria IORDACHE

Abstract: *Employees are exposed to harmful vibrations in their work environment, which can pose risks to their health and work performance. Excessive vibrations can negatively impact the musculoskeletal system, leading to disorders. This study aims to present a conceptual framework that explores the interactions among external factors such as vibrations, psychosocial elements, workplace risks, and individual characteristics that interact with the musculoskeletal system. The results of this study provide insight into how these factors affect the musculoskeletal system, offering suggestions for creating work environments that can help prevent work-related musculoskeletal disorders.*
Key words: *Musculoskeletal disorders (MSDs), occupational safety and health (OSH), vibrations, risk management, prevention.*

1. INTRODUCTION

Musculoskeletal disorders (MSDs) are health problems that impact muscles, tendons, joints, nerves, and the skeleton, indicating issues within the body's movement system. These conditions often arise from prolonged exposure to different levels of pressure and can be triggered by both work-related factors (work conditions) and non-work-related factors (daily activities) [1]. Research has established a connection between MSDs and factors like vibrations and psychosocial influences [2-4].

The human body constantly reacts to environmental influences, with vibrations being a key factor that can impact the entire organism and its systems. Vibrations, especially at low frequencies and with prolonged exposure, can be particularly damaging. Mechanical vibrations can originate from different industrial activities like transportation, construction, and agriculture. Whole-body vibration (WBV) happens when a person is in contact with a vibrating surface, like during travel, while hand-arm vibration (HAV) is transmitted through the hands when using rotating or percussive power tools.

Prolonged exposure to vibrations can heighten the likelihood of musculoskeletal problems, such as back pain, neck pain, and muscle fatigue. Research has emphasized the negative impact of WBV on muscles and the significant risks associated with HAV in the development of MSDs among workers who use vibrating tools like grinders, drills, saws, and hammers [5-10]. Extended exposure to HAV can also lead to health issues that impact the vascular, sensory, and musculoskeletal systems, known as HAV syndrome [11-14].

Workers report different musculoskeletal disorders depending on the type of vibration exposure. Cases linked to whole-body vibration often involve the lower back and neck, while hand-arm vibration is more frequently associated with upper limb disorders, including conditions such as HAVS and carpal tunnel syndrome.

WBV is more commonly linked to conditions such as back pain, neck pain, and muscle fatigue, while HAV is associated with disorders such as hand-arm vibration syndrome (HAVS), carpal tunnel syndrome, and other upper limb conditions [8–11, 14].

Received: 10.09.25; **Similarities**: 20.10.25: **Reviewed**: 10.09./ 10.09.25: **Accepted**:13.11.25.

This data emphasizes the specific risks linked to each type of vibration exposure and the importance of targeted preventive measures to protect workers from these health hazards. Furthermore, the specific frequencies of vibrations also play a critical role in determining their health impacts. Exposure to low-frequency vibrations, ranging from 1 to 20 Hz, has been linked to lower back pain and sciatica, while fluctuations at very low frequencies (below 1 Hz) can cause sensations of imbalance and nausea, like motion sickness [15, 16]. The health impacts of vibrations can occur at frequencies ranging from 0.5 to 80 Hz for WBVs, while disorders of the hand-arm system can be triggered by frequencies between 6.3 and 1250 Hz [17]. Additionally, the duration and pattern of exposure, environmental conditions, and the use of personal protective equipment all contribute to the harmful effects of vibrations [18].

Understanding how vibrations, combined with physical stressors like awkward postures, excessive force, and repetitive movements, can result in conditions such as carpal tunnel syndrome and a higher risk of lower back pain [2, 19]. Exposure to both physical and psychosocial workloads can further increase the likelihood of musculoskeletal injuries [20]. To comprehend the effects of vibrations on the body, it is crucial to analyze mechanical factors like frequency, displacement, acceleration, and energy to determine their impact on health.

The article introduces a theoretical model that explains how exposure influences outcomes, allowing for the quantitative prediction of external factors' effects on the human musculoskeletal system. It specifically investigates the impact of workplace vibrations on worker health, focusing on MSDs. The research's importance for industry lies in its potential to enhance safety protocols and protect workers from MSDs through the application of this model. The aim is to shed light on MSDs occurrences, risk factors, and their connections, aiding in the development of preventive measures to reduce the prevalence of MSDs among workers.

Existing research has yet to integrate these diverse factors into a single model that captures how vibration exposure interacts with psychosocial and organizational conditions to affect musculoskeletal health.

2. METHODS

The research focused on three companies operating in the energy, tire manufacturing, and maritime platform sectors. These sectors were chosen due to the significant exposure of workers to vibrations. Rather than solely assessing the level of vibration exposure in the workplace, the study aimed to develop a conceptual framework to understand how vibration exposure, combined with psychosocial influences, workplace-specific risks, and individual worker characteristics, impacts the musculoskeletal system and contributes to the development of work-related MSDs.

The study employed a cross-sectional approach, analyzing data on vibration exposure types, WBV and HAV, and their effects on the musculoskeletal system. The findings indicated that WBV, experienced when a worker is in contact with vibrating surfaces such as machine seats or floors, and HAV, transmitted through tools held by the worker, both lead to various MSDs, including back pain, neck pain, muscle fatigue, and hand-arm vibration syndrome (HAVS). The interaction between these vibrations and factors like awkward postures, repetitive motions, and psychosocial stress significantly heightens the risk of developing MSDs.

The conceptual framework developed in the study provides a model illustrating how various external factors, including vibration exposure, psychosocial stressors, and individual characteristics, interact and influence the musculoskeletal system. It highlights the importance of a holistic approach to prevent and manage MSDs, considering both direct and indirect effects of these factors on musculoskeletal health.

Based on these insights, the study recommends ergonomic interventions, comprehensive training programs, and regular monitoring of vibration levels as essential strategies to mitigate the risks associated with prolonged vibration exposure in the workplace. By addressing these combined risk factors, employees can better protect workers from

MSDs, improve workplace safety, and promote overall well-being.

3. RESULTS

3.1 Occupational exposure to vibration

Daily exposure to workplace vibrations is common for employees in different job fields. Vibration is a rapid, back-and-forth or oscillating movement. In the workplace, such exposures are generally classified into two types: whole-body vibration (WBV) and hand-arm vibration (HAV). A comparison between these two types of exposure, including typical sources, associated disorders, and affected body regions, is presented in Table 1. Contact with a vibrating surface, such as a machine handle, equipment surface, or moving machine seat, can cause vibrations to be felt throughout the human body. WBV typically occurs when a person sits on a vibrating floor or seat. The vibrations experienced by body parts in contact with surfaces, such as tool seats, backrests, or floors, are the same as those from the vibration source. However, damping can affect different body areas in different ways. Studies have shown that muscles exhibit damping properties determined by the attenuation coefficient. As a result, WBV can influence comfort, performance, and health, with outcomes depending on the intensity, waveform, and duration of exposure.

The level of vibration energy transmitted through the body is also influenced by the stiffness and damping properties of the musculoskeletal system, causing vibration levels to vary as they move through different regions of the body.

Consequently, various body regions may experience different levels of vibration exposure. It is important to note that this exposure can fluctuate continuously or occur at discrete intervals, depending on factors such as the vibration source's parameters, the properties of the body's structure, and the distance from the source.

Various sensors in the human body respond to vibrations, including the body parts in direct contact with the vibrating surface, internal receptors such as skin receptors detecting vibrations, various tissue systems, and the auditory system reacting to WBV. The distribution of vibrations across the body affects how workers move, depending on the frequency and direction of the vibrations and the extent to which the body is connected to the vibration source. WBV is most intensely felt by humans within the 1 to 20 Hz frequency range, although sensitivity varies with the direction of the vibration [21].

Vibrations felt throughout the body can influence the collection of sensory information, levels of interest, fatigue, and intentional behaviors. To understand their movement environment, the brain must integrate these sensory signals into a cognitive model. A worker's perception of their body's position and sense of stability can also be affected. The point of contact between the body and the vibrating source plays a crucial role in how vibrations are experienced. The body's reaction to vibrations involves a combination of forces and movements that can vary depending on the frequency and direction of the vibration.

Hand-arm vibration (HAV) may occur when individuals use handheld power tools or hand-guided equipment, where the vibrations travel to the worker's hands and arms through the palms and fingers.

Table 1. Comparison between whole-body vibration (WBV) and hand-arm vibration (HAV).

Vibration type	Typical sources	Common MSDs	Affected body regions
Whole-body vibration (WBV)	Vehicle seats, vibrating floors, heavy machinery platforms	Lower back pain, neck pain, muscle fatigue	Spine, lower back, neck, pelvis
Hand-arm vibration (HAV)	Power tools (drills, grinders, hammers), vibrating hand-held equipment	Carpal tunnel syndrome, HAVS, finger blanching, upper limb pain	Hands, wrists, arms, fingers

Touch perception involves a combination of various sensory pathways. Factors such as the duration of exposure to vibrations, the manner of exposure, the tools or vehicles generating the vibrations, environmental conditions, the body's response to vibrations, and individual characteristics all influence how vibrations impact the forearm-hand system. Prolonged exposure to HAV from powered tools can lead to increased symptoms and signs of disorders in the vascular, neurological, and musculoskeletal systems of the upper limbs [22]. Hand-arm vibration syndrome (HAVS) encompasses all these disorders.

When body parts encounter a vibrating tool or surface, they experience the same level of vibration as the source. However, the exposure of body parts to vibration can vary due to damping effects. Studies have shown that muscles have damping characteristics, with the damping factor influenced by the attenuation coefficient [23]. Musculoskeletal stiffness and damping play crucial roles in determining how much vibration energy is transmitted. As vibration travels between different body parts, its intensity changes, leading to varying levels of vibration exposure across different areas of the body.

3.2 The interaction between vibrations and the musculoskeletal system

When the human body is viewed as an integrated mental and musculoskeletal system, it becomes clear that external factors can trigger responses that may harm its structures. The musculoskeletal system is composed of bones (skeleton), muscles, cartilage, tendons, ligaments, blood vessels, nerves, joints, and other connective tissues [24]. These interconnected components work together to support movement, stability, and overall physical function. However, when exposed to external stressors such as physical strain, vibrations, or psychological stress, the system can respond in ways that may lead to injury or disorders.

The conceptual framework established in this research is based on Armstrong et al.'s (1993) [25] approach to show how external factors contribute to the development of work-related MSDs. Therefore, this conceptual framework focuses on identifying body structure breakdowns and considering the adverse effects of vibration. The level of exposure is influenced by various external factors and their specific parameters, such as psychosocial factors, workplace-related risk factors, and individual factors such as the worker's age or health status.

The proposed conceptual framework includes a model illustrating how vibrations and other external factors influence the musculoskeletal system and its outcomes, as shown in Figure 1. This model integrates existing theories and research to demonstrate how factors such as vibrations, psychosocial influences, workplace-related risks, and individual characteristics affect musculoskeletal health.

While the model highlights a selection of key risk factors, these examples are not exhaustive and are meant to be illustrative. By examining how vibration exposure, alone or combined with other factors, impacts various components of the musculoskeletal system, including the skeleton, muscles, tendons, ligaments, and nerves, it provides a comprehensive understanding of the associated risks.

Understanding the interactions among these factors is crucial for developing effective strategies to prevent and manage MSDs resulting from vibration exposure. The model emphasizes the need for a holistic approach that considers both direct and indirect influences on musculoskeletal health, laying the groundwork for targeted interventions to reduce the incidence of MSDs in the workplace.

In practical terms, this model can support workplace assessments by identifying specific combinations of risk factors that contribute to musculoskeletal strain. It can also inform training content, job design, and equipment selection by making visible the links between external exposures and internal health outcomes.

Furthermore, the model may be used as a reference framework in future studies aiming to quantify the relative contribution of each factor to MSD development. This can guide both preventive and corrective actions in occupations with high vibration exposure.

The model (Figure 1) integrates biomechanical factors, such as prolonged static postures, repetitive movements, and heavy load handling, with psychosocial factors like occupational stress, job satisfaction, and organizational climate. These elements can either amplify or mitigate the effects of vibration exposure, providing a more detailed understanding of how different risk factors interact to affect worker health.

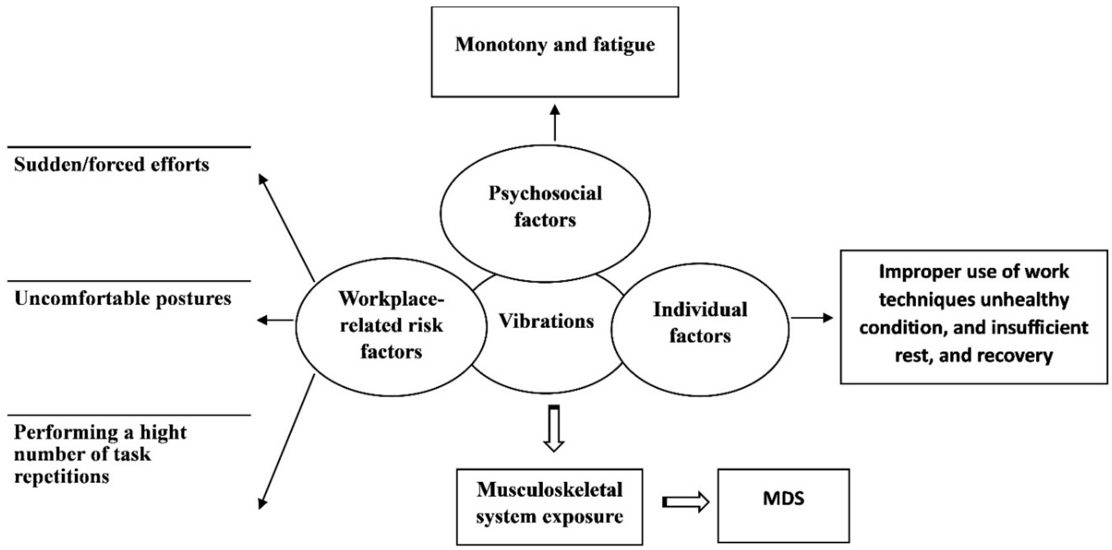

Fig. 1. Conceptual framework of vibration exposure and external risk factors for musculoskeletal disorders.

Additionally, personal factors such as age, sex, physical condition, and health history influence individual vulnerability to MSDs.

A comprehensive understanding of the interplay between physical and psychosocial factors is essential for accurate risk assessment. Workers exposed to prolonged vibrations, especially when combined with poor ergonomic practice or elevated psychosocial stress, face a higher risk of severe MSDs.

The model highlights the necessity for integrated interventions that address both ergonomic improvements and psychosocial support, establishing a strong foundation for developing occupational safety and health policies aimed at preventing MSDs and enhancing overall worker well-being.

Moreover, it is imperative to consider the adaptability of the musculoskeletal system to vibrations. The system's tolerance to repeated or sustained exposure can vary depending on factors such as overall health, physical fitness, and previous vibration exposure. This adaptability influences the body's response to vibrations, which can fluctuate over time. Additionally, the nature and intensity of vibrations, whether high or low, affect the body's response differently. A detailed understanding of these factors facilitates the design of more precise and effective interventions and rehabilitation programs, thereby improving worker health and resilience.

According to the proposed conceptual framework, the musculoskeletal system always responds to vibrations, even when they are combined with other external factors. The body can adapt by either increasing or decreasing its tolerance to repeated or consecutive exposure. The response at any specific moment reflects the adaptability at that time, which can vary from one moment to the next. This adaptability is affected by factors such as the individual's general health, fitness level, and past exposure to vibrations. It is important to consider these factors when evaluating how the body responds to vibrations to enhance training or rehabilitation programs.

In addition, the body's response can be impacted by the type and intensity of the vibrations being felt. For example, high-intensity vibrations may elicit a different response than low-intensity vibrations. Reflecting on these factors can contribute to the design of more effective interventions for those exposed to vibrations.

Implementing ergonomic interventions and providing comprehensive training can help reduce the risks associated with long-term exposure to workplace vibrations. To ensure a safe work environment, employers need to recognize and address these risk factors. Regularly monitoring vibration levels, gathering feedback from employees, and evaluating the situation can help pinpoint areas that need improvement to prevent MSDs.

4. DISCUSSIONS

This study has demonstrated a clear association between vibrations and the prevalence of MSDs among workers. The findings provide insights into how exposure to vibrations, along with other external factors such as psychosocial and workplace-related risks, as well as individual psychological factors, interacts with internal body structures to affect the musculoskeletal system, leading to MSDs. The approach taken in this study builds on previous models, which suggest that the human body consistently responds to repeated exposure to vibrations. According to this concept, vibrations directly affect the musculoskeletal system, while psychosocial factors have an indirect influence on it.

Earlier studies on MSDs have predominantly focused on the combined effects of psychological and physical factors [26-29]. Huang et al. (2002) [30] also explored how biomechanical and psychological factors can impact the human body. Compared to prior research, this study introduces a conceptual framework that emphasizes the interaction between various external factors, particularly the effects of vibrations on the musculoskeletal system. It also considers indirect factors, such as psychological and individual characteristics, and their potential impact on musculoskeletal health.

While earlier studies typically concentrated on either work-related or non-work-related factors in isolation, the conceptual model introduced in this study provides a more comprehensive view by considering the interactions and cumulative impacts of these factors on the musculoskeletal system. This approach offers a holistic understanding of MSDs and their prevention. By considering all factors that can interact with vibrations in the workplace, the study provides valuable insights for developing effective intervention strategies.

Despite ongoing efforts, understanding how vibrations and other external factors affect worker safety and health outcomes remains challenging, particularly due to a limited understanding of the underlying biological mechanisms. Nonetheless, it is widely acknowledged that the harmful effects of using vibrating tools or machines are well-documented, though they are often underestimated. Occupational diseases can result from injuries caused by mechanical vibrations affecting the musculoskeletal system, leading to conditions such as carpal tunnel syndrome and tendonitis, which may cause chronic pain and disability for workers. It is crucial for employers to implement ergonomic practices and provide adequate training to prevent these occupational diseases.

Prolonged exposure to vibrating tools can lead to HAV syndrome and carpal tunnel syndrome, causing pain, numbness, and reduced grip strength. To minimize these risks, workers need proper training and appropriate equipment. Employers can help prevent long-term health issues by educating workers on the risks associated with vibrating tools and safe usage practices. Using anti-vibration gloves and tools with dampening technology can also reduce strain on workers' hands and arms. Ensuring a safe and healthy work environment requires actively addressing the risks linked to vibrating tools. Regular assessments for signs of HAV syndrome, along with breaks and task rotation, can further lower exposure. Prioritizing employee health and safety can prevent injuries, boost productivity, and enhance workplace morale. Investing in training and equipment is essential for fostering a culture of safety and well-being.

To reduce the impact of vibrations transmitted to the hand-arm system, several preventive measures are necessary. These include informing users about associated risks, conducting regular medical check-ups, selecting equipment with low vibration levels, and ensuring it is used correctly.

Continuous or frequent exposure to WBV can lead to MSDs such as back pain and joint issues [31]. Although back pain is the primary health issue associated with WBV, other effects include sciatica, digestive issues, genitourinary problems, hearing loss, and changes in peripheral circulation [22, 32]. Vibration can also affect blood circulation, leading to muscle fatigue and discomfort. To protect workers' safety and well-being, employers should proactively reduce WBV risks through regular risk assessments, appropriate training, and the use of personal protective equipment. Setting up ergonomic workstations and allowing frequent breaks can further lower the risk of MSDs. Encouraging open communication and prompting employees to report discomfort or symptoms can also enhance workplace safety.

Beyond its use in risk assessment, the conceptual model developed in this study could serve as a training tool to improve awareness of vibration-related MSDs among workers, supervisors, and occupational health professionals. Its visual structure and emphasis on interacting factors can support workplace discussions about exposure, job design, and early signs of musculoskeletal strain. Embedding this model in professional training programs may strengthen prevention efforts by linking theoretical risk factors with day-to-day work realities.

Mitigation strategies for WBV effects include minimizing vibrations along transmission paths using specially designed chairs, vibration-insulating platforms, and personal protective equipment. Regular maintenance of machinery and equipment is essential to reduce vibration levels, and training workers on proper posture and ergonomic practices can further help.

Despite ongoing research, understanding the impact of vibrations and other external factors on worker safety and health remains challenging due to limited knowledge of the underlying biological mechanisms. While previous studies have typically examined either work-related or non-work-related factors in isolation, the conceptual model in this study offers a more comprehensive approach by considering both types of factors and their cumulative effects on the musculoskeletal system.

Previous research consistently confirms the link between workplace stress and MSDs, supporting the findings of this study. Eatough et al. (2012) [26] identified job dissatisfaction, lack of control, conflicting roles, and emotional fatigue as factors increasing strain among workers. When these stressors combine with vibration exposure, they significantly contribute to the development of work-related MSDs, affecting tendons, muscles, nerves, bursae, and blood vessels. Raffler et al. (2017) [27] demonstrated a significant correlation between back pain and the combined effects of WBV and awkward postures, emphasizing the critical role of ergonomic and environmental factors at work. Frequent exposure to vibrations, along with repetitive and uncomfortable positions or strenuous exertion, can lead to fatigue and increase the risk of musculoskeletal imbalances. Individual factors such as poor work habits, compromised health, and insufficient rest further exacerbate these risks, as shown in this study.

Given this complexity, the model developed in this study may serve not only as an analytical tool but also as a foundation for applied strategies in occupational health. The conceptual framework may inform the development of digital tools for early risk detection and adaptive interventions. By structuring input variables such as vibration levels, postural data, and self-reported discomfort, the model could support predictive analytics in workplace monitoring systems. Such applications may improve the timeliness and relevance of preventive actions, particularly in high-exposure environments.

However, it is important to acknowledge some limitations in this study, particularly the lack of outcome measures that include clinical examinations and self-reported symptoms. To enhance the study's findings, future research should incorporate these additional outcome measures.

Expanding future research beyond symptom reporting is also necessary to improve prevention efforts in practice. A multidisciplinary approach, involving ergonomics, occupational health, and engineering, may help identify concrete ways to reduce exposure risks. Individual characteristics such as age, fitness level, and history of musculoskeletal disorders may also influence how workers respond to vibration and should be better understood. In parallel, organizational aspects, such as job design, repetitive work cycles, or lack of recovery time, can increase vulnerability to MSDs. These should be systematically assessed when evaluating vibration-related risks.

Another gap concerns long-term effects. Longitudinal studies could clarify how risks accumulate over time and inform better workplace regulations and exposure limits.

5. CONCLUSIONS

This study examined how external factors affect the musculoskeletal system, focusing on workplace vibration exposure and its interaction with psychosocial, organizational, and individual risk factors for MSDs. The findings support preventive measures, including targeted training, workplace adjustments, and technical or administrative controls complemented by personal protective equipment.

This integrated approach considers both physical and psychosocial dimensions of work-related injuries and provides a framework for designing safer work environments and developing effective MSD prevention strategies.

Future work should aim to translate these findings into practical tools for occupational risk assessment (by implementing a collaborative approach as described in [33]). Developing user-friendly methods to identify and monitor vibration exposure, alongside relevant psychosocial or organizational stressors, can improve early detection and inform timely intervention (similar like the findings in [34-36]). Structured monitoring systems and regular evaluation of workplace practices could further support prevention efforts.

6. REFERENCES

[1] Habib, R. R., El Zein, K., Hojeij, S., *Hard work at home: musculoskeletal pain among female homemakers*, Ergonomics, 55(2), 201-211, 2012.

[2] Bovenzi, M., Lindsell, C.J., Griffin, M.J., *Acute vascular responses to the frequency of vibration transmitted to the hand,* Occupational and Environmental Medicine, 57(6), 422–430, 2000.

[3] Bovenzi, M., *A follow up study of vascular disorders in vibration-exposed forestry workers,* International Archives of Occupational and Environmental Health, 81(4), 401-408, 2008.

[4] Huang, G. D., Feuerstein, M., *Identifying work organization targets for a work-related musculoskeletal symptom prevention program,* Journal of Occupational Rehabilitation, 14(1), 13-30, 2004.

[5] Fethke, N. B., Schall, M. C., Merlino, L. A., Chen, H., Branch, C. A., Ramaswamy, M., *Whole-body vibration and trunk posture during operation of agricultural machinery,* Annals of work exposures and health, 62(9), 1123-1133, 2018.

[6] Bovenzi, M., *A prospective cohort study of neck and shoulder pain in professional drivers*, Ergonomics, 58(7), 1103-1116, 2015.

[7] Patterson, F., Miralami, R., Tansey, K.E., Prabhu, R.K., Priddy, L.B., *Deleterious effects of whole-body vibration on the spine: A review of in vivo, ex vivo, and in vitro models,* Animal Models and Experimental Medicine, 4(1), 1–15, 2021.

[8] Heaver, C., Goonetilleke, K.S., Ferguson, H., Shiralkar, S., *Hand-arm vibration syndrome: a common occupational hazard in industrialized countries,* Journal of Hand Surgery (European Volume), 36(5), 354–359, 2011.

[9] Åström, C., Rehn, B., Lundström, R., Nilsson, T., Burström, L., Sundelin, G., *Hand-arm vibration syndrome (HAVS) and musculoskeletal symptoms in the neck and the upper limbs in professional drivers of terrain vehicles—a cross sectional study*, Applied ergonomics, 37(6), 793-799, 2006.

[10] Mahbub, M., Harada, N., *Review of different quantification methods for the diagnosis of digital vascular abnormalities in hand-arm vibration syndrome,* Journal of Occupational Health, 53(2), 123–130, 2011.

[11] Griffin, M.J., *Minimum health and safety requirements for workers exposed to hand-transmitted vibration and whole-body vibration in the European Union: a review,* Occupational and Environmental Medicine, 61(5), 430–435, 2004.

[12] Dias, B., Sampson, E., *Hand arm vibration syndrome: health effects and mitigation,* Proceedings of the IOHA 6th

International Scientific Conference, pp. B1–B4, IOHA, Pilanesberg, 2005.

[13] Cann, A., Salmoni, A., Vi, P., Eger, T., *An exploratory study of whole body vibration exposure and dose while operating heavy equipment in the construction industry,* Applied Occupational and Environmental Hygiene, 18(12), 999–1005, 2003.

[14] Salmoni, A.W., Cann, A.P., Kent, G., Gillen, E., Eger, T., *Case studies in whole-body vibration assessment in the transportation industry: challenges in the field,* International Journal of Industrial Ergonomics, 37(3), 199–207, 2007.

[15] Burström, L., Nilsson, T., Wahlström, J., *Whole-body vibration and the risk of low back pain and sciatica: a systematic review and meta-analysis,* International Archives of Occupational and Environmental Health, 88(4), 403–418, 2015.

[16] Cheung, B., Nakashima, A., *A Review on the Effects of Frequency of Oscillation on Motion Sickness,* Journal of Vibration and Acoustics, 128(2), 123–134, 2006.

[17] Orelaja, O.A., Wang, X., Ibrahim, D.S., Sharif, U., *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(1), 1–10, 2019.

[18] McDowell, T.W., Dong, R.G., Xu, X., et al., *An evaluation of impact wrench vibration emissions and test methods,* Annals of Occupational Hygiene, 51(4), 411–422, 2007.

[19] Lis, A.M., Black, K.M., Korn, M., Nordin, M., *Association between sitting and occupational LBP,* European Spine Journal, 16(2), 283–298, 2007.

[20] Devereux, J.J., Vlachonikolis, I.G., Buckle, P., *Epidemiological study to investigate potential interaction between physical and psychosocial factors at work that may increase the risk of symptoms of musculoskeletal disorder of the neck and upper limb,* Occupational and Environmental Medicine, 59(4), 269–277, 2002.

[21] Golubovic-Bugarski, V., *Assessment of human exposure to vibration and noise in residential buildings,* Contemporary Theory and Practice in Construction, 20(2), 15–28, 2018.

[22] Griffin, M.J., *Handbook of Human Vibration,* Academic Press, ISBN 0123030412, London, 1990.

[23] Wakeling, J.M., Nigg, B.M., Rozitis, A.A., *Muscle activity damps the soft tissue resonance that occurs in response to pulsed and continuous vibrations,* Journal of Applied Physiology, 93(3), 1093–1103, 2002.

[24] Musculoskeletal health in the workplace. *NHS Employers,* https://www.nhsemployers.org/publications/musculoskeletal-health-workplace.

[25] Armstrong, T.J., Buckle, P., Fine, L.J., Hagberg, M., Jonsson, B., Kilbom, A., Kuorinka, I.A., Silverstein, B.A., Sjogaard, G., Viikari-Juntura, E.R., *A conceptual model for work-related neck and upper-limb musculoskeletal disorders,* Scandinavian Journal of Work Environment & Health, 19(2), 73–84, 1993.

[26] Eatough, E.M., Way, J.D., Chang, C-H., *Understanding the link between psychosocial work stressors and work-related musculoskeletal complaints,* Applied Ergonomics, 43(3), 554–563, 2012.

[27] Raffler, N., Rissler, J., Ellegast, R., Schikowsky, C., Kraus, T., Ochsmann, E., *Combined exposures of whole-body vibration and awkward posture: a cross-sectional investigation among occupational drivers by means of simultaneous field measurements,* Ergonomics, 60(12), 1642–1653, 2017.

[28] WorkSafeBC. *How to Implement a Formal Occupational Health and Safety Program,* http://www.worksafebc.com/publications/healthandsafety/bytopic/assets/pdf/howto.

[29] Bugajska, J., Zołnierczyk-Zreda, D., Jędryka-Góral, A., Gasik, R., Hildt-Ciupińska, K., Malińska, M., Bedyńska, S., *Psychological factors at work and musculoskeletal disorders: a one-year*

prospective study, Rheumatology International, 33(12), 2975–2983, 2013.

[30] Huang, G.D., Feuerstein, M., Sauter, S.L., *Occupational stress and work-related upper extremity disorders: concepts and models*, American Journal of Industrial Medicine, 41(5), 298–314, 2002.

[31] Bongers, P.M., Kremer, A.M., ter Laak, J., *Are psychosocial factors, risk factors for symptoms and signs of the shoulder, elbow, or hand/wrist?: a review of the epidemiological literature,* American Journal of Industrial Medicine, 41(5), 315–342, 2002.

[32] Krishnan, K., Raju, G., Shawkataly, O., *Prevalence of Work-Related Musculoskeletal Disorders: Psychological and Physical Risk Factors,* International Journal of Environmental Research and Public Health, 18(5), 2492, 2021.

[33] Dragoi, G., Draghici, A., Rosu, S. M., Cotet, C. E., *Virtual product development in university-enterprise partnership*. Information Resources Management Journal (IRMJ), 23(3), 43-59, 2010.

[34] Choong, S. W. J., Ng, P. K., Yeo, B. C., Draghici, A., Gaureanu, A., Ng, Y. J., ... Selvan, H. K. T. A *Preliminary Study on Ergonomic Contribution to the Engineering Design Approach of a Wheel Loader Control Lever System*. Sustainability, 14(1), 122, 2021.

[35] Constantin, D., Mazilescu, C. A., Nagi, M., Draghici, A., Mihartescu, A. A., *Perception of cabin air quality among drivers and passengers*, Sustainability, 8(9), 852, 2016.

[36] Draghici, A., Dursun, S., Başol, O., Boatca, M. E., Gaureanu, A., *The mediating role of safety climate in the relationship between transformational safety leadership and safe behavior—The case of two companies in Turkey and Romania,* Sustainability, 14(14), 8464, 2022.

Vibrațiile: un risc tăcut în tulburările musculo-scheletice de origine profesională

Operatorii umani sunt expuși la vibrații nocive în mediul lor de muncă, care pot reprezenta riscuri pentru sănătatea și performanța lor la locul de muncă. Vibrațiile excesive pot afecta negativ sistemul musculo-scheletic, conducând la apariția unor afecțiuni. Acest studiu își propune să prezinte un cadru conceptual care analizează interacțiunile dintre factorii externi, precum vibrațiile, elementele psihosociale, alți factori de risc întâlniți la locul de muncă și caracteristicile individuale ale lucrătorilor, care influențează sistemul musculo-scheletic. Rezultatele studiului oferă o înțelegere a modului în care acești factori afectează sistemul musculo-scheletic și propun soluții pentru crearea unor medii de lucru care pot contribui la prevenirea afecțiunilor musculo-scheletice de origine profesională.

Daniel Onuț BADEA, PhD., National Research and Development Institute on Occupational Safety - I.N.C.D.P.M. "Alexandru Darabont" – Bucharest, 35A Ghencea Blvd., Sector 6, Bucharest, Romania, E-mail: dbadea@protectiamuncii.ro, Office Phone: +40213131726.

Doru Costin DARABONT, PhD., National Research and Development Institute on Occupational Safety - I.N.C.D.P.M. "Alexandru Darabont" – Bucharest, 35A Ghencea Blvd., Sector 6, Bucharest, Romania, E-mail: darabont_d@yahoo.com, Office Phone: +40213131726.

Oana Roxana CHIVU, PhD., Professor, National University of Science and Technology POLITEHNICA Bucharest, Faculty of Industrial Engineering and Robotics, Splaiul Independenței 313, Sector 6, Bucharest, Romania, E-mail: virlan_oana@yahoo.co.uk, Office Phone: +40214029100.

Şener KARABULUT, PhD., Professor, Department of Mechanical Program, Hacettepe University, 06930 Ankara, Turkey; senerkara-bulut@hacettepe.edu.tr.

Alina Trifu, PhD., National Research and Development Institute on Occupational Safety - I.N.C.D.P.M. "Alexandru Darabont" – Bucharest, 35A Ghencea Blvd., Sector 6, Bucharest, Romania, E-mail: alinatrifu@yahoo.com, Office Phone: +40213131726.

Raluca Maria IORDACHE, PhD., National Research and Development Institute on Occupational Safety - I.N.C.D.P.M. "Alexandru Darabont" – Bucharest, 35A Ghencea Blvd., Sector 6, Bucharest, Romania, E-mail: iorraluca@yahoo.com, Office Phone: +40213131726.