Investigation of Hand Dexterity Changes in Response to Different Frequencies of Hand-transmitted Vibration

Mohsen Aliabadi[1], Seyed Hojat Mousavi Kordmiri[2]

[1]Department of Occupational Health Engineering, School of Public Health and Occupational Health and Safety Research Center, Hamadan University of Medical Sciences, Hamadan, Iran, [2]Department of Occupational Health Engineering, Esfarayen Faculty of Medical Sciences, Esfarayen, Iran

Abstract

Aim: The use of hand-held vibrating tools exposes workers to hand–arm vibrations. In this study, the effect of hand-transmitted vibration (HTV) on hand dexterity in response to different vibration frequencies has been investigated. **Methods:** Hand dexterity was examined in a controlled laboratory study involving 37 men exposed to 30 min of vibration with the same acceleration (5 m/s² rms) and different frequencies (31.5, 63, and 125 Hz). To assess hand dexterity, the Purdue Pegboard Test (PPT) was used, and the scores for both-hand activities and assembly tasks were recorded before and after each exposure scenario. The data were analyzed using SPSS22 software with descriptive statistics, paired comparisons, and repeated measures analysis of variance (ANOVA). **Results:** The PPT scores significantly decreased after exposure to different HTV scenarios ($P < 0.05$). The results of the repeated measures ANOVA, conducted to compare the mean PPT scores across different sessions, indicated statistically significant differences in the effects of the various vibration scenarios ($P < 0.05$). Comparison of the scenarios revealed that as HTV increased, its impact on hand dexterity also increased. The greatest negative effect on hand dexterity was observed in the vibration scenario with an acceleration of 5 m/s² rms and a frequency of 125 Hz, with an effect size of 0.558, which indicates a moderate-to-large practical impact according to Cohen's criteria. **Conclusion:** The findings of this controlled laboratory study indicate that the frequency of HTV exposure, like the vibration acceleration, plays a significant role in affecting hand dexterity. The evidence suggests that as the frequency of HTV increases, hand dexterity decreases under constant vibration acceleration conditions.

Keywords: Frequency, hand-arm vibration, hand-transmitted vibration, manual dexterity

Introduction

The use of various handheld vibrating tools, including hydraulic, pneumatic, and electric tools such as demolition hammers, angle grinders, drills, concrete vibrators, and other similar equipment, is essential for performing various tasks in the construction industry.[1] With the increased use of these handheld vibrating tools, workers are continuously exposed to hand–arm vibrations (HAVs), which have become a serious occupational hazard for those working with these tools.[2] Continuous exposure to vibrations can lead to injuries in the fingers, hands, arms, and other parts of the body. These injuries depend on the vibration characteristics of the tool and the working conditions.[3]

Despite technological advancements and the implementation of various engineering control techniques, exposure to HAVs from these tools remains undeniable and widespread among this workforce. Workers are exposed to varying levels and frequencies of vibrations while working with these tools.[4,5] According to the latest reports on working conditions in Europe, the construction sector has the highest number of workers exposed to handheld tool vibrations among all active economic sectors.[6]

Epidemiological studies have identified HAV-related disorders as HAV syndrome (HAVS).[7] This syndrome is a complex disorder associated with issues in the nervous, vascular, and musculoskeletal systems of the upper limbs.[8] It is recognized as an occupational disease in many developed countries, and

Access this article online

Quick Response Code:

Website: https://journals.lww.com/IJEH

DOI: 10.4103/ijehe.ijehe_11_25

Address for correspondence: Dr. Seyed Hojat Mousavi Kordmiri, Department of Occupational Health Engineering, Esfarayen Faculty of Medical Sciences, Esfarayen, Iran.
E-mail: hojatmk66@yahoo.com

How to cite this article: Aliabadi M, Kordmiri SH. Investigation of hand dexterity changes in response to different frequencies of hand-transmitted vibration. Int J Env Health Eng 2025;14:29.

Received: 03-03-2025, **Revised:** 12-05-2025,
Accepted: 12-05-2025, **Published:** 29-07-2025

numerous laboratory and experimental studies have been conducted to investigate the various aspects of this disorder. Furthermore, studies have shown that individuals' responses to vibration are primarily dependent on the magnitude of the vibration, frequency, direction of entry, and the duration of exposure.[9] However, there are limited studies regarding the dose-response effects of HAV in causing these disorders, with the aim of comparing the performance of different frequency-weighted vibration doses. Most research has focused on the magnitude of vibration acceleration, with less attention given to the dose–response relationship of vibration frequency in generating these effects.

Hand dexterity, as one of the key indicators of the neural, sensory, and motor responses of the hand to vibration, can serve as a critical factor in evaluating the effects of HAV. This measure can help us simulate individual sensitivities to vibrational changes and provide a more accurate analysis of the risks associated with HAV exposure in this context.[10-12] In this regard, the present study will examine the effect of HAV frequency (31.5, 63, and 125 Hz with the same vibration acceleration of 5 m/s²) in a 30-min exposure pattern on hand dexterity. Therefore, the objective of this study is to investigate the changes in hand dexterity in response to different HAV frequencies.

Table 1: Experimental conditions for study participants

Scenarios	Vibration acceleration (m/s² RMS)	Frequency (Hz)
Scenario 1	5	31.5
Scenario 2	5	63
Scenario 3	5	125

RMS: Root mean square

Figure 1: Hand-transmitted vibration measurement device used in the study

Materials and Methods

Study population and sample

For this study, volunteers were recruited through advertisements in construction projects and the Divar online platform (architecture, civil engineering, and construction section). Based on statistical calculations and the determined sample size, 37 male workers engaged in construction projects with prior experience using vibrating hand tools were randomly selected and assessed according to the study's inclusion criteria. Individuals with musculoskeletal, neuromuscular, sensory-neural, or vascular disorders, as well as those with peripheral nerve impairments, were excluded from the study.

Hand-transmitted vibration exposure

In this study, hand-transmitted vibrations (HTVs) were generated using an electrodynamic shaker with a capacity of 500 Newtons, equipped with two tool-handle simulators. In addition, vibration acceleration was measured and adjusted using a human vibration meter (Model SV106A) in conjunction with a triaxial accelerometer, both manufactured by SVANTEK, Poland [Figure 1].

The exposure scenarios for participants in this study are presented in Table 1.

Hand dexterity measurement tools

To assess participants' manual dexterity and hand skills, the Lafayette Purdue Pegboard Test (PPT) (Model 32020), produced by Lafayette Instrument Co., was employed. This standardized test evaluates fine motor skills by measuring finger and hand dexterity in both unilateral and bilateral tasks.

Study procedure

In this study, volunteers were selected based on predefined criteria and participated in three separate sessions (over 3 days) according to a scheduled timeline. In each session, participants were randomly exposed to one of the predetermined scenarios. Prior to each session, they were instructed to have at least 7 h of sufficient sleep and to avoid caffeine and medications, such as anti-inflammatory drugs that affect the nervous system. Overall, each participant was exposed to three different scenarios for 30 min per session using the electrodynamic shaker [as outlined in Table 1].

At the beginning of each session, in order to acclimate to the experimental environment, each participant sat in a resting position on a chair for 30 min.

In the second step, the participants' hand dexterity was assessed before exposure to vibrations using the Lafayette PPT. As shown in Figure 2, this tool consists of a board with two parallel rows, each containing 25 holes. The rods are positioned on the right and left sides of the cups at the top of the board, and pins and washers occupy the two central cups. During this phase, participants performed two tests. In the first test, the participant used both hands to place as many pins as possible into the holes from top to bottom within a 30-s period, and the total number of pins placed was recorded. In the second test, participants alternately used both hands to assemble "sets," each consisting of a rod, a washer, a nut, and another washer. The participant had to complete as many sets as possible within 1 min. In this "assembly" phase, the dominant hand placed the rod, followed by the nondominant hand placing the washer, then the dominant hand placing the pin, and finally the nondominant hand placing the washer to complete the assembly. The total number of successfully completed assembly sequences within 1 min was documented. The scores from each part of the test were calculated separately, and the final total score was obtained by summing the scores from both tests.

In the third step, during each session, participants were randomly exposed to one of the predetermined scenarios for 30 min (including six 5-min exposure stages with a 1-min rest between each stage), during which HTV was generated by the electrodynamic shaker.

In the final step, immediately after the completion of HTV exposure, the participants' hand dexterity was reassessed using the Lafayette PPT, following the same instructions as before the exposure. Finally, the recorded data from before and after the exposure were analyzed and compared.

Data analysis

Descriptive statistics and graphical representations were used to present the descriptive results. To determine the changes occurring before and after exposure in each session, a paired comparison test was applied. To examine differences between the various exposure scenarios, repeated measures analysis of variance (ANOVA) was used for data analysis. A statistical significance threshold of $P < 0.05$ was considered.

Results

The participants in this study were 37 male workers in the construction industry with experience in using HAV tools.

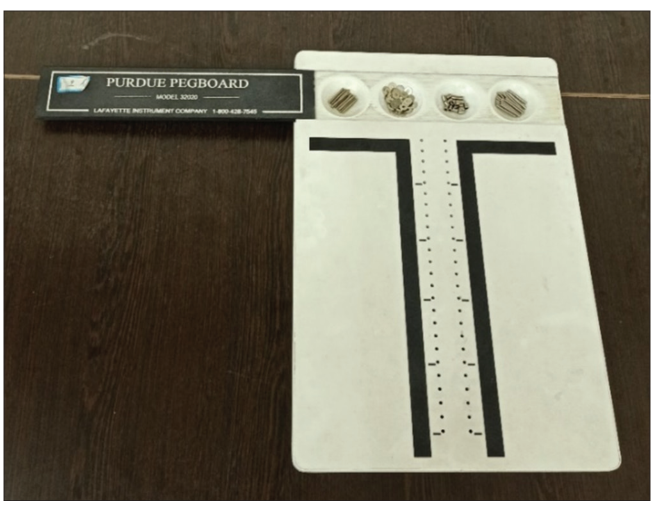

Figure 2: Hand dexterity test device

The mean age of the participants (with standard deviation) was 31.02 ± 3.25 years. The minimum and maximum ages were 25 and 35 years, respectively. The mean work experience (with standard deviation) was 3.94 ± 1.74 years. The minimum and maximum work experience were 1 and 7 years, respectively. Of the total participants, 29 (78.4%) were married.

Hand dexterity was assessed by recording the results obtained from the Lafayette PPT before and after exposure in different scenarios. The scores related to bilateral hand dexterity, including the total number of pins placed and the number of completed assemblies, were recorded. These two scores were summed, and the changes in the total scores were analyzed. The mean and statistical changes in hand dexterity are presented in Table 2.

As shown in Table 2, all exposure scenarios resulted in statistically significant changes in hand dexterity. A comparison of the mean changes in hand dexterity (the difference between pre and postexposure means) for the different scenarios is presented in Figure 3.

Note: Scenario1: HTV (5 m/s^2-31.5 Hz), Scenario2: HTV (5 m/s^2-63 Hz), Scenario3: HTV (5 m/s^2-125 Hz).

As shown in Figure 3, the greatest mean difference in hand dexterity was observed in the scenario of exposure to HTV with an RMS acceleration of 5 m/s^2 and a frequency of 125 Hz, which was higher than in the other scenarios.

The results of the analysis of the mean hand dexterity differences between the various exposure scenarios using repeated

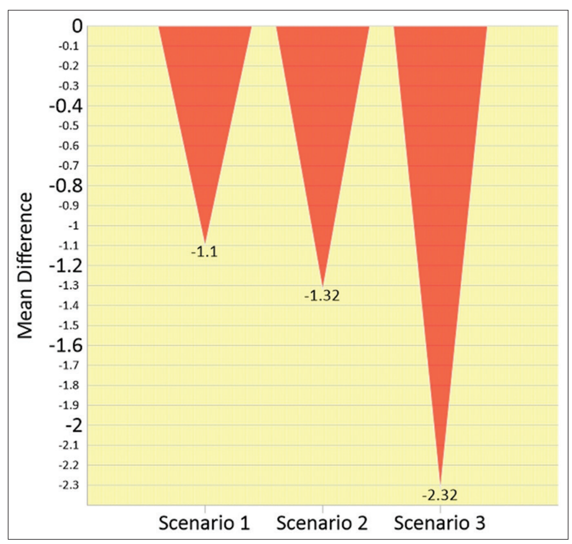

Figure 3: Comparison of mean manual dexterity changes in different exposure scenarios

Table 2: Results of hand dexterity changes before and after exposure in each of the exposure scenarios

Exposure scenarios	Maximum	Minimum	Before exposure, mean±SD	After exposure, mean±SD	*P*
HTV (5 m/s^2-31.5 Hz)	39	22	31.29±3.88	30.18±3.88	<0.001
HTV (5 m/s^2-63 Hz)	39	20	31.37±3.69	30.05±3.82	<0.001
HTV (5 m/s^2-125 Hz)	39	20	31.54±3.73	29.21±4.26	<0.001

SD: Standard deviation, HTV: Hand-transmitted vibration measures ANOVA were statistically significant ($P < 0.05$). Given the significant statistical difference in mean hand dexterity, pairwise comparison and *post hoc* least significant difference (LSD) tests were used to compare the means between exposure scenarios. The results of the pairwise comparison test, examining the interaction effects and effect size of each exposure scenario on the mean hand dexterity difference, are presented in Table 3.

According to the results presented in Table 3, the greatest effect on hand dexterity in the study participants was observed in the scenario of exposure to HTV (5 m/s² rms, 125 Hz). The effect size for this scenario was reported to be 0.558. This value indicates a moderate-to-large effect based on Cohen's criteria.

A comparison between the three scenarios with the same acceleration (5 m/s² rms) and different frequencies (31.5 Hz, 63 Hz, and 125 Hz) indicates that as the frequency increases, the effect of HTV on hand dexterity also increases.

Pairwise comparisons between the different scenarios revealed that no significant difference was observed between the two scenarios of exposure to HTV (5 m/s² rms, 63 Hz) and (5 m/s² rms, 31.5 Hz).

Discussion

In this study, the PPT was used as an effective laboratory tool for the clinical assessment of hand dexterity in individuals exposed to different HAV scenarios [Figure 2]. The results of this study revealed that exposure to HTVs at various frequencies significantly impacted hand dexterity. Notable changes in hand dexterity performance were observed before and after exposure to vibrations [Table 2]. These findings tend to confirm and expand upon previous research, indicating a link between reduced manual skills and sensory-neurovascular and motor symptoms in individuals using handheld vibrating tools. For instance, in a study by Rui *et al*., the PPT was used to assess the manual dexterity of workers exposed to HTVs, and their results were compared with a control group. The results showed that, in a cross-sectional analysis, pegboard scores were significantly lower in workers exposed to hand vibrations compared to the control group. Moreover, over a 1-year follow-up period, pegboard scores were inversely correlated with the use of vibrating hand tools. Specifically, as exposure to vibration increased, pegboard scores decreased. In addition, a significant correlation was found between the reduction in manual dexterity and neurovascular symptoms in the fingers of workers using vibrating hand tools.[13] In another study, Sakakibara *et al*. demonstrated functional and skill-related hand impairments in individuals with HAVS compared to a control group with no occupational exposure to vibrations.[14]

One of the key findings of this study is the impact of increasing vibration frequencies on hand dexterity reduction. Exposure scenarios with 31.5 Hz and 63 Hz vibrations resulted in less change in hand dexterity compared to the 125 Hz frequency [Table 3]. This finding emphasizes the importance of high frequencies in inducing functional changes in hand performance. It appears that vibrations with higher frequencies may place greater strain on the hand's nervous and muscular systems, ultimately leading to reduced hand dexterity. However, conflicting studies exist in this regard. For instance, a cohort study conducted by Bovenzi *et al.* compared the performance of different HAV frequencies and assessed exposure-response relationships in sensory-neurovascular disorders. This study found no difference in predicting finger numbness between exposure measurements using frequency-weighted HTV frequencies, which contradicts the findings of our study. However, other results from this study showed that sensory-neurovascular symptoms, reduced work capacity, and sensory test impairments, including hand dexterity, were significantly more pronounced in workers exposed to HTV compared to the control group, which aligns with our study's findings.[15] In studies by Gerhardsson and colleagues, it was demonstrated that workers exposed to high-frequency and transient vibrations experience a higher prevalence of vibration-induced white fingers and neurosensory symptoms. In addition, musculoskeletal problems such as carpal tunnel syndrome and ulnar nerve entrapment in the hand/wrist were more common.[16,17]

Moreover, both human and animal studies have shown that the negative effects of vibration on the vascular and peripheral nervous systems are frequency dependent. Vibrations at frequencies close to the resonant frequencies of human fingers (100–350 Hz) cause the most severe damage. A study conducted by Krajnak *et al*. revealed that exposure to vibrations at 250 Hz had more pronounced effects compared to exposure at 62.5 Hz. These animal observations are consistent with findings from human studies, which indicate that prolonged exposure to frequencies near resonant frequencies poses the greatest risk for developing vascular and peripheral nervous disorders.[18,19] Studies show that higher vibration frequencies, especially near the resonant range of fingers, cause more damage to the vascular, neurovascular, and musculoskeletal systems. The findings of this study are consistent with previous research, which has shown that occupational exposure to higher

Table 3: Results of the pairwise comparison test and effect size of each exposure scenario on hand dexterity

Exposure scenario	HTV (5 m/s²-31.5 Hz)	HTV (5 m/s²-63 Hz)	HTV (5 m/s²-125 Hz)	Effect size (partial eta squared)
HTV (5 m/s²-31.5 Hz)	-	0.282	<0.001	0.309
HTV (5 m/s²-63 Hz)	0.282	-	<0.001	0.419
HTV (5 m/s²-125 Hz)	<0.001	<0.001	-	0.558

HTV: Hand-transmitted vibration

frequencies, particularly those close to resonant frequencies, has a more significant impact on physiological and functional hand impairments.[9] Thus, it can be concluded that this factor may be responsible for the significant reduction in hand dexterity observed in exposure to the 125 Hz frequency compared to the other two frequencies (31.5 and 63 Hz) in this study.

In this study, a vibration acceleration of 5 m/s^2 (rms) was used to induce vibrations [Table 1]. This vibration acceleration led to a reduction in hand dexterity across all the scenarios examined. In this context, a study by Popević *et al*. is noteworthy, as it demonstrated a statistically significant decrease in manual skills between healthy individuals and those exposed to vibrations. In addition, this study reported a measurable and significant impairment in manual dexterity in the alternating exposure pattern and small cumulative vibration dose. The reasons for these findings may be related to damage caused by vibration to nerve fibers and/or mechanoreceptors, which provide sensory feedback for motor signals that control tasks requiring precise finger movements. These injuries may be responsible for the observed reduction in manual dexterity.[20] In the experimental study by Griffin *et al*., it was also found that hand vibration caused a temporary increase in vibration thresholds, with these changes being related to sensory mechanisms triggered by the vibration, and they were strongly dependent on the vibration frequency.[21]

The assessment of hand dexterity changes revealed that with increasing frequency of HTV, its negative impact on hand dexterity also increased. The greatest decline in hand dexterity was observed in the scenario with 5 m/s^2 rms acceleration and 125 Hz frequency [Figure 3]. These findings indicate that, in addition to acceleration, vibration frequency plays a significant role in hand performance. The ISO 5349-1 frequency weighting curve is not an accurate predictor for HAVS at frequencies above 100 Hz. In this standard, the frequency weighting decreases for frequencies above 16 Hz,[22-26] whereas this study shows that increasing frequency under constant vibration acceleration leads to a more significant decline in hand dexterity. Therefore, the results of this study suggest the need for an updated and more specific frequency weighting approach, rather than relying on the current ISO 5349-1 standard, to better assess HAVS risks at higher frequencies.

The results of this study confirm that vibration exposure and its frequencies reduce hand dexterity. Therefore, in industries like construction, it is recommended to limit exposure duration, acceleration levels, and vibration frequencies. This measure could help prevent the reduction of manual skills required for tasks that demand precision and hand coordination. A decline in sensory perception and hand dexterity may disrupt the ability to control and hold objects and tools, thereby increasing the risk of accidents and safety issues in the workplace. In this regard, the use of modern technologies such as antivibration gloves and well-planned rest periods between vibration exposure sessions can be impactful. In addition, further studies using multiple scenarios, larger samples, and pathological findings are essential to confirm the observed results and explain the underlying reasons for changes in hand dexterity.

Conclusion

The results of this controlled laboratory study indicated that the frequency of HAV exposure, much like the acceleration of exposure, plays a significant role in the development of hand dexterity issues. Data analysis revealed a linear dose–response relationship between different HAV frequency exposure conditions and hand dexterity. Exposure to HAV under constant acceleration conditions (5 m/s^2 rms) showed that with increasing vibration frequency, hand dexterity decreased among participants exposed to various HTV scenarios. In other words, as the vibration frequency increases, its negative impact on hand dexterity and the ability to perform precise and sensitive tasks becomes more pronounced.

These findings suggest that higher vibration frequencies can place additional strain on the hand's neurological and muscular systems, ultimately disrupting the individual's ability to perform precise movements, control, and hold objects. Furthermore, this study demonstrates that even when acceleration remains constant, vibration frequency acts as a crucial determinant in HAV-related injuries.

Acknowledgments

This study was conducted based on a research proposal (Project Number: 1403/10p/187) approved by the Esfarayen Faculty of Medical Sciences. We sincerely appreciate the support of the Esfarayen Faculty of Medical Sciences.

Financial support and sponsorship

This research was financially supported by the Esfarayen Faculty of Medical Sciences.

Ethics code

The Medical Ethics Committee of the Esfarayen Faculty of Medical Sciences approved the study protocol under the ethical code IR. ESFARAYENUMS. REC.1403.016.

Conflicts of interest

There are no conflicts of interest.

Authors' contributions

Mohsen Aliabadi: Conceptualization, Methodology, Review and Editing, Project Administration, Validation; Seyed Hojat Mousavi Kordmiri: Research Design and Implementation, Data Collection and Analysis, WritingOriginal Draft.

References

1. Palathoti S, Al-Qaidi MM, Otitolaiye VO. Study on effects of hand-arm vibration syndrome on construction workers in Oman. Int J Occup Saf Health 2024;14:485-91.
2. Sun Y, Bochmann F, Eckert W, Ernst B, Freitag C, Kaulbars U, *et al.* Quantitative assessment of work-related hand-arm vibration exposure among workers in the construction, underground coal mining, wood working, and metal working industry: The German hand-arm vibration

study. Saf Health Work 2025;16:97-104.
3. Sun Y, Bochmann F, Dohlich J, Eckert W, Ernst B, Freitag C, *et al.* Exposure-response relationship between work-related hand-arm vibration exposure and musculoskeletal disorders of the upper extremities: The German hand-arm vibration study. Int J Occup Saf Ergon 2024;30:304-11.
4. Lai SK, Chui J, Tong L, Sun JQ. A human-based study of hand–arm vibration exposure limits for construction workers. J Vib Eng Technol 2019;7:379-88.
5. Sun Y, Bochmann F, Eckert W, Nigmann U, van den Berg C, Kaulbars U, Raffler N. Frequency-range-specific hand – Arm vibration exposure and the risk of musculoskeletal disorders of the upper extremities: The German hand – Arm vibration study. Vibration 2025;8:6.
6. European Agency for Safety and Health at Work. Workplace Exposure to Vibration in Europe: An Expert Review. Luxembourg: European Communities; 2008.
7. Nilsson T, Wahlström J, Burström L. Hand-arm vibration and the risk of vascular and neurological diseases - A systematic review and meta-analysis. PLoS One 2017;12:e0180795.
8. Qamruddin AA, Husain NR, Sidek MY, Hanafi MH, Ripin ZM, Ali N. Musculoskeletal complications of hand-arm vibration syndrome among tyre shop workers in Kelantan, Malaysia. Int J Occup Saf Ergon 2022;28:213-22.
9. Dong RG, Wu JZ, Xu XS, Welcome DE, Krajnak K. A review of hand-arm vibration studies conducted by US NIOSH since 2000. Vibration 2021;4:482-528.
10. Haward BM, Griffin MJ. Repeatability of grip strength and dexterity tests and the effects of age and gender. Int Arch Occup Environ Health 2002;75:111-9.
11. Saeidnia H, Esmaeili R, Babamiri M, Pourtaghi F, Hassanipour S, Pourtaghi G. Effect of the level of manual performance disability caused by exposure to vibration among sailors working on sailing speed vessels. BMC Musculoskelet Disord 2022;23:515.
12. Toibana N, Ishikawa N, Sakakibara H. Measurement of manipulative dexterity in patients with hand-arm vibration syndrome. Int Arch Occup Environ Health 2002;75:106-10.
13. Rui F, D'Agostin F, Negro C, Bovenzi M. A prospective cohort study of manipulative dexterity in vibration-exposed workers. Int Arch Occup Environ Health 2008;81:545-51.
14. Sakakibara H, Hirata M, Toibana N. Impaired manual dexterity and neuromuscular dysfunction in patients with hand-arm vibration syndrome. Ind Health 2005;43:542-7.
15. Bovenzi M, Prodi A, Mauro M. Relationships of neurosensory disorders and reduced work ability to alternative frequency weightings of hand-transmitted vibration. Scand J Work Environ Health 2015;41:247-58.
16. Gerhardsson L. A follow-up study of vibration-induced injuries in workers exposed to transient and high frequency vibrations. J Occup Med Toxicol 2024;19:27.
17. Gerhardsson L, Ahlstrand C, Ersson P, Gustafsson E. Vibration-induced injuries in workers exposed to transient and high frequency vibrations. J Occup Med Toxicol 2020;15:18.
18. Krajnak K, Miller GR, Waugh S. Contact area affects frequency-dependent responses to vibration in the peripheral vascular and sensorineural systems. J Toxicol Environ Health A 2018;81:6-19.
19. Welcome DE, Krajnak K, Kashon ML, Dong RG. An investigation on the biodynamic foundation of a rat tail vibration model. Proc Inst Mech Eng H 2008;222:1127-41.
20. Popević MB, Janković SM, Borjanović SS, Jovičić SR, Tenjović LR, Milovanović AP, *et al.* Assessment of coarse and fine hand motor performance in asymptomatic subjects exposed to hand-arm vibration. Arh Hig Rada Toksikol 2014;65:29-36.
21. Griffin MJ. Frequency-dependence of psychophysical and physiological responses to hand-transmitted vibration. Ind Health 2012;50:354-69.
22. Bovenzi M. New international criteria for evaluating vascular hand-arm vibration risk and staging and-arm vibration syndrome. G Ital Med Lav Ergon 2019;41:268-73.
23. Bovenzi M, Pinto I, Picciolo F. Risk assessment of vascular disorders by a supplementary hand-arm vascular weighting of hand-transmitted vibration. Int Arch Occup Environ Health 2019;92:129-39.
24. Bovenzi M, Tarabini M. Relation of digital arterial dysfunction to alternative frequency weightings of hand-transmitted vibration. Ind Health 2024;62:32-8.
25. Burström L, Lundström R, Hagberg M, Nilsson T. Vibrotactile perception and effects of short-term exposure to hand-arm vibration. Ann Occup Hyg 2009;53:539-47.
26. Krajnak K, Riley DA, Wu J, McDowell T, Welcome DE, Xu XS, *et al.* Frequency-dependent effects of vibration on physiological systems: Experiments with animals and other human surrogates. Ind Health 2012;50:343-53.