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An experimental Study on the Neurological Effects of Hand-Arm Vibration: Considering Vibration Frequency, Ambient Temperature, and Wrist Posture

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Article

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Abstract

Hand–arm vibration (HAV) is an occupational hazard associated with neurological and sensory disturbances. This study investigated the effects of vibration frequency, ambient temperature, and wrist posture on tactile sensory threshold and motor nerve conduction velocity (MNCV) following hand-transmitted vibration exposure. In this within-subject study, 25 construction workers completed 12 scenarios combining 10 m/s² acceleration, two vibration frequencies (31.5 and 63 Hz), two ambient temperatures (5 and 25°C), and three wrist postures (neutral, flexion, and extension). Each scenario involved 30 minutes of exposure using a hand–arm vibration simulator. Median nerve MNCV was measured before and after exposure, and tactile sensory threshold was assessed by monofilament testing. Changes were analyzed using linear mixed models. All scenarios produced reduced MNCV and increased tactile threshold. The greatest MNCV reduction occurred at 31.5 Hz, 5°C, and wrist flexion (− 2.780 ± 0.465 m/s), whereas the largest increase in tactile threshold occurred at 63 Hz, 5°C, with wrist flexion or extension (0.533 ± 0.467 g). Temperature had the largest effect on tactile threshold ($\eta p^2 = 0.307$), while frequency had the largest effect on MNCV ($\eta p^2 = 0.606$). These findings highlight the importance of frequency, temperature, and wrist posture in HAV risk assessment.

Introduction

Occupational exposure to hand–arm vibration (HAV) is a well-recognized occupational hazard among workers who routinely use vibrating hand-held tools, particularly in construction, forestry, mining, and manufacturing. Prolonged exposure to hand-transmitted vibration can contribute to vascular, neurological, and musculoskeletal disorders collectively referred to as hand–arm vibration syndrome (HAVS) [1–3]. The neurological component of HAVS is of particular occupational-health importance because vibration exposure may be associated with sensory disturbances, peripheral neuropathy, and impaired sensory function, which can adversely affect manual performance and occupational activities [2–5].

Neurological manifestations associated with HAV exposure include numbness, tingling, impaired vibration perception, altered tactile sensation, and abnormalities in peripheral nerve function [2–6]. Electrophysiological assessment, particularly nerve conduction studies (NCS), can provide objective information about peripheral nerve function in vibration-exposed workers. Lander et al. reported that median and ulnar neuropathies proximal to the hand were common among workers assessed for HAVS, supporting the potential value of NCS in the neurological evaluation of vibration-exposed workers [7]. Other electrophysiological investigations have also demonstrated abnormalities in sensory nerve conduction among workers exposed to hand–arm vibration [4, 5, and 8].Sensory testing provides complementary information because vibration-related neurological dysfunction may involve sensory receptors and pathways that are not fully characterized by conventional motor nerve conduction measurements. Quantitative assessment of thermo tactile and vibrotactile thresholds has been investigated as a means of detecting the sensorineural component of HAVS [9]. Ye and Griffin reported increased vibrotactile thresholds at both 31.5 and 125 Hz in fingers associated with numbness or tingling, indicating that sensory threshold measurements can provide useful information regarding vibration-related sensorineural dysfunction [9, 11]. Similarly, studies using vibration perception thresholds and digital sensory nerve conduction velocity have demonstrated the usefulness of sensory and electrophysiological measurements in vibration-exposed workers [6, 10].

The International Organization for Standardization (ISO), through ISO 5349-1, identifies vibration magnitude and frequency as fundamental characteristics in the assessment of human exposure to hand-transmitted vibration [12]. However, the biological response of the hand–arm system is not determined solely by vibration magnitude. Vibration transmission through the hand and upper limb is influenced by biomechanical conditions, including wrist and arm posture, grip force, and the characteristics of the applied vibration [13–16]. Consequently, workers exposed to similar vibration magnitudes may experience different physiological responses under different working conditions. Wrist posture is an important biomechanical factor that may modify vibration transmission through the hand–arm system. Experimental studies have

shown that vibration transmissibility is affected by hand and wrist posture, grip force, and excitation conditions [13–15, 17]. Changes in wrist configuration can modify the mechanical pathway through which vibration is transmitted from the hand to more proximal tissues. Such changes may consequently alter the distribution of vibration energy within the hand and upper limb and may contribute to differences in the physiological response to vibration.

Vibration frequency is another important determinant of the biodynamic response of the hand–arm system. Experimental studies have demonstrated frequency-dependent vibration transmission and energy absorption within the fingers, hand, and forearm [14–16, 18]. The magnitude and distribution of transmitted vibration may therefore differ substantially between low- and higher-frequency exposures. These differences are potentially important when evaluating neurological outcomes because the location and magnitude of vibration transmission may influence the tissues subjected to mechanical stimulation.

Ambient temperature represents another potentially important modifying factor. Cold exposure can alter peripheral vascular responses and tissue temperature and may therefore influence the physiological response to hand–arm vibration [19–21]. Experimental research has demonstrated that hand–arm vibration can interact with thermal conditions and influence skin-temperature responses, while temperature itself can affect vibration-induced responses in peripheral nerves and arteries [19, 20]. Cold-related changes in peripheral circulation may therefore contribute to differences in sensory responses under vibration exposure.

Recent research from the same research group has also demonstrated measurable functional and physiological effects of controlled hand-transmitted vibration in construction workers. Mousavi Kordmiri et al. reported changes in muscle and mental fatigue following simulated construction exposure to hand-transmitted vibration [22]. The same group subsequently reported effects of hand-transmitted vibration exposure on hearing and equilibrium under simulated construction conditions [23]. More recently, Aliabadi and Mousavi Kordmiri demonstrated significant reductions in hand dexterity following 30-minute exposures to different vibration frequencies, including 31.5 and 63 Hz [24]. These findings support the importance of examining different functional and physiological consequences of HAV exposure under controlled experimental conditions. The 2025 study is particularly relevant to the present work because it used controlled 30-minute exposures and directly compared responses across vibration frequencies [24].

Despite extensive research on hand–arm vibration, previous investigations have often examined individual exposure characteristics or focused on a single physiological outcome. Comparatively less attention has been given to the simultaneous evaluation of vibration frequency, ambient temperature, and wrist posture in relation to objective sensory and motor neural outcomes. This is particularly relevant because workers may encounter vibration under different thermal and biomechanical conditions during their daily activities. A better understanding of how these factors influence neurological responses may contribute to a more comprehensive assessment of occupational risks associated with hand–arm vibration.

Therefore, the present study aimed to investigate the effects of vibration frequency, ambient temperature, and wrist posture on changes in tactile sensory threshold and motor nerve conduction velocity (MNCV) following controlled hand–arm vibration exposure. Using a within-subject laboratory design, 25 construction workers were exposed to 12 experimental conditions comprising two vibration frequencies (31.5 and 63 Hz), two ambient temperatures (5 and 25°C), and three wrist postures (neutral, flexion, and extension), while vibration acceleration was maintained at 10 m/s² across all conditions. The study further aimed to determine the relative contribution of these exposure factors to changes in sensory and motor neural function.

Materials and Methods

Study Design and Participants

This controlled, within-subject laboratory study was conducted among 25 male construction workers with previous occupational experience involving vibrating hand-held tools. Participants were required to be in general good health and to have no known neuromuscular disorders, previous serious neurological or musculoskeletal injuries affecting the upper extremities, or other conditions that could influence neurological or neuromuscular function. Participants using medications that could substantially affect neurological or neuromuscular function were excluded. Participants who were unable to complete all experimental scenarios were also excluded. The study protocol was approved by the Ethics Committee of Hamadan University of Medical Sciences (Approval No. IR.UMSHA.REC.1402.140), and all participants provided written informed consent before participation. All methods were performed in accordance with the relevant guidelines and regulations.

Each participant completed 12 experimental exposure scenarios comprising one fixed vibration acceleration level (10 m/s^2), two vibration frequencies (31.5 and 63 Hz), two ambient temperatures (5 and 25°C), and three wrist postures (neutral, flexion, and extension). Each exposure lasted 30 minutes, and the 12 scenarios were conducted on separate days. The order of the exposure scenarios was randomized for each participant to minimize potential order and carryover effects. Scenario 6 (10 m/s^2, 31.5 Hz, 25°C, neutral wrist posture) was defined as the reference exposure condition. The remaining 11 scenarios represented deviations from this reference condition through changes in vibration frequency, ambient temperature, wrist posture, or combinations of these factors. The reference condition was used to facilitate interpretation of changes in tactile sensory threshold and motor nerve conduction velocity across the experimental scenarios.

Experimental Setup and Vibration Exposure

All experimental exposures were performed using a hand–arm vibration simulator installed in a climatic chamber at Hamadan University of Medical Sciences. The simulator was designed to reproduce hand-transmitted vibration exposure representative of commonly used vibrating tools, such as demolition hammers and jackhammers. It allowed controlled adjustment of vibration frequency and acceleration, while the climatic chamber enabled standardized control of ambient temperature throughout each exposure session. The hand–arm vibration simulator and its placement within the climate-controlled chamber are shown in Fig. 1.

The experimental design included two vibration frequencies (31.5 and 63 Hz), two ambient temperatures (5 and 25°C), and three wrist postures (neutral, flexion, and extension), while vibration acceleration was maintained at 10 m/s^2 across all scenarios. This factorial combination resulted in 12 unique experimental exposure conditions. Vibration exposure conditions were established with reference to ISO 5349-1, which provides general requirements for measurement and evaluation of human exposure to hand-transmitted vibration [12].

Neuro-Sensory Measurements

The primary outcomes were tactile sensory threshold and motor nerve conduction velocity (MNCV). All neuro-sensory measurements were performed immediately before and immediately after each 30-minute exposure session.

Motor nerve conduction velocity

Motor nerve conduction velocity of the median nerve was assessed using a standard nerve conduction study protocol with an Axon EMG 4000 system (Negar Andishegan Co., Iran). For MNCV assessment, the median nerve was electrically stimulated at two standardized sites along the upper limb: the wrist and the elbow. The evoked motor responses were recorded for each stimulation site, and onset latency was determined by the electro diagnostic system.

The distance between the two stimulation sites was measured along the course of the median nerve and entered into the system. MNCV across the wrist–elbow segment was calculated from the distance between the two stimulation sites and the difference in onset latency between proximal and distal stimulation. The resulting motor nerve conduction velocity was expressed in meters per second (m/s).

Tactile sensory threshold

Tactile sensory threshold of the palm was assessed using a standard monofilament kit. The monofilament was applied to the designated palmar site according to the manufacturer's testing procedure, and the minimum filament force perceived by the participant was recorded as the tactile sensory threshold. Quantitative sensory threshold assessment has previously been used to investigate sensory dysfunction associated with hand–arm vibration exposure [6, 9, 10, 25]. The equipment and measurement procedures used for the neuro-sensory assessments, including median nerve motor conduction testing and monofilament-based tactile sensory testing, are illustrated in Fig. 2.All measurements were performed immediately before and immediately after each exposure. For each outcome, the change associated with exposure was calculated as the post-exposure value minus the corresponding pre-exposure value: **Δ = post − pre**

Accordingly, negative ΔMNCV values indicated a reduction in motor nerve conduction velocity, whereas positive ΔMonofilament values indicated an increase in tactile sensory threshold.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics. Because each participant contributed repeated observations across the 12 experimental scenarios, linear mixed models (LMMs) were used to account for the within-subject structure of the data. Vibration frequency, ambient temperature, and wrist posture were specified as fixed effects, while participant was included as a random effect. Type III tests of fixed effects were used to evaluate the main effects and interaction terms. Restricted maximum likelihood (REML) estimation was used for model estimation, and the Satterthwaite approximation was used to determine denominator degrees of freedom. Changes in tactile sensory threshold (ΔMonofilament) and motor nerve conduction velocity (ΔMNCV) were analyzed as the dependent variables. Partial eta squared (ηp^2) was used as a measure of effect size for the fixed effects, with larger values indicating a greater relative contribution of the corresponding factor to variability in the outcome.



Figure2. Equipment and procedures used for neuro-sensory assessment, including median nerve motor conduction testing and monofilament-based tactile sensory testing.

Results

A total of 25 healthy male construction workers participated in the study. The mean age of the participants was 38.44 ± 8.14 years (range: 25–54 years). The mean duration of occupational exposure to vibrating tools was 8.36 ± 2.81 years, while the mean total work experience was 13.64 ± 4.69 years. The mean body weight was 86.8 kg, the mean height was 1.77 m, and the mean body mass index (BMI) was 27.9 kg/m^2. None of the participants reported a history of neuromuscular injury affecting the upper extremities.

Effect sizes of the experimental factors

The partial eta squared analysis demonstrated different patterns for the two outcomes. For ΔMonofilament, ambient temperature had the largest effect ($\eta p^2 = 0.307$), followed by vibration frequency ($\eta p^2 = 0.122$) and wrist posture ($\eta p^2 = 0.033$). The main effects of frequency ($p < .001$), ambient temperature ($p < .001$), and wrist posture ($p = .010$) were statistically significant. In contrast, none of the interaction effects reached statistical significance, including frequency × ambient temperature ($p = .110$), frequency × wrist posture ($p = .987$), ambient temperature × wrist posture ($p = .178$), and the three-way interaction ($p = .737$) (Table 1).

For ΔMNCV, vibration frequency showed the largest effect ($\eta p^2 = 0.606$), followed by ambient temperature ($\eta p^2 = 0.242$) and wrist posture ($\eta p^2 = 0.231$). All three main effects were statistically significant ($p < .001$). The interaction effects were not statistically significant, including frequency × temperature ($\eta p^2 = 0.003$, $p = .370$), frequency × wrist posture ($\eta p^2 = 0.013$, $p = .165$), ambient temperature × wrist posture ($\eta p^2 = 0.005$, $p = .515$), and the three-way interaction ($\eta p^2 < .001$, $p = .957$) (Table 1).

Main effects of frequency, temperature, and wrist posture

The analysis of the main effects showed that the two outcomes exhibited different patterns of response. For tactile sensory threshold, exposure at 5°C produced a greater increase than exposure at 25°C, consistent with the larger effect size observed for ambient temperature ($\eta p^2 = 0.307$). For MNCV, exposure at 31.5 Hz produced a greater reduction than exposure at 63 Hz, consistent with the dominant effect of frequency ($\eta p^2 = 0.606$) .Wrist posture also had a statistically significant effect on both outcomes. Across the experimental conditions, wrist flexion was associated with the greatest increase in tactile sensory threshold and the greatest reduction in MNCV.

Table 1

Effect sizes expressed as partial eta squared (ηp^2) for the main and interaction effects of frequency, temperature, and posture

Dependent Variable	Vibration Frequency	ambient Temperature	Wrist Posture	Vibration Frequency × Temperature	Vibration Frequency × Wrist Posture	Temperature × Wrist Posture	Vibration Frequency × Temperature × Wrist Posture
Δ Monofilament (ηp^2)	**.122**	**.307**	**.033**	.009	< .001	.013	.002
P-value	**< .001**	**< .001**	**.010**	.110	.987	.178	.737
Δ MNCV (ηp^2)	**.606**	**.242**	**.231**	.003	.013	.005	< .001
P-value	**< .001**	**< .001**	**< .001**	.370	.165	.515	.957

Changes across the experimental scenarios

All 12 exposure scenarios were associated with a reduction in motor nerve conduction velocity (MNCV) and an increase in tactile sensory threshold. The changes in MNCV were negative across all scenarios, indicating a reduction following exposure, whereas positive changes in monofilament threshold indicated an increase in the force required to perceive tactile stimulation and, consequently, reduced tactile sensitivity. The scenario-specific results for tactile sensory threshold are presented in Table 2. The greatest increase in tactile sensory threshold was observed under 63 Hz, 5°C, and wrist flexion and extension, with a mean change of 0.533 ± 0.467 g in both conditions. This was followed by the 63 Hz, 5°C, neutral posture condition (0.453 ± 0.403 g). At 31.5 Hz and 5°C, the changes were 0.320 ± 0.288 g for both flexion and extension and 0.280 ± 0.258 g for the neutral posture. The smallest change was observed under the reference condition of 31.5 Hz, 25°C, and neutral wrist posture (0.002 ± 0.012 g).

The scenario-specific changes in MNCV are presented in Table 3. The greatest reduction in MNCV occurred under 31.5 Hz, 5°C, and wrist flexion, with a mean change of − 2.780 ± 0.465 m/s. The next largest reductions were observed less than 31.5 Hz, 5°C, with wrist extension (− 2.332 ± 0.447 m/s) and neutral posture (− 2.320 ± 0.456 m/s). In contrast, the smallest reduction was observed under 63 Hz, 25°C, and wrist extension (− 0.804 ± 0.461 m/s), followed by 63 Hz, 25°C, and neutral posture (− 0.816 ± 0.412 m/s).

Reference and most adverse exposure conditions

Scenario 6, consisting of 31.5 Hz, 25°C, and neutral wrist posture, was defined as the reference exposure condition. For tactile sensory threshold, the greatest increase occurred under 63 Hz, 5°C, with wrist flexion or extension (0.533 ± 0.467 g), whereas the smallest change occurred under the reference condition of 31.5 Hz, 25°C, and neutral wrist posture (0.002 ± 0.012 g) (Table 2). For MNCV, the greatest reduction relative to the range of experimental conditions occurred under 31.5 Hz, 5°C, and wrist flexion (− 2.780 ± 0.465 m/s), whereas the smallest reduction occurred under 63 Hz, 25°C, and wrist extension (− 0.804 ± 0.461 m/s) (Table 3).

Overall, the findings demonstrate that the two neuro-sensory outcomes responded differently to the experimental factors. Vibration frequency was the dominant factor affecting MNCV, whereas ambient temperature showed the largest effect on tactile sensory threshold. Although wrist posture also had statistically significant main effects on both outcomes, none of the two-way or three-way interaction effects was statistically significant (Table 1). The scenario-level patterns presented in Figs. 3 are consistent with these findings and demonstrate the contrasting response patterns of tactile sensory threshold and MNCV across the 12 exposure conditions.

Table 2
Changes in Monofilament Sensory Threshold under the 12 experimental scenarios

Scenario	Experimental condition	ΔMonofilament (g, Mean ± SD)	Cohen's dz
1	31.5 Hz – 5°C – Flexion	**0.320 ± 0.288**	**1.11**
2	31.5 Hz – 5°C – Extension	**0.320 ± 0.288**	**1.11**
3	31.5 Hz – 5°C – Normal	**0.280 ± 0.258**	**1.09**
4	31.5 Hz – 25°C – Flexion	**0.149 ± 0.333**	**0.45**
5	31.5 Hz – 25°C – Extension	**0.042 ± 0.200**	**0.21**
6	**31.5 Hz – 25°C – Normal (Reference)**	**0.002 ± 0.012**	**0.20***
7	63 Hz – 5°C – Flexion	**0.533 ± 0.467**	**1.14**
8	63 Hz – 5°C – Extension	**0.533 ± 0.467**	**1.14**
9	63 Hz – 5°C – Normal	**0.453 ± 0.403**	**1.13**
10	63 Hz – 25°C – Flexion	**0.262 ± 0.316**	**0.83**
11	63 Hz – 25°C – Extension	**0.136 ± 0.332**	**0.41**
12	63 Hz – 25°C – Normal	**0.149 ± 0.333**	**0.45**

Table 3
Changes in Motor Nerve Conduction Velocity under the 12 experimental scenarios

Scenario	Experimental condition	ΔMNCV (m/s, Mean ± SD)	Cohen's dz
1	31.5 Hz – 5°C – Flexion	**−2.780 ± 0.465**	**−5.97**
2	31.5 Hz – 5°C – Extension	**−2.332 ± 0.447**	**−5.22**
3	31.5 Hz – 5°C – Normal	**−2.320 ± 0.456**	**−5.08**
4	31.5 Hz – 25°C – Flexion	**−2.184 ± 0.441**	**−4.95**
5	31.5 Hz – 25°C – Extension	**−1.912 ± 0.475**	**−4.02**
6	31.5 Hz – 25°C – Normal (Reference)	**−1.804 ± 0.464**	**−3.89**
7	63 Hz – 5°C – Flexion	**−1.812 ± 0.417**	**−4.35**
8	63 Hz – 5°C – Extension	**−1.168 ± 0.424**	**−2.75**
9	63 Hz – 5°C – Normal	**−1.248 ± 0.406**	**−3.07**
10	63 Hz – 25°C – Flexion	**−1.344 ± 0.463**	**−2.90**
11	63 Hz – 25°C – Extension	**−0.804 ± 0.461**	**−1.75**
12	63 Hz – 25°C – Normal	**−0.816 ± 0.412**	**−1.98**

Discussion

The exposure was associated with measurable changes in both tactile sensory threshold and motor nerve conduction velocity in construction workers. Across the 12 experimental scenarios, MNCV decreased, whereas tactile sensory threshold increased. These findings are consistent with previous evidence of peripheral neurological abnormalities among workers exposed to hand–arm vibration [2–10, 26]. Previous studies have reported impaired peripheral nerve function and sensory abnormalities in vibration-exposed workers. Bovenzi et al. and Giannini et al. reported electrophysiological abnormalities among forestry workers exposed to vibration, while Lander et al. identified median and ulnar neuropathies among workers assessed for HAVS [4, 5, 7]. Similarly, increased vibrotactile thresholds and abnormalities in sensory nerve function have been reported in vibration-exposed workers [6, 9, 10, 28, 30]. These findings support the simultaneous changes in MNCV and tactile sensory threshold observed in the present study. Ambient temperature had a strong influence on tactile sensory threshold. Temperature showed the largest effect among the three main factors for ΔMonofilament ($\eta p^2 = 0.307$), with greater changes at 5°C than at 25°C. Cold exposure can modify peripheral vascular responses and tissue temperature and consequently influence sensory and neural function during vibration exposure [19–21]. Previous studies have similarly demonstrated temperature-dependent effects of hand–arm vibration on skin temperature, peripheral nerves, and vascular responses [19, 20].

Vibration frequency showed a distinct pattern for the two neurological outcomes. Frequency was the dominant factor affecting MNCV ($\eta p^2 = 0.606$), with a greater reduction at 31.5 Hz, whereas the largest increases in tactile sensory threshold occurred at 63 Hz under cold conditions. This differential response is consistent with evidence that vibration transmission, energy absorption, and tissue deformation within the hand–arm system are frequency- and location-dependent [14–16, 18, 31]. Experimental evidence has demonstrated frequency-dependent strains in fingertip tissues associated with mechanoreceptor stimulation [31], while psychophysical and physiological responses to hand-transmitted vibration may exhibit different frequency sensitivities [32]. Therefore, the greater tactile sensory response at 63 Hz and MNCV reduction at 31.5 Hz may reflect differences in vibration transmission and tissue-level mechanical responses, as well as the distinct physiological pathways assessed by these measures. These findings should therefore not be considered contradictory but rather suggest that neurological responses to hand–arm vibration may be frequency-

dependent and outcome-specific. The frequency-related findings are also consistent with controlled laboratory research by Aliabadi and Mousavi Kordmiri, in which 30 minutes of hand-transmitted vibration at different frequencies produced significant changes in manual dexterity [24]. Although manual dexterity differs from MNCV and tactile sensory threshold, these findings further support different frequency-response patterns across functional outcomes. Wrist posture also significantly affected both outcomes, with flexion generally associated with greater neuro-sensory changes than the neutral posture. This finding is consistent with evidence that wrist and hand posture can modify vibration transmissibility and the distribution of vibration energy within the hand–arm system [13–15, 17, 29].

No statistically significant interactions between frequency, temperature, and posture were observed for either outcome, indicating distinct main effects rather than a demonstrated synergistic interaction. Nevertheless, the scenario-level results showed that the most pronounced response differed between outcomes: the greatest MNCV reduction occurred at 31.5 Hz, 5°C, and wrist flexion, whereas the largest tactile threshold increase occurred at 63 Hz under cold conditions with wrist flexion or extension. This emphasizes that the most adverse exposure condition may depend on the neurological outcome considered.

These findings have practical implications for occupational exposure to vibrating tools such as jackhammers and other construction equipment. Risk assessment should consider vibration frequency, ambient temperature, and wrist posture in addition to vibration magnitude. The different frequency-dependent responses of MNCV and tactile sensory threshold also indicate that combining electrophysiological and sensory assessments may provide more comprehensive information about neurological responses to HAV [7, 9, 27].

Several limitations should be considered. Exposure was limited to 30 minutes per scenario, and the findings cannot be directly extrapolated to chronic occupational exposure. The controlled laboratory setting does not fully reproduce workplace conditions, including variations in grip force, vibration direction, and cumulative exposure. In addition, vibration transmissibility, grip force, and local tissue temperature were not directly measured, and only tactile sensory threshold and median motor nerve conduction velocity were assessed. Finally, the inclusion of male construction workers may limit generalizability. Future longitudinal and field-based studies should incorporate sensory, electrophysiological, vascular, and functional outcomes.

Overall, the findings indicate that hand–arm vibration produces distinct neuro-sensory responses depending on exposure conditions and the outcome assessed. Frequency was the most influential factor for MNCV, whereas temperature had the greatest effect on tactile sensory threshold. The contrasting responses at 31.5 and 63 Hz highlight the importance of considering outcome-specific frequency effects, together with temperature and wrist posture, when evaluating occupational neuro-sensory risks associated with hand–arm vibration.

Conclusion

This controlled laboratory study demonstrated that 30 minutes of hand–arm vibration exposure produced measurable changes in tactile sensory threshold and median motor nerve conduction velocity in healthy construction workers. The effects differed according to the exposure factor and neurological outcome. Vibration frequency was the dominant factor affecting motor nerve conduction velocity, with 31.5 Hz producing the greatest reduction, particularly fewer than 5°C and wrist flexion. In contrast, ambient temperature had the largest effect on tactile sensory threshold, with greater increases observed under cold conditions and the most pronounced changes occurring at 63 Hz.

Wrist posture also significantly influenced both outcomes, with wrist flexion generally associated with greater neuro-sensory changes. However, no statistically significant interactions were observed among vibration frequency, ambient temperature, and wrist posture. These findings indicate that vibration frequency, ambient temperature, and wrist posture should be considered alongside vibration magnitude when assessing occupational neuro-sensory risks associated with

hand–arm vibration. Further field-based and longitudinal studies are needed to determine whether these short-term laboratory responses persist or develop during longer and more realistic occupational exposures.

Declarations

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Author Contributions

Seyed Reza Aghazadeh: Conceptualization, methodology, investigation, data collection, formal analysis, and manuscript preparation.
Mohsen Aliabadi: Supervision, methodological guidance, and critical revision of the manuscript.
Rostam Golmohammadi: Supervision, methodological guidance, and critical revision of the manuscript.
Maryam Farhadian: Statistical consultation and critical revision of the manuscript.
All authors: Reviewed and approved the final version of the manuscript.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Declaration of Conflicting Interests

The authors declare that there are no conflicts of interest regarding the publication of this article.

Ethical Approval

The study protocol was approved by the Ethics Committee of Hamadan University of Medical Sciences (Approval No. IR.UMSHA.REC.1402.140).

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Figures



Figure 1

Hand–arm vibration simulator and its placement inside the climate-controlled chamber.

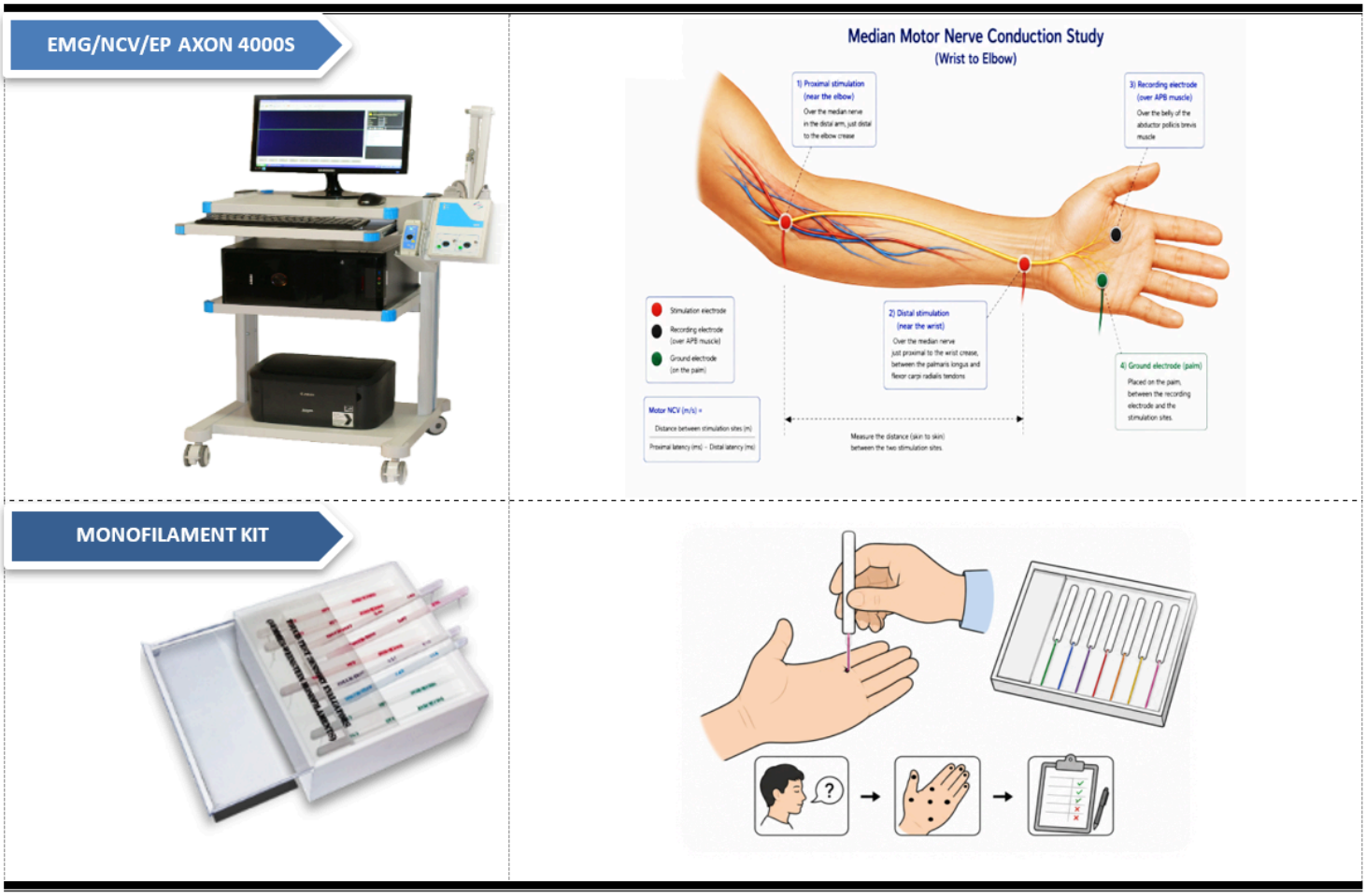


Figure 2

Equipment and procedures used for neuro-sensory assessment, including median nerve motor conduction testing and monofilament-based tactile sensory testing.



Figure 3

Change in Monofilament Sensory Threshold and Motor Nerve Conduction Velocity across Experimental Scenarios