Nerve Function Impairment After Acute Vibration Exposure

Anton Löfgren, BSc, Per Vihlborg, MD, Louise Fornander, PhD, Ing-Liss Bryngelsson, BSc, and Pål Graff, PhD

Objective: This study was to investigate the acute effects of hand-arm vibrations on the nerve functions of the hands, and the impact of the grip force applied to the vibrating tool during exposure. **Methods:** Grip strength and perception of vibration, touch, and temperature were evaluated using quantitative sensory testing (QST) before and after vibration exposure in 21 occupationally unexposed individuals. The procedure was performed twice, with a higher grip force being applied during exposure on the second occasion. **Results:** Vibration perception was significantly impaired after both exposures. Grip strength, perception of touch, and temperature were only significantly affected after the high grip force exposure. **Conclusions:** Exposure to hand-arm vibrations has acute effects on hand nerve function that are sensitive to the grip force applied during exposure.

Keywords: acute effects, grip force, hand-arm vibration, quantitative sensory testing

Learning Objectives

- Become familiar with previous findings on the effects of acute and chronic exposure to vibration on nerve functions in the hands.
- Summarize the new findings on the acute effects of hand-arm vibration on quantitative sensory testing (QST) measurements.
- Discuss the impact of grip force applied during vibration on the hand nerve functions studied.

Prolonged exposure to hand-arm vibrations through work with vibrating tools can cause permanent injury to the nervous, vascular, and musculoskeletal systems.[1,2] The symptoms of these injuries are collectively referred to as hand-arm vibration syndrome (HAVS)[3,4] and/or carpal tunnel syndrome.[5]

In Sweden, occupational exposure to hand-arm vibration is strictly regulated by the Swedish work environment authority, based on an european union directive designed to protect workers against vibration-related health risks.[6,7] Despite this, vibration exposure remains a common cause of work-related disease, especially among men.[8] However, there is an increased number of women working with handheld vibration. Women often report neurological symptoms compare to vascular symptoms. There seems to be no sex difference in the absorption of hand-arm vibration but women reported more difficulty and discomfort performing task with vibrating tools influenced by handle size of the tool and grip strength.[9,10] Current regulations state that workers should be offered a medical examination if their daily vibration exposure, referred to as the $A(8)$ value, exceeds $2.5\,m/s^2$. If the daily limit of $5\,m/s^2$ is exceeded, immediate action must be taken in the workplace.[6,11]

Quantitative sensory testing (QST) is a standardized test that is commonly performed on suspected HAVS patients in occupational medical clinics.[12,13]

While many studies have been conducted on HAVS, systematic literature reviews have concluded that the associated exposure–response relationships are not fully understood, and suggest that health risks may occur even at vibration levels below current exposure limits.[1,14,15]

In addition to the risk of permanent injury, transient symptoms, such as numbness, tingling, and loss of sensation in the hands commonly occur during and after exposure. These symptoms usually disappear within an hour.[1,16,17] Limited knowledge on the underlying pathophysiological mechanisms of the acute effects on hand nerve function after vibration exposure is at present not available. A better understanding of these effects could for instance improve the prevention of vibration health risks.

The nerve functions of the hands are complex. Four types of mechanoreceptors mediate the detection of touch, pressure, and vibration: two slow-adapting types (SAI and SAII) and two fast-adapting types (FAI and FAII). The SAI receptors, which are associated with Merkel discs, detect surface topography, while the FAII receptors, which are associated with Pacinian corpuscles, are the most sensitive to vibration.[18,19] Thermal sensations are detected by cold and warmth receptors, and transmitted by myelinated Aδ-fibers and unmyelinated C-fibers, respectively.[20,21]

The acute effects of vibration exposure on hand nerve function can include shifts in thermal perception thresholds and changes in tactile acuity.[22–24] Additionally, several studies have demonstrated acute changes in vibration perception thresholds[16,25,26] following exposure to hand-arm vibration, and one also found an impact on forearm muscle activity.[26] It has been suggested that the grip force applied during vibration exposure has an independent effect on the temporary threshold shift of vibratory sensation, and on finger blood flow.[27,28] However, other studies revealed no acute effects. For example, a study on truck drivers found no statistically significant changes in grip strength or touch sensation threshold after hand-arm vibration exposure.[29]

AIM

The aim of this study was to investigate the acute effects of hand-arm vibrations on the nerve functions of the hands, and the

From the School of Medical Sciences (Mr Löfgren); Department of Occupational and Environmental Medicine, Faculty of Medicine and Health (Mr Vihlborg, Ms Louise Fornander, Ms Bryngelsson), Örebro University, Örebro, Sweden; National Institute of Occupational Health (STAMI), Oslo, Norway (Mr Graff).

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Clinical significance: The clinical significance of this paper is the finding that grip force together with vibration exposure has acute effects on hand nerve function, these effects depend on the grip force applied during exposure. This indicates that grip force during vibration exposure should be considered when assessing factors for neurosensory symptoms.

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Address correspondence to: Per Vihlborg, MD, Department of Occupational and Environmental Medicine, Örebro University Hospital, SE-701 85 Örebro, Sweden (per.vihlborg@regionorebrolan.se).

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impact of the grip force applied to the vibrating tool during exposure. The study also aimed to evaluate the test-retest reliability of the QST for occupationally unexposed individuals.

MATERIAL AND METHODS

Before the start of the study, 21 individuals not occupationally exposed to hand-arm vibrations were recruited from the Department of Occupational and Environmental Medicine, Örebro University Hospital. They were given full information about the study and their free consent was obtained. To be included, the study participants had to be neurologically and rheumatically healthy with no previous vibration-induced injuries.

All study participants underwent the following steps twice, with 1 to 2 weeks between each study occasion: 1. QST. 2. Vibration exposure. 3. Another QST directly after exposure.

The QSTs were executed according to the manual (see supplement file, http://links.lww.com/JOM/A670) used for patient examinations at the Department of Occupational and Environmental Medicine, Örebro University Hospital. All examinations were performed by the same examiner.

The QST includes tests of vibration perception, touch perception, grip strength, and temperature perception. The tests were done in the order specified above, and perception tests were done on digits II and V (the index and little finger, respectively).[30] In addition, the fingertip temperature was measured. Signs of Raynaud phenomenon and neurosensory symptoms before and after vibration exposure were recorded according to the Stockholm workshop scale.[3,31] Only the dominant hand was studied.

Vibration perception was tested using a VibroSense Meter (VibroSense Dynamatics AB, Sweden), determining the study participants' sensory index (SI) values based on vibration perception thresholds for frequencies of 8, 16, 32, 64, 125, 250, and 500 Hz. Touch perception was tested using monofilaments of five different gauges (0.07, 0.04, 2.0, 4.0, 300 g); the lowest tensile strength perceptible by each participant was recorded.

Three different types of grip strength were tested: whole hand grip strength using a Jamar Hand Dynamometer (Sammons Preston, New York), and pinch and key grip strengths using a Pinch Gauge (B&L Engineering, New York). Each participant made three attempts for each grip, and the mean was calculated for each one. Finally, temperature perception was tested using temperature rolls (Somedic, Sweden) at 25 °C and 40 °C. These were alternately applied on the distal phalanx and rolled proximally along the finger until the person could determine its temperature correctly; a correct determination was recorded as a positive response. The total number of negative responses was then calculated.

Vibration exposure was achieved using a COTECH Polishing Machine, 120 W (Clas Ohlson, Sweden). The study participants were instructed to hold it with a low grip force during the first exposure and with a high grip force during the second exposure. Each exposure lasted for at most 15 minutes, or until an $A(8)$ value (8-hour "energy-equivalent" frequency-weighted acceleration) of 5 m/s^2 was reached, which is the maximum permitted daily occupational hand-arm vibration exposure in Sweden.[6]

During vibration exposure, grip force was recorded using a SV 105BF Triaxial Hand-Arm Accelerometer (Svantek, Poland) attached to the participant's dominant hand. The vibrations were recorded using a SV 150 Hand-arm triaxial accelerometer (Svantek, Poland), which measures acceleration in three directions simultaneously. It was fixed to the handle of the polishing machine, next to the dominant hand. These accelerometers were connected to a SV 106A Human Vibration Meter & Analyser (Svantek, Poland) that processed the data. The vibration exposure was frequency-weighted according to ISO 5349-1:2001.[32] The software used for analysis was SvanPC++ version 3.3.8 (Svantek, Poland).

Ethical Considerations

The vibration exposure in our study was short and could be presumed not to cause the participants any permanent harm. Furthermore, QST examinations are non-invasive and not known to cause any discomfort. None of the study participants had any personal interest in the work aside from their professional interest as employees of an occupational medicine clinic. The project was approved by the Uppsala ethical board (reference number 2019–01022) approved the project.

Statistical Analysis

Descriptive statistics were initially computed based on the data gathered on the study participants. The VibroSense and grip strength results were normally distributed, but the fingertip temperatures and the results of the temperature roll and monofilament tests were not. Therefore, different comparative statistical tests had to be used for the two categories of data. Paired t tests were used to compare the QST results for vibration perception and grip strength before and after vibration exposure, and between the two pre-exposure tests for each study participant. The Wilcoxon signed-rank test was used to compare fingertip temperature measurements and the results of the temperature roll and monofilament tests.

In addition, mixed model analyses were conducted for the vibration perception, grip strength, and fingertip temperature measurements, making it possible to adjust the results for sex, age, vibration dose, and grip force (see Fig. 1).

In this analysis, the fingertip temperature data were log-transformed because of their skewed distribution. For the temperature roll and monofilament results, a logistic regression was performed to adjust for the same variables.

Formula for the mixed model analysis:

Dependent variable* = ßo + ß1Time + ß2Sex + ß3tight_loose + ß4Vibration dose + ß5Grip force + ß5Age + ei

ßo = Intercept, a constant that is the same for all participants.

ß1, = Time: before, after

ß2 =Sex: Male, female

ß3 = Parameter indicating whether the participant had a loose or tight grip.

ß4 = Vibration dose, divided into classes: <=2.04, 2.05-2.89, 2.90+ ß5 = Grip force, divided into classes: <=41.51, 41.52-86.87, 86.88+ ß6 = Age, divided into classes: <=41, 42-54, 55+

ei = measurement error (residual)

Dependent variables: vibration perception on digits II and V, LN fingertip temperature for digits II and V, whole hand grip strength, pinch grip strength, and key grip strength

FIGURE 1. Formula for the mixed model analysis.

IBM SPSS (IBM, North Castle, NY) Statistics 25 was used for all statistical analyses. Two-sided P values of <0.05 were considered statistically significant.

RESULTS

The study group originally consisted of 21 individuals with a mean age of 48 years, of whom 7 were men and 14 were women. Nineteen of the participants were right-handed and two were regular nicotine users when the study was conducted (one smoker, one snuffer). Baseline characteristics of the participants are shown in Table 1.

All study participants underwent the first vibration exposure and series of QST examinations. Before the second study occasion, one participant was excluded from the study because of unexpected swelling of the fingers after the first exposure. As a result, only 20 participants underwent the second exposure.

Because of technical difficulties, the mean $A(8)$ vibration dose was 3.6 m/s^2 on the first exposure but only 2.0 m/s^2 on the second. The vibration level was reduced after 12 study participants had undergone their first exposure.

The daily A(8) limit of 5 m/s^2 was reached during three of the vibration exposures. This limit was not reached in the other 38 exposures, which therefore went on for the maximum time of 15 minutes.

The mean grip force during the first vibration exposure was 41 N, while that for the second exposure was 93 N. Data on the vibration exposures and the associated grip force levels are presented in Table 2.

On both study occasions, all participants experienced transient neurosensory symptoms after vibration exposure. Based on their severity, the symptoms were assigned scores of 1SN ($n = 39$) or 2SN ($n = 2$) on the Stockholm Workshop Scale (see appendix).

The QST results are presented in Tables 3 and 4. Significant reductions in the sensory index, indicating reduced vibration perception, were observed after both exposures. The participants' measured grip strengths did not change significantly after the first exposure. However, reductions in both whole hand grip strength and key grip strength were observed after the second exposure. Touch perception was significantly improved for digit V but not for digit II after the first exposure and for both fingers after the second exposure. Temperature perception was significantly improved after the second exposure but not after the first.

The participants' median fingertip temperatures rose from 28.8 °C to 29.5 °C for digit II and from 29.9 °C to 31.5 °C for digit V ($P = 0.04$) after the first vibration exposure. After the second exposure, the median temperatures of digits II and V rose from 29.2 °C to 30.1 °C and from 32.0 °C to 33.3 °C ($P = 0.01$), respectively.

The pre-exposure QST results for the two study occasions revealed no statistically significant differences in vibration perception, touch perception, whole hand grip strength, or temperature perception. However, there were significant differences in pinch- and key-grip strengths ($P = 0.02$ and $P = 0.01$, respectively).

The differences between the VibroSense measurements acquired before and after vibration exposure remained statistically significant after adjusting for sex, age, vibration dose, and grip force, as did the differences in fingertip temperature on digit V. The estimated differences are shown in Table 5.

The analysis also showed that the differences between the VibroSense results acquired before and after vibration exposure did not differ significantly between men and women for either digit II or digit V.

The logistic regression revealed that there were significantly more negative temperature roll responses (indicating poor temperature perception) before vibration exposure than afterwards (OR = 3.46; 95% CI 1.25 to 9.62), and that women had fewer negative responses than men (OR = 0.30; 95% CI 0.096 to 0.96). It also showed that the diameter of the thinnest detectable monofilament increased significantly after exposure on digit II (OR = 0.23; 95% CI 0.057 to 0.91) but not for digit V (OR = 0.32; 95% CI 0.098 to 1.0), and that the oldest study participants (more than or equal to 55 years) had significantly worse monofilament results for digit II than the younger participants (OR = 0.13; 95% CI 0.020 to 0.87).

TABLE 1. Baseline Characteristics of the Study Participants

		N	%	Mean	Median	Min–Max
Sex	Male	7	33			
	Female	14	67			
	All	21	100	48	50	29–64
Age groups	<35	2	10			
	36–50	9	43			
	>51	10	48			
Dominant hand	Right	19	90			
	Left	2	10			
Smoking habits	Non-smoker	20	95			
	Smoker	1	5			
Snuff habits	Non-snuff user	20	95			
	Snuff user	1	5			

TABLE 2. Vibration and Grip Force Exposure Data

		N	Mean	Median	Min–Max
Vibration dose A(8), m/s^2	First exposure	21	3.6	3.9	1.7–5.0
	Second exposure	20	2.0	2.0	1.8–2.4
Grip force during exposure, *n*	First exposure	21	41	39	11–85
	Second exposure	19	93	93	26–139

TABLE 3. QST Results for Grip Strength and Vibration Perception Before and After Vibration Exposure on Both Study Occasions

Test	Mean	*N*	Mean Difference	95% CI Lower	95% CI Upper	*P*-Value
Low grip force exposure						
Whole hand grip before, kg	37.58	21				
Whole hand grip after, kg	37.13	21	0.46	−0.75	1.66	0.44
Pinch grip before, kg	8.56	21				
Pinch grip after, kg	8.55	21	0.02	−0.26	0.29	0.91
Key grip before, kg	8.53	21				
Key grip after, kg	8.39	21	0.14	−0.12	0.41	0.27
Vibration perception before digit II (SI)	1.06	21				
Vibration perception after digit II (SI)	0.88	21	0.18	0.13	0.23	<0.0001
Vibration perception before digit V (SI)	1.05	21				
Vibration perception after digit V (SI)	0.87	21	0.18	0.12	0.24	<0.0001
High grip force exposure						
Whole hand grip before, kg	38.55	20				
Whole hand grip after, kg	37.69	20	0.86	0.01	1.70	0.05
Pinch grip before, kg	9.13	20				
Pinch grip after, kg	8.94	20	0.19	0.0	0.38	0.05
Key grip before, kg	9.07	20				
Key grip after, kg	8.62	20	0.44	0.20	0.67	<0.001
Vibration perception before digit II (SI)	1.08	20				
Vibration perception after digit II (SI)	0.88	20	0.20	0.13	0.27	<0.0001
Vibration perception before digit V (SI)	1.06	20				
Vibration perception after digit V (SI)	0.91	20	0.15	0.07	0.23	<0.001

DISCUSSION

The aim of this study was to investigate the acute effects of hand-arm vibrations on the nerve function of the hands using quantitative sensory testing. An additional objective was to determine the impact of the grip force applied during exposure and the test-retest reliability of pre-exposure QST results among occupationally unexposed individuals.

The results showed that vibration had an acute effect on hand nerve function and that different parts of the QST were affected differently depending on grip force. The two exposures had very similar effects on vibration perception, but grip strength, temperature perception, and touch perception were only significantly affected by the high grip force exposure.

Previous studies on the neurophysiological responses of mechanoreceptive afferents to vibration exposure showed that vibration causes temporary losses in the excitability of tactile units.[19] This may be the mechanism responsible for the decreased vibration perception seen after exposure in this work.

Increasing the applied grip force during vibration exposure reduced post-exposure grip strength. Two mechanisms may contribute to this outcome. First, it could just be the effect of muscle fatigue after gripping the handle hard.[33] Alternatively, the increased grip force may have caused vibrations to be transmitted higher up the hand-arm system,[34] leading to greater muscle activation in the forearm during the vibration exposure.[26,35]

Both vibration and grip force have been shown to reduce finger blood flow.[28] The reduced blood flow caused by increasing the applied grip force may impair nerve function and thereby reduce touch perception. Alternatively, a high grip force may increase the transmission of vibration to the hand,[36] leading to a greater loss of excitability among the tactile units that detect touch.[19] The grip force may also affect the SAI receptors that detect surface

TABLE 4. QST Results for Monofilament and Temperature Roll Tests Before and After Vibration Exposure on Both Study Occasions

Test	*N*	Min	Max	Mean	Standard Deviation	Variance	*P*-Value
Low grip force exposure							
Monofilaments before digit II, g	21	0.07	2	0.55	0.62	0.39	
Monofilaments after digit II, g	21	0.07	4	0.31	0.15	0.02	0.29
Monofilaments before digit V, g	21	0.07	0.4	0.83	0.99	0.98	
Monofilaments after digit V, g	21	0.07	2	0.66	0.68	0.46	0.02
Temperature rolls, amount of negative answers before	21	0	3	1.24	1.14	1.30	
Temperature rolls, amount of negative answers after	21	0	2	0.57	0.75	0.56	0.05
High grip force exposure							
Monofilaments before digit II, g	20	0.07	2	0.46	0.55	0.30	
Monofilaments after digit II, g	20	0.07	2	0.28	0.16	0.03	0.02
Monofilaments before digit V, g	20	0.07	0.4	0.54	0.50	0.25	
Monofilaments after digit V, g	20	0.07	0.4	0.35	0.12	0.02	0.04
Temperature rolls, amount of negative answers before	20	0	5	1.10	1.65	2.73	
Temperature rolls, amount of negative answers after	20	0	2	0.25	0.64	0.41	0.03

TABLE 5. Differences in Fingertip Temperature and QST Results for Grip Strength and Vibration Perception, Adjusted for Sex, Age, Vibration Dose, and Grip Force During Exposure

Variable		Estimate	95% CI Lower	95% CI Upper	*P*-Value
Vibration perception digit II (SI)	Before	0.19	0.14	0.24	<0.001
	After	0*			
Vibration perception digit V (SI)	Before	0.17	0.12	0.21	<0.001
	After	0			
Whole hand grip, kg	Before	0.63	−0.20	1.45	0.13
	After	0			
Pinch grip, kg	Before	0.09	−0.11	0.29	0.39
	After	0			
Key grip, kg	Before	0.27	0.08	0.46	0.01
	After	0			
Temperature digit II, °C†	Before	−0.03	−0.07	0.01	0.12
	After	0			
Temperature digit V, °C†	Before	−0.06	−0.10	−0.02	0.004
	After	0			

*Reference.
†Log-transformed variable.

topography and/or the FAI receptors,[16] leading to adverse effects on touch perception as revealed by the monofilament test.

Unlike the other studied aspects of nerve function, temperature perception increased after vibration exposure with a high applied grip force. The detection of thermal stimuli requires a change in skin temperature.[21] The effect on temperature perception observed in this study might thus be explained by the increased fingertip temperature seen after vibration exposure; this increase was particularly pronounced after the second exposure, and would have made it easier to detect the low temperature roll but may not have been sufficient to make detection of the warm roll harder. Thermoreceptors also become more sensitive when exposed to sudden increases in temperature, which is another possible explanation for the increased response.[13]

The QST results obtained before performing the two vibration exposures were compared to assess the temporal variation in the QST results of healthy individuals not occupationally exposed to hand-arm vibrations. The pre-exposure results for the two test occasions were generally in good agreement other than those for pinch grip and key grip strength. In keeping with this outcome, a previous study that examined the test-retest reliability of various QST tests concluded that they were highly reliable for both vibration-exposed workers and unexposed referents.[37]

The only variables for which significant differences were observed between the two pre-exposure tests were pinch grip strength and key grip strength. This may be because the participants improved their technique by learning from the first examination. Few studies have examined the test- retest reliability of these two tests specifically, but one study on 27 college women indicated these tests to have high reliability, especially when the mean of three trials was used,[38] as it was in this work.

This study has some limitations that should be taken into account. First, the study group was relatively small and all parts of the QST examination were done in the same order every time. It may be that different results would have been obtained if the order was different because the recovery time after vibration exposure varies among mechanoreceptive afferents.[39] This could be tested by measuring the effect of vibration on a single mode of perception at different times after exposure, as has been done for thermal perception.[23]

The mechanism of neuropathy caused by handheld vibrating tools is not fully understood; in particular, it is not clear how factors such as the grip force affect vibration-related injury. We have shown that the acute responses assessed by different neurosensory tests depend on the grip force in different ways. If this is also true for the chronic effects of vibration, it may be that altering the grip force could change the effects of vibration on different nerve endings in the hand

In conclusion, the results presented here indicate that exposure to hand-arm vibration has acute effects on hand nerve function and that these effects depend on the grip force applied during exposure. In addition, quantitative sensory testing was shown to be a reliable method for assessing acute responses to hand-arm vibration in occupationally unexposed individuals.

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