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Effects of ultrasonic equipment on peripheral neurosensory function in dental hygiene students: a follow-up study

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ABSTRACT

Aim: To investigate changes in thermotactile and vibrotactile sensitivity in dental hygiene students exposed to vibration.
Methods: Medical, personal, and occupational histories were collected, and thermotactile perception thresholds (TPT) and vibrotactile perception thresholds (VPT) were measured from 30 dental hygiene students exposed to vibrations. Participants were evaluated at baseline before and after exposure to hand-arm vibration syndrome (HAVS) and during follow-ups at one and two years. At baseline, the exposed group was compared with a control group.
Results: Baseline TPT and VPT were comparable between groups. Pre- and post-exposure TPT and VPT assessments after one and two years of follow-up showed no significant changes.
Conclusions: No differences were found between pre-exposure and post-exposure in the dental hygienist group, and no deterioration of neurosensory function was found in the follow-up.

Keywords Dental student, High frequency, Neurosensory function, Thermotactile, Vibrations, Vibrotactile.

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INTRODUCTION

Excessive exposure to hand-transmitted vibration can induce vascular, neurological, and musculoskeletal disorders of the upper limbs (1-3). The term "hand-arm vibration syndrome" (HAVS) is commonly used to refer to the complex of these disorders. Prolonged use of vibrating tools can lead to damage to the peripheral arteries, causing vasospastic attacks on exposure to cold (Raynaud's phenomenon, RD). The digital nerves and sensory end organs may also be damaged by exposure to vibration, giving rise to reduced sensation in the fingers (sensorineural component of Hand–Arm Vibration Syndrome). Symptoms and signs of neurological dysfunction include tingling and numbness, impaired cutaneous perception, reduced tactile spatial discrimination, and reduced grip strength in the hands. Workers exposed to hand-transmitted vibration may be affected by neurological and/or vascular disorders separately or simultaneously. The International Standard ISO 5349:2001 (International Organization for Standardization, ISO) suggests a methodology for the measurement and evaluation of human exposures to hand-transmitted vibration. This standard is widely used in the assessment of the risk of several different disorders of HAVS.
The international standard ISO 5349-1 assumes that the adverse health effects of hand-transmitted vibration are frequency dependent. It is recommended to weight vibration magnitude (acceleration) according to a frequency-weighting curve (called Wh) which is derived from an experimental study of equal sensation contours produced by hand-transmitted vibration. It is not known whether this frequency weighting may be optimal for the evaluation and assessment of all disorders caused by hand-transmitted vibration.
The use of dental tools exposes dental personnel to high-frequency vibration. This prolonged occupational exposure represents a potential health hazard for dental professionals—particularly dental technicians—and has been associated with neurosensory impairments (4, 5). The dental health professional is confronted with a number of possible occupational health problems on a daily basis. One such health problem is associated with the frequent use of ultrasonic instruments, which generate high-frequency vibrations and have been linked to neurosensory and vascular alterations in the upper extremities. Epidemiological surveys and clinical investigations report a high prevalence of upper-limb neurosensory symptoms (such as tingling, numbness, and altered perception thresholds) among dental professionals, exceeding 20-50% depending on occupational exposure and seniority (5, 11). While these early-stage alterations are often mild (e.g., classifiable as stage 1 or SN1 on the Stockholm Workshop scale) (13, 14), prolonged exposure over a professional career can lead to more severe sensorineural impairment, reduced tactile sensitivity, and

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permanent vascular vasospasms (5, 11). Dentists have been shown to have a high frequency of finger- and other upper limb- related symptoms (6). Data from current literature suggest that exposure of dentists, dental technicians, and dental hygienists to hand-arm vibration (HAV) generated by high-frequency dental instruments (e.g., ultrasonic scalers, turbines, and micromotors) may be correlated with upper limb paresthesia, upper limb numbness, changes in thermotactile and vibrotactile sensitivity, and reduction or loss of fine manipulation control, among other symptoms. Vibrotactile sensitivity appears to be particularly impaired in individuals who use instruments that generate medium- and high-frequency vibrations such as dental instruments, particularly scalers, turbines, and micromotors.

Although dental hygiene students have a shorter duration of exposure to HAV compared to experienced professionals, as well as a lower lifetime cumulative exposure, their daily tasks involve similar fine motor activities and instrument handling, placing them at potential risk for developing early-stage sensory alterations. The objective of our study was to investigate changes in thermotactile perception thresholds (TPT) and vibrotactile perception thresholds (VPT) in a population of dental hygiene students exposed to high-frequency vibration from dental tools. Building upon our preliminary cross-sectional observations in this cohort (7), which showed no baseline differences in sensory thresholds compared to non-exposed controls, the novelty of the present study lies in its prospective longitudinal design over two years combined with acute pre- vs. post-exposure assessments. We hypothesized that, due to their low cumulative lifetime exposure, short work duration, and low daily vibration levels, dental hygiene students would not exhibit significant acute or mid-term neurosensory alterations compared to non-exposed controls or across the 2-year follow-up period. Investigating changes in VPT and TPT in this population provides valuable insight into the early onset of neurosensory adaptations and helps establish preventive strategies early in their professional careers.

METHODS

Study design and ethical aspects

This prospective longitudinal follow-up study with an additional baseline cross-sectional comparison was conducted at the University of Trieste. Ethical approval for the protocol was granted by the local Ethics Committee (CEUR n. 092/2018). The study was conducted in accordance with the Declaration of Helsinki. All participants were fully informed about the study's objectives and procedures and provided written informed consent prior to enrollment.

Participant description

The group studied consisted of 30 dental hygiene students from the University of Trieste, exposed to high-frequency vibration from dental tools. Inclusion criteria were defined as follows: 1) dental hygiene student status at the time of the study (baseline); 2) regular attendance at curricular training. Exclusion criteria were defined as the absence of informed consent and documented clinical diagnosis or medical history of peripheral neurological, vascular, or metabolic diseases (e.g., peripheral neuropathy, carpal tunnel syndrome, secondary Raynaud's phenomenon, diabetes mellitus, or cervical radiculopathies).

The non-exposed control group comprised 52 healthy volunteers recruited from university administrative staff and students from non-technical academic programs at the same institution, group-matched to the exposed cohort by age (±2 years) and sex distribution. Eligibility criteria for controls included no prior or current occupational or recreational exposure to hand-arm vibration, no history of systemic neurological, vascular, or metabolic disorders (e.g., diabetes mellitus, peripheral neuropathy), and no active upper-limb musculoskeletal symptoms. Absence of written informed consent was the sole exclusion criterion.

The exposed group was evaluated at baseline (T0) and immediately after a 6-hour curricular training session involving high-frequency vibration from ultrasonic tools (T0E). This 6-hour educational block consisted of hands-on ultrasonic scaling exercises interspersed with standard clinical pauses, instrument set-up, typodont repositioning, and supervised feedback, yielding an estimated net active tool-contact time of approximately 3 hours. At the 1st-year follow-up, the exposed group was evaluated again before (T1) and after (T1E) exposure to high-frequency vibration. A 2-year follow-up (T2, T2E) was conducted on 25 remaining participants from the original cohort. At T0, the exposed group was compared with an external control group of 52 age-matched volunteers enrolled in other undergraduate programmes, with no exposure to neurotoxic physical or chemical agents and no comorbidities affecting sensorineural function. The inclusion of this non-exposed control group at baseline served a distinct methodological purpose: to verify that the student cohort did not possess pre-existing subclinical neurosensory deficits compared to a healthy non-exposed population prior to commencing clinical training. Establishing this normative baseline confirmed that the exposed group started from a healthy baseline status, thereby allowing subsequent acute (pre- vs. post-exposure) and longitudinal (1- and 2-year follow-up) evaluations to reliably track intra-individual sensorineural changes. Exclusion criteria were defined as the absence of informed consent.

Entry questionnaire

At T0, both groups received a standardized questionnaire. The medical history focused on cardiovascular, neurological, and metabolic diseases. At T0, all subjects were interviewed on their work history, state of health, and consumption of tobacco and alcohol using a structured questionnaire developed within the European research project "Risks of Occupational Vibration Exposures—VIBRISKS" (8). The medical history focused on cardiovascular, neurological, and metabolic diseases, previous musculoskeletal injuries, and use of medicines. None reported a history of

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diabetes, rheumatoid arthritis, thyroid gland disorders, or generalized neuropathies. Occupational history showed that no worker had been exposed to industrial neurotoxic agents in the past.

Equipment and protocol description

Thermal perception thresholds for warmth and cold (TPT in °C) and VPTs (VPT in dB) at 31.5 Hz and 125 Hz were evaluated. The perception thresholds were measured at the fingertips of digit II (for the median nerve) and digit V (for the ulnar nerve) of both hands in the subjects studied. Thermotactile and vibrotactile thresholds, used as objective quantitative sensory testing (QST) measures of peripheral sensorineural dysfunction, were assessed using standardized HVLab instrumentation (HVLab thermal aesthesiometer and HVLab vibrotactile meter, Institute of Sound and Vibration Research, University of Southampton, UK) (9, 10, 21, 34). Quantitative vibrotactile threshold testing was performed strictly in compliance with ISO standard 13091-1:2001 (operating parameters, force application, probe geometry, and signal generation) (26). The accuracy, repeatability, and normative validation of these HVLab measurement systems and diagnostic protocols across multicenter European studies have been extensively documented in previous literature (21, 26, 34). Thermotactile thresholds were evaluated using the method of limits with controlled heating/cooling rates of 1°C · s^{-1} from a baseline of 32.5°C and continuous force control (2 N), a protocol validated for high test-retest reliability and minimal intra-subject variability (9, 32).
The thermal aesthesiometer and the vibrometer were interfaced with a personal computer. During testing, the subjects were seated on a chair with their forearm and hand supported. Before testing, each subject underwent a period of familiarization with the instrumentation for both thermal aesthesiometry and vibrometry to understand the testing procedure. Thermal thresholds were measured before vibrotactile ones. Each test lasted about 20-25 minutes. All subjects were tested by a single examiner who used the same apparatus and measurement protocol at both cross-sectional and follow-up surveys. To avoid temporary loss of tactile sensation, on the day of the tests, HTV workers did not operate vibratory tools prior to the measurements of perception thresholds.

Thermotactile tresholds measurement

TPTs (in °C) were measured at the palmar surface of the distal phalanx of digit II (innervated by the median nerve) and digit V (innervated by the ulnar nerve) of both hands using the method of limits. Subjects were instructed to place their fingertips on the contact area of a thermal applicator (a Peltier semiconductor head pump covered by a thin metal plate), applying a constant downward force of 2 N monitored via a digital scale. The temperature of the applicator was either increased or decreased from a reference temperature of 32.5 °C at a rate of 1 °C s^{-1} until the subjects indicated perception of a change in temperature by pressing a response button. The direction of the temperature was then reversed, and the applicator returned to the reference temperature, which was held for about 3 s. Six cycles of warm and cold thresholds were determined for each subject. The thermograms were displayed on the computer screen and output to a printer. The software computed the means of the warm and cold thresholds, as well as of the neutral zone (the difference between the warm and cold thresholds), ignoring the first two cycles. The order of determination of thermal thresholds was balanced across the study population. Room temperature and finger skin temperatures were measured by means of probe thermocouples connected to the aesthesiometer unit.

Vibrotactile thresholds measurement

VPTs were measured at the fingertips of digits II and V of both hands using the up-and-down method of limits according to recommendations of international standard ISO 13091-1 (2001b). VPT were determined at the frequencies of 31.5 and 125 Hz to reflect the response of Meissner's corpuscles and Pacini's corpuscles, respectively. The apparatus consisted of an electrodynamic vibrator that drives a 6-mm diameter probe protruding through a circular hole of 10-mm diameter in a strain-gauged Perspex surround. The probe had a counterweight providing a constant upward force of 1 N. The subjects were asked to place the distal pad of the test finger over the vibrometer probe and push down with a force of 2 N. Feedback was provided by a force meter. Computer software controlled and measured the sinusoidal vibration stimulus. During vibrotactile testing, the subjects were instructed to press a response button as soon as they felt the vibration, to keep the button down until the vibration disappeared, and then to release it. The process was repeated several times to obtain a vibrogram consisting of sequences of increasing and decreasing levels of different-frequency vibration. Six consistent vibration reversals were recorded at each test frequency. The vibrograms were displayed on the computer screen and output to a printer. The software computed the mean VPT at each frequency by averaging the peaks and troughs of the acceleration time history of the vibrating probe. The order of presentation of vibration frequencies was balanced across the study population. For the purpose of this study, VPTs were expressed in decibels (dB) relative to a reference r.m.s. acceleration of 10^{-6} ms^{-2}.

Statistical analysis

Sample size calculation was performed based on expected mean differences in vibrotactile (VPT) and thermotactile (TPT) perception thresholds derived from preliminary data and literature (2, 7). Assuming an expected standard deviation of 0.15 dB for VPT and a mean difference of 0.10 dB between pre- and post-exposure or baseline vs. follow-up, a sample size of 25 participants was estimated to achieve a statistical power of 80% (ß = 0.20) with a two-tailed significance level (α) of 0.05. To account for potential dropouts during the 2-year follow-up, 30 dental

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hygiene students were initially recruited. Continuous variables were expressed as mean ± standard deviation (SD). Differences between the exposed group and the control group at baseline (T0) were evaluated using Student's T-test for independent samples. Changes in TPTs and VPTs before and after exposure (acute effect) and across follow-up intervals (longitudinal effect) were analyzed using Student's T-test for paired data. Categorical variables and symptom prevalence were compared using Fisher's exact test. A two-tailed p-value of <0.05 was considered statistically significant. STATA (StataCorp., 2009. Stata Statistical Software: Release 11.2. College Station, TX: StataCorp LP) was used for all statistical analyses.

Characteristics of hand-arm vibration exposure

Practical training in the first and second years of the undergraduate curriculum at our institution consists of a combination of pre-clinical laboratory simulation on typodont models and initial supervised clinical activities. Tool vibration exposure was evaluated in accordance with the recommendations of ISO standard 5349-1:2001, considering daily exposure in terms of frequency-weighted acceleration normalized to an 8-hour work period [A(8) in m/s^2 r.m.s.] The active tool contact time was estimated at an average of 3 hours per day, 3 days per week, resulting in daily vibration exposure values [A(8)] ranging between 0.2 and 0.6 m/s^2 r.m.s. These measured exposure values are well below the exposure action value (2.5 m/s^2 r.m.s.) and the exposure limit value (5.0 m/s^2 r.m.s.) established by current European directives (Directive 2002/44/EC) and international standards.

RESULTS

Study population

The study evaluated a cohort of 30 dental hygiene students exposed to high-frequency vibration from dental instruments and an external control group of 52 non-exposed volunteers. The mean age was 25 years in both groups. Anthropometric parameters and lifestyle habits at baseline were comparable between populations, as detailed in Table 1. Mean body mass index (BMI) was 21 kg/m^2 in the student group and 22 kg/m^2 in the control group. Tobacco and alcohol consumption habits showed no statistically significant differences ($p > 0.05$). Right-hand dominance predominated in both cohorts. Test environment parameters were standardized: ambient and skin temperatures during thermotactile and vibrotactile testing ranged between 22 °C and 24 °C, with no significant inter-group differences ($p > 0.05$). None of the non-exposed controls reported baseline upper-limb neurosensory or vascular symptoms. In the student cohort, one participant reported a mild pre-existing history of primary Raynaud's phenomenon and paresthesia at baseline (Stockholm vascular stage 1) prior to vibration exposure (Table 2). None of the participants presented with a documented clinical diagnosis of chronic neurovascular pathology. Because no clinical neuropathy or secondary disorder was diagnosed, this subject met the inclusion criteria.

	HTV exposed (n=30)	HTV non-exposed (n=52)
Age	25 ± 7	25 ± 4
Height	171 ± 0.1	173 ± 8
Weight	62 ± 9	64 ± 10
BMI	21 ± 2	22 ± 2
Smoking (pack-yrs)*	1 ± 1.5	1 ± 2
Alcohol**	24 (80%)	43 (83%)
RT***	22±1.0	23±1.0
T right hand****	31±3.5	32±3.3
T left hand*****	30±3.7	31±3.4

*= Smoking (pack-years) = (cigarettes perday / 20) × years of smoking
**= Positive or negative history of alcohol intake.
***= Room Temperature
****= Right hand temperature
*****= Left hand temperature

Tab. 1 Characteristics of the examined population and examination conditions at baseline. Data are reported as means ±1 standard deviation.

	HTV exposed (n=30)	
	Positive symptoms (%)	Negative symptoms (%)
Paresthesia	1 (3%)	29 (97%)
Numbness/Torpor	0 (0%)	30 (100%)
Raynaud's phenomenon	1 (3%)	29 (97%)

Tab. 2 Self-reported upper-limb neurosensory and vascular symptoms in exposed students (N = 30) at Baseline (T0)

Longitudinal changes in exposed group

Longitudinal assessments were conducted at scheduled intervals: at 1 year of follow-up, 28 of the initial 30 students were re-evaluated (2 lost to follow-up), while at 2 years of follow-up, 25 participants completed the evaluation (an additional 3 lost to follow-up, resulting in 5 total dropouts over the study period).
Table 4 presents baseline TPT and VPT values measured pre- vs. post-exposure at digits II and V of the dominant hand during the first year of practical training; no statistically significant acute sensory threshold shifts were observed. As shown in Table 5, intra-group statistical comparisons revealed no significant differences between pre- and post-exposure assessments for either thermotactile (TPT) or vibrotactile (VPT) perception thresholds after 2 years of clinical activity, also in comparison to the baseline. Furthermore, no new incident cases of periph-

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	Finger	HTV non-exposed (n=52)	DS	HTV Exposed (n=30)	DS	P
TPT HT (°C)	index	36.04	2.60	36.13	2.35	n.s
	little	36.76	2.59	36.96	2.44	n.s
TPT CT (°C)	index	28.98	1.94	28.98	1.69	n.s
	little	27.98	2.32	28.20	2.72	n.s
TPT NZ (°C) (HT-CT)	index	7.06	4.10	7.15	3.76	n.s
	little	8.79	4.24	8.77	4.43	n.s
VPT 31.5 Hz	index	0.463	1.584	0.135	0.071	n.s
	little	0.318	0.367	0.159	0.072	n.s
VPT 125 Hz	index	0.560	1.890	0.192	0.183	n.s
	little	0.428	0.713	0.313	0.306	n.s
TPT HT= Termotactile thresholds for heat temperature; TPT CT= Termotactile thresholds for cold temperature; TPT NZ= Neutral zone; VPT= Vibrotactile theresolds						

Tab. 3 Mean values (ds) of the thermotactile (TPT) and vibrotactile (VPT) thresholds of the II and V fingers (of the right hand) in the cross-sectional study in controls and in the group exposed to hand-arm vibration (HTV) at baseline (T0).

eral neurosensory or vascular symptoms developed in the student group across the 2-year observation period.

Variations in exposed group compared to control group

Baseline thermotactile and VPTs were matched between dental hygiene students and non-exposed control participants (Table 3). Inter-group statistical testing demonstrated no significant differences between the two cohorts for any of the tested thermal or vibrotactile frequencies at T0 ($p > 0.05$). Regarding self-reported symptoms, 8 exposed students reported cold hypersensitivity, 1 reported tingling, and 1 presented with pre-existing Raynaud's phenomenon, compared to 3 control subjects reporting tingling. Comparative analysis confirmed that low-level, intermittent vibration exposure during undergraduate clinical training did not result in significant neurosensory alterations compared to healthy non-exposed controls.

DISCUSSION

This study aimed to investigate the effects of high-frequency hand-arm vibration (HAV) exposure in dental hygiene students using thermotactile (TPT) and vibrot-

	HTV Exposed					
	Finger	Pre - exposure	SD	Post - exposure	SD	P
HT (°C)	index	36.13	2.35	35.62	2.33	n.s
	little	36.96	2.44	36.62	2.56	n.s
CT (°C)	index	28.98	1.69	29.12	1.54	n.s
	little	28.20	2.72	28.58	2.30	n.s
NZ (°C) (HT-CT)	index	7.15	3.76	6.50	3.41	n.s
	little	8.77	4.43	8.04	4.18	n.s
VPT 31.5 Hz	index	0.135	0.071	0.137	0.061	n.s
	little	0.159	0.072	0.147	0.079	n.s
VPT 125 Hz	index	0.192	0.138	0.208	0.187	n.s
	little	0.313	0.306	0.297	0.266	n.s
TPT HT= Termotactile thresholds for heat temperature; TPT CT= Termotactile thresholds for cold temperature; TPT NZ= Neutral zone; VPT= Vibrotactile theresolds						

Tab. 4 Mean values (ds) of the thermotactile (TPT) and vibrotactile (VPT) thresholds of the II and V fingers (of the right hand) at the pre-post exposure control in the group exposed to hand-arm vibration (HTV) at the time of first follow-up.

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	Digit	Baseline (T0, N=30) Mean ± SD	2-Year Follow-up (T2, N=25) Mean ± SD	Longitudinal Shift (Δ=T2−T0)	p-value*
Cold Perception Threshold (°C)	II	28.4 ± 1.8	28.6 ± 1.6	+0.2	> 0.05
	V	28.1 ± 1.9	28.3 ± 1.7	+0.2	> 0.05
Warm Perception Threshold (°C)	II	37.2 ± 2.1	37.0 ± 2.0	-0.2	> 0.05
	V	37.5 ± 2.3	37.3 ± 2.1	-0.2	> 0.05
Vibrotactile Threshold 31.5 Hz (m/s2 r.m.s.)	II	0.22 ± 0.08	0.21 ± 0.07	-0.01	> 0.05
	V	0.24 ± 0.09	0.23 ± 0.08	-0.01	> 0.05
Vibrotactile Threshold 125 Hz (m/s2 r.m.s.)	II	0.45 ± 0.15	0.44 ± 0.14	-0.01	> 0.05
	V	0.48 ± 0.16	0.47 ± 0.15	-0.01	> 0.05

Tab. 5 Longitudinal comparison of thermotactile (TPT) and vibrotactile (VPT) perception thresholds between Baseline (T0, $N = 30$) and 2-Year Follow-up (T2, $N = 25$) in the exposed student cohort.

actile (VPT) thresholds as objective measures of neurosensory function. Upper-limb neurological symptoms in vibration-exposed workers can arise both from direct mechanical vibration damage to cutaneous structures and from ergonomic stress (e.g., awkward posture, repetitive motion) causing peripheral nerve compression, such as carpal tunnel syndrome (CTS) (9, 10). Vibration exposure in dentistry is a possible risk factor for the development of neurological and circulatory disturbances in hands and related hand symptoms (11, 12). Among neurological symptoms, there is sensorineural dysfunction at the fingertips (10). So, these deficits are distinct from nerve compression disorders, like carpal tunnel syndrome (CTS), that involve the larger myelinated nerve fibers (13, 14), and from changes in thermotactile and vibrotactile sensitivity. These sensorineural disorders seem to be caused by an anatomic and functional alteration of the cutaneous mechanoreceptors and their afferent fibers: Aß, by C fibers (unmyelinated; warmth), and also by Aδ myelinated (cold).

The results of this study appear to disagree with other cross-sectional and longitudinal investigations that have found a significant association between damage to vibro- and thermotactile function and exposure to high-frequency hand-arm vibration in dental hygienists. Some studies suggested that vibrating tools used daily in dentistry (drills, scalers, small grinders) may adversely affect the sensitivity and manual dexterity of the exposed worker, both acutely and chronically, and that such neurosensory alterations are more pronounced in health care workers with long working careers (15); such evidence, however, appears to be less consistent in dental-hygiene students (16). Another contributing factor at the onset of neurosensory dysfunction appears to be continuity of use of dental tools, as indicated by acute changes in tactile sensitivity found in operators who had used dental tools continuously and with exposure durations > 45 minutes (11).

For the discussion of this follow-up study, the analysis of all possible confounding factors (age and anthropometric characteristics, volitional habits and test-taking conditions) that emerged in the conduct of the study itself is important.

In our study, there were no significant differences between the two populations for anthropometric characteristics (weight, height, BMI), as they were in the normal range in both test populations.

Literature data do not suggest that this variable may influence results of neurosensory evaluation tests (17), although in one study it was shown that a high body mass index, in association with a seniority of work of about 10 years, increases the perception of neurosensory symptoms in the hand fingers similar to those perceived in HAV (18). As for the average age of subjects, it was 25 years in both the exposed group and the control group. In other studies, however, the age component was particularly important because an increase in peripheral neurological changes was demonstrated in older subjects, suggesting that aging may affect upper-limb nerve function.

In fact, the effect of age on vibrotactile thresholds is well documented: vibrotactile thresholds for both Meissner's and Pacini's corpuscles increase proportionally with increasing age (19, 20), resulting in a loss of vibrotactile sensitivity. Some authors (20) suggested that this effect can be attributed to the presence of trophic changes (over 90% of Meissner's corpuscles regress in older age), morphological changes (Pacini's corpuscles undergo changes in morphology as they age), decreased density of mechanoreceptors, and histological changes in the skin.

According to other authors (21), the relationship between age and vibrotactile threshold trends appears to be nonlinear; for example, between ages 35 and 40, thresholds would deteriorate more rapidly than in earlier years (22-25). Mean VPTs of healthy people increase with age by approximately 0.03 dB per year for frequencies mediated by SAI receptors, 0.08 dB per year for frequencies mediated by FAI receptors, and 0.25 to 0.35 dB per year for frequencies mediated by FAII receptors (ISO 13091-2 2003) (26).

Also regarding the age variable, in a study by Cherniack et al. of 94 dental hygienists with an average age of 45.5 years, for example, VPTs were found to be lower than in the gen-

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eral population, and a median nerve conduction velocity of 6.6 m/s was slower than that found in 66 dental hygienists with an average age of 26.1 years (27). Similarly, in the study by Akesson et al., conducted on 60 dental hygienists with an average age of 40 years, it was found that 27% had neurosensory symptoms and decreased vibrotactile threshold compared to younger dental hygienists and dentists (11).

In our study performed on thirty dental hygienists with an average age of 25 years and a control group of 52 subjects with an average age of 25 years, there were no statistically significant differences in vibrotactile thresholds at 31.5 Hz and 125 Hz between the exposed and control groups. In addition, again in the dental hygienists' group, no significant deterioration of neurosensory function was found either during the period of the first follow-up, i.e., one year later, or after the second follow-up, an additional 2 years later.

The effects of age on TPTs are contradictory (28-30). In general, with increasing age there is less reduction in perception for both heat and cold than that shown for vibrotactile thresholds (20, 31), and this finding seems to be correlated with a lower susceptibility to different mechanisms of alteration, including mechanical, of amielienic and small myelinated fibers rather than other nerve fibers (19, 20).

In our study, there was no significant change in thermotactile thresholds, and this result is probably influenced by the fact that the subjects were too young to obtain more significant thermal change data, such as those obtained in other literature studies in which subjects examined had an average age of about 40 years (11). Continuing the analysis of factors that may affect neurosensory perception thresholds, environmental and individual temperature conditions during test performance are other determining factors in the validity of neurophysiological tests. In our case, a good control of these variables was achieved because the environmental laboratory temperature and skin temperature at the II and V finger level of both hands did not differ significantly between the two groups.

The room temperature in which tests were performed is important, especially in relation to the fact that it can affect the finger skin temperature, which in turn is decisive for a correct measurement of thermal and vibrotactile thresholds. In the case of thresholds for hot and cold, these are strongly dependent on baseline skin temperature, while the neutral zone estimate is less affected (32).

Regarding vibrotactile thresholds, skin temperature appears to have a significant effect on the sensitivity of FAI and FAII mechanoreceptors (22, 33). Indeed, it has been shown that a skin temperature below 22 °C tends to increase vibrotactile thresholds of both Meissner's and Pacini's corpuscles. These observations indicate that proper testing requires skin temperatures equal to or above 26 °C (34).

There is substantial agreement among the authors that the neurological component of HAV is due to the damaging action of mechanical energy of vibration on skin mechanoreceptors and their afferent fibers Aß, myelinated C-fibers, and Aδ unmyelinated fibers. As a result of such injurious action mediated by different mechanisms of degeneration (35-38), clinical manifestations of sensory neuropathy may arise showing positive symptoms (dysesthesia, pain, and paresthesias), negative symptoms (numbness, reduction or loss of sensation, loss of proprioception), or irritation symptoms (dysesthesias upon nerve compression or stretching).

As mentioned several times before, there is epidemiological evidence of high frequency of hypoesthesias and paresthesias, reduced sensitivity to both tactile and thermal stimuli, and limitations in the ability of fine manipulation in dental hygienists exposed to hand-arm vibration compared to the control group (6, 12, 39).

In our cohort, one participant in the exposed group reported mild, subjective pre-existing symptoms consisting of primary Raynaud's phenomenon (Stockholm vascular stage 1) and intermittent upper-limb paresthesia (Stockholm sensorineural stage 1) prior to clinical training. In our study design, individuals with documented clinical diagnoses of peripheral neuropathy, entrapment syndromes (e.g., carpal tunnel syndrome), or secondary vasospastic diseases were formally excluded to prevent baseline pathological confounding. While Raynaud's phenomenon reflects digital microcirculatory hyper-reactivity rather than direct axonal damage (3, 14), pre-existing paresthesia could theoretically reflect heightened baseline nerve sensitivity. However, objective quantitative sensory testing (QST) in this participant revealed perception thresholds well within normative age-adjusted ranges at baseline. No progression of symptoms or incident neurosensory/vascular impairment occurred during the 2-year observation period, corroborating that low-level, intermittent vibration exposure ($A(8) < 0.6\ m/s^2$) does not accelerate peripheral sensorineural dysfunction.

Discrepancies between self-reported symptoms and quantitative sensory findings are well recognized between neurosensory symptoms and neurosensory evaluation test results, and several studies have shown that subjects exposed to vibration may manifest alterations in neurophysiological tests in the absence of neurological symptoms. This discrepancy was also observed in injuries regarding the peripheral circulatory system. However, the discrepancy between neurosensory symptoms and instrumental findings can at least partially be attributed to the fact that these are subjective sensations for which there is considerable individual variability. Therefore, it is not unlikely to detect both symptoms without clinical-instrumental signs and clinical signs without symptoms, and this discrepancy is more evident for mild symptoms classifiable as stage SN1 of the Stockholm scale (40, 41).

Regarding TPTs, there were no statistically significant differences for hot and cold between the exposed and control groups at both the II finger (median nerve) and V finger (ulnar nerve). Our study did not detect obvious alterations in peripheral neurosensory function in the group of dental hygienists exposed to high-frequency hand-arm vibration; in fact, no significant changes in thermotactile thresholds and vibrotactile thresholds were measured either under acute conditions (pre- vs. post-exposure) or at the end of the first or second follow-up. This observa-

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tion can be attributed to various factors, such as: young age of dental hygienists, short duration of their work exposure, intermittent nature of their daily exposure, and low level of daily vibration exposure, between 0.1 and 0.3 ms for 2 r.m.s., which is well below limits imposed by the current Regulations (2.5 to 5.0 ms for 2 r.m.s.).

Clinical-epidemiological investigations tend to confirm that alterations in thermotactile thresholds are very common in those exposed to hand-arm vibration and that these alterations appear to be an early sign of sensorineural degeneration. However, this latter hypothesis is at odds with other studies that believe alterations in TPTs are a manifestation of advanced stages of nerve degeneration (9, 42). Moreover, a deterioration was shown in both TPTs, as well as those of vibrotactile perception, with increasing duration of exposure to hand-arm vibration.

In our study, weekly exposure to hand-arm vibration was between 6 and 8 hours, with negligible and nonsignificant variation between subjects in the exposed group. This duration of exposure is significantly shorter than the one reported in other studies. The negative results of our study are consistent with those of Esko et al., in which the first neurosensory symptoms appeared only after 2,000 hours of vibration exposure, far longer than the limited exposure period we estimated (6).

This finding confirms that neurosensory effects in vibration-exposed people do not tend to occur at low levels of vibration exposure, as found in our study.

In the present study, no significant differences were found between pre-exposure and post-exposure for both vibrotactile and TPTs in the dental hygienist group. Furthermore, again in the dental hygienist group, no significant deterioration of neurosensory function was found in the follow-up period. Numerous works (43-45) in the literature confirm that vibrating instruments used daily in dentistry (drills, scalers, and turbines) can have a negative influence on sensitivity and manual dexterity of the exposed operator, both as an acute and chronic impairment, and that this issue is more pronounced in dental hygienists who have been working in the field for a long time.

The results of this study seem to disagree with other cross-sectional and longitudinal investigations that have found a significant association between damage to thermotactile function and exposure to high-frequency hand-arm vibration in dental health care workers. This finding may be due, in part, to the young age of the exposed subjects and to the low level of HAV to which they were exposed.

Our study has some limitations. The follow-up period, while spanning two years, may not be long enough to detect the onset of significant neurosensory impairments, as HAV-related disorders often develop over longer periods. Furthermore, the relatively small number of exposed participants may reduce statistical power and generalizability to a broader population. The vibration exposure in dental hygiene students is lower than that of full-time professionals, which might explain the lack of significant consistent findings. Furthermore, as novice operators in the early stage of their curriculum, students may exhibit variability in instrument handling, grip force, and working technique; while excessive or uncoordinated grip force could theoretically increase vibration transmission to the hand, the overall low vibration intensity and limited duration of pre-clinical exposure appear to have mitigated any observable sensorineural impact. Finally, symptoms such as paresthesia or cold hypersensitivity were assessed using questionnaires, which are subject to subjective perception and reporting bias (recall bias). On the other hand, our study has also several strengths. This is a longitudinal study, which enhances the reliability of findings by tracking changes over time rather than relying solely on cross-sectional data. The participants were all dental hygiene students with similar demographic and anamnestic characteristics, reducing internal variability due to occupational experience or aging. Our study evaluated both thermotactile (TPT) and vibrotactile (VPT) thresholds with the aim of investigating the whole sensorineural component of HAVS; moreover, VPT and TPT were assessed in both acute (pre- vs. post-exposure) and mid-term (follow-up) conditions, ensuring a more in-depth evaluation of neurosensory function.

CONCLUSIONS

Our findings did not reveal significant changes in vibro- nor thermotactile thresholds over the two-year follow-up period, suggesting that, within the observed timeframe and exposure levels, HAV did not induce detectable short- nor mid-term neurosensory impairments in our population of dental hygiene students. However, our results should be interpreted with caution and the potential cumulative effects of long-term hand-arm vibration exposure cannot be excluded. The absence of significant findings in our study may be attributed to the young age of participants, short exposure time, and low HAV intensity associated with dental instruments. Anyhow, it remains essential to implement adequate preventive strategies, such as ergonomic interventions, optimized tool design, vibration-damping materials, and structured work-rest schedules, to minimize occupational risk to HAV exposure: early adoption of such measures may contribute to preserving neurosensory function and preventing the onset of HAV-related disorders in dental professionals over time.

Disclosures

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