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Sensorineural and peripheral vascular responses induced by exposure to high-frequency vibration

Kristine Krajnak, PhD[1] ORCID ID 0000-0001-9617-5486, Phillip Chapman, PhD[1] ORCID ID 0000-0003-2722-1973, Stacey Waugh, MS[1] ORCID ID 0000-0001-8559-5389, Mark Jackson, MS[1] ORCID ID 0000-0002-2379-6692, Walter McKinney, MS[1] ORCID ID 0000-0002-5180-8451, Samantha Service, MS[2] ORCID ID 0000-0003-4887-6629, Anna Mnatsakanova, MS[2] ORCID ID 0000-0002-5537-5681, Christopher Warren, MS[1] ORCID ID 0000-0002-5537-5681, Xueyan Xu, PhD[1] ORCID ID 0000-0003-2702-6158, Daniel Welcome, MS[1] 0000-0003-2621-208X

[1]Physical Effects Research Branch

[2]Office of the Director Health Effects Laboratory Division, National Institute for Occupation Safety and Health, Morgantown, WV 26508

Corresponding author:

Kristine Krajnak, Ph.D.

Physical Effects Research Branch

1000 Frederick Lane

National Institute for Occupational Safety and Health

Morgantown, WV 26508

Phone: 304-285-5964

Email: ksk1@cdc.gpv

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3) Author contributions:

- K.K. designed the experiments, performed exposures and physiological tests, performed data analysis, wrote and edited the manuscript.
- P.C. helped perform studies using the current perception threshold test and microvessel system and edited the manuscript.
- S.W. performed studies using the microvessel system and edited the manuscript.

- M.J. wrote the software used to run the vibration exposure system and edited the manuscript.
- W.M. wrote the software used to run the vibration exposure system and edited the manuscript.
- S.S. smoothed blood flow data to account for motion or movement away from the laser doppler probe and edited the manuscript.
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- C.W. helped design and characterized the exposure system and edited the manuscript.
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Clinical significance. Exposure to high frequency vibration (1250 Hz) resulted in reductions in blood flow and an increased sensitivity to pressure in a rat-tail model of vibration-induced dysfunction. Based on these data, high frequency vibration can contribute to the development of hand pain in workers using tools that emit high frequency vibration.

ABSTRACT

Background: Dentists, dental hygienist, and veterinary technicians using drills, scalers and polishers are at risk of developing sensorineural deficits in the fingers and hands. The goal of this study was to determine whether exposure to high-frequency vibration contributed to changes in sensory function.

Methods: The tails of rats were exposed to vibration at 1250 Hz (constant acceleration of $49 m/s^2$) for 4 hours per day, for 10 days. The effects on sensory nerve function, and vascular function were measured.

Results: Vibration increased sensitivity to applied pressure and to transcutaneous electrical stimulation at 2000 and 250 Hz. It also resulted in a reduction in blood flow and myogenic tone.

Conclusions: Exposure to high-frequency vibration has detrimental effects on both peripheral sensorineural and vascular function.

Keywords: Peripheral sensory function, peripheral vascular function, blood flow, Randall Selitto test, current perception threshold, hand-arm vibration syndrome.

Smart Learning Outcomes:

- Dentists, Dental Hygienists, Veterinary Technicians and worker using impact tools, are exposed to high frequency vibration (Frequency >1000 Hz)
- In an animal of vibration induced dysfunction, high frequency vibration exposure reduced blood flow.
- High frequency vibration also increased the sensitivity of animals to applied pressure.

Introduction:

Exposure to vibration generated by powered- and pneumatic-hand-tools can result in workers displaying cold-induced vasospasms that result in blanching of the fingers and hands, reductions in tactile sensitivity, pain and reductions in manual dexterity [1-3]. This set of symptoms is commonly referred to as hand-arm vibration syndrome (HAVS [1, 4]). Although there are many studies describing the pathological changes associated with the symptoms of HAVS (e.g. [3, 5-18]), the dose-response between exposure to occupational vibration, other ergonomic factors that workers are exposed to when using a vibrating hand-tool, such as grip-associated stress on the soft tissues of the hand and awkward postures, and the development of the symptoms of HAVS, is not well understood [3, 19-24]

The International Standards Organization (ISO) standard 5349 [25] and the American National Standards Institute (ANSI) standard 3.34 [26] present mathematical formulas and length of exposure-frequency curves to predict the risk of developing HAVS with exposure to occupational hand-transmitted vibration. However, these standards use weighting factors when predicting the risk associated with exposure to vibration at different frequencies, with most of the weighting emphasizing vibration frequencies less than 100 Hz [19, 25-28]. However, studies in humans [19, 28-30], animal models [18, 23] and in mathematical models [31-33], demonstrate that exposure to vibration in the mid-frequency range (i.e., 100-500 Hz) are more likely to generate the pathophysiology associated with HAVS. There are also other factors that workers are exposed to when using vibrating hand tools, such as compression of the soft tissues of the fingers and hands while gripping a tool [25, 34-36], changes in environmental temperature in the workplace

[2, 25, 37-39], awkward postures [40-42], and individual health-related factors [43-47] that may also affect a worker's risk of developing HAVS.

Recent studies looking at dentists, dental hygienists and veterinary technicians have found that exposure to high frequency vibration (> 1000 Hz) generated by tools such as dental drills, scalers and polishers, is associated with development of symptoms that are indicative of vibration-induced sensorineural injury [48-54]. However, it's unclear if the symptoms in these workers are due to vibration, the pressure applied to the fingertips while holding the tools, the awkward posture of the wrist and hand while working, or a combination of these factors. With an increasing number of veterinarians suggesting dental cleaning and care in pets to improve health, veterinary technicians, who often provide these services, are also at risk of developing sensorineural deficits or HAVS [54-56]. Because of reported incidence of HAVS-like symptoms in workers exposed to high-frequency vibration, and the fact that the current standards provide little guidance on the effects of exposure to vibration at frequencies above 1000 Hz, studies examining the physiological and biological effects of exposure to high-frequency vibration are important so methods can be developed to reduce or eliminate this exposure and the associated health risks.

Impact tools also generate high-frequency vibration during the impact or shock portion of tool use [57, 58] and exposure to impact vibration has also been associated with the development of HAVS and other upper limb disorders [59-62]. As mentioned previously, most of the work that has been done looking at the effects of vibration exposure has looked at the effects of lower-frequency vibration. However, as with use of some of the smaller tools mentioned above, it is possible that the high frequencies (1000 – 25,000 Hz) generated during the impact portion of tool performance also contributes to vibration-induced disorders in workers [17, 63, 64]. Because workers in several occupations maybe exposed to high-frequency vibration, and because the effects of this exposure have not been well described, the goal of the current study was to determine if exposure to high frequency vibration alone induces physiological effects that are seen in workers exposed to vibration.

A rat-tail model of vibration-induced injury has been developed and the biodynamic responses to vibration characterized [65]. Studies done using this model have demonstrated that the physical response of the rat-tail and human fingers to vibration are similar, with the resonant frequency being between 100 and 300 Hz [65]. The effects of vibration on both vascular and sensorineural function are also similar in the rat tail and human fingers, and the rat-tail model has been used to describe the dose response between vibration exposure at mid-range frequencies, and biological and physiological responses to vibration[18, 23, 24]. Given that the responses of the rat tail and human fingers to vibration are similar, this study used the rat-tail model to determine if exposure to high frequency vibration (1250 Hz, 5G amplitude) alone would affect peripheral vascular and sensorineural function, the two systems predominantly affected in HAVs.

METHODS

Animals. Male (n=16) Sprague-Dawley rats (Hla®(SD)CVF®, 12 weeks of age and approximately 320-340 g at arrival), were obtained from Hilltop Lab Animals, Inc. (Scottdale, PA). These animals had similar body weights and were in the same age range as animals in previous studies [23,24]. All rats were free of viral pathogens, parasites, mycoplasma, *Heliobacter,* and cilia-associated respiratory bacillus. Upon arrival, rats were acclimated to the AAALAC

International accredited animal facilities for one week. The animal facility is a specific, pathogen-free, environmentally controlled facility. They were housed in ventilated micro-isolator units supplied with HEPA-filtered laminar flow air (Lab Products OneCage; Seaford, DE), Teklad Sanichip and Shepherd Specialty Paper's Alpha-Dri cellulose, tap water, and autoclaved Teklad rodent diet (Harlan Teklad; Madison, WI) available *ad libitum*. Rats were housed in pairs, and under controlled light cycle (12 h light/12 h dark) and temperature (22 – 25 °C) conditions. One week following acclimation to the animal facilities, rats were randomly assigned to the restraint control (controls) or the vibration-exposure group. The use of animals, housing, exposures, and all other procedures performed on the animals were reviewed and approved by the Institutional Animal Care and Use Committee in compliance with the Public Health Service Policy on Humane Care and Use of Laboratory Animals and the NIH Guide for the Care and Use of Laboratory Animals.

Vibration Exposures. The equipment and protocol for exposing animals to vibration previously were described [65]. Briefly, rats were acclimated to restraint in Broome style restrainers by increasing the time in the restrainer by 1 hr/day until animals were restrained for a total of 4 hrs prior to the beginning of the experiment. Each rat was then assigned to the control or vibration group. On the days of exposure, animals were restrained in Broome style restrainers, and rats in the vibration group had their tail secured to a vibrating platform with Soft-tape (Neurotron Inc, Aurora, CO) as previously described [65]. The vibrating platform was attached to a shaker and rats were exposed to 4-h bouts of vibration at 1250 Hz and an acceleration of 49 m/s^2 root mean squared between 0700 and 1300 h for 10 consecutive days. Control rats were treated identically except that their tails were secured to nonvibrating platforms mounted on isolation blocks.

Control animals were placed in the same chambers with vibrated animals and were exposed to the sound generated by the shakers.

Sensorineural testing. On the day before the exposures began, and on days 2 and 9 of the exposure, each rat was placed in a Broome-style restrainer prior to exposure, and current perception threshold (CPT) measurements were made using a Neurometer CPT/C (Neurotron Inc). We chose to assess rats on day 9 instead of day 10 so that the CPT tests would not interfere with measurement of blood flow. The CPT was performed as described in [24] with minor modifications recommended by the manufacturer. In brief, each rat's tail was cleaned and Goldtrobe electrode gel was applied to the stimulating electrode (ATE1925). The electrode was secured to the ventral surface of the tail, just distal to the C15 tail vertebrae, using Soft-Tape (Neurotron, Inc). A separate skin patch dispersion electrode (SDE44; Neurotron, Inc) was secured on the tail approximately 1.5-2 cm proximal to the stimulating electrode. The CPT was performed using the Rapid CPT test provided by Neurotron. In this test transcutaneous electrical stimulation at frequencies of 2000, 250 and 5 Hz are used to assess the function of large myelinated Aβ nerve fibers, small myelinated Aδ nerve fibers and unmyelinated C-fibers. The test started with a stimulus of 10 mA for the 2000 and 250 Hz stimulus, and 1 mA for the 5 Hz stimulus. The intensity of the stimulus was automatically increased in increments of 1.0 mA until the rat flicked its tail. The intensity that elicited the tail flick was recorded as the CPT for that frequency. Three trials were run at a single frequency before changing to the other frequency. The testing started with the 2000 Hz stimulus, followed by the 250 and 5 Hz stimuli. The tests were run in this order because the lower frequencies can interfere with the response to the 2000 Hz stimulus [66-68]CPTs were measured immediately prior to vibration or restraint-control exposures. Cage-control rats were tested at the same times. The pre- and post-exposure averages CPTs were calculated on each day and used for statistical analysis.

The Randall-Selitto test assessed sensitivity to pressure applied to a 1 mm section of skin. The test was performed pre- and post-exposure on days 1, 5 and 10 of the experiment as described in[69]. Briefly, the bottom of the caliper was placed on the dorsal surface of the tail, and the 1 mm probe was placed on the ventral surface between the C15 and C18 vertebrae. The calipers were gently closed until the animal moved or vocalized. The pressure that induced a response was recorded. This test was performed once because the animals quickly learned to avoid the stimulus (reacted as soon as the calipers touched their tail, without the application of pressure).

Laser Doppler. Laser Doppler measurements were made using a Periflux system 5000 and PF 450 thermostatic small angle probe (Perimed, Stockholm, Sweden) as previously described[69] . Briefly, the rats were weighed, placed in a restrainer, and then put into a sound-attenuating chamber. Each animals' tail was put into the holder that secured the Doppler probe. The probe was placed under the C15–16 region of the tail and the tail was then covered with a piece of foam to keep it in place during the measurement. If the rat moved its tail away from the probe, the tail was quickly re-positioned. Laser Doppler recordings of perfusion units (PUs) were made for 5 minutes at 0.2 Hz immediately before and after exposures on days 1, 5, and 10 of the experiment.

Because rats occasionally move during the recording period, and this results either in a rapid, acute increase in the Doppler signal, or a loss of signal, data were sent to a biostatistician for smoothing. Regions were identified as motion artifact if the recorded number of PUs was greater than 200, and a loss of signal was defined as less than 0.2 PUs. The regions, that were out of range, were identified and running means were calculated to replace the regions with motion artifact or loss of signal. To calculate the running mean, the 10 measures before and 20 measures after motion artifact were used to calculate an average and these averages (i.e., running means) were used to replace data that were identified as motion artifact or loss of signal [70].

Euthanasia. The morning after the last exposure, animals were euthanized by injecting an overdose of sodium pentobarbital euthanasia solution (i.p., 100 - 300 mg/kg body wt.), and exsanguination by blood collection through left ventricle of the heart. Serum was separated from clotted blood and samples were centrifuged, serum was aliquoted in 200 µl aliquots, and frozen at -80°C until assayed using ELISAs. The tail between C-15-18 was dissected and placed in cold Dulbecco's Modified Eagle's Media (DMEM) until the ventral artery was dissected and assessed for sensitivity to vasoconstricting and dilating factors.

Microvessel. Ventral tail arteries were dissected from the C15–18 region of the tail and mounted in a microvessel chamber (Living Systems, Burlington, VT, USA). All vasoconstricting and vasodilating factors were obtained from Sigma Chemicals (St Louis, MO USA) unless otherwise noted. Vessels within the chambers were maintained at 37°C in HEPES bicarbonate solution and held at a constant pressure of 60 mmHg. To assess the effects of vibration on α 2C-adrenoreceptor mediated vasoconstriction, dose-response curves to the agonist UK14304 were generated by applying the agonist in half-log increments (from -10 to -5.5) and measuring the internal diameter 5 min after drug application. This agonist was used because it has been shown that both vibration and cold result in an increased responsiveness of arteries to this agonist [71-73]. Vessels were then rinsed, and arteries allowed to recover to baseline diameters. To assess the effects of vasodilating factors arteries were first constricted to approximately 50% of their resting diameter using the α1 adrenoreceptor agonist, phenylephrine. Dose-response curves to acetylcholine (ACh) were generated by adding increasing concentrations of ACh in half-log increments (from -10 to -5.5 M). Changes in the internal diameter of arteries were continuously measured during treatments using a XC-ST30 video camera mounted onto a Nikon T1-SM inverted microscope, a video dimension analyzer (Living systems) and Data-Q Instruments software (Akron, OH USA).

Data Analyses. For the microvessel data, the diameter of the artery after treatment with PE or ACh was divided by the diameter of the artery prior to any drug treatment (baseline diameter). These values are referred to as the % change from starting baseline, and it were these data that were analyzed using 2 (condition) x 10 (dose) repeated-measures analysis of variance (ANOVA). Data were also analyzed in Prism GraphPad 10.0 to generate dose-response curves and calculate the dose of the drug that induced a 15% constriction (for UK14304) or 50% re-dilation (for ACh). An effective dose 50 was not calculated for UK14304 because the doses used in this experiment do not generate a 50% constriction of the blood vessel.

Blood flow data (perfusion units or PUs) were smoothed using a running mean to remove artifact or loss of signal due to motion[70]. Average blood flow prior to vibration exposure was measured using a 2 (condition) x 3 (1, 5 and 10d of exposure) ANOVA with animal added as a random variable (to account for repeated measures). The 0.4 Hz peak was identified by performing Fast Fourier Transform analyses on the data for each animal and analyzing the amplitude of the 0.4 Hz peak using 2 (condition) x 3 (1, 5 and 10d exposure) ANOVA with animal added as a random variable. Blood flow measures on day 10 were missing for 2 controls because of a technical problem. These two animals were removed from the analyses.

Randal-Selitto data prior to exposure any exposure, and before the exposure on days 2 and 9 of the experiment, were analyzed using a 2 (condition) x 3 (days of exposure) ANOVA with animal added as a random variable. This analysis allows us to determine if there are effects of vibration on the CPT that are maintained over the course of the experiment. The acute effects of vibration from on a single day exposure (pre-post exposure measures) were analyzed by subtracting the post-exposure value from the pre-exposure value and using the difference to perform a 2 (condition) x 3 (days of exposure) ANOVA. Pre-exposure CPT data at each frequency were analyzed separately using 2 (condition) x 3 (days of exposure) ANOVAs with animal added as a random variable. Acute, pre-post exposure differences were calculated as described for the Randall-Selitto test and analyzed using a 2 (condition) x 3 (days of exposure) ANOVAs.

All data were analyzed using JMP 16.1 and SAS 9.4 (SAS Institute, Cary, NC) unless otherwise noted. Differences with $p < 0.05$ were considered statistically significant. Data are reported as the mean ± SEM.

Results

Vascular effects

Sensitivity to UK14304 and ACh. Exposure to 10 days of high-frequency vibration at 1250 Hz did not alter the sensitivity of the ventral tail artery to UK14304-induced vasoconstriction or ACh-induced re-dilation (Fig 1A and B).

Laser Doppler. Exposure to 1250 Hz vibration induced a significant reduction in average blood flow after 5d of exposure (Fig 2A), with blood flow being lower in tails from exposed animals than in 5d controls and 1d vibration exposed animals. Average blood flow was also lower after 10d of exposure than after 1d, but this reduction was not significant when compared to controls ($p < 0.07$). High-frequency vibration exposure resulted in a reduction in the amplitude of the 0.4 Hz signal after 5 and 10 d of exposure as compared to controls (Fig 2B). This signal is representative of myogenic tone [(74, 75)] or the stiffness of the arteries.

Sensorineural Effects

Randall-Selitto Anesthesiometry (applied pressure) test. Exposure to vibration resulted in a progressive increase in sensitivity (reduction in the threshold) to applied pressure (Fig 3A). After 5d of exposure to vibration the threshold to applied pressure was lower in vibrated than control animals, and after 10d of exposure, thresholds were lower in vibrated than control animals, and lower than thresholds of animals exposed to 1d of vibration. There were no differences in thresholds across the exposure in control animals. Figure 3B shows the difference between pre- and post-exposure thresholds on each day. After 1d and 5d of exposure post-vibration exposure, the thresholds were lower than the pre-exposure value (pre – post was a positive value). However, after 10d of exposure, control animals tended to have lower post-exposure thresholds, but vibrated animals did not show a pre-post exposure difference.

Current perception threshold (CPT). The CPT at 2000 Hz tests the of sensitivity of large, myelinated Aß-fibers. Because there were group differences at some testing frequencies prior to any exposure, data at all frequencies are reported as the change from the pre-exposure baseline. After 2d and 9d of exposure to vibration, there was an increased sensitivity (reduced threshold) to the 2000 Hz CPT stimulus in the test that was performed prior to vibration exposure (Fig 4A). Vibrated animals had lower thresholds than same day controls, and lower than pre-exposure thresholds. When the acute effects (i.e., the pre-post exposure differences) were analyzed, there were no significant differences in either group (Fig 4B).

The 250 Hz CPT stimulus tests the sensitivity of small myelinated Aδ-nerve fibers. Exposure to 2d of vibration resulted in a reduction in the threshold for the 250 Hz stimulus in the test that was performed prior to vibration exposure that day (or an increase in sensitivity; Fig 5A). Thresholds in vibrated animals to the 250 Hz stimulus were lower than those of same day controls and pre-exposure values. After 9d of exposure, the 250 Hz threshold was lower in vibrated than control animals. However, it was not different than pre-exposure values. There also were no difference in pre-post 250 Hz CPTs in either the control or vibrated groups (Fig 5B).

The 5 Hz CPT stimulus tests the sensitivity of unmyelinated nerve fibers. There were no significant changes in the 5 Hz stimulus when pre-exposure thresholds were analyzed (Fig 6A). However, when pre-post exposure differences were analyzed (Fig 6B), the post-exposure CPT in the vibrated group increased (pre-post value was negative) compared to controls on day 9 of exposure.

Discussion

The goal of this study was to determine if exposure to high-frequency vibration (> 1000 Hz) results in changes in peripheral vascular and sensorineural function. The effects of high-frequency vibration exposure were similar to those seen with exposure to vibration at the resonant frequency [24], with vibration exposure resulting in a reduction in average blood flow in the tail, a reduction in the amplitude of the 0.4 Hz signal (myogenic tone), an increased sensitivity to applied pressure using the Randall-Selitto test, and an increased sensitivity of Aß- and Aδ-nerve fibers to transcutaneous electrical stimulation (measured using the CPT).

The reduction in tail blood flow after exposure to vibration is similar to that reported in other studies examining the effects of vibration exposure at 250 Hz in the rat tail model[70] and in studies examining the effects of vibration on human fingers[76-78]. There was also a reduction in the amplitude of the 0.4 Hz signal. This signal is indicative of myogenic tone and can be an indicator of the stiffness of the artery [74, 76, 78]. These data are consistent with previous studies looking at exposure to lower-frequency vibration in the rat-tail model [70]. The reduction in the amplitude of the 0.4 Hz pulse, or myogenic tone, may be indicative of a thickening of the smooth muscle wall of the artery and/or an increased stiffness of the artery [74, 79]. These changes could be associated with the reduction in overall blood flow seen in tails from animals exposed to vibration. Future studies will determine if there are morphological changes in the ventral tail artery or blood vessels in the skin after exposure to vibration, as well as if determine if high-frequency vibration induces changes in other markers of vascular dysfunction such as changes in concentrations of reactive oxygen species, vascular remodeling factors, and markers of inflammation or tissue hypoxia.

The changes in blood flow in response to exposure to high-frequency vibration were not associated with changes in responsiveness to α2C-adrenoreceptor-induced constriction or ACh-induced re-dilation of the ventral tail artery as has been seen with exposure to vibration at lower frequencies [23, 72, 80]. It is possible that the vibration signal was not transmitted far enough into the tissue to affect the ventral tail artery [36, 81]. If this is the case, the changes in blood flow may instead have been due to changes in the superficial blood vessels of the skin. On the other hand, if the vibration stimulus did reach the ventral tail artery, it's possible that the low level of displacement did not result in enough tissue stress and strain in the ventral-tail artery to induce the translocation of the α2C-adrenoreceptor to the surface of the vascular smooth muscle walls, or result in a large enough sympathetic response, to induce changes in vascular sensitivity to vaso-modulating factors. It is also possible that because the ventral tail artery does not show myogenic tone when in the microvessel system, it is not as sensitive at detecting some of the earlier changes that occur in response to vibration exposure. However, because the artery maintains tone *in vivo*, laser doppler can pick up these more subtle changes. Studies examining morphological and biochemical changes in the tail arteries will help determine the mechanism(s) by which exposure to high-frequency vibration induces changes in vascular function.

Exposure to high-frequency vibration has primarily been associated with hand pain, reductions in tactile sensitivity and carpal tunnel syndrome in workers using dental tools [48-50, 82,

[83], and with hand pain, loss of sensory function, vascular dysfunction, and upper limb injuries in workers using impact tools [57, 84, 85]. These changes were usually attributed to awkward postures and nerve impingement [48, 82]. However, based on the findings of this study, it appears that exposure to high-frequency vibration alone, in the absence of awkward postures, can induce changes in sensory function. Exposure to vibration resulted in an increased sensitivity to applied pressure using the Randall-Selitto meter. These findings are consistent with reports from studies using lower frequency vibration or applied force which mimics grip [69, 86]. This increased sensitivity to the noxious pressure stimulus is most likely associated with injury to the nerves and nerve-endings in the skin that carry pressure information to the central nervous system [17, 63, 87].

The changes in responsiveness to the Randall-Selitto test were also associated with changes in the CPT. After both 2d and 9d of exposure to vibration, there was a reduction in the CPT at 2000 Hz and 250 Hz. In this experiment, the reduction in the threshold at both frequencies occurred after 2d of exposure to high-frequency vibration. However, in previous studies exposure to vibration at 250 Hz, a frequency within the resonant frequency range of the rat tail and human finger, did not change the pre-exposure CPT at 2000 Hz until animals had been exposed to vibration for 7d[88].

The pre-post calculations of sensory function (or the acute effects) were variable. After 1 and 5d of exposure to high-frequency vibration, there was an increased sensitivity to applied pressure (using the Randal Selitto test). However after 10d of exposure the pre-post exposure values were similar in vibration-exposed and control animals, and they were lower than the pre-post measures on day 1 in vibration exposed animals. This change on day 10 may be due to the fact that the pre-exposure response was reduced, and that an additional single day of vibration exposure did not result in an additional change in the post-exposure threshold. It might also suggest that the nerves are becoming less sensitive to the stimulus. A reduction in sensitivity would be more consistent with the 2000, 250 and 5 Hz CPT pre-post exposure data seen after 9d of exposure, where post-exposure CPTs were higher than pre-exposure (resulting in a negative difference value). These findings are consistent with longer term changes seen in sensory function in response to vibration (i.e., there is a loss of sensitivity to tactile stimuli)[86].

In conclusion, the results of this study demonstrated that exposure to high-frequency vibration (1250 Hz) alone affects both sensorineural and peripheral vascular function in a rat-tail model for studying vibration-induced finger disorders. However, dentists, dental hygienists and veterinary technicians can be exposed frequencies in the 5-8,000 Hz range [48-50, 54, 82], and workers using tools that generate a shock or impact can be exposure to frequencies up to 25,000 Hz [58, 63, 89-91]. Therefore, additional data examining the effects of exposure to higher frequencies needs to be collected to determine if these higher frequencies also result in changes in sensory and vascular function. In addition, the influence of other ergonomic risk factors such as posture [48, 49, 82] and force applied to the finger tips [69] need to be examined. The effects of high-frequency vibration exposure on females also needs to be evaluated given the changing demographics of women in the workforce, including dental hygienists and veterinarian technicians, who are primarily female [48, 49, 54, 82]. Understanding the effects of high-frequency vibration is also important because these data can be used to help determine how to revise the ISO-5349 standard to include this risk associated with exposure to these higher frequencies.

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FIGURE CAPTIONS

Figure 1. Dose-response curves to the α2C-receptor agonist UK14304 that induces vasoconstriction (A), and the vasodilator ACh (B) In the ventral tail artery of rats exposed to restraint control (control) or vibration (1250 Hz). Exposure to high-frequency vibration did not alter the responsiveness of the ventral tail arteries to either substance. Data are shown as the average % change in the internal diameter of the artery from baseline ± SEM (n = 8/grp).

Figure 2. These data show the average pre-exposure blood flow measured by Laser Doppler (A) and the average amplitude of the 0.4 Hz peak which is representative of myogenic tone or arterial stiffness (B). Average pre-exposure blood flow was reduced after 5 d of vibration exposure as compared to same day controls (*$p < 0.05$) and after 5 and 10 d of exposure as compared to 1d measures (^ $p < 0.06$; # $p < 0.05$). The amplitude of the 0.4 Hz peak was also reduced after 5 and 10d of exposure as compared to same day controls and 1d measures. All data are presented as the mean ± SEM (n = 8/grp).

Figure 3. Pre-exposure thresholds in response to applied pressure (g) using a Randall-Selitto meter (A). After 5 and 10d of exposure to vibration, there was a reduction in amount of pressure needed to elicit a tail flick as compared to both same day controls (*$p< 0.05$), and after 10d of exposure the threshold was significantly lower than on day 1 of exposure (# $p < 0.05$). Pre-post exposure data are presented in (B). On days 1 and 5 of exposure, vibrated animals displayed a reduction in the pre-post threshold (a positive value). However, after 10d of exposure, vibrated

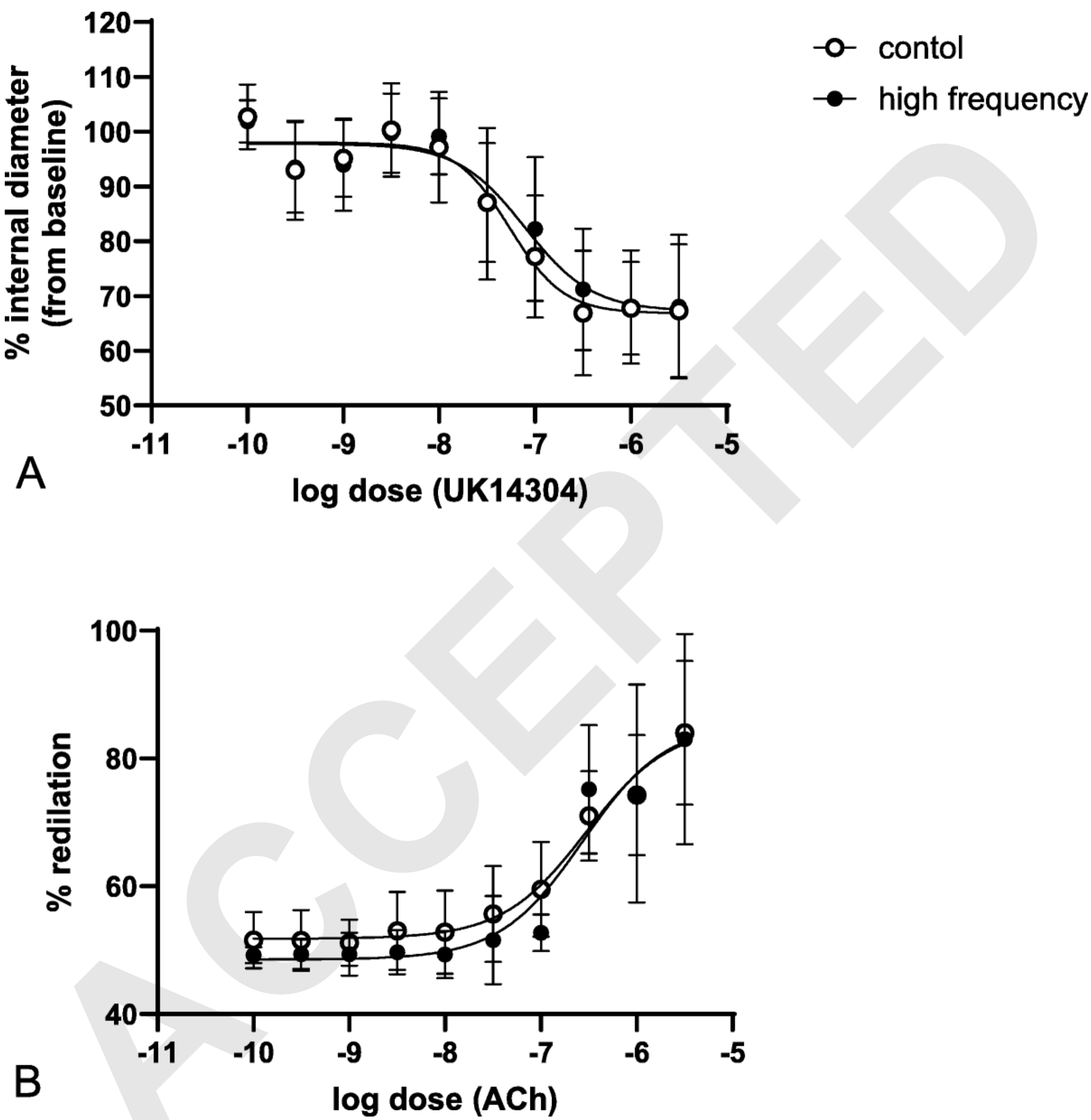
animals did not display a pre-post difference in the threshold. All data are presented as the mean ± SEM (n = 8/grp).

Figure 4. The pre-exposure CPTs at 2000 Hz (A) and the pre-post exposure change in the CPT at 2000 Hz (B). After 2d and 9d of exposure, the 2000 Hz threshold was reduced as compared to same day controls (* $p < 0.05$) and pre-exposure measures in the same condition (# $p < 0.05$, ^ $p < 0.06$). There were no significant differences between pre-and post-exposure CPTS in either the control or vibration-exposed groups (n = 8/grp).

Figure 5. The pre-exposure CPTs at 250 Hz (A) and the pre-post exposure change in the CPT at 250 Hz (B). After 2d exposure, the 250 Hz threshold was reduced as compared to same day controls (* $p < 0.05$) and pre-exposure measures in the same condition (# $p < 0.05$). After 9d of exposure, the 250 Hz CPT was lower in vibrated than control animals on that day. There were no significant differences between pre-and post-exposure CPTS in either the control or vibration-exposed groups (n = 8/grp).

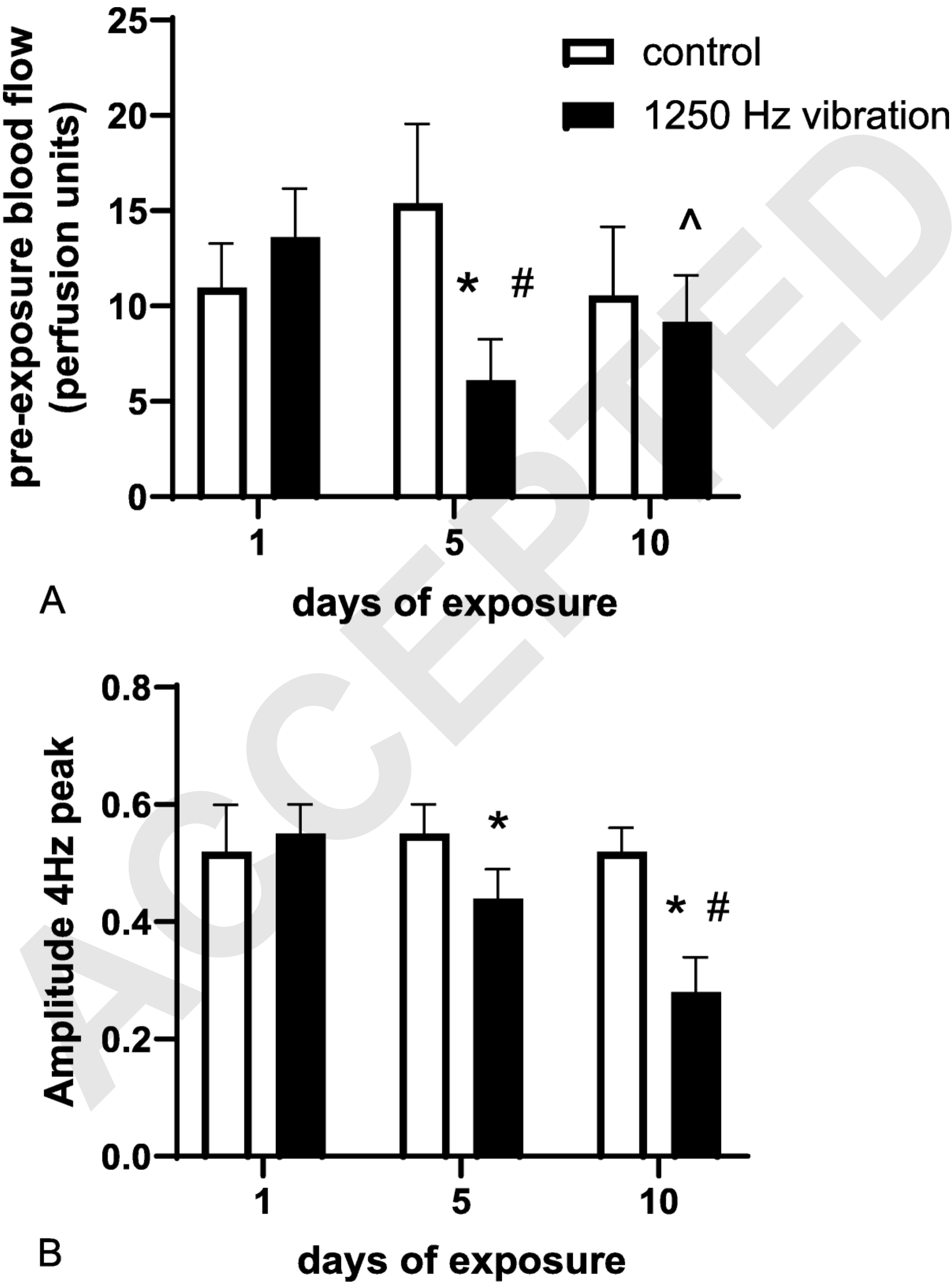
Figure 6. The pre-exposure CPTs at 5 Hz (A) and the pre-post exposure change in the CPT at 5 Hz (B). There were no significant exposure-related changes in the 5 Hz CPT. On day 9, the threshold in response to the 5Hz stimulus was significant higher after exposure than before exposure (negative pre-post change) and this change was significantly different than that seem in controls (*$p < 0.05$; n = 8/grp).

Figure 1



% internal diameter (from baseline)
120
110
100
90
80
70
60
50
-11
-10
-9
-8
-7
-6
-5
log dose (UK14304)
A
contol
high frequency
% redilation
100
80
60
40
-11
-10
-9
-8
-7
-6
-5
log dose (ACh)
B

Figure 2



control
1250 Hz vibration
pre-exposure blood flow (perfusion units)
25
20
15
10
5
0
* #
^
1
5
10
A
days of exposure
Amplitude 4Hz peak
0.8
0.6
0.4
0.2
0.0
*
* #
1
5
10
B
days of exposure

Figure 3

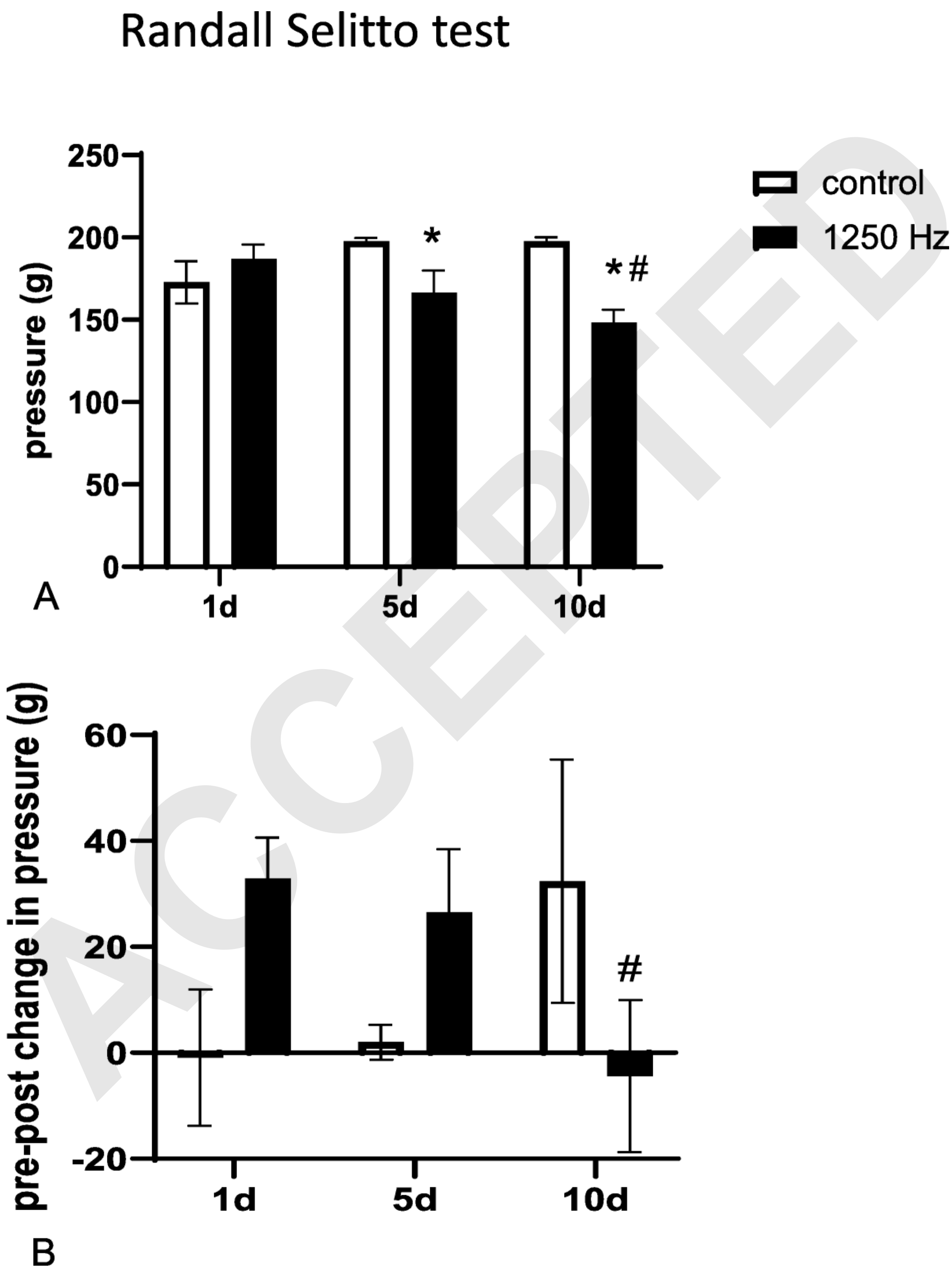

Randall Selitto test
250
200
150
100
50
0
pressure (g)
control
1250 Hz
*
*#
1d
5d
10d
A
60
40
20
0
-20
pre-post change in pressure (g)
#
1d
5d
10d
B

Figure 4

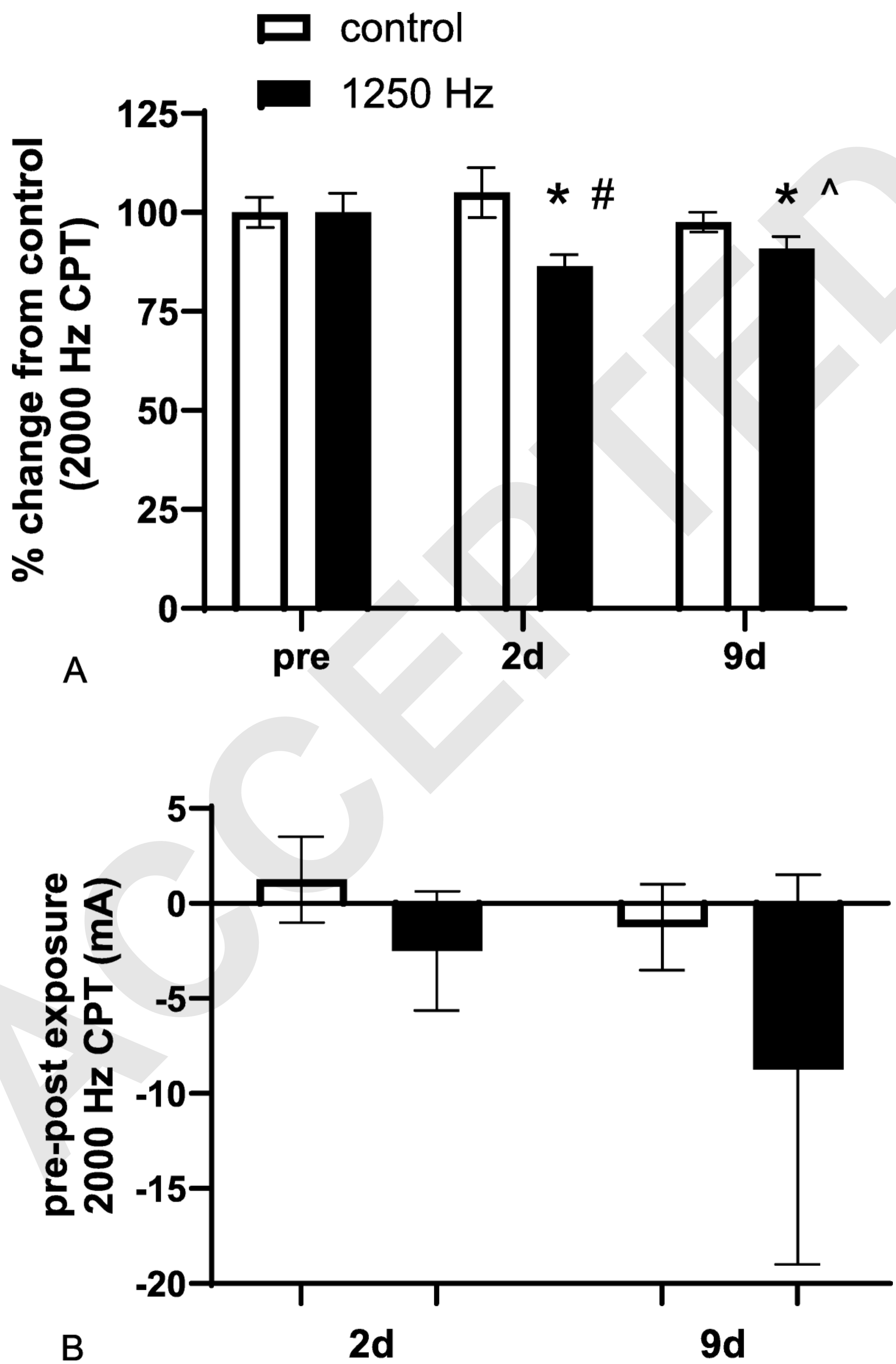

control
1250 Hz
% change from control
(2000 Hz CPT)
125
100
75
50
25
0
* #
* ^
pre
2d
9d
A
pre-post exposure
2000 Hz CPT (mA)
5
0
-5
-10
-15
-20
2d
9d
B

Figure 5

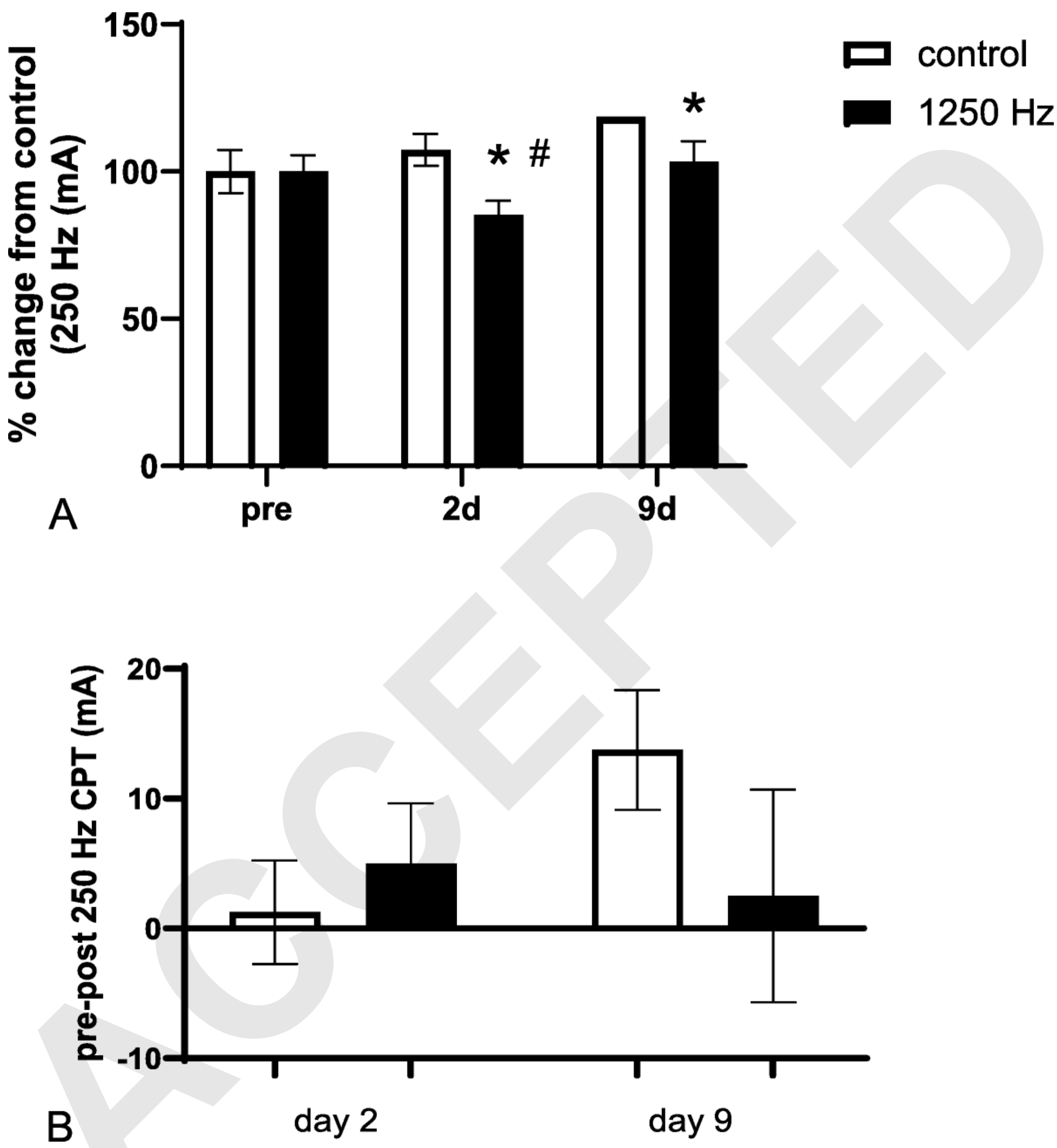
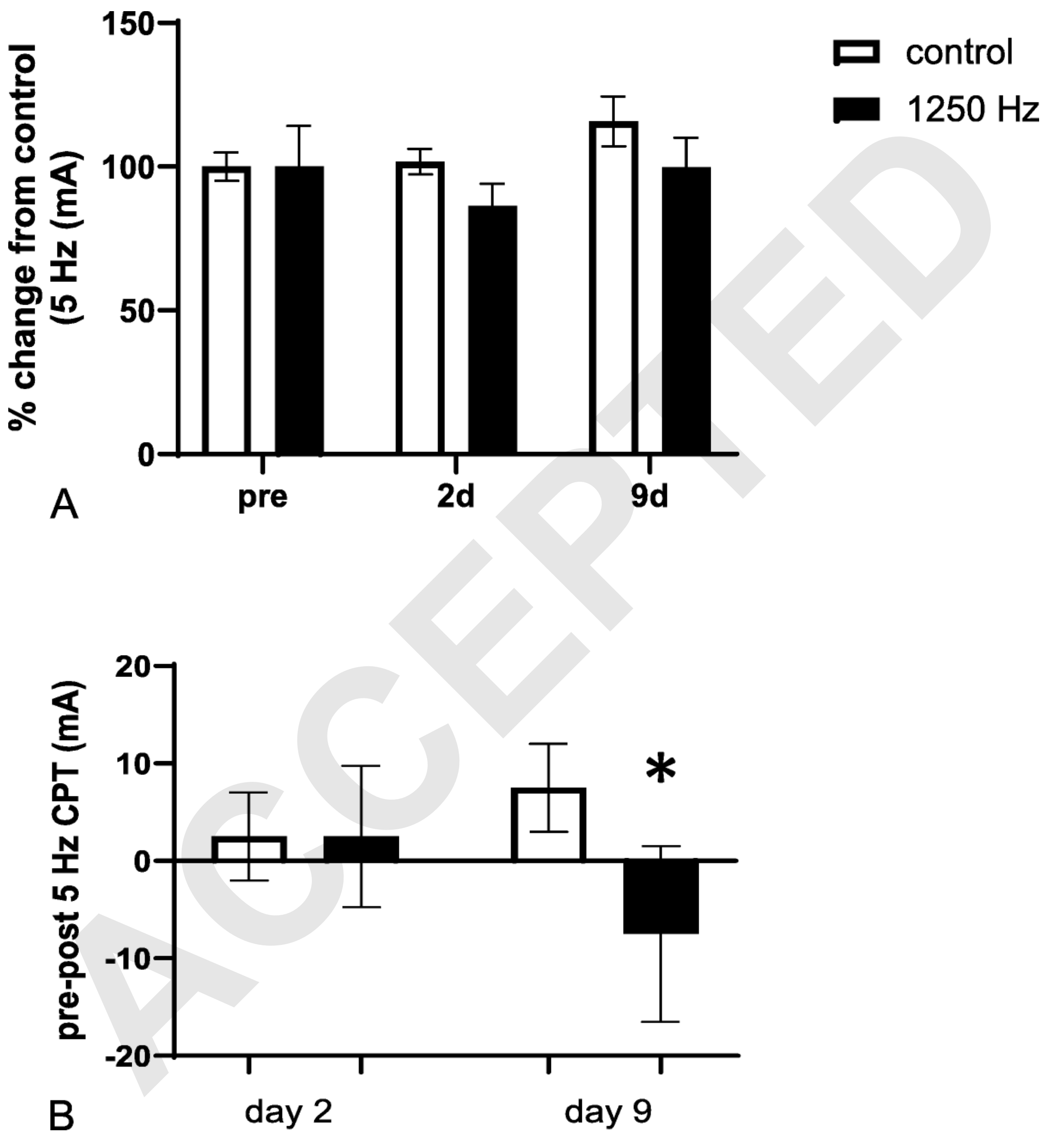
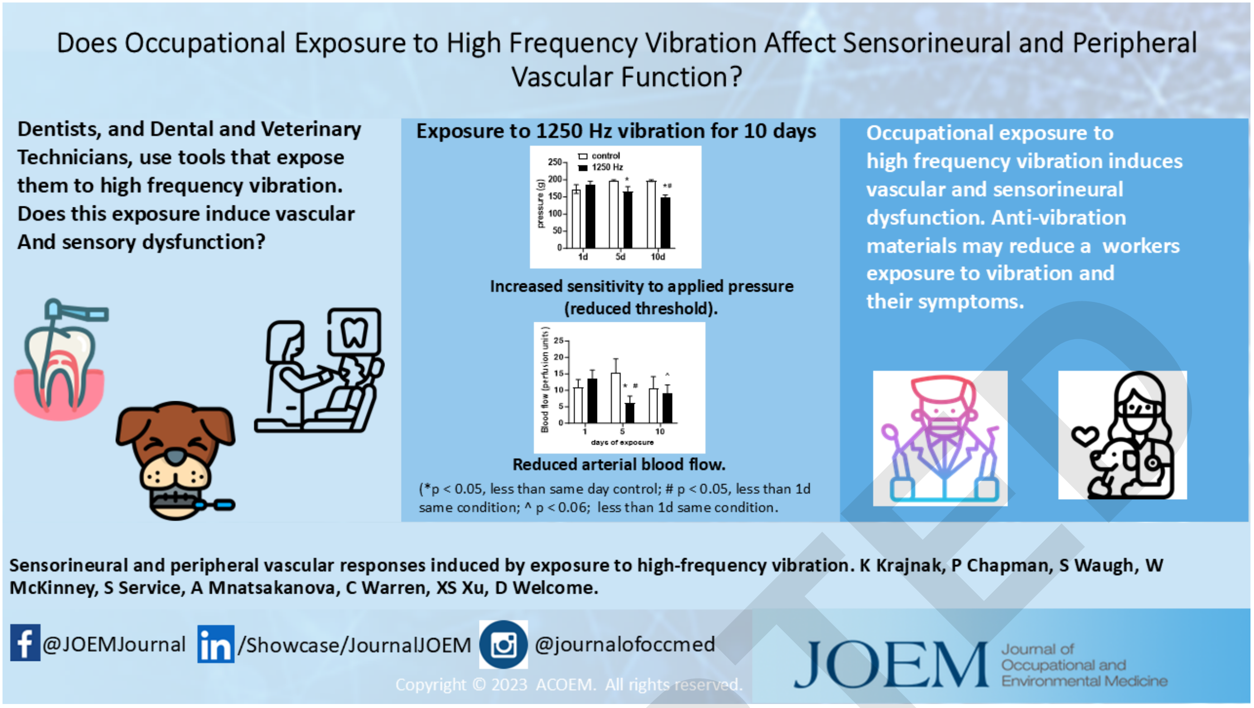

150
100
50
0
% change from control
(250 Hz (mA)
control
1250 Hz
* #
*
pre
2d
9d
A
20
10
0
-10
pre-post 250 Hz CPT (mA)
day 2
day 9
B

Figure 6


150
100
50
0
% change from control
(5 Hz (mA)
control
1250 Hz
A
pre
2d
9d
20
10
0
-10
-20
pre-post 5 Hz CPT (mA)
*
B
day 2
day 9


Does Occupational Exposure to High Frequency Vibration Affect Sensorineural and Peripheral Vascular Function?
Dentists, and Dental and Veterinary Technicians, use tools that expose them to high frequency vibration. Does this exposure induce vascular And sensory dysfunction?
Exposure to 1250 Hz vibration for 10 days
control
1250 Hz
pressure (g)
1d
5d
10d
Increased sensitivity to applied pressure (reduced threshold).
Blood flow (perfusion units)
days of exposure
Reduced arterial blood flow.
(*p < 0.05, less than same day control; # p < 0.05, less than 1d same condition; ^ p < 0.06; less than 1d same condition.
Occupational exposure to high frequency vibration induces vascular and sensorineural dysfunction. Anti-vibration materials may reduce a workers exposure to vibration and their symptoms.
Sensorineural and peripheral vascular responses induced by exposure to high-frequency vibration. K Krajnak, P Chapman, S Waugh, W McKinney, S Service, A Mnatsakanova, C Warren, XS Xu, D Welcome.
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