Drewno 2019, Vol. 62, No. 203
DOI: 10.12841/wood.1644-3985.298.04

Ashish Kumar Singh, Makkhan Lal Meena, Himanshu Chaudhary, Sougata Karmakar

ASSESSMENT OF LOW-COST INTERVENTION (FOAM RUBBER) AMONG WOOD CARVERS EXPOSED TO HAND-ARM VIBRATION AND NOISE

Despite having diversified products, some part of Indian handicrafts is still untapped with lack of awareness about new traditions. This interventional study is first of its kind to investigate the occupational use of carving hand tool that contributes to the development of hand-arm vibration (HAV) and noise. Reductions in HAV were evaluated using low-cost foam rubber as damping intervention on the tool handle. Sound pressure levels under actual work conditions were measured. The exposure was monitored from twenty experienced wood carvers. We used system usability scale as a basis to analyse the usability of foam rubber on bare handle. The daily vibration exposure indicated reduction by around 20% when compared to conventional handle. Mean equivalent sound pressure level (Lex, 8 h) was quite high (93.17 dB (A)), exceeding the exposure limit. The intervention was effective in curtailing frequency-weighted acceleration in dominant axes, but, deficient in reducing peak values during the field testing. The damping intervention showed a positive effect on usability ratings. The other contribution of the study is to propose the insight to develop a hand tool that could prevail over HAV to a greater extent. The implementation of hearing conservation programmes and practice of personal protective equipment's have been suggested.

Keywords: wood carving, handicrafts, hand-arm vibration (HAV), noise exposure, hand tool intervention, ergonomics

Introduction

Depending upon the nature of the work and design of hand tool, handicraft operatives can be exposed to awkward posture, forceful gripping, high repetitiveness, and hand-arm vibration (HAV) hazard. These variables are directly associated with the symptoms of carpal tunnel syndrome [Armstrong

Ashish Kumar Singh✉ (*singh.mechanical@yahoo.com*), Sougata Karmakar (*karmakar.sougata@gmail.com*), Department of Design, Indian Institute of Technology (IIT) Guwahati, Assam, India; Makkhan Lal Meena (*mlmeenamnit@gmail.com*), Himanshu Chaudhary (*hchaudhary.mech@mnit.ac.in*), Department of Mechanical Engineering, Malaviya National Institute of Technology

1983; Mital and Kilbom 1992; HSE 2003a; Atroshi 2009]. This research is concerned with HAV emanates from the holding of materials against a mechanical process [HSE 2003b].

HAV health risks due to prolonged use of vibration transmitting hand tools have a direct association with the vascular and peripheral sensory-neural disorders. Moreover, it is also associated with the loss in handgrip strength, vibration white finger (VWF), and carpal tunnel syndrome [NIOSH 1997; Chetter et al. 1998; Bovenzi et al. 2003; HSE 2003b; Pettersson 2013; Azmir et al. 2015]. Kihlberg and Hagberg [1997] opined that the upper arm, elbow, and shoulder were most pretentious regions using low-frequency impact tools whereas, the wrist symptoms were more prominent using high-frequency impact tools [Singh et al. 2019]. Collectively, hand vibration propagates from the direct point of contact of the vibrating surface resulting in HAV exposure symptoms.

In the handicrafts industry, noise exposure from hand-held non-powered and powered tools is rather common. The average noise exposure permitted is 90 dB(A) for the 8-hour working day and shall not be exposed to noise level exceeding 115 dB(A) at any time [OSHA; CPCB 1948]. According to the National Institute of Occupational Safety and Health [NIOSH 1996], the average noise exposure recommended is 85 dB(A) for the 8 h working day and shall not be exposed to continuous, varying, intermittent, or impulsive noise exceeding 140 dB(A) at any time. The workers exposed to hand-transmitted vibration and noise are at higher risk in loss of hearing threshold varies with frequency [Pettersson et al. 2011; Pettersson 2013].

Indian handicrafts industry possesses around 50% of the national product by informal sector which makes it the largest producer and exporter in the international market [NSC 2012]. The export of Indian handicrafts rose exceptionally to US$ 335 billion in the year 2015-2016 [EPCH 2015a]. According to the provisional data available the exports of handicrafts have shown an increase of US$ 231.17 million, i.e., the exports increased by 13.5% in one year [EPCH 2015b].

Apart from blue pottery, leather crafts, hand-knotted carpets, and imitation jewellery, Rajasthan is also famous for producing wood crafted products. Major buyers of wooden wares are Australia, Canada, France, and Germany [EPCH 2015a]. The export of wooden wares in 2015-16 was US$ 587.5 million which were 18.21% of India's total handicrafts exports [EPCH 2015c]. The woodcraft sector is vital to the economy and personal livelihoods. The state of Rajasthan is also widely known for its exotic sandalwood. Wood carving is potentially famous especially in Jaipur, Bassi, Jodhpur, Pratapgarh, Udaipur and Bikaner region within the state. Rosewood, teak, sandalwood, and walnut are commonly used for carving intricate designs. These kinds of wood are used for carving sculpture, statue, wooden toys, furniture, decorative items, gift items, utility items, and other home interior decoration structures. It is believed to be of great religious importance and therefore religious figures, carved sculptures and prayer beads are considered sacred in all traditions.

Intricate craftsmanship, lesser innovation and outdated techniques, lack of infrastructural facilities, and poor working conditions are the major barriers to effective work performance in this industry. Consequently, make it less competent to other handicrafts supplying countries [Singh et al. 2017]. Productivity in the area of craft products primarily depends on the handwork practices involved as the earning depends on manual work. For improving the productivity, occupational health and safety issues, as well as poor work practices, need to be addressed [Choobineh et al. 2007; Wani and Jaiswal 2012; Singh et al. 2018a]. Therefore, we believe these factors somehow linked with the ergonomic perspective.

Studies carried out in the past have mostly assessed musculoskeletal disorders (MSDs), working conditions, and physiological factors among the workers in the handicraft industry [Choobineh et al. 2004a; Gangopadhyay et al. 2010; Ghosh et al. 2010; Chaman et al. 2015; Mrunalini and Logeswari 2016]. Besides these factors, the design of hand tools contributes to building up the risks of carpal tunnel syndrome (CTS). Design of hand tools developed the foundation to ease the efforts of the workers, thus resulting in lower MSDs among them [Choobineh et al. 2004b; Motamedzade et al. 2007].

Mukhopadhyay and Srivastava [2010] investigated the musculoskeletal risk factor involved blue pottery, handloom and gota patti craft sectors of Jaipur in India. Ergonomics job analysis methods were used to indicate the immediate need for hand tool and workstation interventions. Furthermore, the lack of rationale for the use of the methods to characterize ergonomics challenges during handicraft work in different informal sectors suggests that the area needs to be explored. Much research in recent years has focused on muscular and neurological examinations, palpation, range of motion, muscle strength tests and visual demand assessments in the imitation jewellery occupation [Untimanon et al. 2006; De et al. 2012; Salve 2015a; Salve 2015b].

Susanha and Sujitra [2007] in their study pointed out that woodcarving workers were at risk to occupational health problems that include backache, asthma, gastric ulcer, eyesight problems, and skin problems. Past studies suggested that woodworkers are highly prone to respiratory tract problems due to exposure to wood dust during woodworking causing respiratory symptoms such as chronic bronchitis, cough, and breathlessness [Scheeper et al. 1995; Bosan and Okpapi 2004; Soongkhang and Laohasiriwong 2017].

However, major concerns of these studies were only on assessing the prevalence of occupational health hazards among handicraft operatives. A literature review indicates that no significant research has carried out so far in wood carving from occupational vibration and noise exposure perspective, despite heterogeneous tools used. Wood carving is vibrant since the 17^{th} century and is much more tedious and extremely labour intensive as compared to other crafting tasks.

There remains a need for assessing exposure to hand-transmitted vibration and noise among the workers involved in the manufacturing of wooden crafts. Therefore, we sought useful to take up the issues of the ergonomic study of workers. The research aimed to determine the transmissibility of HAV and prevalence of noise exposure to them. In low-income countries, informal sectors are not willing to use expensive tools, and that makes it challenging to implement the research interventions to overcome the worker's problems [Singh and Khan 2014]. This study hypothesizes that relatively low-cost foam rubber coatings used on the tool handle reduce the hand transmitted vibrations significantly.

Materials and methods

Task involved in wood carving

During this study, we have investigated the HAV and noise exposure among the workers involved in wood carving crafts trade. The details of the tasks involved in this occupations have been discussed. The outlines of the final figure were first sketched on the wooden block. The woodcarver sits in a squat posture holding the wooden block and carving it using different types of cutters. Highly precise works are still done using these tools. They produce quick work by the ease in tracing the patterns and smooth transition in round edges. As the cutter head is forced on the wooden block, it carves with the vibration against the wood. The final polishing was done by forcing the half round and square files against the semi-finished sculpture. The woodcarvers are exposed to hand vibration and noise during both the processes. Figure 1a shows some of the finished carved products. For the HAV measurement, the carving was done to produce a sculpture on a cylindrically shaped sandalwood block with diameter 3 cm and length 12 cm dimension (fig. 1b).

Participants

The exploratory study was conducted within the urban and rural area of Jaipur region. The selection of male participants was based on their respective occupations. A total of 20 male participants, aged between 23 and 46 (mean 33.2; SD 7.2) were randomly selected for the experiment from five workshops of handicrafts manufacturers. All of them were right hand dominant with no history of upper extremity disorders and permanent hearing impairment. No participants underwent audiometric screening during the past and reported no documented sensorineural hearing loss. These workshops were situated at different locations in Bagru, and Kalwar regions within Jaipur district. Minimum 3 year of work experience on the same job was the inclusion criteria for this study. The university Institutional Review Board approved all experimental procedures, and the study received written approval from the workshops prior to their participation in the study.

Fig. 1. (a) Finished wood carved craft products; (b) Semi-finished work piece developed in the present study

Table 1 shows the demographic description and general information of woodcarvers related to work. The description of mean BMI was 22.2 ±1.8 (normal) [WHO 2000]; mean BSA was 1.64 ±0.1 m^2 (normal). The daily hours spent by the participants was 9.8 ±0.42 hours with rest of 45-60 minutes each day, and weekly workload was 67.2 ±3.6 hours (7 days working). It was observed that all the participants were having education below secondary.

Table 1. Demographic statistics and general information of woodcarvers (n=20)

Demographic Characteristics	Mean ±SD
Age of subject (years)	33.2 ±7.2
Weight of subject (Kg)	59.1 ±6.9
Stature of subject (cm)	163.1 ±4.8
BMI (Kg/m^2)	22.2 ±1.9
BSA (m^2)	1.64 ±0.1
Experience (years)	11.1 ±7.1
Daily workload (hour)	9.8 ±0.42
Weekly Workload (hour)	67.2 ±3.6

Prototype handle

The physical structures of the traditional wood carving tooling arrangement are shown in figure 2, and their technical characteristics are presented in table 2. A prototype intervention of carving handle was constructed as per ergonomic design principles [Lewis and Narayan 1993]. Nitrile Polyvinyl Chloride (NPVC) foam rubber grip was used on the tool handle as a low-cost solution to prevail HAV. Besides aesthetic advantages, they also protect the metal from rust, scratches, vibration, impacts and, cracks [Fellows and Freivalds 1991]. The shore hardness value (Type A) of NPVC was measured using shore durometer (flat cone point (0.79 mm) 35° included angle) and found to be 30HA.

Based on the anthropometric measurements from the study of Meena et al. [2013] on 160 handicraft workers, the 95th percentile value of handbreadth at metacarpal was used to calculate the length of the prototype handle [Lewis and Narayan 1993; Das et al. 2005; Dewangan et al. 2008]. Taking, 0.5 cm clearance on both sides, the handle length came out to be 10.8 cm. Less than 5th percentile value of the inside grip diameter was recommended for the better gripping [Lewis and Narayan 1993; Dewangan et al. 2008]. Therefore, the diameter of the handle was taken as 3.4 cm. Foam rubber sheet of thickness 1.25 cm was used to attain the required diameter of the handle. Foam rubber to metal handle bonding was done using Araldite standard rubber based epoxy adhesive (Resin + Hardener).

Fig. 2. Physical structure of conventional wood carving tool arrangement. (a) driving motor and pulley arrangement; (b) carving tool handle; (c) various cutters used during carving, chisel, tool handles and a wooden work piece; (d) cutters used for examining HAV during the present study

Table 2. Technical characteristics of conventional wood carving tools

Parameters	Driving motor	Tool handle	Cutter 1	Cutter 2	Cutter 3	Cutter 4
Power, kW	1.12	–	–	–	–	–
Voltage, V	220-240	–	–	–	–	–
Max speed, min^{-1}	1740-2200	–	2500-3000	2500-3000	2500-3000	2500-3000
Length, cm	–	12	–	–	–	–
Max Diameter, cm	–	2.5	3	4.2	1.8	1.2
No. of teeth	–	–	17	26	20	15
Material	–	steel	heat treated steel	heat treated steel	heat treated steel	heat treated steel

Vibration measurement

The hand vibration was measured with a tri-axial accelerometer [PCB Piezotronics Inc., Depew, NY], model 356A01 (1.0-gram weight, 6.35 mm × 6.35 × 6.35 mm size, ±1000 g peak shock survival) [PCB Piezotronics Inc.]. The accelerometers were chosen by the expected vibration magnitude (5 mV/g, ±20%) and frequency range (2 to 8000 Hz, ±5%) during the wood carving in the normal environmental conditions [ISO 8041:2005]. The raw acceleration output was collected using sensor signal conditioner/amplifier (model 482C05, PCB Piezotronics Inc., Depew, NY), NI cDAQ-9171 chassis [NIC manual] and NI-DAQmx, programmable Data Acquisition Unit, Model No. NI 9234 (4 differential analog input channels, 51.2 kS/s per channel sample rate, ±5 V measurement range, 24-bit resolution) (National Instruments Corporation, Austin, TX) [NIC 9234 manual]. The calibration standards and procedures strictly followed as per the manufacturer's guidelines. The NI Data Acquisition Unit and PCB Piezotronics accelerometers have a calibration certificate. Routine calibration of tri-axial accelerometers and associated instrumentation are done on an annual basis. These acceleration values were displayed in LabVIEW software (version 13, National Instruments Corporation, Austin, TX) at a chosen sampling rate of 1024 samples per channel per second and equivalent vibrations along x, y and z-direction were calculated.

For the most practical measurements, the accelerometers were firmly mounted on the back of the dominant hand using double-sided tape. The accelerometer for the hand positioned x-axis, i.e., the longitudinal axis of the third metacarpal bone. It was oriented parallel to the sides of the digits. The y-axis was set perpendicular to the x-axis, and parallel to an imaginary line passing through the palm in the normal anatomical hand position. The z-axis was set perpendicular to the other two axes and directed parallel to the knuckles [ISO 2001] (fig. 3b).

Fig. 3. (a) Typical working posture during carving the wooden specimen; (b) Orientation of accelerometer on workers hand

Task assigned for experiment/ procedure for measurement

The procedure defined in IS/ISO 5349-1:2001 [ISO 2001] was followed to measure the vibration levels and the frequency spectra in all the three axes simultaneously. Each of the subjects was asked to carve the wooden specimen using their typical working posture as they would during normal work (fig. 3a). The carving was done on a cylindrically shaped sandalwood block with diameter 3 cm and length 12 cm dimension (fig. 1b). Four different types of cutters (fig. 2d) were used to chipping off extra wood, and fine details were worked out. Three readings were taken for each tool, and each reading was taken of at least 60 s. The testing sequence for each participant was randomized. The un--weighted vibration data were collected for the last 10 s of each testing session. For the most practical purpose, mean daily usage for each cutter was taken as 120 minutes for calculating estimated daily exposure, A(8) value. The daily vibration exposure depends on the magnitude of the combined values of the frequency-weighted acceleration for the three axes and the duration of the exposure.

Two tool handles (conventional and prototype) and four cutters were considered as independent variables for conducting the experiments. Therefore, eight conditions were formed for each participant. A total of 160 experimental (8 experiment × 20 subjects) runs were performed for the response output (HAV), and the corresponding performance data were collected.

Crest factor and power in the band were calculated from the acquired signals. The crest factor defines to the ratio between the crest value (maximum peak value of the signal during the considered period) and RMS value of the signal for that period [Dron and Bolaers 2004]. Higher crest factor indicates the harmful content of vibration and represents high impulsive vibration [Morioka and Maeda 1998]. Power in band measures the total power within any specified frequency range or band. The range considered was 8 Hz to 12.5 kHz as the lower and upper bound of the frequency band.

Usability scores

Modified product usability scale (SUS) [Bangor et al. 2008; Bangor et al. 2009] was deployed to evaluate the usability of the prototype intervention. It is a validation tool having a 5-point Likert scale that ranged from Strongly Disagree to Agree Strongly. The mean SUS score having a scale of 0 to 100, if tends to 100 implies higher perceived usability. Some researchers have found the scoring of SUS complicated involving calculation on both positive and negative statement among the ten questions [Sauro and Lewis 2011]. However, the inventor himself [Brooke 2013] [46] provided sufficient evidence of its simplicity and reliability (alpha = 0.91) when doing usability evaluations.

Noise exposure measurement

Wood carving work was performed in small workshops (area: < 300 ft^2). The noise exposure was monitored using a logging noise dosimeter (Noise Pro DLX-1 ANSI S1.25-1991, Cole-Parmer Instrument Company, Vernon Hills, IL) with A-frequency weighing, having an exchange rate of 5 dB (A), criterion level at 90 dB (A), criterion time of 8 h, threshold level at 80 dB (A), resolution of 0.1 dB, and with Fast response rate exponential averager. Calibration was performed prior to and following each field study using Quest calibrator (3M Quest QC-10) complying with ANSI S1.40-1984 and IEC 942:1988 Class 1 standards. The 3M Quest field calibrator device was also recalibrated annually by manufacturer's service engineer.

Each participant was monitored for 8 effective hours starting from 9 am to 5 pm as the measurement time for this study. In order to avoid the effect of the variability of the noises that a carver can suffer, the data was recorded during the work and rest time [Jackson-Oman et al. 1994]. No other tools were used in the workshop other than carving cutters, and most of the work locations for wood carving consists of 1-2 employees working at the same time. The microphone was attached to the dominant hand collar of the monitored worker at a distance 10 and 15 cm from the ear. Indexes such as the equivalent sound pressure level (L_{ex}, 8 h) and peak sound pressure level (L_{peak}) were measured and further downloaded into the spreadsheets for further analysis.

Statistical analysis

Tool handles (conventional and prototype) and cutters were taken as independent variables, while vibration level, peak value, crest factor and power in band at the dominant hand were considered the dependent variables. Student's t-test was conducted to evaluate the effectiveness of the intervention with the hypothesis that significant difference in the vibration values, peak values, crest factor and power in band values in dominant directions before and after the prototype intervention. These data were analysed using SPSS version 22 for significance at 95 and 99% confidence intervals.

Results and discussion

Acceleration time-history and frequency spectra

This study presents the evidence that the vibration magnitudes may be influenced by the ergonomic design of the hand tools, albeit to a moderate degree. It seems higher frequencies (> 100 Hz) of vibration tend to be involved during wood carving task. Studies reported that the vibration frequencies above 100 Hz are primarily absorbed in hand and wrist [Kihlberg and Hagberg 1997; Singh et al. 2019]. Moreover, these ranges of frequencies can produce physiological changes in the vascular system that may cause dysfunction of the neurovascular system [Krajnak et al. 2010]. Even though, lower frequencies are also undesirable and should not be discounted [Dale et al. 2011; Singh et al. 2018b]. The elbow, upper arm, and shoulder are prone to be affected by the use of low-frequency impact tools [Kihlberg and Hagberg 1997].

Vibrations are transmitted to hand from the tool handle. Some of the vibrations were absorbed by the foam rubber used in prototype handle for the tool. The frequency profiles were investigated from the data obtained for both the tool handles, and the peak frequency spectrum (from the FFT computations) were examined graphically. The peak frequency values for all the cutters except cutter 4 were dominant in z-direction and minimum in the x-direction in line with the results obtained for vibration magnitudes. For cutters (1, 2 and 3), the peak frequency values ranged 95 to 112 Hz in the y-direction, 103 to 125 Hz in the z-direction and less than 25 Hz for all recordings in x-direction respectively. For the cutter 4, the frequency ranged 108 to 220 Hz in the y-direction and 110 to 125 Hz in the z-direction. Although, the peak frequency seemed in the range of 110 to 220 Hz for all recordings in x-direction respectively. The reason could be due to the fact that cutter 4 was used to carve intricate designs on the sculpture with different wrist positions.

Descriptive statistics for vibration levels

Table 3 provides descriptive statistics for RMS frequency un-weighted and weighted acceleration magnitudes for the back of the dominant hand in x, y and z-axes corresponding to different combinations of cutters used. The peak and crest value corresponding to un-weighted acceleration magnitudes were assessed to document the effect of handle material on them. It was evident that the magnitude of vibration for prototype handles was reduced and absorbed by the material used in the prototype handles when compared with the bare handle. The RMS frequency-weighted acceleration magnitudes recorded in the case of all the cutters was dominant in the z-direction for both conventional, and prototype handles. The results indicated that minimum vibrations were found in the x-direction for the tool handles in each cutter (fig. 4).

A box plot plotted for the comparative study shows that the total value (a_{hv}) for cutters was found larger for the conventional handle as compared to new prototype handle developed (fig. 5). The estimated daily exposure, A(8) value, for the conventional handle was notably larger as compared to permissible limits (table 4), and the workers were at significant risk of developing the HAVS. Importantly, A(8) value, for prototypes handle in all cutter combination (2.4 m/s^2) were significantly reduced by 20% compared to conventional handle (3.0 m/s^2).

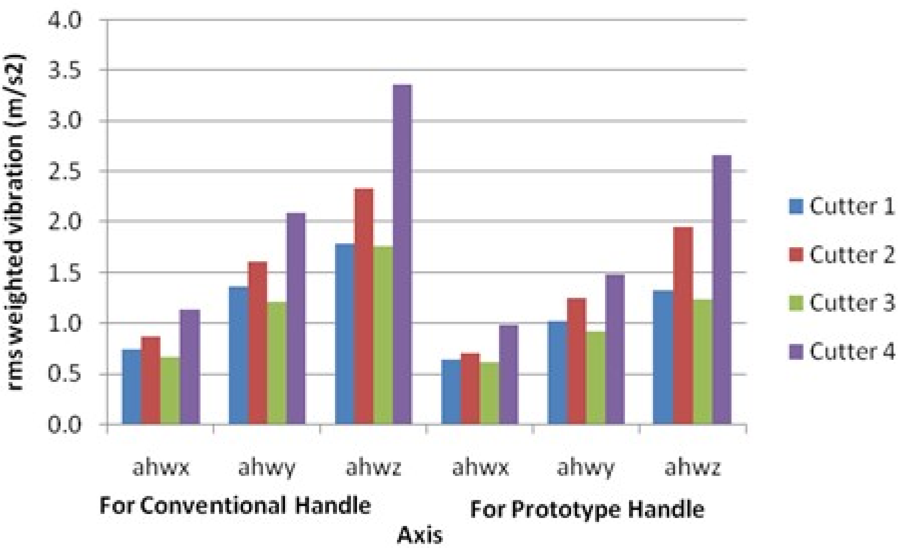

Fig. 4. The mean values of RMS vibrations (m/s^2) recorded for all cutters at both conventional and prototype tool handles

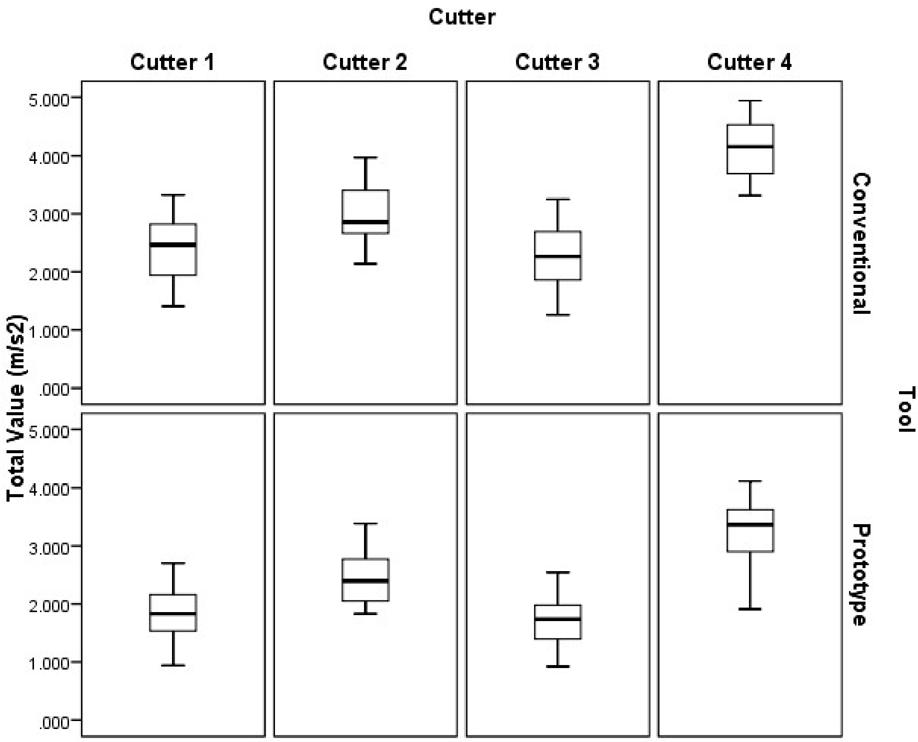

Fig. 5. Box Plot showing RMS value of hand vibration (m/s^2) for all cutters in conventional and prototype tool handles

Note: The box represent inter-quartile range containing 50% of the total value of RMS frequency-weighted vibration. The horizontal line inside the box represents the median value of total value of RMS frequency-weighted vibration. The whiskers indicate the smallest and largest data values.

Meanwhile, this study presents the evidence of the reduction in vibration exposure values among the workers in wood carving industries proposing the insight to develop a better design. This finding is in agreement with the past studies indicating the effective ergonomic interventions to reduce the vibration values to a significant level [Edwards and Holt 2006; Dale et al. 2011; Coenen et al. 2014]. Ko et al. [2011] in their study evaluated the worker's perception in terms of the exposure to the vibration for several designs of the tool handles. According to Mallick [2008], a proper selection of the design parameters of the handles can minimize the HAV. It is also advisable to introduced job rotation to reduce the exposure time.

Table 3. Descriptive statistics of vibration analysed data for all the cutters at the three axes in conventional and prototype tool handles

Tool handle	Cutter	Axis	RMS unweighted acceleration a_h (m/s^2)	Peak value	Crest factor	RMS frequency-weighted acceleration a_{hw} (m/s^2)	Total value a_{hv} (m/s^2)
Conventional	Cutter 1	x	5.00 (1.86)	38.24 (14.55)	8.49 (4.18)	0.74 (.20)	2.38 (0.58)
		y	9.77 (2.95)	77.84 (24.04)	8.18 (2.25)	1.38 (0.33)	
		z	11.57 (3.34)	107.51 (36.63)	9.54 (2.92)	1.79 (0.44)	
	Cutter 2	x	6.15 (1.62)	46.26 (23.50)	7.48 (3.40)	0.87 (0.21)	2.98 (0.57)
		y	12.48 (3.08)	92.33 (33.64)	7.37 (1.86)	1.61 (0.45)	
		z	15.63 (2.73)	94.59 (40.64)	5.97 (2.05)	2.34 (0.36)	
	Cutter 3	x	4.92 (1.80)	40.62 (20.72)	7.82 (2.36)	0.67 (0.21)	2.25 (0.62)
		y	9.55 (3.39)	78.94 (31.82)	8.32 (2.20)	1.22 (0.29)	
		z	11.87 (3.77)	101.94 (33.88)	8.78 (2.71)	1.76 (0.53)	
	Cutter 4	x	12.76 (2.37)	124.75 (39.70)	9.95 (3.31)	1.15 (0.14)	4.13 (0.50)
		y	23.10 (3.13)	205.05 (47.05)	8.89 (1.85)	2.10 (0.29)	
		z	26.77 (3.15)	205.55 (64.87)	7.64 (2.12)	3.37 (0.40)	
Prototype	Cutter 1	x	4.79 (1.93)	33.80 (12.75)	8.32 (5.08)	0.65 (0.22)	1.82 (0.56)
		y	7.65 (3.17)	62.74 (22.75)	8.83 (3.06)	1.03 (0.35)	
		z	10.13 (3.64)	89.62 (32.08)	9.22 (2.64)	1.34 (0.42)	
	Cutter 2	x	5.70 (2.04)	40.72 (19.86)	7.71 (4.43)	0.71 (0.25)	2.44 (0.45)
		y	10.45 (3.53)	65.55 (24.58)	6.43 (2.11)	1.26 (0.38)	
		z	13.84 (3.52)	79.28 (29.67)	5.92 (2.42)	1.95 (0.28)	
	Cutter 3	x	4.43 (1.69)	33.35 (16.15)	7.33 (2.32)	0.62 (0.20)	1.68 (0.47)
		y	8.39 (3.18)	63.63 (28.19)	7.63 (1.87)	0.93 (0.31)	
		z	10.28 (4.03)	91.56 (28.97)	9.39 (2.78)	1.24 (0.32)	
	Cutter 4	x	10.83 (3.08)	104.51 (23.24)	10.08 (2.81)	0.99 (0.27)	3.22 (0.67)
		y	19.03 (4.40)	158.47 (43.71)	8.62 (2.88)	1.48 (0.34)	
		z	22.13 (4.62)	174.08 (45.99)	8.14 (2.69)	2.67 (0.58)	

Equivalent vibration levels, peak value, crest value and power in band at hand in z and y-direction

As the acceleration magnitudes for the cutters was dominant in z-direction and y-direction, the data for vibration transmitted, peak value, crest factor, and power in band were tested for significance as per ISO 5349-1:2001 for hand-transmitted vibrations (table 5). It was observed that the vibration transmitted at the back of the hand was maximum in cutter 4 and minimum in cutter 3 for both z and y-direction for both types of handles.

Table 4. Total vibration values of three component values for conventional and prototype tool handles for all cutters and daily vibration exposure A(8)

Tool Handle	Cutter	Total vibration value (m/s^2)	Mean daily usage (min)	A(8)
Conventional	Cutter 1	2.38	120	3.0
	Cutter 2	2.98	120	
	Cutter 3	2.25	120	
	Cutter 4	4.13	120	
Prototype	Cutter 1	1.82	120	2.4
	Cutter 2	2.44	120	
	Cutter 3	1.68	120	
	Cutter 4	3.22	120	

The result from the t-test indicates that there was a significant drop ($p < 0.01$) in RMS frequency-weighted acceleration magnitudes and power in band for both z and y-axes while using prototype handles. Interestingly, the peak values for cutter 4 (significant, $p < 0.05$) and cutter 2 (marginal, $p < 0.05$) in y-direction were reduced by applying the foam rubber coating to the bare handle. However, surprisingly, no significant difference was found in peak values, and crest factor in both z and y-direction in most of the cases for conventional and prototype tool handles.

The material used for reducing the vibration, i.e., NPVC foam rubber showed promising results in curtailing frequency-weighted acceleration in dominant axes, but surprisingly, was deficient in reducing peak values incurred during wood carving. Therefore, it is advisable to explore materials that may bring down the peak values and in turn crest factor to reduce the harmful impulsiveness. Nonetheless, on the basis of transmitted vibration from tool to hand, it could be concluded that the coating certainly curtailed the vibration magnitudes to an extent but fail to reduce the impact during the process. A low--cost solution was recommended in the present research.

In agreement with the vibration transmissibility, a positive effect of the foam rubber coating on handles was also found on the usability rating. The mean SUS score for the conventional and prototype handle were 52.50 (ranging from 38 to 60.5) and 77.25 (ranging from 61.5 to 90.5). Probably it is due to the reason that the workers at the palm contact felt the lower magnitude of vibration. Additionally, the diameter of the handle and softness along the handle provided greater comfort. The finding suggests and has an interpretation that this

Table 5. Vibration transmitted, peak value, crest factor and power density in the dominant directions

Axis	Tool handle cutter type	Conventional	Prototype		Conventional	Prototype		Conventional	Prototype		Conventional	Prototype	
		r.m.s. frequency-weighted acceleration, a_{hwy} (m/s^2)		*p* value	peak value		*p* value	crest factor		*p* value	power in band		*p* value
y	Cutter 1	1.38 (0.33)	1.03 (0.35)	0.000**	77.84(24.04)	62.74(22.75)	0.166	8.18 (2.25)	8.83 (3.06)	0.593	1.956072 (0.730379)	1.359223 (0.438566)	0.002**
	Cutter 2	1.61 (0.45)	1.26 (0.38)	0.002**	92.33(33.64)	65.55(24.58)	0.057	7.37 (1.86)	6.43 (2.11)	0.302	2.119281 (0.638541)	1.598556 (0.509515)	0.000**
	Cutter 3	1.22 (0.29)	0.93 (0.31)	0.000**	78.94(31.82)	63.63(28.19)	0.270	8.32 (2.20)	7.63 (1.87)	0.463	1.612495 (0.475075)	1.177133 (0.442873)	0.000**
	Cutter 4	2.10 (0.29)	1.48 (0.34)	0.000**	205.05(47.05)	158.47 (43.71)	0.034*	8.89 (1.85)	8.62 (2.88)	0.809	3.667020 (0.806381)	2.642368 (0.576326)	0.000**
z	Cutter 1	1.79 (0.44)	1.34 (0.42)	0.000**	107.51(36.63)	89.62(32.08)	0.261	9.54 (2.92)	9.22 (2.64)	0.799	3.406743 (1.404685)	2.279290 (0.881971)	0.002**
	Cutter 2	2.34 (0.36)	1.95 (0.28)	0.000**	94.59(40.64)	79.28(29.67)	0.349	5.97 (2.05)	5.92 (2.42)	0.960	4.880307 (1.106574)	3.184329 (0.805726)	0.000**
	Cutter 3	1.76 (0.53)	1.24 (0.32)	0.000**	101.94(33.88)	91.56(28.97)	0.471	8.78 (2.71)	9.39 (2.78)	0.622	3.006541 (1.204759)	1.918146 (0.676399)	0.000**
	Cutter 4	3.37 (0.40)	2.67 (0.58)	0.001**	205.55(64.87)	174.08(45.99)	0.227	7.64 (2.12)	8.14 (2.69)	0.646	8.693340 (1.854312)	6.020380 (1.840483)	0.000**

*($p < 0.05$).
**($p < 0.01$).

prototype handle is easy to use and compatible to hand size since it provided higher usability scores. The higher SUS score has an interpretation that the usability of the product is generally acceptable [Bangor et al. 2008; Bangor et al. 2009]. Therefore, in terms of usability, the handles for the prototypes seem to be better than the conventional tools with bare handles.

Equivalent sound pressure levels and dose assessment

The experimental workers were exposed to a high dose of noise level that exceeds the permissible limits of daily equivalent A-weighted level for an 8-hour period. Results of the noise measurements reveal that equivalent sound pressure level (Lex, 8h), and peak sound pressure level (Lpeak) under study ranged from 89.6 dB(A) to 98.8 dB(A) (mean 93.17 dB(A)) and 98.2 dB(A) to 115.8 dB(A) (mean 108.27 dB(A)). Evidence showed that the sound pressure level within the work environment was quite high (exceeding the maximum exposure limit of 90dB (A)) [CPCB 1948] and potentially harmful to the health of the workers. All the workers suffered noise exposure above NIOSH recommended limit of 85 dB(A). Two out of twenty workers were exposed to noise level exceeding 115 dB(A) Lpeak at any time, not complying with the current regulation.

Further longitudinal work is needed to explore the ergonomic designs of carving hand tool interventions that are adjustable in terms of the anthropometric dimensions, i.e., fit for 5^{th} to 95^{th} percentile of the workers. It is advisable to carry out studies to unravel the specific materials for handles that may reduce the vibration magnitudes, peak and crest level to a greater extent. Application of wooden handles may further reduce vibration level at the surface of handle due to damping properties of wood [Singh and Khan 2014; Singh et al. 2018b]. Solutions for curtailing sound pressure level within the acceptable limits should be taken on an immediate basis. Perhaps, it leads to effective sustainability and the improvement in the quality of work life among the workers.

This is the first empirical study of its kind to investigate the prevalence of noise level among the group of wood carvers in India. The approach should be considered in light of several limitations that should be acknowledged. Though, sound pressure level was extensively high during the daily work. The Indian industries should be encouraged to implement hearing conservation programmes, and the workers should be motivated to use personal protective equipment’s (PPE) [Singh et al. 2009; Singh et al. 2013; Singh 2018]. The shift in hearing threshold was not considered in the present analysis. The loss in the hearing abilities has been positively associated with the HAV and the intensity and duration of noise exposure [Pyykkö et al. 1987; Pettersson et al. 2011; Pettersson 2013]. Moreover, it must be borne in mind that small sample size, control of grip and feed forces limits the ability to make statistical inferences and generalizations about the results. However, this study reflects a drop in vibration level for each cutter used in handle intervention. The repetition of hand movements and postural positions for a prolonged period can be considerable factors in imposing discomfort. Postural assessment and estimation of permanent threshold shift (PTS) in woodcraft workers is the future scope of the study.

Conclusions

Based on the results, it is evident that the workers are significantly influenced by the use of improperly designed hand tools. Therefore, it is necessary for the contractors in the informal sectors to take responsibility for occupational health and safety of the craftsmen. The crux of the study indicates that conventional work practices were promptly associated with hand-transmitted vibration. It is preferable to use foam rubber coating on tool handles as a temporary low-cost solution as it was damping vibrations effectively. The research also points a higher propensity of noise exposure (as per IS 7194:1994 standards) among the wood carvers.

This study demonstrates the potential risk factors and further research is hence needed to explore the better ergonomic interventions to curtail the peak values and harmful impulsiveness. It must be borne in mind that this study was only conducted on a small exposed group of wood carvers. No generalized conclusion could be drawn for using the prototype tools before further studies, but a positive sign of the test response was directed towards the insight to develop a better design. We have considered equal exposure time (120 min) for each cutter, thereby limiting the A(8) value. The mean daily usage for each cutter may vary as per the sculpture size and shape which is the limitation of this study. It should be noted though; the daily exposure may increase or decrease with relatively longer or shorter duration of individual cutters.

The research also points that further longitudinal work is needed to explore shift in hearing threshold in the carving occupation. Future directions include assessment of loss in hearing threshold due to the occupational use of carving hand tools, implementation of hearing conservation programmes and practice of personal protective equipment's.

References

Armstrong T.J. [1983]: An ergonomics guide to carpal tunnel syndrome. American Industrial Hygiene Association. Akron, Ohio, USA

Atroshi I. [2009]: What is the evidence for a cause-and-effect linkage between occupational hand use and symptoms of carpal tunnel, In: Evidence-Based Orthopaedics: The Best Answers to Clinical Questions. 1st ed. Philadelphia, PA: Saunders/Elsevier, ISBN: 978-1-4160-4444-4

Azmir N.A., Ghazali M.I., Yahya M.N., Ali M.H., Song J.I. [2015]: Effect of hand arm vibration on the development of vibration induce disorder among grass cutter workers. Procedia Manufacturing 2:87-91. ISSN 2351-9789

Bangor A., Kortum P., Miller J. [2009]: Determining what individual SUS scores mean: Adding an adjective rating scale. Journal of usability studies 4 [3]: 114-23

Bangor A., Kortum P.T., Miller J.T. [2008]: An empirical evaluation of the system usability scale. International Journal of Human–Computer Interaction. 24 [6]: 574-594

Bosan I.B., Okpapi J.U. [2004]: Respiratory symptoms and ventilatory function impairment among wood workers in the Savannah Belt of Northern Nigeria. Annals of African Medicine 3 [1]: 22-27

Bovenzi M., Rui F., Versini W., Tommasini M., Nataletti P. [2003]: Hand-arm vibration syndrome and upper limb disorders associated with forestry work. La Medicina del lavoro. 95 [4]: 282-296. PMID: 15532961

Brooke J. [2013]: SUS: a retrospective. Journal of usability studies 8 [2]: 29-40

Central Pollution Control Board (CPCB) [1948]: Noise pollution norms – model rules of the factories act. ministry of environment and forests. [accessed: 19.11.2016]. Available from: http://envfor.nic.in/citizen/specinfo/noise.html

Chaman R., Aliyari R., Sadeghian F., Shoaa J.V., Masoudi M., Zahedi S., Bakhshi M.A. [2015]: Psychosocial factors and musculoskeletal pain among rural hand-woven carpet weavers in Iran. Safety and Health at Work 6: 120-127

Chetter I.C., Kent P.J., Kester R.C. [1998]: The hand arm vibration syndrome: A review. Cardiovascular Surgery 6 [1]: 1-9. DOI: https://doi.org/10.1177/096721099800600101

Choobineh A., Hosseini M., Lahmi C., Jazani R.K., Shahnavaz H.. [2007]: Musculoskeletal problems in Iranian hand-woven carpet industry: Guidelines for workstation design. Applied Ergonomics 38: 617-624

Choobineh A., Shahnavaz H., Lahmi M. [2004a]: Major health risk factors in Iranian hand--woven carpet industry. International Journal of Occupational Safety and Ergonomics 10 [1]: 65-78

Choobineh A., Tosianb R., Alhamdic Z., Davarzanieb M. [2004b]: Technical note: Ergonomic intervention in carpet mending operation. Applied Ergonomics. 35: 493-496

Coenen P., Formanoy M., Douwes M., Bosch T., de Kraker H. [2014]: Validity and inter--observer reliability of subjective hand-arm vibration assessments. Applied Ergonomics 45 [4]:1257-1262. DOI: 10.1016/j.apergo.2014.03.003

Dale A.M., Rohn A.E., Burwell A., Shannon W., Standeven J., Patton A., Evanoff B. [2011]: Evaluation of anti-vibration interventions for the hand during sheet metal assembly work. Work 39 [2]: 169-76

Das B., Jongkol P., Ngui S. [2005]: Snap-on-handles for a non-powered hacksaw: an ergonomics evaluation, redesign and testing. Ergonomics 48 [1]: 78-97

De A., Dhar U., Virkar T., Altekar C., Mishra W., Parmar V. [2012]: Mutakekar M, Iqbal R and Chandra A.M. A study of subjective visual disturbances in jewellery manufacturing. Work 41 [Supplement 1]: 3404-3411

Dewangan K.N., Owary C., Datta R.K. [2008]: Anthropometric data of female farm workers from north eastern India and design of hand tools of the hilly region. International Journal of Industrial Ergonomics 38 [1]: 90-100

Dron J.P., Bolaers F. [2004]: Improvement of the sensitivity of the scalar indicators (crest factor, kurtosis) using a de-noising method by spectral subtraction: application to the detection of defects in ball bearings. Journal of Sound and Vibration. 270 [1]: 61-73

Edwards D.J., Holt G.D. [2006]: Hand-arm vibration exposure from construction tools: results of a field study. Construction Management and Economics 24 [2]: 209-17. DOI: 10.1080/01446190500310643

Export Promotion Council for Handicrafts (EPCH) [2015a]: Country wise export's share of handicrafts during 2015–2016. New Delhi [online]. Available from: http://www.epch.in/moreDetails.htm [accessed 10 September 2016]

Export Promotion Council for Handicrafts (EPCH) [2015b]: Review Exports during 2015–2016. New Delhi [online]. Available from: http://www.epch.in/policies/exportdata.pdf [accessed 10.09.2016]

Export Promotion Council for Handicrafts (EPCH) [2015c]: Export import data bank during 2015–2016, 2015c. New Delhi [online]. Available from: http://www.commerce.nic.in/eidb/ecom.asp. [accessed 12.09.2016]

Fellows G.L., Freivalds A. [1991]: Ergonomics evaluation of a foam rubber grip for tool handles. Applied Ergonomics 22 [4]: 225-30

Gangopadhyay S., Das B., Das T., Ghoshal G., Ghosh T. [2010]: An ergonomics study on posture-related discomfort and occupational-related disorders among stonecutters of West Bengal, India. International Journal of Occupational Safety and Ergonomics 16 [1]: 69-79. DOI: 10.1080/10803548.2010.11076830

Ghosh T., Das B., Gangopadhyay S. [2010]: Work-related musculoskeletal disorder: An occupational disorder of the goldsmiths in India. Indian Journal of Community Medicine 35 [2]: 321

HSE [2003a]: Essentials of health and safety at work, The Health and Safety Executive, London.

HSE [2003b]: Hand-arm Vibration, The Health and Safety Executive, London. Document ref: HSG88

Jackson-Oman, P.A., Wynne, M.K., Kasten, R.N. [1994]: Prediction of 8-hour noise dose from brief duration samples. Journal American Academy of Audiology 5: 402-411

Kihlberg S., Hagberg M. [1997]: Hand-arm symptoms related to impact and nonimpact hand-held power tools. Int. Arch. Occup. Environ. Health 69[4]: 282-288

Ko Y.H., Ean O.L., Ripin Z.M. [2011]: The design and development of suspended handles for reducing hand-arm vibration in petrol driven grass trimmer. Int. J. Ind. Ergon. 41 [5]: 459-470. DOI:10.1016/j.ergon.2011.04.004

Krajnak K., Miller G.R., Waugh S., Johnson C., Li S., Kashon M.L. [2010]: Characterization of frequency-dependent responses of the vascular system to repetitive vibration. J. Occup. Environ. Medicine 52 [6]: 584-594

Lewis W.G., Narayan C.V. [1993]: Design and sizing of ergonomic handles for hand tools. App. Ergon. 24 [5]: 351-356

Mallick Z. [2008]: Evaluation and optimization of handle design parameters of a grass trimming machine. Int. J. Occup. Saf. Ergon. 14 [3]: 343-349

Meena M.L., Dangayach G.S., Bhardwaj A. [2013]: Measuring anthropometric data for designing hand tools in handicraft industries. Int. J. Process Management and Benchmarking 3 [3]: 334-351

Mital A., Kilbom A. [1992]: Design, selection and use of hand tools to alleviate trauma of the upper extremities: Part II – The scientific basis (knowledge base) for the guide. Int. J. Ind. Ergon. 10 [1-2]: 7-21

Morioka M., Maeda S. [1998]: Measurement of hand-transmitted vibration of tapping the long cane for visually handicapped people in Japan. Ind. Health 36 [2]: 179-190

Motamedzade M., Choobineh A., Mououdi M.A., Arghami S. [2007]: Ergonomic design of carpet weaving hand tools. Int. J. Ind. Ergon. 37: 581-587

Mrunalini A., Logeswari S. [2016]: Musculoskeletal problems of artisans in informal sector – a review study. Int J Environ, Ecology, Family and Urban Studies. 6 [1]: 163-170

Mukhopadhyay P., Srivastava S. [2010]: Ergonomic design issues in some craft sectors of jaipur. The Design J. 13 [1]: 99-124

National Institute for Occupational Safety and Health (NIOSH) [1997]: MSDs and workplace factors; DHHS (NIOSH). Publication No. 97-141

National Institute for Occupational Safety and Health (NIOSH) [1996]: Criteria for A Recommended Standard Occupational Noise Exposure Revised Criteria. 1996. Accessed: 19.11.2016. Available from: http://www.cdc.gov/niosh/docs/98-126

National Instruments Corporation (NIC 9234), 4-channel circuit board. National Instruments Corporation, Austin, Texas. Available from: http://www.ni.com/datasheet/pdf/en/ds-316

National Instruments Corporation (NIC) cDAQ-9171 chassis. National Instruments Corporation, Austin, Texas. Available from: http://www.ni.com/pdf/manuals/372838e.pdf

National Statistical Commission (NSC) [2012]. Report of the Committee on Unorganized Sector Statistics. [online] Available from: http://www.lmis.gov.in/sites/default/files/NSC-report-unorg-sector-statistics.pdf (accessed 14 July 2016)

Occupational Safety and Health Administration. (OSHA). Technical Manual Noise Measurement. Regulations and Standards, Section III: Chapter 5. Accessed: 18.11.2016. Available from: https://www.osha.gov/dts/osta/otm/new_noise/.

PCB Piezotronics Inc, 356A01 accelerometers. PCB Piezotronics Inc., Walden, NY. Available from: https://www.pcb.com/contentstore/docs/PCB_Corporate/Vibration/Products/Manuals/356A01.pdf

Pettersson H., Burström L., Nilsson T. [2011]: The effect on the temporary threshold shift in hearing acuity from combined exposure to authentic noise and hand-arm vibration. Int. Arch. Occup. Environ. Health 84 [8]: 951-957

Pettersson H. [2013]: Risk of hearing loss from combined exposure to hand-arm vibrations and noise [Doctoral dissertation]. Umeå universitet; Retrieved June 26, 2016, Available from: https://www.diva-portal.org/smash/get/diva2:589455/FULLTEXT01.pdf

Pyykkö I., Pekkarinen J., Starck J. [1987]: Sensory-neural hearing loss during combined noise and vibration exposure. Int. Arch. Occup. Environ. Health 59 [5]: 439-454

Salve U.R. [2015a]: Prevalence of musculoskeletal discomfort among the workers engaged in jewelry manufacturing. Indian J. Occup. Environ. Med. 19: 44-55

Salve U.R. [2015b]: Vision-related problems among the workers engaged in jewellery manufacturing. Indian J. Occup. Environ. Med. 19: 30-35

Sauro J., Lewis J.R. [2011]: When designing usability questionnaires, does it hurt to be positive?. InProceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 2215-2224). ACM

Scheeper B., Kromhout H., Boleij J.S. [1995]: Wood-dust exposure during wood-working processes. The Annals of Occupational Hygiene 39 [2]: 141-154

Singh A.K. [2018]: Comparative assessment of shift in hearing threshold among handicraft operatives' in India. Ergonomics 62 [1]: 88-102. DOI: 10.1080/00140139.2018.1519121

Singh A.K., Meena M.L., Chaudhary H., Dangayach G.S. [2017]: Ergonomic assessment and prevalence of musculoskeletal disorders among washer-men during carpet washing: guidelines to an effective sustainability in workstation design. Int. J. Human Factors Ergon. 5 [1]: 22-43

Singh A.K., Meena M.L., Chaudhary H. [2018a]: Ergonomic evaluation of cumulative trauma disorders among female carpet weavers in India: guidelines to an effective sustainability in work system design. Int. J. Human Factors Ergon. 5 [2]: 129-150

Singh A.K., Meena M.L., Chaudhary H. [2018b]: Assessment of low cost tool intervention among carpet alignment workers exposed to hand-arm vibration and shift in hearing threshold. Int. J. Human Factors Ergon. 5 [3]: 189-209

Singh A.K., Meena M.L., Chaudhary H. [2019]: Ergonomic evaluation of low-cost intervention for carpet trimming workers exposed to hand vibration and noise. Noise Vibration Worldwide 50 [30]: 78-91. DOI: 10.1177/0957456519834545

Singh J., Khan A.A. [2014]: Effect of coating over the handle of a drill machine on vibration transmissibility. Appl. Ergon. 45 [2]: 239-246

Singh L.P., Bhardwaj A., Deepak K.K., Raman B.E. [2009]: Occupational noise exposure in small scale hand tools manufacturing (forging) industry (SSI) in Northern India. Ind. Health 47 [4]: 423-430

Singh L.P., Bhardwaj A., Deepak K.K. [2013]: Occupational noise-induced hearing loss in Indian steel industry workers an exploratory study. Human factors: The J. Hum. Fact. Ergon. Soc. 55 [2]: 411-424

Soongkhang I., Laohasiriwong W. [2017]: Respiratory tract problems among wood furniture manufacturing factory workers in the northeast of Thailand. Kathmandu University Medical Journal 13 [2]: 125-129

Susanha Y., Sujitra T. [2007]: Self-care health behaviors among woodcarving workers. Nursing J. 34: 58-59

Untimanon O., Pacharatrakul W., Boonmeepong K., Thammagarun L., Laemun N., Taptagaporn S., Chongsuvivatwong V. [2006]: Visual problems among electronic and jewelry workers in Thailand (Occupational health/safety in the world). Journal of Occupational Health 48 [5]: 407-412

Wani K.A., Jaiswal Y.K. [2012]: Health risk factors in different seasons of carpet industry in Kashmir, India. Int. J. Occup. Saf. Ergon. 18 [4]: 571-577

World Health Organization [2000]: The Asia Pacific perspective: redefining obesity and its treatment. Geneva, Switzerland

List of standards

IS 7194:1994 Assessment of noise exposure during work for hearing conservation purpose

ISO 8041:2005 Human response to vibration- Measuring Instrumentation

ISO 5349-1:2001 Mechanical vibration. Measurement and evaluation of human exposure to hand-transmitted vibration. Part 1

ISO 5349-2:2001 Mechanical vibration. Measurement and evaluation of human exposure to hand-transmitted vibration. Part 2

Submission date: 14.08.2018

Online publication date: 14.05.2019