Assessment of low-cost tool intervention among carpet alignment workers exposed to hand-arm vibration and shift in hearing threshold

Ashish Kumar Singh*, M.L. Meena
and Himanshu Chaudhary

Department of Mechanical Engineering,
Malaviya National Institute of Technology,
Jaipur, 302017, India
Email: singh.mechanical@yahoo.com
Email: mlmeenamnit@gmail.com
Email: hchaudhary.mech@mnit.ac.in
*Corresponding author

Abstract: The aim of this study was to assess the hand-arm vibration (HAV), noise exposure, and loss in hearing threshold (HT) due to the hand tools used in carpet alignment. The effect of new handles on the transmissibility of HAV was tested. Data about HAV and noise level were collected from 10 experienced workers. A case-control study was conducted to compare the HT and hand grip strength (GS) among the workers with a control group. The daily vibration exposure, A(8) for prototypes tools for both hands indicated reduction by over 26% when compared to the conventional tools. Mean equivalent sound pressure level (L_{eq}) was quiet high (97.62 dB), exceeding the exposure limit. In agreement with dose consumed, exposed workers exhibits mild to moderate hearing impairment in the frequency range of 1500–6000 Hz with the loss in GS. Strain Index score revealed that the current working posture requires urgent action. As the main outcomes, a low cost intervention was found effective in curtailing HAV during the field testing.

Keywords: carpet alignment; hand arm vibration; HAV; noise exposure; hearing threshold; SI; strain index; hand tool intervention; ergonomics; low frequency vibrations; non-powered hand tools; noise induced hearing loss; NIHL; handicrafts.

Reference to this paper should be made as follows: Singh, A.K., Meena, M.L. and Chaudhary, H. (2018) 'Assessment of low-cost tool intervention among carpet alignment workers exposed to hand-arm vibration and shift in hearing threshold', *Int. J. Human Factors and Ergonomics*, Vol. 5, No. 3, pp.189–209.

Biographical notes: Ashish Kumar Singh is a Research Scholar in Department of Mechanical Engineering in Malaviya National Institute of Technology (MNIT), Jaipur. He graduated in Mechanical Engineering from University of Rajasthan, Jaipur. He obtained his Master's in Quality Management from Birla Institute of Technology and Science (BITS), Pilani. His research areas are ergonomics, work system design, human response to vibration exposure, noise exposure, quality, and productivity engineering.

M.L. Meena is an Assistant Professor in Department of Mechanical Engineering in Malaviya National Institute of Technology (MNIT), Jaipur. He graduated in Mechanical Engineering from University of Rajasthan, Jaipur in 2005. He obtained his Master's in Manufacturing System Engineering from Malaviya National Institute of Technology Jaipur. He earned his PhD from MNIT, Jaipur. He has published 73 research papers in various national and international journals and conferences. His research areas are quality, ergonomics and productivity engineering. He has 10 years of teaching and research experience.

Himanshu Chaudhary is an Associate Professor in Department of Mechanical Engineering in Malaviya National Institute of Technology (MNIT), Jaipur. He graduated in Mechanical Engineering from Engineering College, Kota. He obtained his Master's in Solids Mechanics & Design from IIT Kanpur. He earned his Doctorate in Machine Design from IIT Delhi. He is actively working in the field of Kinematics and Dynamics of Machinery. He is more interested in dynamic and balancing of multibody systems such as closed-loop mechanisms and manipulators. He has published in about 50 journal and conference papers and a book "Dynamics and Balancing of Multibody Systems" by Springer (2009). He is the reviewer of several international journals and his current activities include studies and design of agricultural machinery.

1 Introduction

Carpet repairing is an important stage in carpet production which has a direct effect on the carpet economy (Choobineh et al., 2004a). Carpet alignment is carried out before any other repairing work. It corrects the length and breadth, border, flowers, figures and halves of the carpet to appropriate relative positions. Furthermore, each one of them needs to be aligned taking no other part into account. Aligning uses metal rod, different chisels, an inch tape and also performed at the back of a carpet.

During alignment, the worker sitting in squatting posture holds the chisel in their non-dominant hand and a metal rod in their dominant hand. They hammer the rod against the chisel to align the threads into the carpet (Figure 1). This type of work results in repetitive wrist deviation of the dominant hand. Holding both the tools throughout the process of alignment leads to forced cylindrical grasping in each of the hand. Intermittent but prolonged use of these hand tools also leads exposure to the hand-transmitted vibration and high sound pressure levels.

The poor design of hand tool, awkward posture, forceful gripping, high repetitiveness, mechanical stress, and hand vibration are linked with the symptoms of carpal tunnel syndrome (Atroshi, 2009; Armstrong, 1983; Mital and Kilbom, 1992). Safety guidelines for the upper extremity prevented workplace injuries, and reduced the risk of cumulative trauma disorders (CTD) (HSE, 1990).

Occupational hand arm vibration (HAV) exposure due to prolonged use of vibration transmitting hand tools has a direct association with the vascular and peripheral sensory-neural disorders. Moreover, it was also associated with the loss in hand grip strength, and carpal tunnel syndrome (Azmir et al., 2015; Bovenzi et al., 2003; NIOSH, 1997; Chetter et al., 1998; Pettersson, 2013). Kihlberg and Hagberg (1997) opined that the upper arm, elbow and shoulder were more affected regions during the use of low-frequency impact tools. Whereas, the wrist symptoms were more prominent while using high-frequency impact tools.

Figure 1 (a) A typical postural position adapted to perform carpet alignment and (b) conventional chisel and hammering rod (see online version for colours)

(a) (b)

The maximum sound pressure level permitted is 90 dB(A) for 8h per day and shall not be exposed to noise level exceeding 115 dB(A) at any time (OSHA, n.d.; CPCB, 1948). According to the National Institute of Occupational Safety and Health (NIOSH, 1996), the maximum sound pressure level permitted is 85 dB(A) for 8h per day and shall not be exposed to continuous, varying, intermittent, or impulsive noise exceeding 140 dBA at any time. The workers exposed to hand-transmitted vibration and noise are at higher risk in loss of hearing threshold (Pettersson, 2013; Pettersson et al., 2011).

Researches carried out in the past have mostly assessed musculoskeletal disorders (MSDs), working conditions, and physiological factors among the workers in the hand-woven carpet industry (Choobineh et al., 2004b; Chaman et al., 2015; Durlov et al., 2014; Afshari et al., 2014; Nazari et al., 2012). Besides these factors, the design of hand tools contributes to build up the risks of carpal tunnel syndrome (CTS) (Choobineh et al., 2004a; Motamedzade et al., 2007). A majority of related studies were undertaken in the Persian countries during the past decade.

Literature related to the carpet industries workers of India is available to a limited extent and primarily focused on the occupational health problems during weaving (Durlov et al., 2014; Metgud et al., 2008; Das et al., 1992; Rastogi et al., 2003; Pandit et al., 2013). Investigations concerned with the working environment of weavers during different seasons in the state of Kashmir and Madhya Pradesh (India), were carried out. They brought attention that these workers were prone to several health risks during different seasons (Wani and Jaiswal, 2012; Wani and Khan, 2015).

The literature review confirmed that no significant research has been carried out so far in carpet alignment from occupational vibration and noise exposure perspective, despite heterogeneous tools used. It is much more difficult and labour intensive as compared to the other repairing tasks. Therefore, we sought useful to take up the study on the alignment workers. The research aimed to determine and evaluate the effect of new handles on the transmissibility of HAV and prevalence of noise exposure to them. In achieving these objectives, the following hypotheses were set in:

- this study hypothesises that the values of HAV would be significantly lower with the use of prototype intervention when compared to values measured with the conventional tools
- the other hypothesis is that the workers exposed to HAV and high noise will have a significant loss in hearing threshold and hand grip strength when compared to the control group.

2 Methods

Task involved in carpet alignment:

There was no preferential flow which has to be followed for aligning the different parts of a carpet. It was done on what comes while inspecting. In the carpet alignment, hammering was done at the sides of the chisel. An inch tape was used to measure how much alignment is needed. If something needs to be put straight, then a thread was tied for the direction, and different chisels were used for setting the positions of figures and flowers.

Participants:

Ten male respondents, aged between 20 and 46 (mean 32.2; SD 9.53) took part in the exploratory study. All of them were right hand dominant with no history of upper extremity disorders and permanent hearing impairment. No participants underwent audiometry screening during the past and reported no documented sensorineural hearing loss. The study was conducted within the urban area of Jaipur. All male subjects were selected for the survey from a workshop of a carpet manufacturer. This workshop was situated 40 Km away from Jaipur in Sadwa region.

A control group of 10 subjects (carpet repairing/mending) were selected from the same workshop. The demographic description for the exposed and control groups depicts in tabulated form in Table 1. Mean age of the exposed group was statistically matched (at p value of less than 0.05) with the control group. Inclusion criteria for the control group included a hearing acuity threshold of at least 30 dB hearing level (dBHL) for nine frequencies between 250 kHz and 8000 kHz in both ears. All experimental procedures were approved by the university Institutional Review Board, and the study received written approval from the company prior to their participation in the study.

A well-structured questionnaire was administered to the participants with Hindi translation based on the general information, perceptual effort rating scale, and usability rating scale. The checklist comprised three parts:

- general information
- vibration and noise exposure data collection
- Borg scale (Borg, 1982) and usability rating scale (Brooke, 1996).

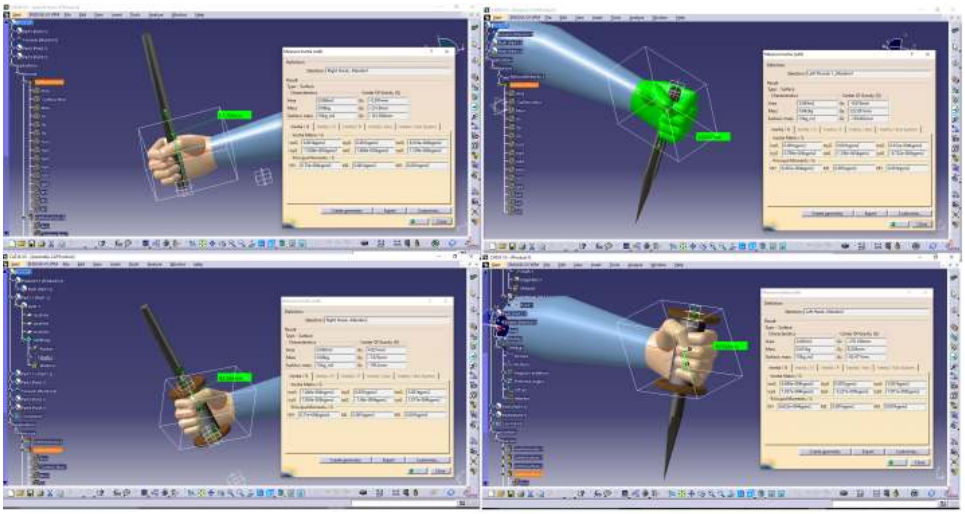
The 0–10 scale over 6–20 scale was used as it is easy to understand by the workers having low literacy rate. As opined by Borg (1982), the 0–10 scale is simple and easy to understand by the lay of the population that is not familiar with technical terminologies. Each participant got a verbal explanation about the Borg scale and usability rating scale prior to the survey.

Prototype tools:

One prototype intervention of hammering rod and chisel was constructed by modifying the conventional tools adopted by the alignment workers. Heat treated plain carbon steel from the leaf springs of scraped vehicles was utilised to make these hand tools. Weaving knife blade and beaters are also made up from the similar material. These prototypes were developed in CATIA software as per the ergonomic design principles. The criteria such as tool weight, the centre of gravity, handle size and handle material were taken into the consideration. Foam rubber grip and Indian teakwood were used on the tool handles. Since, besides aesthetic advantages, they also protect the metal from rust, scratches, vibration, impacts and cracks (Fellows and Freivalds, 1991).

Four hand dimensions have been identified which were considered useful for the prototype tools design. A sliding Vernier Caliper with least count of 0.1 mm and a steel rule were used for hand length, maximum hand breadth and hand breadth at metacarpal measurements. Inside grip diameter was measured using a wooden cone specially made for the purpose.

Figure 2 Dimensional structures of carpet aligning tools in virtual environment (conventional and prototypes) (see online version for colours)



Based on the anthropometric considerations (Table 2), the 95th percentile value of hand breadth at metacarpal was used to calculate the length of the prototype handle (Lewis and Narayan, 1993; Dewangan et al., 2008; Das et al., 2005). Taking, 0.5 cm clearance on both sides, the handle length came out to be 10 cm. 1 cm thick flange head on both sides were incorporated to prevent the hand from slippage (Das et al., 2005). 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 4 cm.

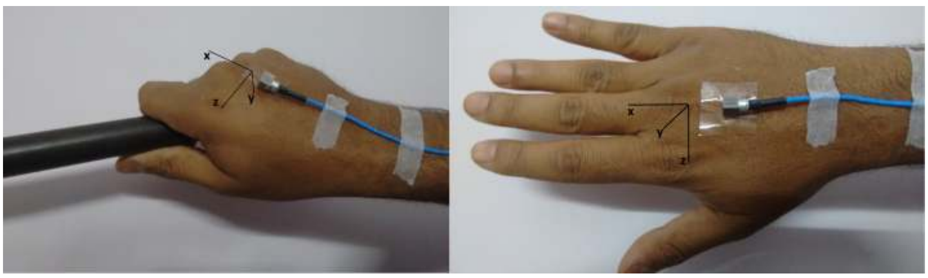
Conversely, the dimensions of the conventional tools measured were ergonomically unsuitable and not gratifying the needs of the workers. It was observed that conventional handles were kept bare with no damping sleeve on it due to which it was uncomfortable in holding. Additionally, the centre of mass of the tool should be as close to the centre of the hand as possible (Strasser, 2007). The variation in centre of mass between hand and tool has been reduced by adding foam rubber grip and Indian teakwood on the prototype tool handles (Figure 2).

Vibration measurement:

The measurement of vibration included two PCB Piezotronics Inc. tri-axial accelerometers, model 356A01 (1.0 g weight, 6.35 × 6.35 × 6.35 mm size, ± 1000 G peak shock survival) (PCB Piezotronics Inc., https://www.pcb.com/contentstore/docs/PCB_Corporate/Vibration/Products/Manuals/356A01.pdf). The accelerometers were chosen by the expected vibration magnitude and frequency range during the carpet alignment in the normal environmental conditions (ISO 8041:2005) (ISO, 2005). Their output was collected using PCB Piezotronics, model 482C05 sensor signal conditioner/amplifier, NI cDAQ-9171 chassis (NIC manual) and NI-DAQmx, programmable Data Acquisition Unit, Model No. NI 9234 (4 differential analogue input channels, 51.2 kS/s per channel sample rate, ±5 V measurement range, 24-bit resolution) (NIC 9234 manual). The acceleration values were displayed in LabVIEW software version 13 at a sampling rate of 10,000 samples per second.

For the most practical measurements, the accelerometers were firmly mounted on the back of both hands using a double-sided tape. The accelerometers for both the hands 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) (Figure 3).

Figure 3 Orientation of accelerometer on workers hand (see online version for colours)



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 provided with an intermittent alignment task using the conventional and the prototype tools. The alignment was done on 9×12 ft^2 sized carpet having 14 counts

(14 × 14 knots/inch) using their typical working posture and grip force as they would during normal work. Three readings of vibration were taken for each tool and each reading was taken of at least 60 s. The testing sequence for each participant was randomised. Vibration recordings began just prior to each trial and un-weighted vibration data were collected for the last 10 s of each testing session.

As per the guidelines specified in IS/IS0 5349-1:2001 (ISO, 2001), the RMS of frequency-weighted acceleration for measuring the HAV is the most important term because hand injuries have dependencies on a different frequency. Therefore, it is recommended that the RMS acceleration values from one-third-octave band analysis can be used to calculate the corresponding frequency-weighted acceleration, a_{hw} using the following equation:

$$a_{hw} = \sqrt{\sum_i \left(W_{hi}\, a_{hi}\right)^2}$$

where,

W_{hi}: Weighting factor for the *i*th one-third-octave band

a_{hi}: RMS acceleration measured in the *i*th one-third-octave band, in m/s^2.

According to IS/IS0 5349-1:2001 (ISO, 2001), the hand tools transmit equally detrimental vibration on the hand from all the three measurement axes. The combined values of the frequency-weighted acceleration for the three axes, a_{hwx}, a_{hwy} and a_{hwz} substitute for the total vibration, a_{hv} using the following equation:

$$a_{hv} = \sqrt{a_{\text{hwx}}^2 + a_{\text{hwy}}^2 + a_{\text{hwz}}^2}$$

where,

a_{hwx}, a_{hwy}, a_{hwz} are frequency-weighted acceleration values for the *x*, *y* and *z* axis.

The daily vibration exposure depends on the magnitude of the vibration total value (a_{hv}) and the duration of the exposure. The workers dealt with more than one tool during the alignment task with the different magnitudes of vibration. The daily vibration exposure, $A(8)$ was estimated based on the following mathematical equation:

$$A(8) = \sqrt{\frac{1}{T_0} \sum_{i=1}^{n} a_{\text{hvi}}^2 T_i}$$

where,

a_{hvi}: Vibration total value for the *i*th operation

n: Number of individual vibration exposures

T_i: Duration of the *i*th operation

T_o: Reference time (8 h = 28,800 s).

Crest factor

The crest factor defines to the ratio between the crest value (maximum peak value of the signal during the considered period of time) and RMS value of the signal for that period of time (Dron and Bolaers, 2004):

$$\text{Crest Factor} = \frac{\text{Peak value}}{\text{RMS value}}$$

Higher crest factor indicates the harmful content of a vibration and represents high impulsive vibration (Morioka and Maeda, 1998).

Noise exposure measurement:

Carpet stretching and alignment work were performed on the first floor in a concrete building hall (area: 9000 ft^2). The noise during the carpet alignment was impulsive or intermittent. The noise exposure was monitored using a logging noise dosimeter (Make: Noise Pro DLX-1 ANSI S1.25-1991) having an exchange rate of 3 dB (A), criterion level at 90 dB (A), criterion time of 8 h, threshold level at 80 dB (A), measuring range from 70–140 dB (A), resolution of 0.1 dB, and with F/S response rate.

The noise level on the floor was steady but impulsive since the alignment was carried out by several workers at a time that cannot be synchronous. The 0.52 inch Electret Condenser 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_{eq}) and peak sound pressure level (L_{peak}) were measured and further downloaded into the spreadsheets for further analysis.

Pure tone audiometric test:

All the participants were invited to perform the pure tone audiometric test using ARPHI PROTON DX5 portable pure tone audiometer. The test was performed in an acoustically treated chamber at the institute laboratory. A control group of 10 subjects (carpet repairing/mending) were also selected from the company. Carpet mending and repairing were performed on the second floor with no direct exposure to the noise.

The test was performed for both the ears at low pitch frequencies of range 0.25–1 kHz, moderate pitch frequencies of range 1–4 kHz and higher pitch frequencies of range 4–8 kHz. The degree of hearing loss was determined by their hearing thresholds. The method followed as reducing the level of tone by 10 dB step until no response obtained. Thereafter, increasing the step by 5 dB until they respond and so-on for other frequency ranges.

Hand grip strength test:

The test was conducted to monitor and analyse the difference in handgrip strength between the exposed and control group of workers. To undertake the test Baseline® hydraulic hand dynamometer (UPC: 714905013552) was used. The workers were tested with a sitting posture including their hips and knees flexed at 90°, elbow flexed at 90°, forearm rotation at 0° and wrist at a neutral position (Nurul Shahida et al., 2015). The workers using their dominant hand (Petersen et al., 1989) applied as much grip pressure as possible for 5 s and repeated the test for the 3 time. The average value was computed to get the physical grip performance (Mackenzie, 2002).

Usability scores:

The usability of the prototype handle was evaluated by using the modified product usability scale (SUS) (Bangor et al., 2008, 2009). The SUS comprised 10 statements, each having a 5-point Likert scale that ranged from *Strongly Disagree* to *Strongly Agree*. The mean SUS score (ranging from 0 to 100) indicate the perception of usability of the product. The close the score tends to 100, implying higher perceived usability. Interview assistance was provided to the respondent to complete the questionnaire. Self-enumeration was difficult due to less understanding and low literacy rate among the participants. As workers of these workshops were mostly illiterate or less educated, statements of the scoresheet/questionnaire were translated to the local language of the state, i.e., Hindi. The interview was conducted by the authors in the local language and responses were entered in scoresheet/questionnaire.

Postural analysis:

The strain index (SI) was designed to meet the objectives of predicting the risk of disorders in distal upper extremity while performing high repetitive tasks (Moore and Garg, 1995). Furthermore, the higher rates of forceful exertion and repetition are associated with carpal tunnel syndrome (Moore et al., 1991; Muggleton et al., 1999).

In this technique, the six task variables i.e. intensity of exertion, duration of exertion per cycle, efforts per minute, wrist posture, speed of exertion, and duration of task per day were measured during the alignment task. The scores were assigned to the corresponding variable. The total evaluated score was used to recognise the degree of risk associated with the task. Digital photographs and videotapes were used as data collection tools for the analysis. Supplementary, the alignment task was divided into the subtasks, i.e., hammering with the dominant hand and holding the chisel with the non-dominant hand.

Statistical analysis:

Student's *t* test was conducted to test the Hypothesis H1 (a) "significant difference in the vibration values, peak values, crest factor and power density values between the conventional and prototype tools".

A Shapiro-Wilk's test ($p > 0.05$) (Shapiro and Wilk, 1965; Razali and Wah, 2011) and a visual inspection of their histograms, normal Q-Q plots and box plots showed that the hearing threshold values and static grip strength were not normally distributed for both exposed and control cases.

Mann-Whitney U test was performed to test the Hypothesis H1 (b) "significantly high hearing threshold within the exposed group as compared to the control group". The other Hypothesis tested was H1 (c) "significant difference in the grip strength of both the hands among the exposed and control group". Mann-Whitney U test is a non-parametric alternative to the independent sample t-test and used when ANOVA's distributional assumptions are not met (Day and Quinn, 1989).

These data were analysed using the Statistical Package for Social Science (SPSS) for Windows version 22.0 (IBM SPSS Statistics for Windows Version 22, Armonk, NY: IBM Corp).

3 Results

The present analyses used data on 10 healthy male carpet alignment workers. Their age ranged from 20 to 46 years (mean 32.2 years; SD 9.53 years). Table 1 shows the demographic description and general information related to the profession. The description of mean body mass index (BMI) was 21.85 ± 2.14 Kg/m^2 (normal) (WHO, 2000); mean body surface area (BSA) was 1.61 ± 0.10 m^2 (normal). It was observed that all the participants were having education below secondary; all had their right-hand dominant. The daily hours spent by the participants was 9.5 ± 0.53 h with a rest of 45–60 min each day and weekly workload was 66.5 ± 3.69 h (seven days working). The mean value of carpet aligned per day was 110 ± 13.12 sq. ft. per worker. The intensity of exertion for left and right hand was 3.9 and 5.5. The mean perceived exertion among the workers was 4.7. Hand anthropometric data of the participants is presented in Table 2.

Table 1 Demographic characteristics of exposed (alignment workers) and control group of workers

Demographic characteristics	*Experimental group Mean (SD)*	*Control group Mean (SD)*	*p value*
Age (years)	32.2 (9.53)	34.4 (8.62)	0.65
Weight (Kg)	57.65 (5.95)	59.77 (6.18)	0.545
Stature (cm)	162.45 (5.12)	163.6 (3.44)	0.472
BMI (Kg/m^2)	21.85 (2.14)	22.29 (1.70)	0.705
BSA (m^2)	1.61 (0.10)	1.65 (0.1)	0.545
Experience (years)	11.8 (8.94)	13 (7.12)	0.543
Weekly workload (hours)	66.5 (3.69)	62.3 (2.21)	0.01*

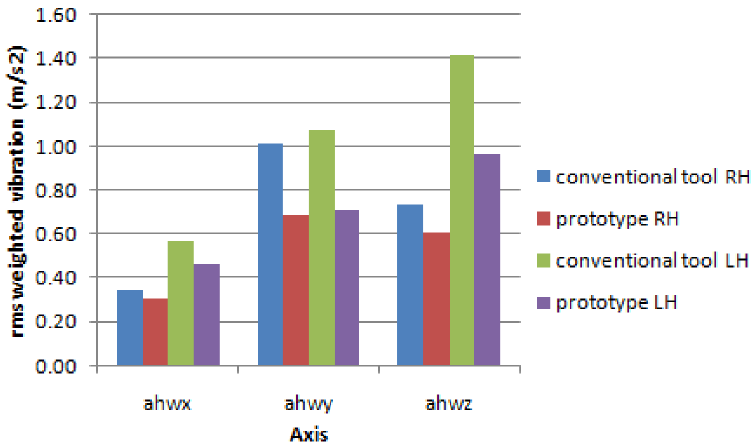
*($p < 0.05$).

Table 2 Hand anthropometric data of participants in the study ($n = 10$)

	Mean (SD)		*5th*		*50th*		*95th*	
Dimensions	*Right hand*	*Left hand*	*Right hand*	*Left hand*	*Right hand*	*Left hand*	*Right hand*	*Left hand*
Hand length (cm)	17.54 (0.97)	17.63 (1.05)	16.19	16.15	17.55	17.70	18.86	19.07
Hand breadth at metacarpal (cm)	8.31 (0.6)	8.24 (0.59)	7.55	7.49	8.30	8.20	9.11	9.00
Maximum hand breadth (cm)	9.75 (0.51)	9.69 (0.53)	9.05	8.99	9.85	9.80	10.37	10.31
Inside grip diameter (cm)	5.21 (0.54)	5.28 (0.58)	4.50	4.49	5.35	5.40	5.81	5.96

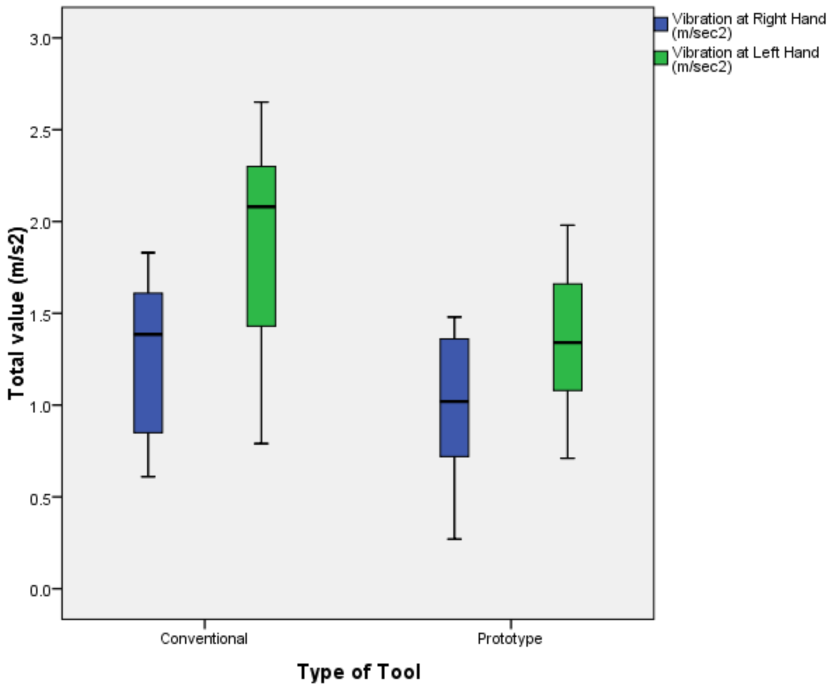
HAV values were collected while the workers were aligning the carpet as part of their normal daily work. Vibrations are transmitted to hand from the tool. Some of the vibrations were absorbed by the wood and foam rubber used in prototype handles for both the tools. It was evident that the magnitude of 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 the left hand (chisel handles) was dominant in z direction (1.42 m/s^2) while for the right hand (hammering tool handles), the dominant axis was y axis (1.09 m/s^2). The results indicated that minimum vibrations were found in x direction for the tools in each hand (Figure 4). The total value (a_{hv}) for left and right hand was found larger for the conventional tools (1.89 m/s^2 and 1.31 m/s^2) as compared to new prototype tools (1.32 m/s^2 and 0.99 m/s^2) developed (Table 3). A box plot of RMS magnitudes of vibration was plotted for the comparative study (Figure 5). Importantly, the estimated daily exposure, *A*(8) values, for prototypes tools for both right and left hand (1.7 m/s^2) were significantly reduced by more than 26% compared to conventional tools (2.3 m/s^2).

Figure 4 The mean values of RMS vibrations (m/s^2) recorded at both hands for conventional and prototype tools (see online version for colours)



RH (Right Hand); LH (Left Hand).

Figure 5 Box plot showing RMS value of hand vibration (m/s^2) for right and left hand in conventional and prototype tools (see online version for colours)



According to the results, maximum RMS vibration values for left hand in conventional and prototype tools were found to be 1.42 m/s^2 and 0.96 m/s^2, respectively. The highest RMS vibration values for right hand in conventional and prototype tools found to be 1.01 m/s^2 and 0.69 m/s^2, respectively. As the acceleration magnitudes for left hand (chisel handles) and right hand (hammering tool handles) was dominant in *z* direction and *y* direction, the data for vibration transmitted, peak value, crest factor and power density were tested for significance as per ISO5349-1:2001 for hand-transmitted vibrations (Tables 4 and 5). The results indicated that there was a significant decrement in the RMS frequency-weighted acceleration magnitudes and power density while using prototype handles. Surprisingly, no significant difference was found in peak values and a crest factor in both *z* and *y* direction for conventional and prototype chisel and hammering tool handles.

Table 3 Descriptive statistics for mean (SD) root mean square (RMS) vibration acceleration magnitudes for left and right hand at the three axes for conventional and prototype tools

Tool	*Hand*	*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	Right	*x*	0.55 (0.18)	6.21 (1.92)	11.36 (0.99)	0.34 (0.12)	1.31 (0.42)
		y	1.04 (0.36)	17.38 (7.75)	16.02 (3.10)	1.01 (0.29)	
		z	1.05 (0.44)	13.52 (6.48)	12.60 (1.50)	0.73 (0.38)	
	Left	*x*	0.96 (0.30)	14.89 (5.35)	15.61 (2.40)	0.57 (0.23)	1.89 (0.58)
		y	1.96 (0.72)	53.48 (15.52)	28.51 (6.26)	1.07 (0.46)	
		z	2.58 (1.24)	48.11 (23.63)	19.24 (4.44)	1.42 (0.40)	
Prototype	Right	*x*	0.46 (0.17)	4.37 (1.89)	10.27 (4.52)	0.31 (0.10)	0.99 (0.41)
		y	0.84 (0.31)	13.68 (5.67)	16.46 (4.52)	0.69 (0.32)	
		z	0.94 (0.38)	11.49 (5.80)	11.82 (2.61)	0.60 (0.32)	
	Left	*x*	0.89 (0.25)	12.68 (4.69)	14.32 (3.12)	0.46 (0.19)	1.32 (0.40)
		y	1.60 (0.62)	45.96 (14.32)	30.55 (9.98)	0.71 (0.21)	
		z	2.24 (1.19)	40.92 (21.91)	18.81 (4.48)	0.96 (0.43)	

Table 4 Root mean square values of vibration levels, peak values, crest factor and power density in *z* direction for conventional and prototype chisel handles

		RMS frequency-weighted acceleration, a_{hwy} (m/s^2)				*Power density*	
Tool	*Hand*	*Mean*	*SD*	*Peak value*	*Crest factor*	*Mean*	*SD*
Conventional	Left	1.42	0.40	48.11 (23.63)	19.24 (4.44)	0.620855	0.478785
Prototype		0.96	0.43	40.92 (21.91)	18.81 (4.48)	0.192641	0.114110
p value		0.045*		0.45	0.88	0.008**	

*($p < 0.05$).

**($p < 0.01$).

Table 5 Root mean square values of vibration levels, peak values, crest factor and power density in *y* direction for conventional and prototype hammering tool handles

		RMS frequency-weighted acceleration, a_{hwy} (m/s^2)				*Power density*	
Tool	*Hand*	*Mean*	*SD*	*Peak value*	*Crest factor*	*Mean*	*SD*
Conventional	Right	1.01	0.29	17.38 (7.75)	16.02 (3.10)	0.217849	0.188713
Prototype	Right	0.69	0.32	13.68 (5.67)	16.46 (4.52)	0.083035	0.041946
p value		0.038*		0.199	0.762	0.005**	

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

As for the frequency spectra of vibration, there were differences in values of amplitude with respect to frequency among the directions. Values of all the axes were quite small compared to the dominant axes. For left hand (*z*-axis), the frequency ranged 45–50 Hz while for the right hand (*y*-axis), the dominant frequency was in the range of 25–30 Hz. Although, it seems very small magnitude of vibration in x direction for both the tools, the peak frequency ranged 20–25 Hz, respectively.

It is also interesting to note that the wood and foam rubber used on both the handles had a positive effect on the usability ratings. The mean SUS score for the hammering rod and chisel handles were 73.25 (ranging from 52.5 to 82.5) and 75.5 (ranging from 62.5 to 87.5). These findings suggest that these prototype handles are easy to use and compatible to hand size since it provided higher usability scores.

Our survey shows that the subjects were exposed to high dose of noise level that exceeds the permissible limits of daily equivalent A-weighted level for the 8-hour period. Results of the noise measurements reveal that equivalent sound pressure level (L_{eq}), and peak sound pressure level (L_{peak}) under study ranged from 95.7 dB(A) to 100.4 dB(A) (mean 97.62 dB(A)) and 104.6 dB(A) to 113.5 dB(A) (mean 108.48 dB(A)). It clearly shows that all the workers, suffer a daily exposure exceeding maximum exposure limit of 90 dB(A), that implies an immediate action according to the current regulation. No workers were exposed to noise level exceeding 115 dB(A) L_{peak} at any time complying with the current regulation.

All volunteers received the air conduction audiometric treatment. In agreement with the amount of dose consumed, the exposure to the high sound pressure level in the exposed group caused higher hearing threshold in all the frequency bands than the control group. Statistical analysis of the data of these groups (with and without noise exposure) revealed a significant difference in the outcome (Table 6). Audiograms for the left and right ear in the exposed group shows slight impairment in the frequency range of 0.25–1.5 kHz and moderate impairment in the frequency range 2–6 kHz (Figure 6).

It was observed that there was a marginal drop in the handgrip strength of the exposed group compared to the control group for the right hand for a chosen level of significance ($p < 0.05$). No significant loss was observed in the left hand (Table 7).

It was evident from strain index (Table 8) that the high values of exertion variables for a prolonged period could cause the discomfort feeling and may directly linked with the CTS. The intensity of exertion on both the hands was evaluated by the perceptual effort rating on the Borg scale during aligning. The duration of effort during hammering and holding the chisel was found to be 0.5 to 0.6 seconds during each effort. Effort frequency was found 100 to 120 efforts per minute. These ranges were taken using a stopwatch on multiple videos recorded. These values were recorded by re-speeding (30 frames/s to 150 frames/s) several videos using a slow motion and time-lapse video software.

Table 6 Descriptive and hearing threshold parameters in exposed and control group of workers for right and left ear at different pitch frequency bands

Parameters	*Experimental group*	*Control group*	*p value*
Frequency at right ear			
250	25.5 (4.4)	24 (6.15)	0.477
500	27 (4.2)	23.5 (5.30)	0.144
1000	29.5 (6.4)	20 (5.77)	0.005**
1500	28.5 (5.8)	23.5 (5.80)	0.081†
2000	36 (5.2)	21 (4.60)	0.000**
3000	43.5 (4.7)	22.5 (5.89)	0.000**
4000	46.5 (5.3)	21.5 (7.09)	0.000**
6000	51 (6.6)	24.5 (6.85)	0.000**
8000	30 (3.3)	19 (6.15)	0.001**
Frequency at left ear			
250	27 (6.32)	22.5 (5.89)	0.111
500	28 (5.4)	23 (6.32)	0.083†
1000	32 (7.9)	21 (5.68)	0.004**
1500	31.5 (8.5)	23.5 (4.74)	0.021*
2000	34.5 (9.6)	22 (4.83)	0.003**
3000	41 (9.4)	21.5 (7.09)	0.000**
4000	43.5 (7.8)	23 (6.75)	0.000**
6000	46 (5.7)	23.5 (6.69)	0.000**
8000	35.5 (6.0)	18.5 (5.30)	0.000**

*($p < 0.05$).
**($p < 0.01$).
†(Slight but not significant).

Table 7 Hand grip strength between exposed and control group

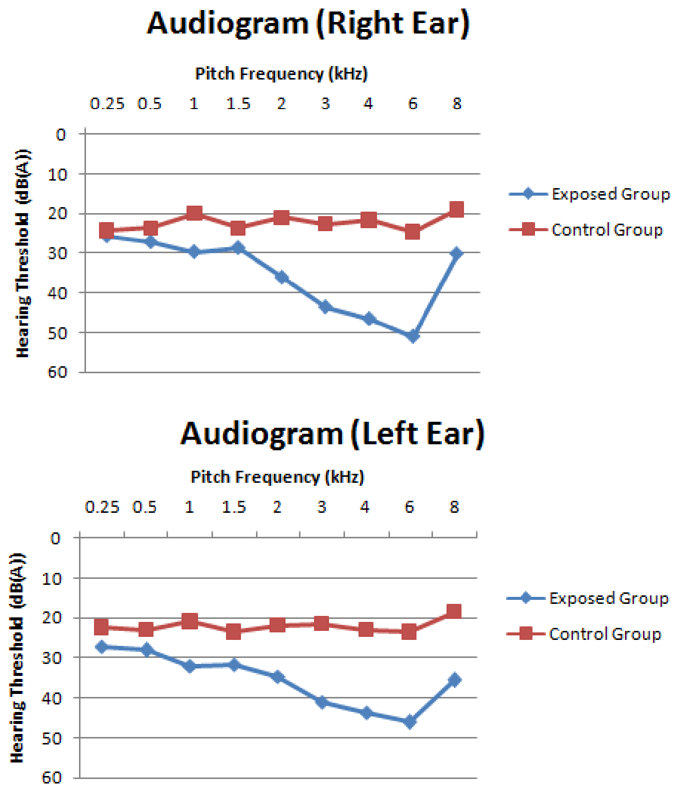
Groups	*Hand*	*Hand grip strength dominant hand* (Kg) *(Mean (SD))*	*Mean rank*	*p*
Exposed group	Right	35.5 (9.1)	7.7	0.034*
Control group		45.5 (9.9)	13.3	
Exposed group	Left	37.2 (8.1)	9.25	0.344
Control group		40.9 (6.3)	11.75	

*($p < 0.05$).

Table 8 Strain index priority score during carpet alignment (sample scoresheet of one subject)

Task (carpet alignment)	*Intensity of exertion*		*Duration of exertion per cycle*		*Efforts per minute*		*Hand and wrist posture*		*Speed of exertion*		*Duration of task per day*		*Strain index score*		*Overall priority*	
	L	*R*	*L*	*R*	*L*	*R*	*L*	*R*	*L*	*R*	*L*	*R*	*L*	*R*	*L*	*R*
Hammering (dominant hand-right) Holding Chisel (non-dominant hand-left)	3	6	3	3	3	3	1	2	1	1	1	1	**27**	**108**	Probably hazardous	Probably hazardous

Figure 6 Audiogram of mean hearing threshold for right and left ear in exposed and control group (see online version for colours)



It was evident from SI analysis that the combinations of scores for dominant hand (hammering subtask) and non-dominant hand (holding chisel subtask) were having a very high overall priority score (SI > 7) for all the subjects. It has an interpretation that a detailed investigation should be immediately done and possible changes should be required in the level of exertion and present posture.

4 Discussion

The findings from this study suggest that the vibration magnitudes may be influenced by the ergonomic design of the hand tools, albeit to a moderate degree. This is the first case-control study of its kind to investigate the prevalence of hearing impairment among the group of the carpet industry workers in India.

There was evidence of the statistically significant influence of the ergonomic design of the hand tools on the average frequency weighted vibration acceleration magnitudes (a_{hvi}) for both the hands. The values of vibration transmitted were reduced in case of prototype handles (coated with wood and foam rubber) indicating improved performance on the basis of hand vibration transmitted. Nonetheless, there was a pronounced fall in the daily exposure, $A(8)$ values associated with an 8-hour period of working, during the use of the prototype tools than conventional. Although, the values of crest factor for dominant direction in both handles were still not significantly different. Hence, the material used for reducing the vibration i.e. wood and foam rubber was deficient in reducing peak values incurred during the carpet alignment. Therefore, it is advisable to explore materials that may bring down the peak values and in turn crest factor to reduce the harmful impulsiveness. It seems only low frequencies (around 25–50 Hz) of vibration tend to be involved during alignment task due to hard gripping of the hand tools for precision and to avoid slippage. The upper arm, elbow and shoulder are prone to be affected during the use of low-frequency impact tools (Kihlberg and Hagberg, 1997).

A low-cost solution was recommended in the present research. This finding is in agreement with the past studies indicating the effective ergonomic interventions to reduce the vibration values to a significant level (Dale et al., 2011; Edwards and Holt, 2006; Coenen et al., 2014). Ko et al. (2011) used the rubber mounts on the prototype handles to reduce the dynamic effects of the vibrations. Their study evaluated the workers 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 minimise the HAV.

In agreement with the HAV values, a positive effect of the new prototype handles was also found on the usability rating. The higher SUS score has an interpretation that the usability of the product is generally acceptable (Bangor et al., 2008, 2009). Therefore, in terms of usability, the handles for the prototypes seem to be better than the conventional tools with no handles.

The equivalent sound pressure level (L_{eq}) limit value was still exceeding the safe limits, and the workers were at significant risk of developing the permanent hearing threshold shift (PTS). Evidence showed that the sound pressure level within the carpet aligning environment was quite high (exceeding maximum exposure limit of 90 dB (A)) (CPCB, 1948) and potentially harmful to the health of the workers. Job rotation could be introduced to reduce the exposure time. In the interview, it was reported by the workers that the mean value of the carpet area aligned per day was 110 ± 13.12 sq. ft. per worker and the wages were fixed as Rs. 2/sq. ft. The monthly earning was in the range of Rs. 6500–7500. The job requires more physical effort and fatigue resulting in sense of dissatisfaction among the workers. The more work provides more opportunity to earn in the carpet industry.

The loss in the hearing abilities has been positively associated with the HAV and the intensity and duration of noise exposure (Pettersson, 2013; Pettersson et al., 2011; Pyykkö et al., 1987). Indeed, the empirical evidence also suggests that the alignment workers suffer from the loss in hearing threshold, compared to the workers involved in other jobs in the same carpet sector. Exposed workers showed the hearing impairment in the frequency range of 1500–6000 Hz, therefore, leading to the PTS. Quite surprisingly, there was no significant difference between the exposed and control group in mean hearing threshold in the frequency range 250, 500 and 1500 Hz for the right ear and 250 and 500 Hz for the left ear. 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, 2013).

Physical examination revealed that there was a marginal loss in grip strength in the right hand among the two groups. Perhaps, the reason could be that the hammering was done by the dominant hand and the worker holds (cylindrical grasp) the tool throughout the daily work. The earlier studies suggested that the effect of HAV also cause a loss in the grip strength (Haward and Griffin, 2002; Bovenzi et al., 1991; Radwin et al., 1987; Azmir et al., 2015). It is noteworthy that the test was conducted on a small group of workers. This could be the only weaker dimension in approaching to a similar conclusion as pointed out in the previous studies.

The priorities of the hand exertion values reveal that the corrective measures should be taken on an immediate basis. The high intensity of exertion for a prolonged period of time could cause the discomfort feeling in the different hand regions. Moreover, the repetitiveness in the exertion and the hand vibrations were extensively high during the daily work. Nevertheless, the HAV can be a considerable factor in imposing the high intensity of exertion during the alignment task.

Further longitudinal work is needed to explore the ergonomic designs that are adjustable in terms of the anthropometric dimensions, i.e., fit for 5th to 95th percentile of the workers. It is advisable to carry out studies to unravel the specific materials that may reduce the vibration magnitudes and sound pressure level within the acceptable limits. Perhaps, it leads to an affective sustainability and the improvement in the quality of work life among the workers.

5 Conclusion

Overall, this study suggests that the workers are significantly influenced by the use of improper designed hand tools. The crux of the study indicates that a low-cost intervention could reduce the hand-transmitted vibration. The research also points the prevalence of noise exposure among the carpet alignment workers. Their hearing thresholds were compared with the workers involved in other jobs in the same industry. A higher propensity to hearing impairment was observed in the alignment workers.

It must be borne in mind that this study was only conducted on a small exposed and control group of workers. Further research is hence needed to explore the better ergonomic interventions of hand tools which can be used for the whole duration of the workday. No generalised conclusion could be drawn for using the prototype tools before further studies but a positive sign of the test response was directing towards the insight to develop a better design.

Acknowledgements

The authors express their deepest gratitude to the authority of Jaipur Rugs Foundation, for admitting official permission to take-up this study on carpet alignment workers. The authors acknowledge the encouragement and cooperation extended by the whole team of Jaipur Rugs Foundation and all the workers without which this study would not have been possible. We would also like to show our gratitude to Professor Abid Ali Khan for sharing his pearls of wisdom with us during the course of this research. All the anonymous reviewers are thanked for very useful comments on this study.

References

Afshari, D., Motamedzade, M., Salehi, R. and Soltanian, A.R. (2014) 'Continuous assessment of back and upper arm postures by long-term inclinometry in carpet weavers', *Applied Ergonomics*, Vol. 45, pp.278–284.

Armstrong, T.J. (1983) 'An ergonomics guide to carpal tunnel syndrome', *Am. Ind. Hyg. Assoc.*, 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', *Evidence-Based Orthopaedics: The Best Answers to Clinical Questions*, 1st ed., Saunders/Elsevier, Philadelphia, PA, ISBN: 978-1-4160-4444-4.

Azmir, N.A., Ghazali, M.I., Yahya, M.N., Ali, M.H. and Song, J.I. (2015) 'Effect of hand arm vibration on the development of vibration induce disorder among grass cutter workers', *Procedia Manuf.*, Vol. 2, pp.87–91, ISSN 2351-9789, DOI: http://dx.doi.org/10.1016/j.promfg.2015.07.015

Bangor, A., Kortum, P. and Miller, J. (2009) 'Determining what individual SUS scores mean: adding an adjective rating scale', *J, Usability Studies*, Vol. 4, No. 3, pp.114–123.

Bangor, A., Kortum, P.T. and Miller, J.T. (2008) 'An empirical evaluation of the system usability scale', *Int. J. Hum. Comput. Interact.*, Vol. 24, No. 6, pp.574–594.

Borg, G. (1982) 'Psychophysical bases of perceived exertion', *Med. Sci. Sports Exerc.*, Vol. 14, pp.377–381.

Bovenzi, M., Rui, F., Versini, W., Tommasini, M. and Nataletti, P. (2003) 'Hand-arm vibration syndrome and upper limb disorders associated with forestry work', *La Medicina del lavoro*, Vol. 95, No. 4, pp.282–296, PMID: 15532961.

Bovenzi, M., Zadini, A., Franzinelli, A. and Borgogni, F. (1991) 'Occupational musculoskeletal disorders in the neck and upper limbs of forestry workers exposed to hand-arm vibration', *Ergonomics*, Vol. 34, No. 5, pp.547–562, doi:10.1080/00140139108967336

Brooke, J. (1996) 'SUS-a quick and dirty usability scale', *Usability Evaluation in Industry*, Vol. 189, No. 194, pp.4–7.

Central Pollution Control Board (CPCB) (1948) *Noise Pollution Norms – Model Rules of the Factories Act*, Ministry of Environment and Forests, Retrieved 19 November, 2016, http://envfor.nic.in/citizen/specinfo/noise.html

Chaman, R., Aliyari, R., Sadeghian, F., Shoaa, J.V., Masoudi, M., Zahedi, S. and Bakhshi, M.A. (2015) 'Psychosocial factors and musculoskeletal pain among rural hand-woven carpet weavers in Iran', *Safety and Health at Work*, Vol. 6, pp.120–127.

Chetter, I.C., Kent, P.J. and Kester, R.C. (1998) 'The hand arm vibration syndrome: a review', *Cardiovasc. Surg.*, Vol. 6, No. 1, pp.1–9, DOI: https://doi.org/10.1177/096721099800600101

Choobineh, A., Shahnavaz, H. and Lahmi, M. (2004b) 'Major health risk factors in iranian hand-woven carpet industry', *International Journal of Occupational Safety and Ergonomics (JOSE)*, Vol. 10, No. 1, pp.65–78.

Choobineh, A., Tosian, R., Alhamdi, Z. and Davarzanie, M. (2004a) 'Ergonomic intervention in carpet mending operation', Appl. Ergon., Vol. 35, No. 5, pp.493–496.

Coenen, P., Formanoy, M., Douwes, M. Bosch, T. and de Kraker, H. (2014) 'Validity and inter-observer reliability of subjective hand-arm vibration assessments', *App. Ergon*., Vol. 45, No. 4, pp.1257–1262, doi:10.1016/j.apergo.2014.03.003.

Dale, A.M., Rohn, A.E., Burwell, A. Shannon, W., Standeven, J., Patton, A. and Evanoff, B. (2011) 'Evaluation of anti-vibration interventions for the hand during sheet metal assembly work', *Work*, Vol. 39, No. 2, pp.169–176.

Das, B., Jongkol, P. and Ngui, S. (2005) 'Snap-on-handles for a non-powered hacksaw: an ergonomics evaluation, redesign and testing', *Ergonomics*, Vol. 48, No. 1, pp.78–97.

Das, P.K., Shukla, K.P. and Öry, F.G. (1992) 'An occupational health programme for adults and children in the carpet weaving industry, Mirzapur, India: a case study in the informal sector', *Soc. Sci. Med.*, Vol. 35, No. 10, pp.1293–1302.

Day, R.W. and Quinn, G.P. (1989) 'Comparisons of treatments after an analysis of variance in ecology', *Ecol. Monogr*., Vol. 59, No. 4, pp.433–463.

Dewangan, K.N., Owary, C. and Datta, R.K. (2008) 'Anthropometric data of female farm workers from north eastern India and design of hand tools of the hilly region', *Int. J. Ind. Ergon*., Vol. 38, No. 1, pp.90–100.

Dron, J.P. and 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*, Vol. 270, No. 1, pp.61–73.

Durlov, S., Chakrabarty, S., Chatterjee, A., Das, T., Dev, S., Gangopadhyay, S., Haldar, P., Maity, S.G., Sarkar, K. and Sahu, S. (2014) 'Prevalence of low back pain among handloom weavers in West Bengal, India', *International Journal of Occupational and Environmental Health*, Vol. 20, No. 4, pp.333–339.

Edwards, D.J. and Holt, G.D. (2006) 'Hand-arm vibration exposure from construction tools: results of a field study', *Constr. Manage. Econ*., Vol. 24 No. 2, pp.209–217, doi:10.1080/01446190500310643

Fellows, G.L. and Freivalds, A. (1991) 'Ergonomics evaluation of a foam rubber grip for tool handles', *Appl. Ergon*., Vol. 22, No. 4, pp.225–230.

Haward, B.M. and Griffin, M.J. (2002) 'Repeatability of grip strength and dexterity tests and the effects of age and gender', *Int. Arch. Occup. Environ. Health*, Vol. 75, No. 1, pp.111–119, doi: 10.1007/s004200100285

Health and Safety Executive (HSE) (1990) *Upper Limb Disorders in the Workplace*, HSG60, London, HMSO, ISBN 978 0 7176 1978 8.

International Organization for Standardization (ISO) (2001) *Mechanical Vibration. Measurement and Evaluation of Human Exposure to Hand-Transmitted Vibration. Part 1 and Part 2. (Standards No. 5349-1:2001 and 5349-2:2001)*, ISO, Geneva, Switzerland.

International Organization for Standardization (ISO) (2005) *Human Response to Vibration-Measuring Instrumentation*, ISO 8041, Geneva, Switzerland.

Kihlberg, S. and Hagberg, M. (1997) 'Hand-arm symptoms related to impact and nonimpact hand-held power tools', *Int. Arch. Occup. Environ. Health*, Vol. 69, No. 4, pp.282–288.

Ko, Y.H., Ean, O.L. and 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*., Vol. 41, No. 5, pp.459–170, doi:10.1016/j.ergon.2011.04.004

Lewis, W.G. and Narayan, C.V. (1993) 'Design and sizing of ergonomic handles for hand tools', *App. Ergon.*, Vol. 24, No. 5, pp.351–356.

Mackenzie, B. (2002) *Grip Strength Test* [cited 1 January, 2016], Available from: http://www.brianmac.co.uk/grip.htm

Mallick, Z. (2008) 'Evaluation and optimization of handle design parameters of a grass trimming machine', *Int. J. Occup. Saf. Ergon*., Vol. 14, No. 3, pp.343–349.

Metgud, D.C., Khatri, S., Mokashi, M.G. and Saha, P.N. (2008) 'An ergonomic study of women workers in a woolen textile factory for identification of health-related problems', *Indian J. Occup. Environ. Med.*, Vol. 12, No. 1, p.14.

Mital, A. and 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.*, Vol. 10, Nos. 1–2, pp.7–21.

Moore, A., Wells, R. and Ranney, D. (1991) 'Quantifying exposure in occupational manual tasks with cumulative trauma disorder potential', *Ergonomics*, Vol. 34, No. 12, pp.1433–1453.

Moore, S.J. and Garg, A. (1995) 'The strain index: a proposed method to analyze jobs for risk of distal upper extremity disorders', *Am. Ind. Hyg. Assoc.*, Vol. 56, No. 5, pp.443–458.

Morioka, M. and Maeda, S. (1998) 'Measurement of hand-transmitted vibration of tapping the long cane for visually handicapped people in Japan', *Industrial Health*, Vol. 36, No. 2, pp.179–190.

Motamedzade, M., Choobineh, A., Mououdi, M.A. and Arghami, S. (2007) 'Ergonomic design of carpet weaving hand tools', *International Journal of Industrial Ergonomics*, Vol. 37, pp.581–587.

Muggleton, J.M., Allen, R and Chappell, P.H. (1999) 'Hand and arm injuries associated with repetitive manual work in industry: a review of disorders, risk factors and preventive measures', *Ergonomics*, Vol. 42, No. 5, pp.714–739.

National Institute for Occupational Safety and Health (NIOSH) (1997) *MSDs and Workplace Factors*, DHHS (NIOSH), Publication No. 97-141.

National Institute Occupational Safety and Health (NIOSH) (1996) *Criteria for A Recommended Standard Occupational Noise Exposure Revised Criteria*, Retrieved 19 November, 2016 http://www.cdc.gov/niosh/docs/98-126

Nazari, J., Mahmoudi, N., Dianat, I. and Graveling, R. (2012) 'Working conditions in carpet weaving workshops and musculoskeletal complaints among workers in Tabriz–Iran', *Health Promotion Perspectives*, Vol. 2, No. 2, pp.265–273.

Nurul Shahida, M.S., Siti Zawiah, M.D. and Case, K. (2015) 'The relationship between anthropometry and hand grip strength among elderly Malaysians', *International Journal of Industrial Ergonomics*, Vol. 50, pp.17–25.

Occupational Safety and Health Administration (OSHA) (n.d.) *Technical Manual Noise Measurement. Regulations and Standards*, Section III: Chapter 5, Retrieved 18 November, 2016, from https://www.osha.gov/dts/osta/otm/new_noise/

Pandit, S., Kumar, P. and Chakrabarti, D. (2013) 'Ergonomics problems prevalent in handloom units of North East India', *Int. J. Sci. Research Pub.*, Vol. 3, No. 1, pp.1–7.

Petersen, P., Petrick, M., Connor, H. and Conklin, D. (1989) 'Grip strength and hand dominance: challenging the 10% rule', *American Journal of Occupational Theory*, Vol. 43, No. 7, pp.444–447.

Pettersson, H. (2013) *Risk of Hearing Loss from Combined Exposure to Hand-Arm Vibrations and Noise*, Doctoral Dissertation, Umeå universitet, Retrieved 26 June, 2016, https://www.diva-portal.org/smash/get/diva2:589455/FULLTEXT01.pdf

Pettersson, H., Burström, L. and 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*, Vol. 84, No. 8, pp.951–957.

Pyykkö, I., Pekkarinen, J. and Starck, J. (1987) 'Sensory-neural hearing loss during combined noise and vibration exposure', *Int. Arch. Occup. Environ. Health*, Vol. 59, No. 5, pp.439–454.

Radwin, R.G., Armstrong, T.J. and Chaffin, D.B. (1987) 'Power hand tool vibration effects on grip exertions', *Ergonomics*, Vol. 30, No. 5, pp.833–855, doi:10.1080/00140138708969772

Rastogi, S.K., Ahmad, I., Pangtey, B.S. and Mathur, N. (2003) 'Effects of occupational exposure on respiratory system in carpet workers', *Indian J. Occup. Environ. Med.*, Vol. 7, No. 1, p.19.

Razali, N.M. and Wah, Y.B. (2011) 'Power comparisons of Shapiro-Wilk, Kolmogorov-Smirnov, Lilliefors and Anderson-Darling tests', *Journal of Statistical Modeling and Analytics*, Vol. 2, No. 1, pp.21–33.

Shapiro, S.S. and Wilk, M.B. (1965) 'An analysis of variance test for normality (complete samples)', *Biometrika*, Vol. 52, Nos. 3–4, pp.591–611.

Singh, L.P., Bhardwaj, A., Deepak, K.K. and Raman, B.E. (2009) 'Occupational noise exposure in small scale hand tools manufacturing (forging) industry (SSI) in Northern India', *Ind. Health*, Vol. 47, No. 4, pp.423–430.

Singh, LP., Bhardwaj, A. and 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.*, Vol. 55, No. 2, pp.411–424.

Strasser, H. (2007) 'Assessment of the ergonomic quality of hand-held-tools and computer input devices', *Ergonomics. Human Factors and Safety*, Volume 1, IOS Press, Amsterdam, Berlin, Oxford, Tokyo, Washington DC.

Wani, K.A. and Jaiswal, Y.K. (2012) 'health risk factors in different seasons of carpet industry in Kashmir, India', *International Journal of Occupational Safety and Ergonomics (JOSE)*, Vol. 18, No. 4, pp.571–577.

Wani, K.A. and Khan, R.M. (2015) 'Evaluation of occupational exposure of carpet weavers in northern province of Madhya Pradesh (India) during different seasons', *Indian J. Occup. Environ. Med.*, Vol. 19, No. 2, p.110.

World Health Organization (WHO) (2000) *The Asia Pacific Perspective: Redefining Obesity and Its Treatment*, Geneva, Switzerland.

Websites

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

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

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