ERGONOMIC EVALUATION AND DESIGN OF HAND-TOOL INTERVENTIONS IN HANDICRAFT INDUSTRY

Ph.D. THESIS

BY

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MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

JULY 2019

A Doctoral Thesis on

Ergonomic Evaluation and Design of Hand-Tool Interventions in Handicraft Industry

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to

DEPARTMENT OF MECHANICAL ENGINEERING

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July 2019

DECLARATION

I, **Ashish Kumar Singh**, declare that this thesis titled, "**Ergonomic Evaluation and Design of Hand-Tool Interventions in Handicraft Industry**" and the work presented in it, are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this university.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this university or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself, jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

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CERTIFICATE

This is to certify that the thesis entitled "**Ergonomic Evaluation and Design of Hand-Tool Interventions in Handicraft Industry**" being submitted by **Ashish Kumar Singh (2015RME9514)** to Malaviya National Institute of Technology Jaipur for the award of the degree of **Doctor of Philosophy** in the Department of Mechanical Engineering is a bona-fide record of original research work carried out by him. He has worked under our guidance and supervision and has fulfilled the requirement for the submission of this thesis, which has reached the requisite standard.

The result contained in this thesis have not been submitted, in part or full, to any other University or Institute for the award of any degree or diploma.

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ACKNOWLEDGEMENTS

First and foremost, I gratefully acknowledge the guidance, support, help, advice and encouragement received from my thesis supervisors **Dr. M. L. Meena**, Associate Professor and **Prof. Himanshu Chaudhary**. Without their invaluable and unremitting contribution towards accomplishing my research work, I could not have completed my doctoral research in this span of time.

I would like to express my gratitude to **Prof. G.S. Dangayach** (Convener, DPGC) for his invaluable encouragement and guidance.

I would like to thank **Prof. Dilip Sharma**, Head, MED for all the facilities provided in the department. I am grateful to the DREC committee members for their suggestions during progress presentations. I would like to thanks Ministry of Human Resource Development (MHRD) for providing the financially assistanceship for pursuing the research work.

Unforgettable thanks goes to **Prof. Abid Ali Khan**, Ergonomics Research Division, Aligarh Muslim University for sharing his pearls of wisdom with us during the course of this research. I must thank to show our gratitude to **Mr. Nand Kishore Chaudhary**, CMD, Jaipur Rugs for his faith in my abilities and admitting official permission to take-up this study on carpet workers. I express their deepest gratitude to the authority of all the handicraft manufacturers and workers for their help and support in my research work.

I wish to express my sincere gratitude for the valuable advice and suggestions that I received from departmental research evaluation committee. Also, I also intend to extend my thanks to my friends, and fellow Ph.D. research scholars for their support and advices.

I am thankful to my brother for his unrelenting support and encouragement during my research work and studies. Last but not the least, I am very grateful to my wife for her encouragement during my studies and sharing my workload at home which gave me more time to work on my thesis. Finally, I give my deepest gratitude to my parents, who were my guiding stars throughout the execution of this thesis.

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ABSTRACT

Handicraft work is the traditional artistic activity performed by artisans which shares a significant part of the Indian informal economy. The development of occupational disorders is the most persistent problem among the workers employed in the handicraft industry. Depending on the nature of the craft activity, 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 musculoskeletal disorders (MSDs). The main idea of this thesis is shedding light on the problems encountered during craft working and design of ergonomically efficient hand tool interventions to ease the efforts of the workers.

Overall, two hundred eighty-two (130 female and 152 male) randomly selected participants (from 27 workshops) were surveyed coming from seven different handicraft occupations, and the data about pain occurring in the body and palmar regions were collected by questionnaire. The study was divided into two phases, i.e., ergonomic assessment and intervention. During the first phase of this study, all 242 participants were investigated. While, 40 participants were randomly selected during the second phase of the study. Physical parameters like static muscular strength were measured using hydraulic hand and pinch grip dynamometers. Different combinations of hand tool prototypes were developed and tested over handicraft workers in the field experiments. Output response about goniometry and electromyography were taken as dependent variables during different experiments considering carpet weaving knife design. Also, to tackle the difficulty of knife selection with several output responses, three multi-criteria optimization approaches have been compared. During field testing in alignment, trimming, and wood carving occupations, the tool handles (conventional and prototype) 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.

Most of the participants reported discomfort in different body and palmar regions. The results of the questionnaire revealed that the most prominently affected body and hand regions among the handicraft workers were lower back, wrist, shoulders, and metacarpal, thenar eminence, and hypothenar. Loss of static muscular strength is the most common work-related problem among handicraft workers involved in hand-intensive jobs.

MANOVA results showed that the effect of both blade width and angle were significant at wrist angles. Also, the magnitude of effect size on both blade width and angle was highest for the wrist angles. Despite the same weighing criteria, a slight difference was evident between the ranks from optimization methods. The higher blade widths and smaller angular orientations should be recommended for reduction of wrist deviation and muscle activity during weaving. The best possible combination of weaving knife evaluated using multi-criteria optimization was 25mm x 100˚. Results demonstrated that the low-cost handle interventions (using foam rubber and/or Indian teak wood) reduced the total value of root mean square frequency-weighted vibrations substantially when compared to the conventional handle in carpet alignment, trimming and wood carving occupations.

As the handicraft manufacturing is a traditional artistic activity in India, special attention should be sought to the artisans in this much-neglected sector. The occupational problems cannot be eliminated entirely, however, this study provides an insight that the implementation of some positive ergonomic interventions and guidelines can eventually enhance the health conditions and productivity of the workers. Based on this preliminary work, we have found that low-cost prototype hand tools were effective in curtailing wrist deviations and HAV. Several guidelines were recommended that may help in designing ergonomically efficient work system to prevent MSDs among workers.

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LIST OF ABBREVIATIONS

MSDs	Musculoskeletal disorders
CTDs	Cumulative trauma disorders
CTS	Carpal tunnel syndrome
HAV	Hand-arm vibration
HAVS	Hand-arm vibration syndrome
NIHL	Noise-induced hearing loss
EMG	Electromyography
MCDM	Multi-criteria decision making
TOPSIS	Technique for order performance by similarity to ideal solution
VIKOR	Vlse Kriterijumska Optimizacija Kompromisno Resenje, means Multi-criteria Optimization and Compromise Solution
TLF	Taguchi’s loss function
BMI	Body mass index
BSA	Body surface area
ANOVA	Analysis of variance
IQR	Interquartile range
SD	Standard deviation
RPE	Rating of perceived exertion
ECRB	Extensor carpi radialis brevis
FCR	Flexor carpi radialis
FCU	Flexor carpi ulnaris
ECU	Extensor carpi ulnaris

RMS	Root mean square
NEMG	Normalized EMG
DOEs	Design of experiments
MANOVA	Multivariate analysis of variance
AHP	Analytic hierarchy process
IS	Indian Standard
USD	United States Dollar

CHAPTER 1

INTRODUCTORY OVERVIEW

1.1. Ergonomics background

The term ‘ergonomics’ was derived from the Greek words, ‘ergon’ (work) and ‘nomos’ (natural laws). It is the scientific study of the relationship between man and his working environment (Murrell, 1965). It is also known as ‘human factors engineering’ which is the scientific discipline concerned with the man’s behavior in relation to his work (Grandjean, 1980). It deals with all aspects of human activity including physical, cognitive, social, organizational, and environmental factors. Human factors engineering at a workstation is applied to improve the interaction between human capabilities and workplace conditions. Workstation or workplace is defined as the place where an employee is engaged in doing some productive activity over which the employer has the full right of access or control.

1.2. Work-related Musculoskeletal Disorders

Work-related Musculoskeletal Disorders (MSDs) are injuries or pain in human musculoskeletal system, which includes the joints, ligaments, nerves, tendons, muscles, and structures that support upper and lower extremities, neck and back. MSDs could arise from sudden exertion, repeatedly motions, repetitive strain, repeated exposure to force, vibration (hand-arm or whole body) or awkward postures. These musculoskeletal strain may affect different body parts (upper and lower back, neck, shoulders and extremities). The most common categories of MSDs include cumulative trauma disorders (CTDs), epicondylitis, tendinitis, back pain, tension neck syndrome, and hand-arm vibration syndrome (HAVS).

Repetitive, sustained, or forceful motions occurring over time may compromise the integrity or functioning of the soft tissues producing inflammation of the tendons or compression of the peripheral nerves leading to a group of CTDs. Perhaps the most well-known CTD is carpal tunnel syndrome (CTS) (Silverstein, 1986). The previous longitudinal studies reported that poor design of hand tool, awkward posture, forceful gripping, high repetitiveness, mechanical stress and vibration on hand and palm regions are directly associated with symptoms of CTS (Atroshi, 2009; Armstrong, 1983; Mital, 1992; Silverstein, 1987). Questionnaire and/or checklists and experiments are required to carry out a risk assessment of physical working conditions.

Several postural assessment could be done using techniques that assesses a working posture and the associated level of risk in a short time frame and with no need for equipment beyond pen and paper. The most used postural assessment techniques are rapid upper limb assessment (RULA), rapid entire body assessment (REBA), strain index (SI), etc.

1.3. Ergonomic risk factors of MSDs

1.3.1. Repetitive work

Silverstein et al., (1987) argued that a repetitive activity is the same fundamental motion in which either the worker spends more than 50% of the cycle time while performing a specific task or a cycle time of less than 30 seconds. They also point out that CTS was strongly associated with highly repetitive jobs and the odds ratio for the highly repetitive jobs was more than 15 ($p<0.001$) when compared to low repetitive jobs. Several studies have established the direct association of repetitive movement of the digits and wrist with CTS (Singh et al., (*in press (c)*); Singh et al., 2018a). The hand grip strength and pinch grip strength (tip, key and palmar grip), of workers from different occupations involving highly repetitive movements varies significantly due to repetitive use of hand tools (Singh et al., 2018 (*in press (a)*).

1.3.2. Monotonous work

A few researchers opined that monotony in work is associated with occupational risk factors, albeit to a moderate degree (Pope et al., 1997; Linton, 1990). The largest odds for the relative risks were for back, neck and shoulders.

1.3.3. Awkward posture

Awkward postures refer to the considerable deviation of the body parts from the neutral position while performing a specific task (Dhar, 2007). These deviations may affect the individuals in many different ways. The development of MSDs is the most common problem among the workers employed in any industry and are mostly associated with awkward postures. Several postural assessment techniques are used to assess the substantial postural deviations in body parts during a specific task. These assessment make use of digital photographs, videography, and goniometry for the accurate measurements (Singh et al., *(in press (c))*; Singh et al., 2017).

- Static posture**:** As a part of awkward posture, the sustained non-neutral working posture for longer durations is a major risk factor that may contribute to high prevalence of MSDs.

1.3.4. Exposure duration

The overall priority score in most of the postural assessment techniques are assessed by the combination of scores in the various categories on the task identification data sheet. The effort type (static, intermittent and repeated) and duration of effort during the specific task are one of the essential variables. Gangopadhyay et al. (2015) reported that while performing the chikan embroidery activity, the complaints of CTS increased gradually with longer exposure time. The weavers exposed to longer duration of exertion in conjunction to higher repetitiveness (efforts/minute) showed higher prevalence of discomfort (Singh et al., 2018a; Singh et al., (*in press (d)*).

1.3.5. Muscle activity

Several studies in the past have used electromyography (EMG) for evaluating discomfort and muscle activity during different tasks involving different limb movements (Afshari et al., 2014; Bhardwaj and Khan, 2018; Bano et al., 2012). In a recent investigation, it was confirmed that the EMG and goniometric evaluation could provide a criterion for the ergonomic hand tool design to avoid overexertion (Singh et al., (*in press (c)*).

1.3.6. Interventional/Workstation design

The design of work system developed the foundation to ease the efforts of the workers by improved postures, thus resulting in lower MSDs among the workers (Choobineh et al., 2004b; Motamedzade et al., 2007; Singh et al., *in press (c)*; Afsharia et al., 2015). Pheasant (1991) have shown that the work system design interventions can improve the productivity among the users.

1.3.7. Force, Vibration and Noise

Apart from other variables discussed above, depending upon the nature of the work and hand tool design, industrial workers can be exposed to forceful gripping, noise exposure and hand-arm vibration (HAV) hazard (Atroshi, 2009; Armstrong, 1983; Singh et al., (2018b); Singh, *in press* *(b)*; Mital and Kilbom, 1992). Therefore, the measurement of these variables are vital to workplace safety.

1.4. Handicraft industry and need for the study

1.4.1. Overview of Indian Handicraft Industries

Handicrafts have been in vogue in India since the Harappa civilization three thousand years ago (Bead Crafts, 2017). Handicraft manufacturing is vibrant since the 17th century and is much more tedious and extremely labor intensive as compared to other jobs. The Indian handicrafts industry is part of the small manufacturing industries, and a significant part of the Indian population is dependent on handicraft sector. It possesses around 50% of the national product by informal sector which makes it the largest producer and exporter in the international market (NSC, 2012). Roughly over 0.5 million workers are presently employed in the Indian handicrafts industry, and it is likely to generate more employment opportunities, mainly in the rural regions of the country (Ministry of Commerce & Industry, 2011). According to the National Statistical Commission, 90% of the country's workforce are accounted for by the informal economy (NSC, 2012; Meena et al., 2013).

1.4.2. Role of Handicrafts in Informal Economy

Exports of art-wares have a massive market demand mainly in American and European markets (IBEF, 2016; Singh et al., 2017). The export of Indian handicrafts rose exceptionally, over the period of establishment (1986–1987) of the export promotion council for handicraft (EPCH, 2015a). According to the provisional data available the exports of handicrafts have shown an increase of USD 231.17 million, i.e., the exports increased by 13.5% in one year (EPCH, 2015b).

Now the handicrafts industry is growing with its notable achievements from the states of Rajasthan, Andhra Pradesh, Karnataka, Assam, Kashmir, Himachal Pradesh, Uttar Pradesh, Punjab and, Gujarat within the country. For the enhancement of the world market share of craft products especially hand-knotted carpets, these belts need gearing up in particular (Srivastava & Goswami, 2007). Residents of rural families in Northern and Western provinces of Rajasthan depend mainly on agriculture and livestock. The country supports 7 million people and contributes a substantial part of the total workforce from India (Gopal, 2015). With a gradual influx of commercialization in this industry, labor-use arrangements have also undergone a change. From an occupational point of view, the workers often engaged in rigorous hand-intensive work and spent long working hours to obtain target specific productivity (produce more output in a short period of time) (Mukhopadhyay and Srivastava, 2010).

1.4.3. Different Handicraft sectors

Some of the numerous handicrafts items manufactured in India include: hand knotted and tufted carpets, woodwork, imitation jewelry, pottery, leather crafts, metal crafts, hand block printing, screen printing, embroidery, jute crafts, bamboo crafts, etc.

The Indian craftsmen have been creating all types of qualities with specific design since the medieval period. Though, lesser innovation and outdated techniques, lack of infrastructural facilities, poor working conditions, and labour law issues are the major barriers in this industry. Consequently, make it less competent to other carpet supplying countries. Productivity in the area of handicrafts sector plays a significant role as the earning depends on the manual work practices involved. To improve the productivity, poor work practices and occupational health and safety issues need to be addressed (Choobineh et al., 2007; Wani and Jaiswal, 2012).

1.4.4. Need for research

Nearly no research has been done in the area of ergonomic development in handicraft manufacturing sector in India. The main idea of this research is to assess the ergonomic aspects at grass-root level and proposing the need of a better design interventions and approaches.

In lower-middle-income countries, a large number of occupations in the informal industry uses non-ergonomic hand tools as primary hand tools which may result in work-related health problems. The handicraft industry is also such sector where different kinds of non-powered hand tools are commonly used. Handicraft manufacturing is the most common and traditional part of the informal sector in India. Home-based crafting profession is still common among women in contemporary society. It demands high skill and precision and the workers are often exposed to MSDs and CTS (Choobineh et al., 2004a; Singh et al., 2018a). Several past investigations have shown that the effects of muscle activation were most apparent during high precision and repetitive work (Visser et al., 2003; Escorpizo and Moore, 2007; Laursen et al., 1998). Moreover, non-ergonomic hand tools and work station may results in increased muscle activity in different body parts which may lead to increased risk of developing muscle fatigue mainly in neck and shoulder region, elbow and lower back (Allahyari et al., 2016; Motamedzade et al., 2014).

1.5. Research Objectives

This thesis titles "Ergonomic evaluation and hand-tool interventions in handicraft industry" aims to answer some of the problems as stated above. The objectives of the study are stated below.

1. To assess the work related health problems in handicraft occupations.
2. To design and develop ergonomically efficient hand-tool interventions to improve occupational health of the workers.
3. To validate the ergonomically designed work system/ hand-tool interventions.

1.6. Phases of study - A general summary layout of methodology followed

This study was divided into two major phases. These phases has been discussed in detail in chapter 3:

Phase 1: Assessment Study - It has been sub-classified into following sections:

- Evaluation of the general health status of the workers engaged in handicraft occupations.
- Evaluation of the prevalence of the musculoskeletal disorders and cumulative trauma disorders among the handicraft workers.

Phase 2: Intervention Study - It has been sub-classified into following sections:

- Empirical Investigation of EMG and goniometric responses for prototype weaving knives.
- Application of multiple-response optimization methods for the ergonomic evaluation of carpet weaving knife.
- Evaluation of the effect of low-cost tool intervention for workers exposed to hand-arm vibration.

CHAPTER 2

REVIEW OF LITERATURE

2.1. Classification of Literature

Numerous studies dealing with the assessment and implementation of ergonomics in workplace have been published over the past couple decades, but the topic is still under considerable development. Literature on various topics related to the theme of this thesis was collected from the available electronic database resources. The classification of literature includes screening, applying inclusion/exclusion criterion, and extracting relevant literature for further study.

2.1.1. Screening of Literature

The literature review was done based on a systematic article search on three electronic databases viz. PubMed, ScienceDirect, and Google Scholar and six renowned publishers (i.e., Elesevier, Taylor & Francis, SAGE, Wiley, Inderscience, and DE GRUYTER). Search terms were based upon articulation of interest. For example, during the literature search of 'risk exposure among handicraft workers', the search strings included "handicraft workers", "musculoskeletal disorders", "carpal tunnel syndrome", "work-related injury", and "discomfort".

To improve the literature search, one of the criteria used by the author's when assessing papers is the extent to which the work is integrated and up to date with the existing body of literature. Therefore, the reference lists of the retrieved articles were checked so that the commentary needs to be brought fully up to date to provide proper context for the study and its findings.

We look to the papers that establish a thread with other relevant research published specially in top quality 'ergonomics' emphasized journals, with the aim of representing a body of research rather than just a collection of individual papers. The objective was to address the literature that is situated within the research inline to the area of ergonomics.

2.1.2. Inclusion/exclusion criterion

Lack of access to literature other than English caused limited extent to review, therefore, only the articles written in English were included in the review. The articles were screened for relevance to the study objectives based on reading either their abstract or the complete document. However, some of irrelevant articles were removed after reading the abstracts. It was ensured that the articles included in the literature review had enough content and were directly related to the objectives of the study. No upper and lower limits on sample population, and age were applied on the literature search.

Studies were excluded if: (a) there was any duplicity in the information provided; (b) full document is not available online; (c) study population had not been provided. Studies having relevance with the objectives set in, but, are having workers from occupation other than handicrafts were also included for the further analysis. The filtering of inclusion/exclusion criteria was based on how well it links to the objective of the research.

2.1.3. Data extraction

The distribution of articles in this literature review was explored in related areas. A summary of collected literature according to the focus area is given in Table 2.1. All these papers were classified in content such as authors' last name and country, publication year, study objective, study design, sample size, contribution to research, any other remarks.

Table 2.1. Summary of papers collected

Parameters	*No. of Papers*
Ergonomics in small scale and handicraft industries	22
Health related problems among handicraft workers	21
Design of non-powered hand tools	11
• Use of hand anthropometry	12
• Grip strength	12
Hand-arm vibration and noise exposure	16
Electrogoniometry and Electromyography	17
Multiple-criteria Optimization techniques	11
Total	**122**

2.1.4. Search results

A total of 271 articles were found during the initial phase of review. After applying the inclusion/exclusion filter on the comprehensive literature search, it was found that 11 articles (mostly Iranian studies) were written in other than English language. Another 110 articles were screened out due to their non-relevance to objectives and duplicate publication. The other 19 and 9 articles were discarded due to incomplete information and coauthor's discretions/wisdom. Further, 122 articles were selected for the review. Figure 2.1 depicts the selection methodology of literature search process.

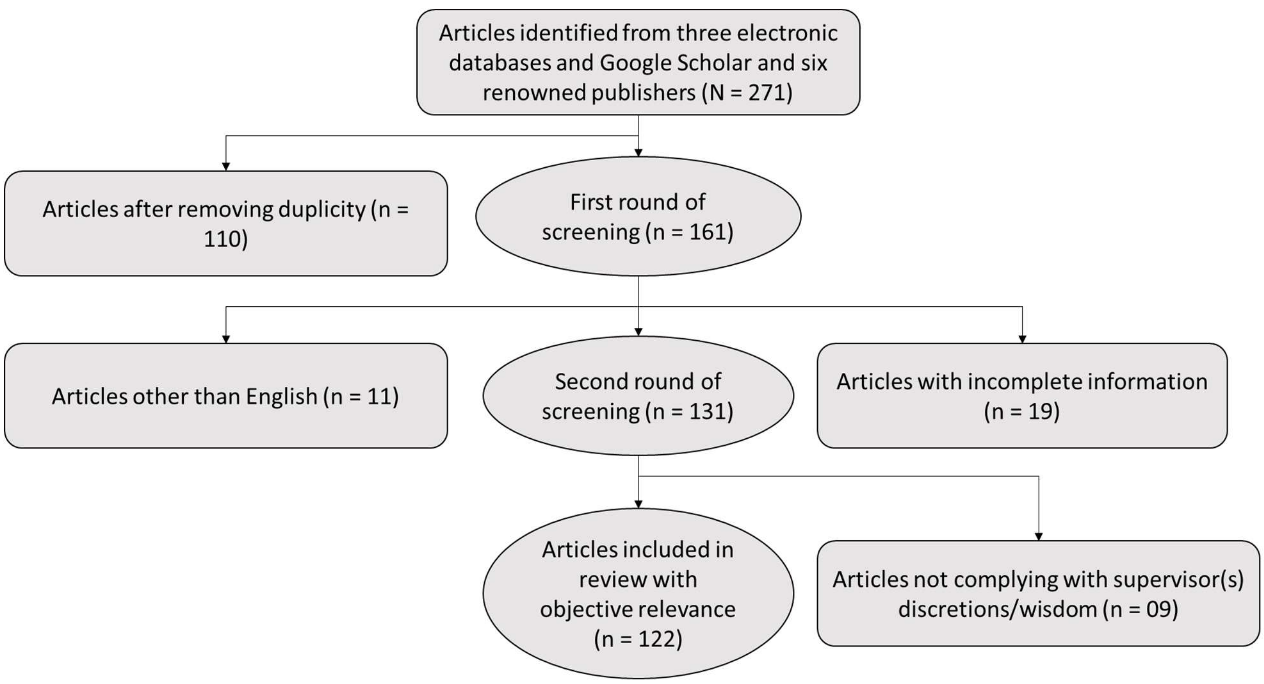

Figure 2.1. Flow diagram of the identification methodology and literature review process.

This literature review refer to the set of history, methodologies and contributions on the base of different research areas that comes in our specific work. The literature reveals the various ergonomic assessment methods, postural and health related problems in industrial workers.

2.2. Ergonomics in small scale handicraft industries

Handicraft manufacturing is a traditional artistic activity and shares some common work characteristics such as the involvement of lower-arm, hand-eye coordination and fine dexterity of the worker (Das et al., 2018). Depending on the nature of the job 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 CTD (Atroshi, 2009; Armstrong, 1983; Mital and Kilbom, 1992; HSE, 2003a). Safety guidelines for the upper extremity could prevent workplace injuries and reduce the risk of CTD (HSE, 2003b).

Occupational disorders are the most persistent problem among the manual workers in many parts of the world. It has been linked to severe neurological and vascular symptoms (Bovenzi et al., 1991). In developing countries, informal sectors employ a high percentage of the women workforce (Chen, 2001). Due to the flexibility of home-based work, women victims of occupational disorders are often seen in the handicraft sector. The craftwork involves various types of repetitive task. Although it may be a problem in handicraft industries, it is also as much of a problem in other industrial sectors that involve the repeated use of hand tools.

2.3. Health related problems among handicraft workers

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. Productivity in the area of craft products primarily depends on the handwork practices involved as the earning depends on the manual work. For improving the productivity, occupational health and safety issues, as well as poor work practices, need to be addressed (Wani and Jaiswal, 2012; Choobineh et al., 2007). Therefore, we believe these factors somehow linked with the ergonomic perspective.

Handicraft work is a challenging occupation in which workers may suffer from various work-related problems. The assessment of occupational health hazards among handicraft operatives was the primary concern of the researchers found from the literature. Majority of the researchers have contributed towards the assessement of MSDs, working conditions, and physiological factors among the workers in the handicraft industry (Ghosh et al., 2010; Mrunalini and Logeswari, 2016; Gangopadhyay et al., 2010; Choobineh et al., 2004a; Chaman et al., 2015). A large-scale study surveyed 979 handicraft workers from 281 small-scale workshops in northern Thailand and opined that low competency mainly induces the occupational risks in health and safety management, which may risk workers' physical health (Tangkittipaporn, 2006). Another study on Thai handicraft workers in a laboratory setting was based on investigating the trunk discomfort due to the type of sitting posture (Areeudomwong et al., 2012). Besides these factors, the design of hand tools contributes to building up the risks of 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 jewelry occupation (Salve, 2015a; Salve, 2015b; Untimanon et al., 2006; De et al., 2012).

Susanha and Sujitra (2007) in their study pointed that woodcarving workers were at risk of 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 (Bosan and Okpapi, 2004; Soongkhang and Laohasiriwong, 2017; Scheeper et al., 1995).

2.4. Design of non-powered hand tools

The literature review suggest that most of the investigations were done on non-powered hand tools like scissors, screwdrivers and knives (Adeleye and Akanbi, 2015; Shimomura et al., 2015; Dianat et al., 2017a; Dianat et al., 2017b; Dempsey et al., 2004; Mital and Channaveeraiah, 1988; McGorry et al., 2003; Szabo et al., 2001). Some of the published work were found related to redesigning shovels, trowels, handsaws, hacksaws, wrenches, chisels, and hammers (Jain et al., 2018; Bakhtiari et al., 2018; Dianat et al., 2015; Mital and Channaveeraiah, 1988). Much researchers have focused on designing/re-designing commonly used knifes, but, only one article dealt with re-designing weaving hand tools that includes weaving knife, scissors and weaving comb (Motamzade et al., 2007). However, these designs were made considering simple ergonomic principles and anthropometric characteristics of Iranian weavers. To the best of author's knowledge, no hand tool design studies were found related to other carpet manufacturing occupations viz. carpet alignment, washing and trimming.

The major issues targeted by the previous researchers include work-related health problems, and prevalence of MSDs among handicraft workers (Das et al., 2018; Singh et al., 2018a; Singh et al., 2018b). These investigations were the foundation steps for initializing the present research related to the improvement in hand-tools used by the handicraft workers.

Numerous studies (Singh et al., 2018a; Atroshi, 2009; Armstrong, 1983; Mital, and A. Kilbom, 1992) have established the fact that un-ergonomic design of hand tool are directly associated with risk of upper extremity disorders. Though the design interventions could be costly, small low-cost interventions can also be effective in curtailing those risks (Singh et al., 2018c; Singh et al., *in press (c)*). For example, a study showed that the foam rubber grip and Indian teak wood could be used on tool handles since besides aesthetic advantages, they also protect the metal from rust and corrosion, scratches, vibration, impacts and, cracks (Fellows and Freivalds, 1991). Ko et al. (2011) used the rubber mounts on prototype handles to reduce the dynamic effects of vibrations. Their study evaluated the workers perception in terms of exposure to vibration for several designs of tool handles. According to Mallick (2008), a proper selection of design parameters of handles can minimize HAV. Overall, the hand tool interventions are necessary to prevail work-related health issues among the workers (Dewangan et al., 2008; Das et al., 2005; Motamedzade et al., 2007). Hand anthropometry and muscle strength also plays a vital role, which has been discussed in the late text.

Some commendable effort was put forth by Jain et al. (2018) in reviewing the hand tool design considerations consisting human, product, task and qualitative/usability related factors. Some of the other aspects in design considerations of hand tool interventions were added using other studies (Singh et al., 2018a; Lewis and Narayan, 1993; Strasser, 2007). The variables in these factors are mentioned below:

- Human factors: Anthropometry, muscle strength (hand grip and pinch grip), muscular effort and frequency, wrist movement, biomechanical stress, electromyography, etc.
- Product related factors: Hand-tool dimensions, weight, material cost, slipperiness, shape, sharp edges, centre of mass of the tool, etc.

- Task related factors: Awkward postural positions, repetitiveness, tool orientation, goniometry, etc.
- Usability factors: Functionality, discomfort, hand-arm vibration, noise exposure, fatigue, dissatisfaction, performance, appearance, ease of gripping, etc.

2.4.1. *Use of hand anthropometry in design*

Hand dimensions have always been identified useful for the prototype tools designs. A sliding vernier caliper and a steel rule could be used for determining the hand length, maximum hand breadth and hand breadth at metacarpal measurements. Inside grip diameter could be measured using a wooden cone specially made for the purpose. Based on the anthropometric considerations, the 95th percentile value of hand breadth at metacarpal can be used to calculate the length of the prototype handle (Lewis and Narayan, 1993; Dewangan et al., 2008; Das et al., 2005). Lewis and Narayan (1993) and Dewangan et al. (2008) recommended the 5th percentile value of the inside grip diameter for better gripping of the hand tool. Moreover, it was observed in several studies that the tools handles were kept with damping sleeve for comfort in holding. Additionally, the centre of mass of the tool should be as close to the centre of the hand as possible (Strasser, 2007). Table 2.2 shows the key contributions of several researchers with a primary focus on hand anthropometry.

2.4.2. *Grip strength*

Liu and Chu (2006) reported that the physical demand of the occupations is directly associated with the grip strength of the workers. Highly repetitive activities in handicraft work are another ergonomic risk factor which may lead to the risk of upper-limb MSDs (Das et al., 2018). Silverstein et al. (1987) also point out that CTS was strongly associated with highly repetitive jobs and the odds ratio were significantly high compared to low repetitive jobs. A large number of clinical investigations have reported that the reduction in grip strength is related to the high repetitiveness of the upper limbs (Atroshi, 2009; Armstrong, 1983; Singh et al., 2018a; Singh et al., 2018b). Apart from the loss of grip strength, repetition plays a vital role in the development of physiological stress among workers (Das, 2014). The earlier studies suggested that the effect of HAV also cause loss in the grip strength (Haward and Griffin, 2002; Bovenzi et al., 1991; Radwin et al., 1987; Azmir et al., 2015).

Table 2.2. Key contributions of some studies with a focus on hand anthropometry.

Author and year	Industry	Objective	Subjects	No. of hand dimensions	Results/Key Findings
Davies et al., 1980a	Industry workers	To determine: whether there was any difference in hand size between the three female ethnic groups.	51 West Europeans. 21 Indians (from the Punjab) and 20 West Indians were included in the study.	Twenty-eight measurements:	• Europeans *v* West Indians: Out of 28 measurements only three are not significantly different at the 0·01 level. In 25 cases the West Indian dimensions are greater than the Europeans. • European v Indian: five of the comparisons are significantly different. Thirteen Indian measurements are larger than the European, three are equal and 12 are smaller. • West Indian v Indian: Twenty-one measurements are significantly different at the 0·01 level. Twenty-four or the West Indian measurements are larger than the Indian figures.
Kar et al., 2003	Agriculture Workers	Eight hand dimensions of right and left hand have been identified which were considered more useful for designing agricultural hand tools.	Agricultural workers (Male: 200; Female: 204) have been collected from West Bengal state, Eastern India.	Eight hand dimensions	• It was noted that there was a significant difference ($p<0.001$) in body dimensions between right and left hand in both sexes. • The data of male and female subjects may be used for designing hand tools separately for them. • Further, considering the socio-economic condition and common habitual practice of the Indian farmers, the design of hand tools having the same dimensions for both men and women may be adopted.
Vyavahare and Kallurkar, 2012	Agriculture Workers	The review on the studies carried out so far to generate the anthropometric and strength data of agricultural workers for equipment design and ergonomic evaluation of farm equipment.	►Review study carried out for anthropometric, strength parameter, and ergonomic evaluation of farm equipment.	Stature and Hand measurements	• Review shows that many of the studies are focused on anthropometric data and very few have considered strength parameters. • For very few regions in India, anthropometric and strength data is available and it is essential to generate exhaustive region specific data, which was found varying from region to region, for rest of the regions to suite the population in the particular region.

Dewangan et al., 2008	Agriculture Workers	The data as obtained are intended to be used for the design/design modifications of agricultural hand tools/implements/machinery	400 subjects ranged 18–60 years of three tribes from Arunachal Pradesh, viz. Adi, Apatani and Nishi and one Mizo tribe from Mizoram were selected.	►Seventy-six body dimensions, including age and body weight. ►In the standing position, there are 43 measurements. ► These include 10 heights, 6 breadths, 5 circumferences, 1 depth, 9 reaches and 12 other dimensions. ► In the sitting posture there are 16 measurements namely 7 heights, 3 breadths, 1 depth and 5 reaches. ► In sitting/standing postures the number is 17, namely, 7 feet, 7 hands and 3 heads.	• Values of body dimensions of tribal female workers from two NE states of India are lesser than those of eight other countries. • Variation in most of the body dimensions between Adi tribe with Apatani, Nishi and Mizo tribes are statistically significant. • Based on the anthropometric considerations, the length of handle should accommodate the maximum dimension of hand breadth at thumb. The 95th percentile value of the above dimension is 9.8 cm. Taking a clearance 0.5 cm on each side of the grip, the length of the handle comes to 10.8 cm and this value is recommended for the length of the handle. • For better grip the handle diameter should not exceed the inside grip diameter of the operator. Therefore, the handle diameter should be according to 5th percentile value of the inside grip diameter to accommodate the larger population group. This value is 3.82 cm. • The diameter of the handle should be a little lesser than the inside grip diameter (Nag et al., 1988). Thus the diameter of the handle recommended is 3.32 cm.
Pal et al., 2014	Medical Students	►To find correlation between the stature and hand length. ►To collect baseline information for further population based study in the eastern part of India so that the anthropologist and forensic experts can estimate the height of adult individuals of either sex by use of either of the hand.	235 medical students of both sexes (110 female and 125 male between 20-23yrs of age) in two medical colleges-one in Cuttack, Odisha and another in Kolkata, WestBengal.	Stature, Right Hand Length and Left Hand Length	• Positive correlation between the stature and the hand length. • Separate regression equations are derived for males and females.
Davies et al., 1980b	Industry workers	An anthropometric study of female hands was carried out for the design of machinery and machine guards:	92 subjects	Twenty-eight measurements: Same as in Sr. No. 1	The comparisons are significantly different.

Gite and Yadav, 1989	Agriculture Workers	The collected anthropometric data were analysed to calculate mean, range, standard deviation and 5th, 50th and 95th percentile values. Through some examples, an effort is made here to illustrate the use of the data in the design of farm equipment.	39 farm workers	Fifty-two body dimensions have been identified which were considered useful for farm machinery design:	• Use of the data in designing equipment: 1. Size of grip for hand tools and manually operated equipment 2. Handle height for animal-drawn equipment 3. Layout of a tractor driver's workplace 4. Design of feeding chute of a thresher
Agarwal and Sahu, 2010	plastic surgery unit, Medical College, Jabalpur over a period of one year	To determine correctly the TBSA represented by the palmar surface of the entire hand and palm in the Indian population.	300 healthy adult (male and female) and 300 healthy children (male and female)	►Hand Length ►Hand Width ►Hand Area ►mean palm area ►hand ratio ►palm ratio	• The hand's percentage of BSA (hand ratio) was determined by dividing hand area by total BSA. • The palm's percentage of BSA (palm ratio) was determined by dividing the palm area by total BSA. Mean hand area in adult was 139.462 ± 16.21 cm and the same for child was 85.646 ± 21.11 cm. • Mean palm area in adult and children was 75.756 ± 9.938 cm and 50.675 ± 12.603 cm , respectively • The mean hand ratio in adult was 0.921 ± 0.088 and for children it was 1.065 ± 0.110. • Mean palm ratio in adult was 0.502 ± 0.065 and in child was 0.632 ± 0.084. • The results of the study differ with that of western studies. The hand area as compared to TBSA more closely represents 1% of TBSA in Indian population.

2.5. Hand-arm vibration and Noise exposure

The risk of developing hand–arm vibration (HAV) syndrome and noise-induced hearing loss (NIHL) depend on the magnitude of vibration transmitted to the tool handle and noise exposure suffered by the industrial workers (Atroshi, 2009; Armstrong, 1983; Mital and Kilbom, 1992; Nandi and Dhatrak, 2008). To protect workers from increasing HAV syndrome and NIHL, a number of criteria/guidelines have been proposed in different countries. HAV health risks due to prolonged use of vibration transmitting hand tools involves vascular and peripheral sensory-neural disorders. Moreover, it is also associated with the circulatory disorders (e.g. vibration white finger), motor disorders, musculoskeletal disorders (MSDs), loss in handgrip strength, and carpal tunnel syndrome (CTS) (HSE, 2003; Azmir et al., 2015; Bovenzi et al., 2003; NIOSH, 1997; Chetter et al., 1998; Pettersson, 2013). The effects of HAV on the workers have been studied by many researchers. In a study, Kihlberg and Hagberg (1997) demonstrated that the upper arm, elbow, and shoulder were most affected regions while using impact tools transmitting low-frequency vibrations. Whereas, the wrist symptoms were more prominent while using high-frequency impact tools. Collectively, hand vibration propagates from the direct point of contact of the vibrating surface resulting in HAV exposure symptoms.

Most of the researchers (Choobineh et al., 2004a; Afshari et al., 2014; Chaman et al., 2015; Nazari et al., 2012; Wani and Jaiswal; 2015; Singh et al., 2017) targeted the assessment of work-related MSDs among the carpet workers in handicraft occupation. A few studies have investigated physical and physiological factors among handicraft workers (Singh et al., 2017; Singh et al., 2018a; Singh et al., *in press (a)*). Another study on carpet alignment workers was based on curtailing low-frequency hand-arm vibrations by a low-cost intervention (wooden handle with foam rubber grip) (Singh et al., 2018b). These workers were also exposed to noise over permissible limits and shift in hearing threshold.

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 3074:2002; 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 8h working day and shall not be exposed to continuous, varying, intermittent, or impulsive noise exceeding 140 dB(A) at any time. A number of studies have attempted to determine the real effects of hand-transmitted vibration and noise on risk of loss of hearing threshold among the workers (Pettersson, 2013; Pettersson et al., 2011). The number of industrial workers with hearing impairments are much high than ever before. The workers with sensory and mobility impairments face challenges with activities of daily living (Singh, *in press (b)*).

2.6. Electrogoniometry and Electromyography

The researchers have commonly used electrogoniometry and electromyography (EMG) techniques for evaluating discomfort and muscle activity during physical work involving high repetition, force or awkward postures (Maity et al., 2016; Afshari et al., 2014; Farooq and Khan 2014; Bano et al., 2012). Singh et al., 2018a opined that the assessment of limb movements is an essential evaluation measure for designing hand tool interventions by focusing on the path of movement of the tool. Furthermore, the evaluation of EMG activity along muscles could provide a criterion for the ergonomic workstation design to avoid overexertion. In one recent study, EMG responses on biceps brachii and extensor carpi radialis brevis muscles were investigated using seven different tool handle orientations (Bhardwaj and Khan, 2018).

A few Iranian articles (Mahdavi et al., 2016; Motamedzade et al., 2014; Allahyari et al., 2016) emphasized on the risk factors due to the muscle fatigue among carpet weavers. Lack of access to literature other than English caused limited extent to review (Mahdavi et al., 2018). Furthermore, all these studies primarily acquired EMG responses in laboratory settings and investigated upper trapezius muscle fatigue. The muscle activities during the field study may differ from the artificial environmental conditions. Unfortunately, despite all these claims, no significant research was evident in the domain of EMG study which has investigated other body parts (lower back, upper and lower hand) during carpet weaving. Afshari et al. (2014) examined the estimated loads on the L4/L5 spinal segment during weaving and postulated that the work system interventions should focus on reducing trunk flexion as the weavers spent 25% of their work time with trunk flexed greater than 20˚. Moreover, to the authors' knowledge and literature review, no significant research has been carried out in the area of carpet weaving in India, especially in EMG and goniometric perspective.

2.7. Multiple-criteria Optimization techniques

Optimum selection is an essential requirement in the design and development of the products. The effectiveness and reliability of the product often depend on the selected alternative. In order to solve the optimization issues of the engineering design process, plenty of decision-making approaches have been developed to increase the effectiveness of the design having multiple-responses (Jung and Freivalds, 1991). TOPSIS (technique for order performance by similarity to ideal solution) (Çalışkan et al., 2013; Behzadian et al., 2012), VIKOR (Vlse Kriterijumska Optimizacija Kompromisno Resenje, means Multi-criteria Optimization and Compromise Solution) (Opricovic and Tzeng, 2004; Çalışkan et al., 2013), ELECTRE (elimination and choice expressing the reality) (Shanian and Savadogo, 2006), PROMETHEE (preference ranking organization method for enrichment evaluation) (Chatterjee and Chakraborty, 2012) are such multi-criteria decision making (MCDM) techniques.

Most of the published literature on the Taguchi approach was based on single output optimization, as initially it was designed to solve single quantity output response (Ross, 1988). Several modifications were suggested to the traditional approach for a robust experimental design that seeks to obtain the best combination set of factors/levels (Jeyapaul et al., 2005). Multivariate statistical methods infer about the differences between multiple treatments groups to be tested on linear combinations of the outputs. They also control the type 1 error rate at the desired level. However, when more than one output responses are analyzed having a different set of best alternatives, it becomes challenging to find a feasible solution (Jobson, 2012; Hall, 1989).

The Taguchi's quality loss function (TLF) methodology has proved to be an effective optimization approach for multiple responses, but, surprisingly a very little attention has been devoted to these types of problems in engineering design (Jeyapaul et al., 2005). It employs relative weighting factors to each characteristic before computing total loss function to obtain multi-response signal-to-noise ratio (Antony, 2001). In this thesis, two MCDM methods and TLF are compared, in order to reveal and to compare the procedural basis of these the three optimization methods.

2.8. Summary of literature review and research gap

The approaches and techniques used for designing/re-designing the hand tools were collected form the literature review which is presented in Figure 2.2. Some of these design consideration were applied to improve the existing hand-tool interventions. The critical review of relevant literature on the topic leads to identification of following gaps which needs further probe:

1. Existing ergonomic studies are limited to the assessment of health related problems (higher visual problems, cardiovascular and musculoskeletal load) among handicraft workers, only few articles dealt with redesigning hand tools despite of variety of hand tools being used.
2. In Indian context, most of the studies were focused on handloom, hand block textile printing, blue pottery, imitation jewelry sectors. Literature review indicates that no significant research has been carried out in hand woven-carpet sector and wood carving from ergonomic perspective.
3. Most of the ergonomic studies in the hand-woven carpet industry were conducted in Persian countries. No significant research has been carried out so far in carpet weaving and repairing from the viewpoint of ergonomic design of hand tools.
4. To the best of our knowledge, no investigations were carried out for designing hand tools considering electromyography and goniometry in any handicraft industry.

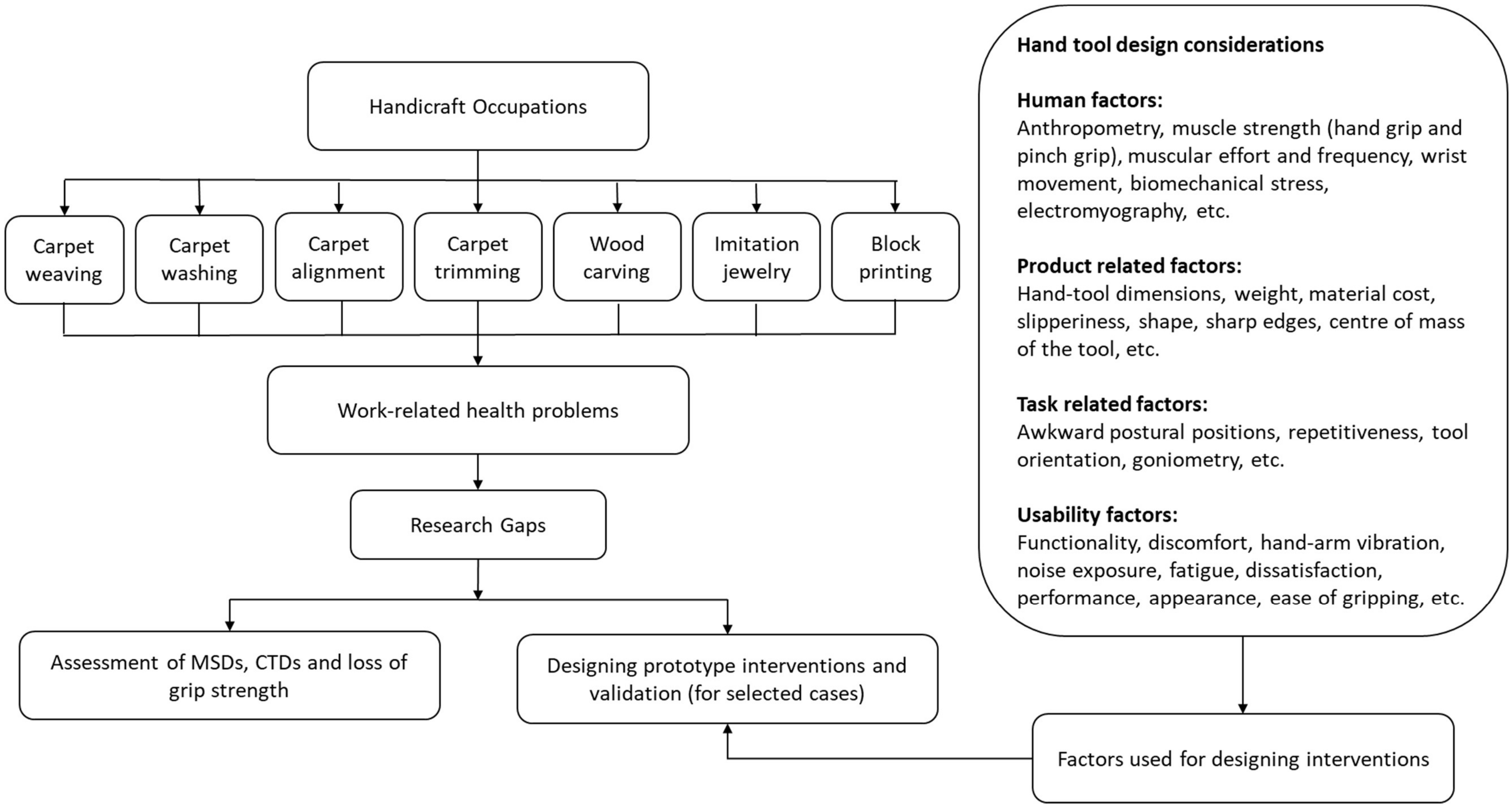

Figure 2.2. Brief summary of literature and work done.

CHAPTER 3

MATERIAL AND METHODS

3.1. Selection of Participants

The study was conducted within the rural area of Jaipur and its nearby districts. 282 participants, aged between 16 and 50 (mean 31.28; SD 7.62) were randomly selected from 27 workshops of several handicraft manufacturers for the exploratory study. The average work experience of the participants in the present occupation was 11.14 ± 7.01 years. Minimum 1 year of work experience on the same job was the inclusion criteria for the assessment part of the study. The inclusion criteria was a minimum of 3 year of work experience for the intervention phase of the study. The belongingness of all the participants was from the state of Rajasthan, Uttar Pradesh and Bihar (India). All subjects were professional handicraft workers and all had normal conditions of health and having no history of upper extremity disorders.

The summary of subject selection and inclusion/exclusion criteria is shown in Figure 3.1. The study design was cross-sectional and interventional. They were divided into seven groups as per their occupation, viz., carpet weavers, washer-men, carpet alignment workers, trimming workers, wood carvers, hand block printing workers and imitation jewelry workers. Of these participants, 130 were female, and 152 male workers. These workshops were situated at different locations in Sadwa, Maanbagh, Khore, Ramgarh, Sitapura, and Sanganer regions within Jaipur, Tonk and Sikar districts.

The demographic and professional description for the participants is depicted in tabulated form in Table 3.1. The mean age of the women participants was 29.34 ± 7.18 year, whereas, the mean age of the male participants was 32.43 ± 7.32 year. The nutritional status of the participants was assessed from their BMI values (WHO, 2000), and it was found that the mean value of BMI (21.33 ± 2.41) was within the normal range. From data analysis, we found that most of the demographic variable distribution of participants were normal. For example, a skewness of 0.51 (SE = 0.45) and 0.63 (SE = 0.49) and a kurtosis of –0.41 (SE = 0.76) and –0.57 (SE = 0.81) was found for the age and experience in workers. Also, the BMI and BSA were found to be normally distributed for a chosen level of significance ($p>0.05$), for all the cases.

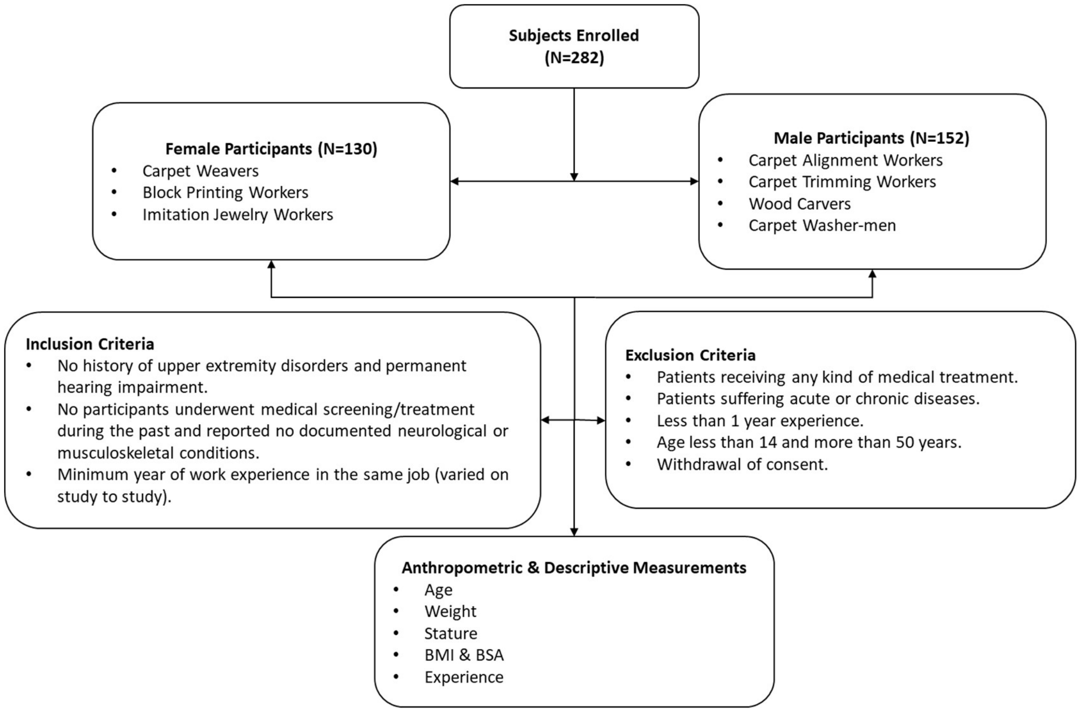

Figure 3.1. Summary of subject selection and inclusion/exclusion criteria for 282 participants.

Table 3.1. Physical parameters (mean and standard deviation for demographic variables) of the participants.

Variable	Mean (SD)							
	Overall (n=282)	Weavers (n=55)	Block Printers (n=45)	Jewelry Workers (n=30)	Washer-men (n=30)	Alignment Workers (n=40)	Carpet Trimmers (n=42)	Wood Carvers (n=40)
Age of subject (years)	31.28 (7.62)	27.01 (6.22)	30.82 (7.66)	32.2 (7.0)	32.8 (8.15)	31.32 (8.11)	33.4 (7.77)	32.25 (7.13)
Weight of subject (Kg)	54.85 (7.03)	47.54 (8.38)	47.52 (8.45)	49.29 (8.05)	59.63 (5.44)	59.14 (6.01)	60.07 (5.90)	61.41 (5.89)
Stature of subject (m)	1.59 (0.05)	1.53 (0.06)	1.55 (0.07)	1.55 (0.06)	1.63 (0.04)	1.63 (0.05)	1.64 (0.05)	1.65 (0.06)
BMI (Kg/m^2)	21.33 (2.41)	20.01 (3.59)	19.91 (3.51)	20.58 (3.42)	22.32 (1.66)	22.02 (1.89)	22.05 (1.86)	22.30 (1.71)
BSA (m^2)	1.53 (0.11)	1.42 (0.11)	1.42 (0.14)	1.45 (0.13)	1.64 (0.09)	1.63 (0.10)	1.64 (0.11)	1.65 (0.11)
Experience (years)	11.14 (7.01)	9.88 (6.54)	13.33 (6.95)	11.83 (6.93)	12.01 (7.19)	10.23 (7.16)	11.11 (7.58)	10.25 (6.91)

* *($p<0.01$)*

3.2. Tasks Involved in Handicraft activities

During this study, we have investigated the various parameter (prevalence of MSDs, grip strength, goniometry, muscle activity, HAV) among workers involved in seven different crafts trades, viz. carpet weavers, washer-men, carpet alignment workers, trimming workers, wood carvers, hand block printing workers and imitation jewelry workers, depending upon articulation of interest. The details of tasks involved in these occupations have been discussed later in the text.

3.2.1. Task involved in weaving

During weaving, the weavers sat next to each other and wove the carpet as per the provided map using conventional hand tools. These hand tools include weaving knife, weaving comb, and a beater. The weaving knife is used to cut the knot after the completion of each knot. The weaver holds the knife throughout the process of knotting which leads to forced fisted cylindrical grasping in their dominant hand. The weaving comb and beater are used after finishing a row of knots and weft.

The weaving of a carpet usually takes several months, depending upon the size, and as per urgency of the customer. Weaving requires enormous concentration and long duration of sitting (Figure 3.2a). Long hours of same squat posture could cause musculoskeletal disorders in different body regions. The process requires repetitive movement of digits and wrist that could be directly associated with cumulative trauma disorder (Singh et al., 2018a).

3.2.2. Task involved in hand block printing

Hand block printing is carried out in standing or sitting position and prints were made using a block die tool. It is used to replicate the shape of die block on the cloth extending high static muscular loads on the forearm (Figure 3.2b). The worker holds the tool throughout the process which leads to forced pinch grasping in their dominant hand. Nevertheless, the block printing requires extensive repetitiveness and reaching out to punch the die into the cloth on the work table with unusual, awkward postures (Singh et al., *in press (a)*).

3.2.3. *Task involved in imitation jewelry making (Pearl Hole Drilling/Setting)*

The worker sits in a squat posture holding the pearl to be drilled and placing it on the powered drill to make a hole. The drill bit of size greater than the size of the necklace thread was forced against the pearl creating hand vibration, and noise expose (Singh et al., in press (a)). The vibration is transmitted from the finger to the hand while holding the pearl to a correct position (Figure 3.2c).

Figure 3.2. Different handicraft processes viz. a) Carpet weaving; b) Hand block printing; c) Imitation jewelry bead drilling.

3.2.4. Task involved in Carpet Washing:

Waste produced from carpet can be Pre-consumer and Post-consumer based on their source of origin. Pre-consumer carpet waste comprises off cuts or scraps, spots, and strains set up during weaving and mending. Post-consumer carpet waste contains dust, dirt, chemicals and other materials, accumulated during service that makes carpet about 30% heavier (Sotayo et al., 2015). The purpose of washing carpets is to clean these scraps left behind during weaving and mending. The study only concentrates on washing pre-consumer waste.

Carpet washing starts with mopping the carpet with a broom to remove light density dust. Subsequently, back burn (burning the extra pills using controlled puff of LPG fire) provides the uniformity of piles. And finally, chemical solutions applied to the carpet are rinsed several times with clean water. The washer-men standing next to each other exert pressure on the wet carpet with the conventional wiper so that water along with chemicals and other contaminations leaves its surface (Figure 3.3a). A carpet generally requires 6-7 hours of washing and washing it multiple times is done for different reasons which justify that much time. The wiping of a carpet usually ranges from 90 to 120 minutes, depending upon the size of the carpet and repeated several times in the shift (Singh et al., 2017).

3.2.5. Task involved in Carpet alignment:

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 (Singh et al., 2018b).

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 3.3b). 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 lead exposure to the hand-transmitted vibration and high sound pressure levels.

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.

Figure 3.3. A typical postural position adapted to perform a) carpet washing; b) carpet alignment.

3.2.6. Task Involved in Wood Carving:

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 touches 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. The study focuses on the vibration and noise exposure from the cutters used in carving. Figure 3.4a shows postural position and HAV measurement done to produce a sculpture on a cylindrically shaped sandalwood block.

3.2.7. Task involved in Carpet trimming:

Before any repairing work is done on the carpet, its trimming is essential to be carried out. Carpet trimming is carried out after its alignment (Singh et al., 2018b), washing (Singh et al., 2017) and before any other repairing work. It is the process of removing unwanted threads (silk and wool) while maintaining the uniformity in thickness of the carpet. Before trimming, the design of carpet is indistinguishable, since its surface is covered with long, directionless piles. Unless these piles are cut up to a certain level, the actual design of carpet cannot be seen. Besides, with these massive piles, the other flaws in the carpet design would not be visible for the repairing purpose.

Carpet trimming levels the carpet to appropriate relative thickness. Furthermore, carpet needs to be trimmed taking no other part of repairing into account. A shearing machine performs cutting at the front of the carpet. This device has a cutter blade and a roller. It cuts up to a particular length which could be set beforehand by setting the cutter and the roller of the device. In this process, the piles are cut equal to the length where it becomes easier to work on design and color parts of the carpet front. Sometimes scissors are used for precision cutting of the border, flowers, figures, and halves of the carpet.

During trimming, the worker sitting in split squat posture (heel sitting posture) holds the machine in their dominant hand. They guide the device against the carpet to trim the threads into the carpet. This type of work results in repetitive wrist deviation of the dominant hand. Holding the metallic strip/handle throughout the process of trimming leads to forced cylindrical grasping in the dominant hand. Continuous and prolonged use of this machine tool also leads exposure to the hand-transmitted vibration and high sound pressure levels. The typical postural position adopted during carpet trimming is depicted in Figure 3.4b.

Figure 3.4. A typical postural position adapted to perform a) wood carving; b) carpet trimming.

3.3. Study Design and Phases of Study

The study were divided into two phases i.e., ergonomic assessment and intervention. Overall, a total of 282 female and male handicraft workers participated. While, out of those participants, 120 female, and 122 male handicraft workers were randomly selected for assessment phase. The objective of this assessment phase of the study was to get familiarize with the most prominent problems involved during craft activities. The remaining 40 participants were screened during the second phase (intervention) of the study. In the interventional experiments, we have not included the participants investigated during the assessment phase. The flowchart in Figure 3.5 depicts the elaboration strategy of the experimental design during this study.

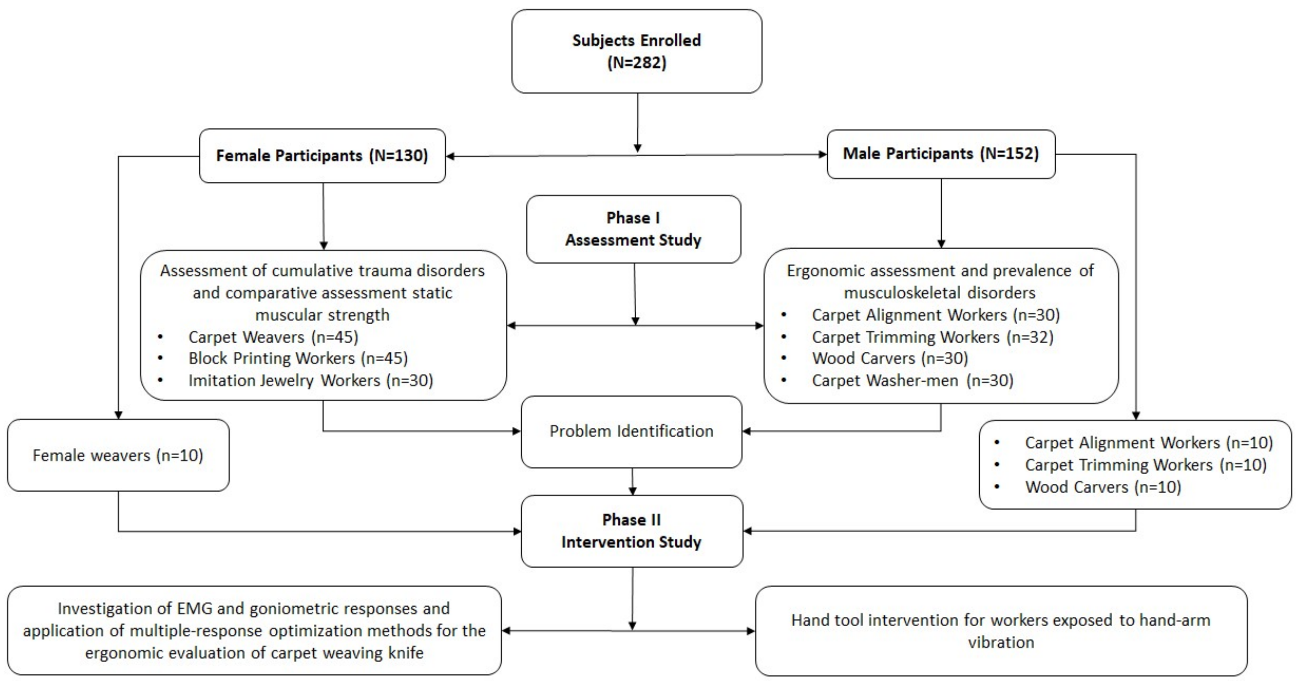

Figure 3.5. Elaborative flowchart of the experimental design.

3.4. Ergonomic Assessment Techniques

The following assessment techniques were used during the two phases of the study:

3.4.1. Questionnaire Assessment:

Modified Nordic Musculoskeletal Questionnaire (Kuorinka et al., 1987) was used to collect the required information from the different groups of 282 handicraft workers. Self-enumeration was difficult due to less understanding and low literacy rate among the participants. The main benefit of the interviewer-assisted over self-enumeration data collection method is that by personalizing the interview, survey population with low literacy rates can be covered and response rate and quality of data could be increased. Generally, the response rate for self-enumeration surveys is less than 70% (Fellegi, 2003). Therefore, interview assistance was provided to the respondent to complete the questionnaire.

3.4.2. *Physical Parameters:*

The physical parameters such as height and weight were measured by Holtain Harpenden Stadiometer (Made in Britain) and Accusure Digital Weighing Machine (Model GBS710). The body surface area (BSA) and body mass index (BMI) of the subjects were computed (Mosteller, 1987). The detailed description of measuring other physical parameters such as handgrip and pinch grip strength is discussed below:

- *Hand Grip Strength Test:*

The objective of the test was to monitor and analyze the hand grip strength. To undertake the examination, Baseline® hydraulic hand dynamometer (UPC: 714905013552) was used (Figure 1, Appendix-II). According to the American Society of Hand Therapists, the second handle position (grip span of 4.8 cm) of the hand dynamometer was recommended to be the best level for grip evaluation (Incel et al., 2002; Kuzala et al., 1992). In a study by Trampisch et al. (2012), the results showed accurate grip strength measurements taken at a single standard handle position. Therefore, we have used second handle position as the standard position for measuring grip strength. The participants were tested while sitting on a chair without armrest. The sitting posture included their hips and knees flexed at 90°, elbow flexed at 90°, forearm rotation at 0° and wrist at the neutral position (Nurul Shahida et al., 2015). The participant using their dominant hand (Peterson et al., 1989) applies as much grip pressure as possible on the dynamometer for 5 seconds. The readings were recorded for three times, and the participant was given rest for 120 seconds in between the trials (Caldwell et al., 1974). The participant repeated the test for the non-dominant hand, and the average value from three replications was used to assess the participant's performance (Mackenzie, 2002).

- *Pinch Grip Strength Test:*

Hand grip strength test was followed by tip (two-point) pinch, key (lateral) pinch and palmar (three-jaw chuck) pinch strength test with their dominant hand and non-dominant hand (Mathiowetz V. et al. 1984; Mathiowetz V. et al. 1985). The dominant hand was tested first, and the test was repeated for non-dominant hand (Mathiowetz V. et al. 1984). To undertake the test Baseline® hydraulic pinch grip dynamometer (UPC: 714905013811) with a fixed grip span (2.1 cm) was used (Figure1, Appendix-II). The participants were tested with the same posture mentioned above except for the wrist between 0° and 30° dorsiflexion and between 0° and 15° of ulnar deviation. The readings of three successive trials were recorded, and the average value was used to assess the participant's performance.

3.4.3. Vibration Measurement

In this study, the HAV was tested over the tool handles. The vibration values were taken using a lightweight PCB Piezotronics Inc. tri-axial accelerometers, model 356A01 (1.0-gram weight, 6.35 mm X 6.35 X 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 handicraft task in the normal environmental conditions (ISO 8041:2005).

The raw data of acceleration was acquired using PCB Piezotronics, model 482C05 sensor signal conditioner/amplifier, NI cDAQ-9171 chassis (NIC cDAQ-9171 manual, n.d) 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) (NIC 9234 manual, n.d) (Figure 2, Appendix-II). The calibration standards and procedures strictly followed as per the manufacturer's guidelines. The PCB Piezotronics accelerometers and NI Data Acquisition Unit have their calibration certificates and need to be documented. The routine calibration of tri-axial accelerometers and associated instrumentation are done on an annual basis. The acceleration values were displayed in LabVIEW code written in version 13 at a chosen sampling rate (1.5k samples per channel per second). The equivalent vibrations along each of the directions (x, y, and z) were calculated. A secondary LabVIEW based code was developed to filter the selected portion of unweighted acceleration data into frequency-weighted acceleration (between 6.3 Hz and 1250 Hz) using 2^{nd} order bandpass filter (IIR Butterworth) related to the center frequencies of the one-third octave bands (Figure 1 and Figure 2. (Appendix-IV)).

As per the ISO standard to fix the sensor and for the most practical measurements, the accelerometers were firmly mounted on the back of the dominant hand using double-sided tape. The displacement of the accelerometer while moving the joint was prevented by using medical tape (3M™ Durapore™). 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 standard anatomical hand position. The z-axis was placed perpendicular to the other two axes and directed parallel to the knuckles (Figure 3.6 (online Appendix)) (ISO, 2001).

Figure 3.6. Orientation of accelerometer on workers hand.

3.4.4. EMG and Goniometry Measurement:

The surface EMG and electrogoniometry tests were done simultaneously, and the data was acquired by data logging software which is discussed later in the text within chapter 5.1. Only right-hand side of the body was taken into consideration.

3.5. Experimental Design

The experimental designs of the individual phases of the study are discussed within the methodology section of the 4^{th} and 5^{th} chapters.

3.6. Ethical Approval

Before the experiments, the participants were instructed about the procedure and the possible risks involved in the experiment. The university ethics committee approved all experimental procedures, and the study received written approval from the handicraft manufacturers prior to their participation in the study.

3.7. Statistical Analysis

Data analysis was carried out using SPSS for Windows version 22.0 and MS Excel. The outcomes of results from the analyses were checked for significance at 95% and 99% confidence intervals. 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 were used to test if the group categories were normally distributed for the data to be analysed. Non-parametric tests were used as an alternative to parametric tests whenever distributional assumptions are not met for a chosen level of significance ($p<0.05$). The following statistical tests (along with descriptive statistics) were used to infer about the hypothesis set in the chapters:

1. Independent sample t-test
2. Kruskal-Wallis H test
3. Mann-Whitney U test
4. Related Samples Wilcoxon Signed Rank test
5. Chi-square test
6. Analysis of Variance (ANOVA)
7. Multi-variate analysis of variance (MANOVA)

CHAPTER 4

PRELIMINARY INVESTIGATION OF WORK-RELATED HEALTH PROBLEMS AMONG HANDICRAFT OPERATIVES'

4.1. Assessment of cumulative trauma disorders among female handicraft worker's and cross-sectional comparative assessment static muscular strength in different handicraft occupations

4.1.1. General Introduction

Weavers, block printing, and imitation jewelry workers are often recognized as the occupational groups that are most sought-after female workers because it can be set up within the household or nearby workshops. Hence, lack of occupational health and safety practices are common among the operatives in these handicraft professions. Women with responsibilities of running the home and taking care of the family, find it convenient to do part-time jobs near their homes (Dasgupta, 2016). Moreover, these jobs were paid less compared to other work. Therefore, it was observed that the work was not popular with male workers working in the same handicrafts industry.

Grip strength is one of the essential characteristics of a healthy hand (Swanson et al., 1970). Moreover, it has also shown a significant difference between healthy and subacute patients (del Pozo-Cruz et al., 2013). A few studies have shown that the exposure to CTS and HAV among workers engaged in hand-intensive jobs suffered lower grip strength (Singh et al., 2017b; Singh et al., 2017c; Bovenzi et al., 1991). Unfortunately, the inadequate literature leads to a need for assessing static muscular strength among the workers involved in the different crafts trades. Therefore, it was thought that this study shall determine the prevalence of CTDs and estimate the muscle strength among three handicraft occupations. The objective of the present research is to determine some essential static muscular strength, such as hand grip strength, pinch grip strength (tip, key, and palmar grip) of female workers coming from different occupations involving highly repetitive movements. This study hypothesizes that the strength values for handicrafts operatives in different vocations, exposed to different hand tools are relatively different from each other. In low-income countries like India, 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 part of the study assesses the ergonomic aspects at the grass-root level and proposes the insight to develop a better design of hand tools and workstation.

4.1.2. Methods

4.1.2.1. Selection of Participants

The cross-sectional study was carried out on female participants working in three craft occupations, viz., carpet weavers, hand block printing workers and imitation jewelry workers. These 120 asymptomatic female participants were mainly engaged in handicraft work in three different vocations. Of these participants, 45 were carpet weavers, 45 hand block printing workers, and 30 imitation jewelry workers. They were randomly selected from 16 handicraft workshops which were situated within the urban and rural area of Jaipur and its nearby districts.

The average work experience of the participants in the present occupation was 11.89 ± 7.14 years. Minimum one year of work experience in the same job and right-hand dominance was the inclusion criteria for this study. Only dominant right-hand workers were selected for the survey for minimizing any discrepancy in overall statistical significance or familywise error rate due to hand dominance. They were having no history of upper extremity disorders and chronic and acute diseases. All subjects were professional weavers and all had normal conditions of health and having no history of upper extremity disorders. The experimental weavers were divided into three groups according to the categories of perceived dissatisfaction rating toward weaving hand tools (0-3 for highly satisfied, 4-7 for moderate/mixed opinion and 8-10 for extreme dissatisfaction).

Since the workshops were situated at different locations; it was not possible to invite all the workers at the institute laboratory. The anthropometry and static grip strength tests of the experimental cohort were collected at their respective work locations. The study was designed in a way that every participant's data was recorded in a similar way, unfatigued prior to work. Therefore, they were asked to come to the workshop before the work shift. Repeated surveys were done over two months to obtain the data. The data were collected from 07:00 to 09:00 at the workshops.

The demographic description of the participants is depicted in tabulated form in Table 4.1.1. The mean age of the women participants was 29.81 ± 7.36 years. The nutritional status of the participants was assessed by their BMI values (WHO, 2000), and it was found that the mean value of BMI (20.13 ± 3.53) was within the normal range. The daily hours spent by the participants were 7.82 ± 0.84 hours with a rest of 30-45 minutes each day and weekly workload were 54.76 ± 5.88 hours during 7 days working. It was observed that 96.2% of participants were having education below primary; 94.9% had their right-hand dominant. From data analysis, it was found that most of the demographic variable distribution of participants were not normal. For example, a skewness of 0.43 (SE = 0.40) and 0.68 (SE = 0.45) and a kurtosis of –0.42 (SE = 0.85) and –0.68 (SE = 0.81) was found for the age and experience in weavers. Whereas, the BMI and body surface area (BSA) were found to be normally distributed for a chosen level of significance ($p>0.05$), for all the cases.

4.1.2.2. Questionnaire Survey

The checklist consisted four parts: (a) general information, i.e. age, demographic characteristics, working hours, years of experience, level of education, marital status, health habits, etc. and, (b) Body part discomfort interview i.e. pain/discomfort at different body regions, palm and finger regions, perceptual rating on dissatisfaction toward hand tools used during craft activity. The study was concentrated on the dominant hand of the participants (Hall and Kibom, 1993), (c) Physical Strength measurement i.e. hand grip and pinch grip strength, (d) The worker's dissatisfaction using the hand tools was measured using 0-10 rating scale.

The questionnaire was translated from English to Hindi for the ease of study. Each participant got verbal explanation about 0-10 rating scale prior to the survey. In order to measure worker's satisfaction using the hand tools, we use a rating scale to ask "On a scale of 1 to 10, what's your overall dissatisfaction with the hand tools?". We tried to measure the perceptual satisfaction/dissatisfaction of participants using hand tool on 0-10 scale, thus modified the scale. The 0-10 scale was used as it is easy to understand by the workers having low literacy rate (Preston and Colman, 2000; Likert, 1932). As opined by Borg (1982), the 0-10 scale is simple and easy to understand by lay of population that are not familiar with technical terminologies. Therefore, we sought to use the new 0-10 rating scale.

Table 4.1.1. Demographic characteristics of the group of workers.

Variable	Median (Interquartile Range)				Kruskal Wallis *p* value
	Overall (*N* = 120)	Weaver (*n* = 45)	Block Printer (*n* = 45)	Jewelry Worker (*n* = 30)	
Age of participant (years)	30.0 (24.0-35.0)	26.0 (22.0-35.0)	32.0 (24.0-35.0)	32.0 (26.0-35.0)	0.107
Weight of participant (Kg)	46.35 (41.80-53.68)	44.0 (41.7-51.8)	47.30 (41.4-52.6)	47.20 (41.6-55.5)	0.328
Stature of participant (m)	1.54 (1.50-1.58)	1.53 (1.49-1.57)	1.54 (1.50-1.58)	1.54 (1.52-1.59)	0.158
BMI	19.16 (17.26-22.79)	18.92 (17.51-22.68)	19.77 (16.88-22.22)	19.42 (17.59-23.52)	0.766
BSA (m^2)	1.42 (1.32-1.50)	1.36 (1.32-1.46)	1.43 (1.33-1.49)	1.45 (1.34-1.55)	0.164
Experience (years)	10.50 (6.0-16.0)	10.0 (4.5-15.0)	15.0 (8.0-20.0)	11.0 (5.75-17.0)	0.135

** (p<0.05)*
Note: BMI = Body mass index; BSA = Body surface area; Medians and Interquartile Ranges (IQR, 25th-75th percentile) for physical parameters (non-normally distributed).

4.1.2.3. Physical Parameters

The physical parameters were measured as per instructions given in Chapter 3.

Grip Strength Test

The test was administered using the Baseline® hydraulic hand and pinch grip dynamometers. The objective of the test was to monitor and evaluate the static muscle strength among the groups of female workers in working in three different handicraft occupations.

4.1.2.4. Statistical Analysis

A Shapiro-Wilk's test (p>0.05) and a visual inspection of their histograms, normal Q-Q plots and box plots showed that the experience, and age were not normally distributed for the group categories of perceptual dissatisfaction rating. Also, the static grip strength values (hand and pinch grip) were not normally distributed for each of the individual group. Also, static grip strength was not normally distributed for overall cases. Therefore, the following statistical tests were conducted to check the mentioned hypothesis:

1. Kruskal-Wallis H test was conducted to test the Hypothesis H1 (a) “the perceived dissatisfaction rating is greater with higher age and experience of the workers.”
2. Kruskal-Wallis H test was conducted to test the hypothesis that “there is a difference in the grip strength values of both the hands between and among the groups.” A Bonferroni correction was used to control for type-I error inflation due to pair-wise comparisons.
3. Mann-Whitney U test was performed to test the other hypothesis that “there is a difference in the static muscular strength of dominant (right) and non-dominant (left) hands within groups.”

Occupational groups (weavers, block printing workers, jewelry workers) were taken as independent variables, while static muscular strength (hand and pinch grip) at the dominant and non-dominant hand were considered the dependent variables. Kruskal-Wallis H test and Mann-Whitney U test is a non-parametric alternative to the one-way analysis of variance (ANOVA) test and independent sample *t* test and used when ANOVA’s distributional assumptions are not met (Day and Quinn, 1989).

4.1.3. Results

Figure 4.1.1 shows the percentage rated scale for the level of dissatisfaction with hand tools during handicraft activities. 54.2% of the participants complain extreme dissatisfaction toward the hand tools used while working; 25% were having mixed opinion about satisfaction level; 20.8% feel extremely satisfied. The overall rating among the female workers was 7.4 ± 2.5. Table 4.1.2 shows the association of experience and age with the categories of dissatisfaction rating. The treatments/grouping category was the subjective rating of dissatisfaction with hand tools while the age and experience were considered under these treatments from the questionnaire.

The results of the Kruskal-Wallis test were significant, $\chi2$ (0.01, 2) = 54.889, pointing out that the mean score of the perceived dissatisfaction rating were significantly higher with greater experience. Furthermore, the perceptual dissatisfaction was increased with higher age ($\chi2$ (0.01, 2) = 14.442). (Table 4.1.2).

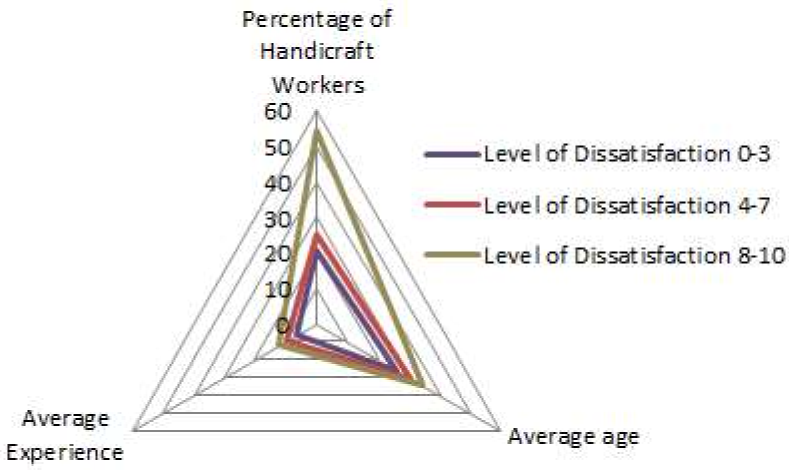

Figure 4.1.1. Spider diagram for level of discomfort from hand tools w.r.t age and experience

Table 4.1.2. Kruskal Wallis Sum Rank test for test fields (experience and age) by perceived rating of dissatisfaction toward hand tools.

	Level of Dissatisfaction					
Test Fields	Mean Rank (0-3)	Mean Rank (4-7)	Mean Rank (8-10)	χ^2	*df*	*p*
Experience (years)	9.14	20.19	58.81	54.889	2	<0.000**
Age (years)	22.45	31.08	46.11	14.442	2	0.001**

Notes. Low dissatisfaction – Mean Rank (0-3), Moderate dissatisfaction – Mean Rank (4-7), Extreme dissatisfaction – Mean Rank (8-10)
**($p<0.01$)

Figure 4.1.2 shows the most commonly affected body regions among the handicraft workers during last 12 months. Lower back, shoulders, wrist, elbows, knees, and ankles were the prominent regions of discomfort among female weavers and imitation jewelry workers. Block printing workers showed least discomfort in all the regions as compared to other two groups. The sole of the foot is other most affected body region among the weavers due to prolonged squat sitting posture with bare feet on a wooden plank. Figure 4.1.3 depicts the most commonly affected palmar surface regions among the handicraft workers during last 12 months. Index finger distal phalanx, index finger proximal and medial phalanx were most affected regions among all the groups. The other prominent regions of discomfort were thenar eminence, and metacarpal. Quite surprisingly, discomfort in middle digit were most prominent among imitation jewelry workers. Overall, it could be seen that the highest discomfort were prominent in weavers and imitation jewelry workers.

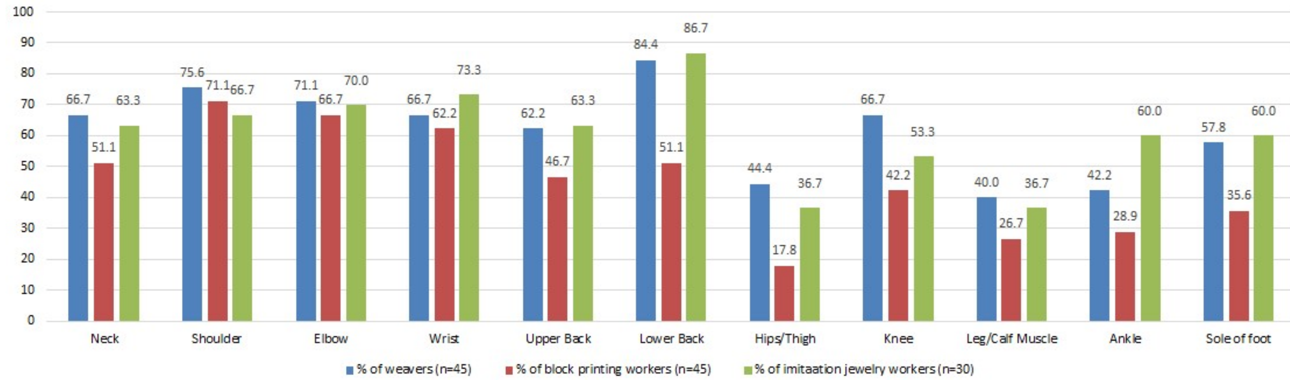

Figure 4.1.2. Frequency of reported symptoms in different body regions among female operatives in last 12 months.

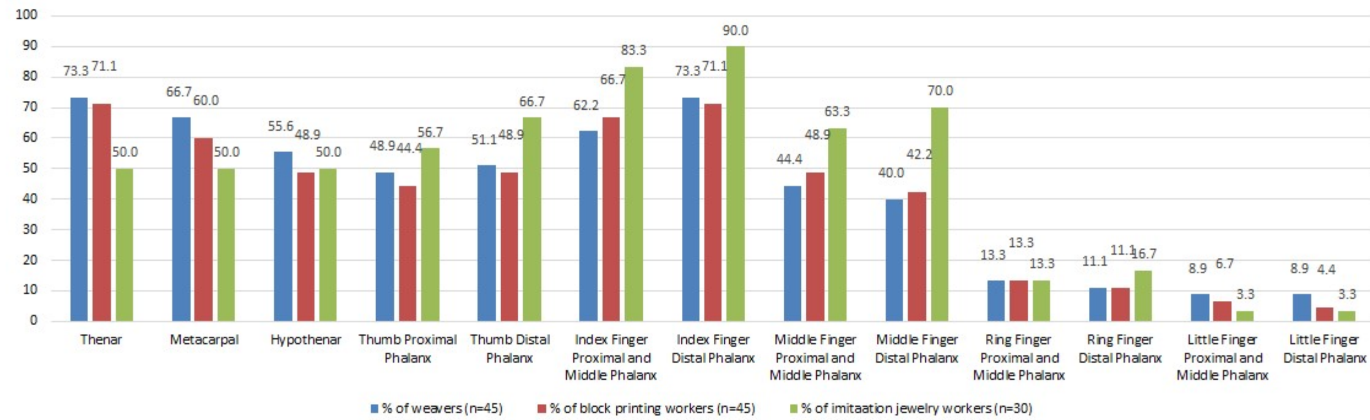

Figure 4.1.3. Frequency of reported symptoms in different palmar surface regions among female operatives in last 12 months.

The data of 120 participants were collected working in three different trades targeted for the study. Table 4.1.3 presents the correlations associated with the static muscle strength and demographic characteristics among all the workers. It also depicts overall means and standard deviations of the parameters. The results demonstrated that there were an inverse and significant correlation between age and muscle strengths in the dominant and non-dominant hand. No correlation was found between the physical parameters (weight, stature, BMI, and BSA) and muscle strength variables (handgrip, tip, key and palmar grip). Whereas, the experience was negatively associated with muscle strengths in both the hands. It was evident that the highest correlations were achieved between the right and left-hand grip strength followed by the tip and key pinch strength in the dominant right hand. Whereas, the lowest correlation for pinch strength in both dominant and non-dominant hand was found between the tip and palmar strength. It was not surprising that the highest correlations were achieved between the right and left hand for each grip strength scores (e.g., right tip pinch and left tip pinch strength).

A box plot plotted for the comparative assessment shows that the muscular strength was higher among the block printing workers when compared to the other two groups (Figure 4.1.4 and 4.1.5). It could be seen that static muscle strength among the jewelry workers was more in their non-dominant hand. Overall, the interquartile range (IQR) for handgrip and tip pinch was 4.42 and 0.68 kg in both hands. The IQR for key and palmar pinch grip in the left hand was 0.91 and 0.79 kg, whereas in right hand it was 1.25 and 1.36 kg. As shown in the graph, most of the outliers were of the same cases or participants, it can be concluded that the data contain no instrumental error. However, the muscular strength of the participant can be the parameter due to which the observation was numerically distant from the rest of the data. To support the preceding results, Shapiro-Wilk's test was also conducted to test the skewness, indicated that the data was not normally distributed. So, the non-parametric approach was opted for the statistical analysis.

The comparisons of static muscle strengths between the groups were performed using the Kruskal-Wallis H test. Mann Whitney test was used to test the difference in grip strength between both the hands. The static muscle strength values for both hands in the three groups are shown in Table 4.1.4-4.1.7. The confidence interval is constructed using bootstrap re-sampling based on function type set to percentile and variations at 1000 bootstrap subset samples. The results from the analyses translate that with 95% confidence, the true mean strength of workers is somewhere between about the upper and lower confidence limits.

From these results, it was evident that the tip, key and palmar pinch grip strength in the right and left hand of weavers and jewelry workers were significantly different. Furthermore, the handgrip and pinch strengths in dominant hand were found weaker than the non-work hand among jewelry workers. However, block printing workers showed no significant difference in strength values for both the hands. The results from the Kruskal-Wallis test shows that the all the groups were statistically different ($p<0.05$) in all the strength measurement scores for the right hand. Key pinch and palmar pinch strengths were significantly different ($p<0.01$) among each group for the left hand. Though the summary illustrates no specific details that may conclude about the difference in static muscle strength for non-dominant hand among each group of workers.

Table 4.1.3. Pearson correlations, means and standard deviations associated with static muscle strength and demographic characteristics among all the workers.

Parameter	Hand Grip Strength-L	Hand Grip Strength-R	Tip Pinch-L	Tip Pinch-R	Key Pinch-L	Key Pinch-R	Palmar Pinch-L	Palmar Pinch-R	Age	Weight	Stature	BSA	BMI	Experience	Mean	SD
Hand Grip Strength-L	1														30.40	2.77
Hand Grip Strength-R	0.890**	1													30.77	2.73
Tip Pinch-L	0.146	0.069	1												2.44	0.67
Tip Pinch-R	0.126	0.132	0.720**	1											2.53	0.68
Key Pinch-L	0.095	0.037	0.634**	0.541**	1										2.96	0.68
Key Pinch-R	0.166	0.187*	0.643**	0.805**	0.683**	1									2.98	0.70
Palmar Pinch-L	0.101	0.055	0.426**	0.404**	0.485**	0.485**	1								4.76	0.65
Palmar Pinch-R	0.246*	0.321**	0.456**	0.606**	0.499**	0.737**	0.533**	1							4.76	0.79
Age	-0.386**	-0.431**	-0.392**	-0.280*	-0.377**	-0.290*	-0.457**	-0.428**	1						29.81	7.36
Weight	0.056	-0.055	0.098	-0.065	0.056	0.101	-0.105	-0.101	0.354**	1					47.57	8.30
Stature	0.109	0.178	-0.057	0.032	0.059	0.059	0.188	0.050	0.156	0.237*	1				1.54	0.06
BSA	0.069	0.032	0.084	-0.060	0.058	0.047	-0.087	-0.096	0.361**	0.974**	0.446**	1			1.42	0.13
BMI	0.023	-0.043	0.087	-0.051	0.048	0.083	-0.108	-0.096	0.277**	0.881**	-0.244*	0.755**	1		20.13	3.53
Experience	-0.345**	-0.415**	-0.259*	-0.231*	-0.337**	-0.317**	-0.418**	-0.405**	0.686**	-0.028	0.192*	0.018	-0.102	1	11.89	7.14

*** Correlation is highly statistically significant at the 0.01 level (2-tailed).*

** Correlation is statistically significant at the 0.05 level (2-tailed).*

Note. L = Left Hand; R = Right Hand; BSA = Body surface area; BMI = Body mass index.

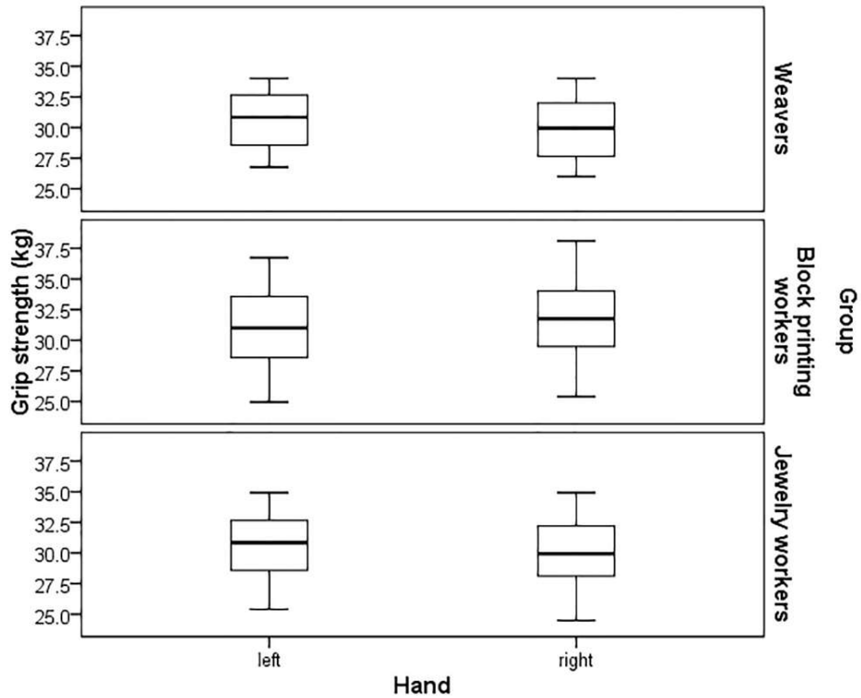

Figure 4.1.4. Box plot showing hand grip strength values among the three groups for right and left hand.

Note: Error bars (whiskers) denote the variability outside the upper and lower quartiles.

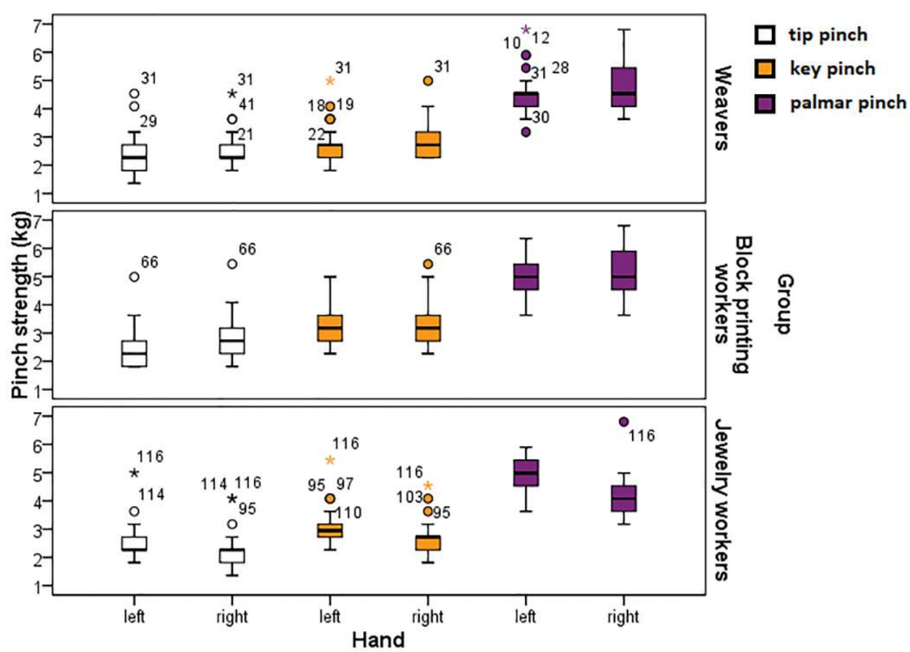

Figure 4.1.5. Box plot showing tip, key and palmar pinch grip strength values among the three groups for right and left hand.

Note: Error bars (whiskers) denote the variability outside the upper and lower quartiles. Circle denotes the data points that are within 1.5 times the interquartile range (IQR) above the upper quartile located but outside the whiskers. Star indicates the outliers that are larger than 1.5 times the IQR. Most of the outliers were of the same cases or participants. Here, 116 shows the participant's serial number/case.

Table 4.1.4. Hand grip strength (kg) among the handicraft workers group.

Participant	Right Hand		Left Hand		Mann Whitney *p* value
	Mean	95% CI [LCL, UCL]	Mean	95% CI [LCL, UCL]	
Weavers	30.5	29.8, 31.2	29.8	29.1, 30.6	0.193
Block Printing Workers	31.6	30.7, 32.5	30.9	30.0. 31.8	0.290
Jewelry Workers	29.9	29.0, 30.9	30.5	29.5, 31.5	0.374
Kruskal Wallis *p* value	0.046*		0.217		

** (p<0.05)*

*** (p<0.01)*

Note. CI = Confidence Interval; LCL = Lower confidence limit; UCL = Upper confidence limit.

Table 4.1.5. Tip pinch grip strength (kg) among the handicraft workers group.

Participant	Right Hand		Left Hand		Mann Whitney *p* value
	Mean	95% CI [LCL, UCL]	Mean	95% CI [LCL, UCL]	
Weavers	2.5	2.3, 2.7	2.3	2.1, 2.5	0.037*
Block Printing Workers	2.8	2.5, 3.0	2.5	2.3, 2.7	0.086†
Jewelry Workers	2.2	2.0, 2.5	2.5	2.3, 2.7	0.027*
Kruskal Wallis *p* value	0.003**		0.092†		

** (p<0.05)*

*** (p<0.01)*

† (slight but not significant)

Note. CI = Confidence Interval; LCL = Lower confidence limit; UCL = Upper confidence limit.

Table 4.1.6. Key pinch grip strength (kg) among the handicraft workers group.

Participant	Right Hand		Left Hand		Mann Whitney p value
	Mean	95% CI [LCL, UCL]	Mean	95% CI [LCL, UCL]	
Weavers	2.9	2.7, 3.1	2.7	2.5, 2.9	0.044*
Block Printing Workers	3.2	3.0, 3.5	3.1	3.0, 3.3	0.627
Jewelry Workers	2.7	2.5, 2.9	3.1	2.9, 3.3	0.005**
Kruskal Wallis p value	0.001**		<0.001**		

** (p<0.05)*

*** (p<0.01)*

Note. CI = Confidence Interval; LCL = Lower confidence limit; UCL = Upper confidence limit.

Table 4.1.7. Palmar pinch grip strength (kg) among the handicraft workers group.

Participant	Right Hand		Left Hand		Mann Whitney p value
	Mean	95% CI [LCL, UCL]	Mean	95% CI [LCL, UCL]	
Weavers	4.8	4.6, 5.0	4.5	4.3, 4.7	0.028*
Block Printing Workers	5.1	4.9, 5.4	4.9	4.8, 5.1	0.104
Jewelry Workers	4.2	3.9, 4.4	5.0	4.8, 5.2	<0.001**
Kruskal Wallis p value	<0.001**		<0.001**		

** (p<0.05)*

*** (p<0.01)*

Note. CI = Confidence Interval; LCL = Lower confidence limit; UCL = Upper confidence limit.

In the present analyses, a Bonferroni adjustment was used to control for the familywise type-I error rate in determining whether Kruskal-Wallis H test was significant (Table 4.1.8). Despite the overall significance in the grip strength of right-hand, only jewelry and block printing workers were significant beyond the 0.05 level, two-tailed test after using a Bonferroni correction. Also, for right-hand tip pinch strength, jewelry workers were significant from block printing workers (*at* $p<0.01$). Although the key and palmar pinch strengths in the left-hand between weavers and block printing workers were statistically significant *(at* $p<0.01$*)*, no significance was observed in the right-hand. The difference in palmar pinch strength between the weavers and jewelry workers were found significant in both the hands. Furthermore, key pinch strength in only left-hand showed the asymptotic significant difference between weavers and jewelry workers *(at* *p<0.05)*. Therefore, it could be inferred from the results that jewelry workers had the weakest work hand when compared with other groups.

Table 4.1.8. Kruskal-Wallis H test post hoc multiple comparisons (Bonferroni analysis) to explore all possible pair-wise comparisons between the groups.

Group (I)	Group (J)	significance at 95% and 99% confidence interval			
	Grip Strength at Right Hand	Hand Grip	Tip Pinch Grip	Key Pinch Grip	Palmar Pinch Grip
1	2			†	†
	3				**
2	3	*	**	**	**
	Grip Strength at Left Hand				
1	2			**	**
	3			*	**
2	3				

** (p<0.05)*

*** (p<0.01)*

† (slight but not significant)

Note: Group 1 = Carpet weavers; Group 2 = Block printing workers; Group 3 = Imitation jewelry workers. Blank pair imply no significant difference between the groups after using a Bonferroni correction.

4.1.4. Discussion

The results showed that the evidence of the prevalence of CTDs due to various factors among the female weavers in handicraft industries. The average age and experience of female workers complaining extreme dissatisfaction were 34.19 years and 12.13 years which were relatively higher compared to workers feeling satisfied with the hand tools. To support the preceding results, Kruskal-Wallis test showed that the variations were too great to be explained by chance alone. There was a strong evidence of statistical difference in age and experience on the categories in perceived dissatisfaction. It signify that as the experience and age grows, the perception of dissatisfaction toward hand tools also tend to develop.

The earlier studies investigated that poor design of hand tool, posture, gripping, repetitiveness, and vibration on hand regions are associated with CTS (Atroshi, 2009; Armstrong, 1983; Mital, and Kilbom, 1992). Safety guidelines were presented to minimize injuries on workplace and may reduce the risk of CTS (HSE, 1990). Kutluhan et al. (2001) opined that hand knotted carpet weavers using non-ergonomic hand tools were exposed to varying degrees of repetitive and forceful hand and wrist motions and developing increased risk of upper extremity repetitive strain and CTS.

Lower back, shoulders, elbow, knees, neck, wrist, and upper back are the most affected body regions due to high force exertion on limbs during handicraft work. The results of this study were in agreement with previous Persian studies (Choobineh et al., 2004; Chaman et al., 2015; Nazari et al., 2012) signifies that geographical and demographic characteristics are independent of discomfort in the handicrafts profession. Based on previous literature, lower back and shoulders were recognized as the two common sites found among the weavers, which is in line with the findings of the present work. Some studies recognized that increased spinal load and lower back pain occurs during prolonged standing or sitting posture without back support (Genaidy and Karwowski, 1993; Andersson, 1986). Shoulder, elbow, and wrist pain were most prominent in dominant hand due to repetitive use while operating respective hand tools. Chaman et al. (2015) indicated that the odds of low back and neck pain among the weavers who have pain in their right shoulder increases by 2 times and 3.05 times, respectively. Afshari et al. (2014) pointed out that apart from poorly designed workstation, awkward posture of the trunk, low seat height, and speed of arms could be the prime risk factors for back and shoulder pains.

This was the first study of its kind to provide palmar surface discomfort regions in handicraft profession. Index finger and thumb distal phalanx were the most affected regions among carpet weavers and imitation jewelry workers due to constant tying of knots and pearl drilling. Thenar, and metacarpal regions were affected due to grasping of the non-ergonomic hand tools for the whole workday. The palmer regions are therefore exposed to direct contact stresses for long periods that might result in swollen finger joints, permanent deformation of the fingers (Radjabi, 1983).

This study also presents the evidence that static muscle strength may be influenced due to repetitive use of hand tools for a prolonged period, albeit to a moderate degree. This is the first cross-sectional comparative study of its kind to evaluate the static muscle strength among the handicraft operatives of different vocations in India.

Previous studies (Mathiowetz V. et al. 1985; Mohammadian et al., 2014) have established that there are an inverse and significant correlation between age and muscle strengths. Results from our study were also in line with them showing a negative association between age and all measured strengths in dominant and non-dominant hand. Also, the experience was significantly and inversely associated with all grip and pinch strength values. Thus it signifies that as the experience and age grow, the muscular strength among the worker's also tends to decrease. A few studies (Schmidt and Toews, 1970; Balogun et al., 1991) have reported a positive correlation between grip strength, weight, and stature in healthy participants. On the contrary, Robertson et al. (1996) recognized that a positive relationship between grip strength, and anthropometry may not occur in individuals with hand dysfunction. Based on our results, no significant correlation could be obtained between the grip strength values, weight, and stature among the handicraft workers. Perhaps a larger sample size may infer accurate information about the association.

The experimental analysis reveals that the exposure to jewelry work was associated with an apparent decrease in pinch strength measures when compared to other hand-intensive jobs. This is further exemplified in a reciprocal comparison to the strength of the contralateral limb. The overall interpretation of the results from strength comparisons suggests that the jewelry workers had consistently weaker hand and pinch grip strength parameters than the other groups. An apparent decrease in muscle strength that jewelry workers suffered could be due to work exposure.

In every group aside from jewelry, the non-work hand was either weaker or equivalent to the work hand, which makes sense, due to handedness and from natural hypertrophy due to the physical nature of work. However, with the jewelry workers, the work hand was weaker than the non-work hand in each of these measurements, perhaps even implying an increased risk of injury due to the type of daily work. In fact, the grip strength of their non-work hand was more or less similar to that of other groups. Perhaps, the reason could be that their dominant right hand was exposed to hand-arm vibration during pearl hole drilling. The difference in grip strength in work and non-work hand indicate that the exposure to hand tools for a prolonged period is highly associated with a reduction in muscle strength. Several investigators have suggested that the effect of hand vibrations are directly associated with a loss of static grip strength (Haward and Griffin, 2002; Bovenzi et al., 1991; Radwin et al., 1987; Azmir et al., 2015).

Some quantitative studies have demonstrated that the major health-related problems associated with carpet weavers are MSDs in lower back, shoulders, elbow, and wrist regions due to high force exertion on limbs during weaving (Choobineh et al., 2007; Choobineh et al., 2004;

Singh et al., 2017b). The risk of CTS and upper extremity MSDs (shoulders, elbow and hand/wrist disorders) is due to repetitive movement of hand and wrists muscles during weaving (Kutluhan et al., 2001). The findings of the previous literature examined that the upper extremity MSDs is associated with the significant drop in grip strength (Alperovitch-Najenson et al., 2004; Sande et al., 2001; Marciano and Tayyab, 2017). It also depends on the type of work (Cotelez et al., 2016). Based on the results from the present study, it could be seen that the pinch grip strength of the non-dominant (left) hand among weavers was lowest among other groups. The drop in pinch grip strength could be due to repetitive use of the distal phalanx in digits during knotting which involves both hands. The long cycle repetitive pinching movements (knotting) and forced cylindrical grasping (weaving knife) could be the cause of variation in the static muscle strength.

Unlike the other groups, block printing workers showed no noticeable difference in the static muscle strength between both the hands. They have also shown a relatively higher muscle strength than the other two group of workers, which may partly be attributed lower level of occupational stress during block printing. The inferences drawn from the present results could be supported by the study showing that the complaints of work-related MSDs among hand block printing workers were lower back pain, shoulders pain, upper back pain and knee pain due to the improper ergonomically designed workstation. Not much discomfort was reported in wrist/hand regions (Meena et al., 2014).

Liu and Chu (2006) reported that the physical demand of the occupations is directly associated with the grip strength of the workers. Pearl bead drilling is challenging and extremely labor intensive as compared to other imitation jewelry tasks. The physical examination in this research showed that the jewelry workers suffered a significant loss in the tip, pinch and palmar pinch grip strength in their work hand as compared with the non-work hand. The reason seems to be due to high force exertion on digits and prolonged awkward working posture exerting excessive muscle pressure during drilling holes. Perhaps, the worker holds (pinch grasp) the pearl against the bit throughout their daily work. No noticeable difference was observed in the left hand with the other groups since the process of drilling requires the minimum use of the left hand.

Further longitudinal work is needed to explore the ergonomic designs of work system and hand tool interventions that are adjustable in terms of the anthropometric dimensions of the jewelry workers. It is advisable to carry out studies to unravel the specific fixtures that may reduce the vibration magnitudes and sound pressure level within the acceptable limits. Perhaps, it leads to effective sustainability and the improvement in the quality of work life among the workers.

Highly repetitive activities in the handicraft work is another ergonomic risk factor which may lead to the risk of upper limb MSDs (Das et al., 2018). Silverstein et al. (1987) also point out that CTS was strongly associated with high repetitive jobs and the odds ratio for the high repetitive jobs was more than 15 *(at $p<0.001$)* when compared to low repetitive jobs. A large number of clinical investigations have reported that the reduction in grip strength is related to the high repetitiveness of the upper limbs (Singh et al., 2018; Atroshi, 2009; Armstrong, 1983). Apart from the loss of grip strength, repetition plays a vital role in the development of physiological stress among the workers (Das, 2014). Singh et al. (2017, 2018) carried out the physiological assessment of the workload by recording the heart rate and blood pressure of the carpet washer-men and weavers before and after the continuous work activity. The results revealed that there was a tendency to rise in blood pressure and heart rate after continuous work activity during carpet washing. However, no significant effect was reported in blood pressure during the weaving, though an increase in heart rate was observed.

4.1.4.1. Recommended Guidelines:

This section presents the major contributions of the study and recommended guidelines were established based on the evidence of the problems in handicraft work. These guidelines may help in designing hand tools and workstation to prevent CTDs and improve working posture. Furthermore, these guidelines had dealt with an issue of affective sustainability, attaining to product optimization.

- Neck, shoulder, elbow, wrist, or back regions are most affected by physical work demanding awkward postures. The ergonomically designed hand tools should be introduced that curtail the pain and fatigue by maintaining the neutral posture whenever possible (Lewis and Narayan, 1993; Johnson, 1990). To maintain a straight wrist, bent handles or angulations of handles should be necessary for hand tools (Das et al., 2005; Patkin, 2001). The hand tools should be designed using hand anthropometry of the region of concern (fit for 5th to 95th percentile of the workers) (Singh et al., 2018a).
- Adding soft material sleeve to coat the tool handle may prevent the prevalence discomfort in thenar eminence, metacarpal and hypothenar regions (Fellows and Freivalds, 1991;

Lewis and Narayan, 1993). It may reduce the harmful contact pressure on hand while using more force (Kuijt-Evers, 2005; Fransson-Hall and Kilbom, 1993). Additionally, efforts should be made to coat the tool handle with non-slippery sleeve for a better grip.

- A weaving knife is used to cut the open or untied end of the thread. During each cut, the weaver moves the wrist with > 15° ulnar deviation and > 15° flexion. These movements are repeated for each knot (3500 knots/day) and certainly increase intracarpal pressure that may lead to CTDs. The knife blade can be an essential evaluation measure and should be redesigned so that wrist movement can be minimized. During the impact of weaving beater/comb on the edge of the carpet, the wrist acts as a fulcrum and the impact force has a turning effect (moment) about the fulcrum. These tools can be further redesigned by focusing the path of movement of the tool. Additionally, the centre of mass of the tool should be as close to the center of the hand as possible (Strasser, 2007).
- The implementation of stretching exercises and yoga training program to reduce the effects of static muscle loading among the workers which in turn improves the strength and flexibility (Costa and Vieira, 2008; Gura, 2002).

4.2. Ergonomic assessment and prevalence of musculoskeletal disorders among male handicraft workers

4.2.1. General Introduction

The development of MSDs is the most common problem among the workers employed in the handicraft industry. Handicraft work is much more difficult and extremely labour intensive as compared to other informal jobs. Therefore, it sought useful to take up the issues of ergonomic study of handicraft operatives, with an objective to determine the prevalence of MSDs while crafting work. This study hypothesizes that there would be significant association of age, experience and health habits on perceived exertion. The research aimed to propose certain workstation guidelines which could be beneficial for designing new workstation that may improve the working conditions and reduce symptoms of MSDs to an affective sustainability. This study investigates the problems encountered during hand crafting work and establishes the guidelines for ergonomically efficient workstation. As the main outcomes, this study proposes certain workstation guidelines that may reduce the symptoms of MSDs, lead to the improvement in working posture and efficiency of the worker. This study assesses the ergonomic aspects at grass-root level and proposing the insight to develop a better design.

4.2.2. Material and Methods

4.2.2.1. Participants

The study was conducted within the urban area of Jaipur. All 122 male respondents, aged between 19 and 50 (mean 31.9; SD 7.65) were selected for the survey from 13 workshops of several handicraft manufacturers. These workshops were situated within the urban and rural areas of Jaipur in Sadwa, Maanbagh, Khore and Ramgarh regions. Carpet washer-men, alignment workers, trimming workers and wood carvers were randomly selected for this part of the study. The experimental subjects were divided into three groups according to the categories of perceived exertion (0-3 for light exertion, 4-7 for moderate exertion and 8-10 for extreme exertion).

4.2.2.2. Questionnaire Survey

The checklist consisted three parts: (a) general information, i.e. age, demographic characteristics, working hours, years of experience, level of education, marital status, health habits, etc., (b) Body part discomfort interview i.e. pain/discomfort at different body regions, palm and finger regions, and (c) perceptual rating on dissatisfaction toward hand tools used during craft activity. The worker's perceived exertion/ dissatisfaction using the hand tools was measured using 0-10 rating scale as discussed in section 4.1.

4.2.2.3. Physical Parameters

The physical parameters were measured as per instructions given in Chapter 3.

Sample Characteristics and Statistical Analysis

Kruskal-Wallis H test was conducted to test the Hypothesis H1 (a) "there is a difference in the rating of perceived exertion (RPE) and health habits (smoking and drinking)". It was performed to test the Hypothesis H1 (b) "the perceived exertion rating is greater with higher age and experience of the workers."

4.2.3. Results

During the study, 122 male handicraft workers were asked to participate. Table 4.2.1 shows the demographic description and general information related to work. The average work experience of the participants in the present occupation was 10.2 ± 6.8 years. These craft professions are most sought after male workers due to the fact that it requires high physical strength. The demographic description of mean BMI was 22.4 ± 1.7 (normal) (WHO, 2000); mean BSA was 1.65 ± 0.10 m^2 (normal). The daily hours spent by the participants was 9.2 ± 0.74 hours with a rest of 45-60 minutes each day and weekly workload was 63.5 ± 5.04 hours (7 days working). It was observed that 86.7% of participants were having education below secondary. It was reported that 90% of them use right hand as their dominant hand. 63.3% of the participants had health habits (smoking and drinking) at varying levels either light, medium or heavy.

Figure 4.2.1a depicts the mean perceived rating among the handicraft workers during respective craft tasks according to Borg's RPE scale (Borg, 1982). The mean perceived rating among the male craft workers was 6.8 ± 3.3. 51.6% of the participants complain extreme physical exertion while working with the hand tools; 28.7% feel moderate physical exertion; 19.7% feel the light physical exertion (Figure 4.2.1b).

Table 4.2.1. Demographic statistics and personal characteristics of the study population (N=122)

Characteristics of samples		Washer-men (n=30)	Wood Carver (n=30)	Carpet Trimmer (n=32)	Alignment Workers (n=30)	Overall (N=122)	Kruskal-Wallis p value
		Mean ± SD					
Age of subject (years)		32.8 ± 8.15	31.4 ± 7.26	33.5 ± 7.37	30.1 ± 7.81	31.9 ± 7.65	0.119
Weight of subject (Kg)		59.63 ± 5.44	62.51 ± 5.81	61.72 ± 5.09	60.84 ± 6.09	60.84 ± 6.10	0.258
Stature of subject (cm)		163.37 ± 4.06	165.53 ± 5.19	163.81 ± 4.88	164.68 ± 5.11	164.12 ± 5.09	0.184
BMI index		22.32 ± 1.66	22.59 ± 1.69	22.44 ± 1.68	22.38 ± 1.70	22.4 ± 1.70	0.684
BSA index		1.64 ± 0.09	1.66 ± 0.10	1.64 ± 0.11	1.65 ± 0.10	1.65 ± 0.10	0.329
Experience (years)		12.01 ± 7.19	9.23 ± 6.80	10.20 ± 6.51	9.22 ± 6.62	10.2 ± 6.8	0.112
Daily workload (hour)		9.1 ± 0.71	8.9 ± 0.68	9.3 ± 0.78	9.3 ± 0.79	9.2 ± 0.74	0.214
Weekly Workload (hour)		63.7 ± 4.98	61.2 ± 4.81	63.9 ± 5.14	63.9 ± 5.19	63.5 ± 5.04	0.221
	Category	Frequency (%)					
Education	Illiterate	33.3	50	53.33	60	49.23	
	Primary education	53.3	36.67	40	23.33	38.35	
	Secondary education	13.3	13.33	6.67	16.67	12.40	
Marital Status	Unmarried	3.3	6.67	3.3	3.33	4.14	
	Married	96.7	93.33	96.7	96.67	95.86	
Hand Dominance	Right Hand	90	100	96.67	96.67	95.85	
	Left Hand	10	0	3.33	3.33	4.15	
Level of Smoking	No	36.7	50	60	46.67	48.53	
	Light (<15 cigarettes)	16.7	40	36.67	43.33	34.22	
	Medium (15-25 cigarettes)	30	6.67	3.33	6.67	11.53	
	Heavy (>25 cigarettes)	16.7	3.33	0	3.33	5.74	
Level of Drinking	No	30	60	66.67	43.33	50.27	
	Light (<125 ml)	10	33.33	33.33	26.67	25.96	
	Medium (125-250 ml)	36.7	6.67	0	30	18.04	
	Heavy (> 250 ml)	23.3	0	0	0	5.73	

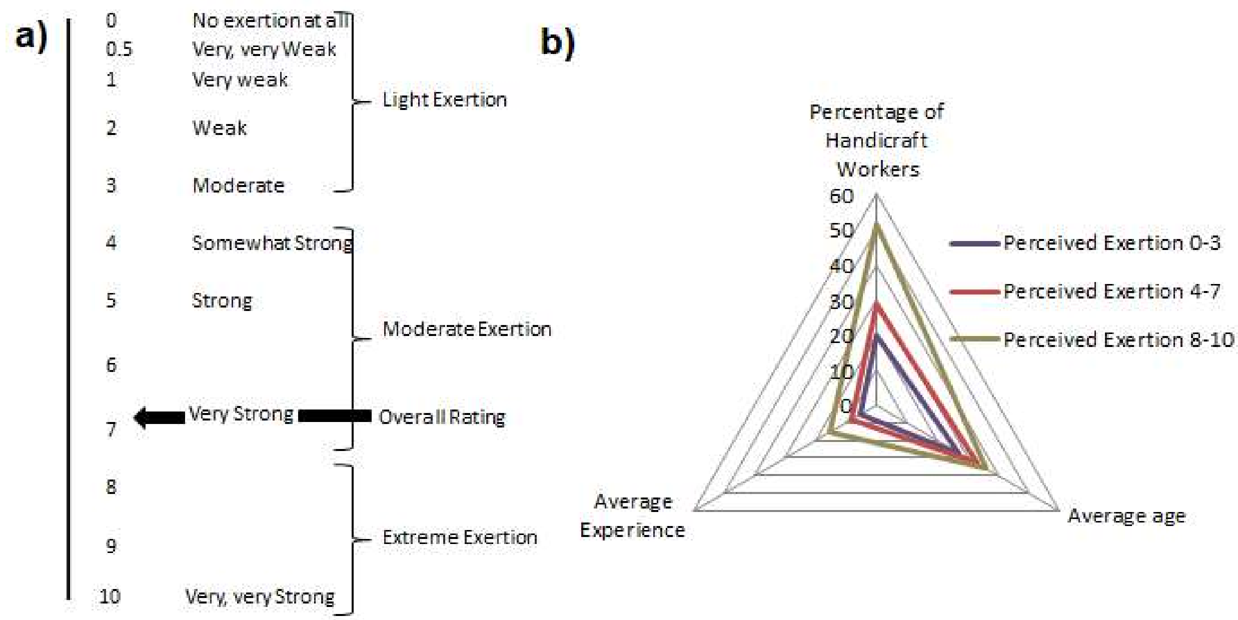

Figure 4.2.1. a) Mean perceived rating among the handicraft workers; b) Spider diagram for perceived rating w.r.t age and experience

Table 4.2.2 shows the association of experience and age with the perceived exertion. The results of the Kruskal-Wallis test were significant, χ^2 (0.05, 2) = 12.519, pointing out that the mean score of the perceived exertion were significantly higher with greater experience. The perceptual effort rating increased marginally with higher age (χ^2 (0.05, 2) = 9.515). There was no evidence of a significant difference of health habits (smoking) on the categories in perceived exertion (χ^2 (0.05, 2) = 2.296). It was observed that there was a strong evidence of a significant difference of health habits (drinking) on the categories in perceived exertion (χ^2 (0.05, 2) = 14.114) (Table 4.2.2).

Figure 4.2.2 shows the results of the questionnaire, revealed that the frequency of most commonly affected body regions among the handicraft workers in the past 12 months were Wrist, Lower back, Shoulders, Elbows, Leg/Calf muscle, and Hips/Thigh. The sole of the foot is other most affected body region among the washer-man.

Figure 4.2.3 shows the results of the questionnaire, revealed that the frequency of most commonly affected palmar surface regions among the handicraft operatives in the past 12 months were metacarpal, thenar eminence, and hypothenar.

Table 4.2.2. Kruskal Wallis Sum Rank test for test fields (experience, age, health habits) by perceived exertion

	Feeling of perceived exertion					
Test Fields	Mean Rank (0-3)	Mean Rank (4-7)	Mean Rank (8-10)	χ^2	*df*	*p*
Experience (years)	11.82	9.15	23.11	12.519	2	<0.000*
Age (years)	10.42	9.55	21.15	9.515	2	0.004*
Level of Smoking	9.81	16.49	18.14	2.296	2	0.215
Level of Drinking	6.71	13.55	20.08	14.114	2	<0.000*

($p<0.01$*)

Notes. Light exertion – Mean Rank (0-3), Moderate exertion – Mean Rank (4-7), Extreme exertion – Mean Rank (8-10)

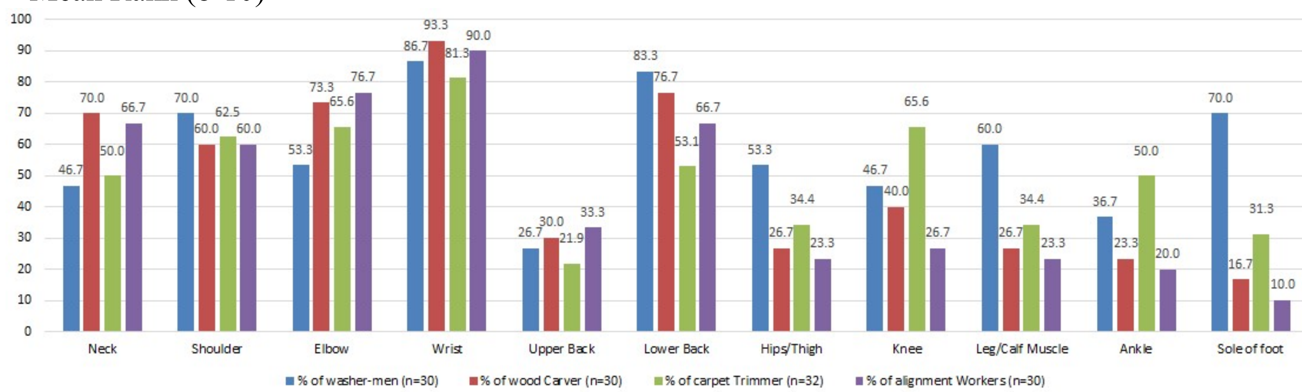

Figure 4.2.2. Frequency of reported symptoms in different body regions among male workers in last 12 months

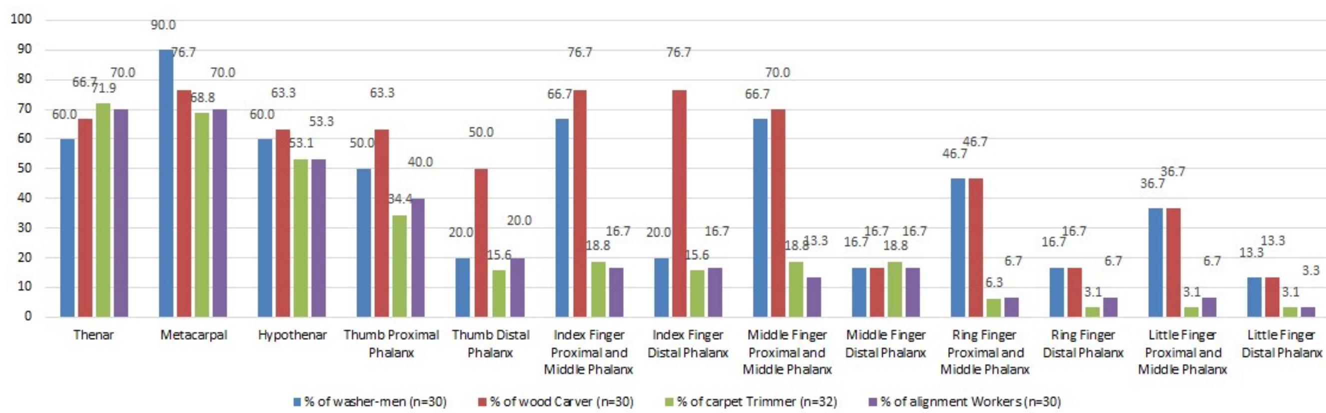

Figure 4.2.3. Frequency of reported symptoms in different palmar surface regions among male workers in last 12 months.

4.2.4. Discussion

This study presents the evidence of the prevalence of MSDs among the workers in handicraft industries. In addition to that, the study suggests that the perceived physical exertion may be influenced by the age and experience of the workers, albeit to a moderate degree. The average age and experience of participants complaining of feeling extreme physical exertion were 35.69 years and 15.12 years which were relatively higher compared to participants feeling moderate or low physical exertion. To support the preceding results, Kruskal-Wallis test showed that the variations were too great to be explained by chance alone. There was a strong evidence of statistical difference in age and experience on the categories in perceived exertion.

Somewhat surprisingly, there was a no evidence of a statistically significant effect of smoking on the categories in perceived exertion. Nonetheless, there was a pronounced trend for the inebriate workers to feel more exertion. Most of the participants smoke and drink at varying levels, which could be considerable factors on the musculoskeletal health of the handicraft workers. Research suggests that alcohol consumption has a direct effect on the musculoskeletal system. The effect of alcohol is not only limited to people who drink excessively, albeit small daily consumption causes weakening in skeletal system (Turner, 2000; Drug Rehab Florida, 2013; Hodges et al., 1986; Burke et al., 2007).

Wrist, Lower back, Shoulders, Elbows and Hips/Thigh were the most affected body regions during craft work. Metacarpal, thenar eminence and hypothenar were the prominent regions of discomfort. The high exertion of force against the hand tool with bare hands requires hard gripping on the tool handle. The palmer regions were therefore exposed to shear stress for long periods.

4.2.4.1. Recommended Guidelines:

This section presents the major contributions of the study and recommended guidelines were established based on the evidence of the problems in handicraft workers. These guidelines may help in designing a new workstation to prevent MSDs and improve working posture. Furthermore, these guidelines had dealt with an issue of affective sustainability, attaining to product optimization.

- The introduction of stretching exercises and yoga training among the workers to relax muscles so as to reduce the effects of static muscle loading which in turn improves the strength and flexibility (Costa and Vieira, 2008; Gura, 2002). Choi and Woletz (2010) summarized of the effects of stretching exercises on WMSDs in different occupations.

- As indicated in the study of Kogi et al. (2003), ensuring rotation of handicraft workers every 2 hours between high-repetition tasks and low-repetition tasks.
- Efforts should be made to coat the handle of the hand tools with soft material that has a non-slip surface for a better grip. Adding this sleeve may prevent the prevalence discomfort in metacarpal, thenar eminence and hypothenar regions (Fellows and Freivalds, 1991; Lewis and Narayan, 1993). Additionally, it may reduce the harmful contact pressure on hand while using more force (Kuijt-Evers, 2005; Fransson-Hall and Kilbom, 1993).
- Awkward postures require more demands on the body and may affect neck, shoulder, elbow, wrist, or back posture. The hand tools that minimize the pain and fatigue by maintaining the neutral posture whenever possible should be introduced (Lewis and Narayan, 1993; Johnson, 1990). Bent handles or angulations of handles should be necessary for tools, to maintain a straight wrist (Das et al., 2005; Patkin, 2001). Efforts should be made to achieve tool handles that are adjustable in terms of anthropometric dimensions i.e. fit for 5th to 95th percentile of the workers.

CHAPTER 5

EMPIRICAL INVESTIGATION OF LOW-COST TOOL INTERVENTIONS AMONG HANDICRAFT WORKERS

5.1. Empirical investigation of EMG and goniometric responses for prototype weaving knives

5.1.1. General Introduction

In lower-middle-income countries, a large number of occupations in the informal industry uses non-ergonomic hand tools as primary hand tools which may result in work-related health problems. The carpet industry is also such sector where different kinds of non-powered hand tools are commonly used. Hand-knotted carpet weaving is the most common and traditional part of the informal sector in India. Home-based carpet weaving profession is still common among women in contemporary society. Weaving demands high skill and precision and the weavers are often exposed to MSDs and CTS (Choobineh et al., 2004a; Singh et al., 2018a). Several past investigations have shown that the effects of muscle activation were most apparent during high precision and repetitive work (Visser et al., 2003; Escorpizo and Moore, 2007; Laursen et al., 1998). Moreover, non-ergonomic hand tools and work station may results in increased muscle activity in different body parts which may lead to increased risk of developing muscle fatigue mainly in neck and shoulder region, elbow and lower back (Allahyari et al., 2016; Motamedzade et al., 2014).

Squatting and sitting with folded legs are the most common posture taken by Indian female craft workers during their professional and domestic work (Maity et al., 2016). During weaving, stooping and squatting postures are frequently observed in workshops that were adopted by the weavers during prolonged weaving task. The problem emanating out of these postures are discomfort and occupation-related diseases. Apart from awkward postures, forceful gripping and high repetitive movement of hand and wrists muscles during weaving are directly associated with the symptoms of CTS (Kutluhan et al., 2001). The continuous hand knotting with poorly designed hand tools may result in swollen finger joints, finger joint arthritis, and loss of tissues and wrist inflammation which could cause permanent finger deformation (Singh et al., 2018a).

This study is concerned with evaluating the flexors/extensors muscles which are responsible for causing discomfort in the forearm regions using surface EMG (Khan et al., 2009). The objective is to quantify and estimate the effect of different knife combinations on the output responses from goniometry and EMG activities.

5.1.2. Methods

5.1.2.1. Pilot Study

Before carrying out the actual experiment, a pilot study was conducted with two female participants (right-hand dominant) and muscle activities were evaluated using surface EMG. The objective of this preliminary investigation was to get familiarize with the most actively involved muscles during weaving. Based on the findings of that study, extensor carpi radialis brevis (ECRB), flexor carpi radialis (FCR), flexor carpi ulnaris (FCU), and extensor carpi ulnaris (ECU) were found to be actively involved. In the present experiment, we have not included the data from muscle activities recorded during the pilot experiment. Also, the postural analysis using electrogoniometer revealed a significant concern over the wrist deviation from the neutral position.

5.1.2.2. Participants

The field study was conducted within the rural area of Jaipur. Ten female participants, aged between 23 and 31 (mean 26.85; SD 4.5) were randomly selected from three carpet manufacturing workshops. All the asymptomatic participants were skilled weavers with no history related to upper extremity disorders and reported no documented MSDs. Minimum three year of work experience in the same job and right-hand dominance was the inclusion criteria for this study. The average work experience of the participants in the present occupation was 6.80 ± 3.75 years. Only dominant right-hand workers were selected for the data collection to minimize any discrepancy in overall statistical significance or familywise error rate due to hand dominance.

5.1.2.3. Prototype Tools

Weaving knife blade is made from heat treated plain carbon steel from the leaf springs of scrapped vehicles (Figure 5.1.1a). Nine prototype intervention of knife blade was constructed by modifying the conventional blades adopted by the weavers. The criteria such as blade width and angle (between the cutting edge and the axis parallel to the tool handle) were taken into consideration (Figure 5.1.1b). These modification criteria's was taken based on the contributions of a recent study. It was recommended in their guidelines that the knife blade can be an essential evaluation measure and should be redesigned so that wrist movement can be minimized (Singh et al., 2018a). In the present study, nine pairs of knife blades were produced for testing over the existing weaving knives. A few combinations of blade designs are shown in Figure 5.1.1c.

The design combinations for the knife blade were selected on the basis of a pilot survey carried out in the workshops where the carpet weaving was being carried. The survey revealed that the weavers were performing the weaving task with existing knives having blade angle and width in the range of 102-121˚ and 18-30 mm. Accordingly, the width (w) of the blade was adjusted to three different combinations (20, 25 and 30 mm). The angle (θ˚) between the cutting edge and the axis parallel to the tool handle was given three sets of orientation (100˚, 110˚ and 120˚). Repeated measuring obtained the accuracy in angles and grinding was performed over the side face of the part that was inserted into the handle. These different sets of blade combinations were selected in anticipation that they may benefit the weavers during weaving tasks.

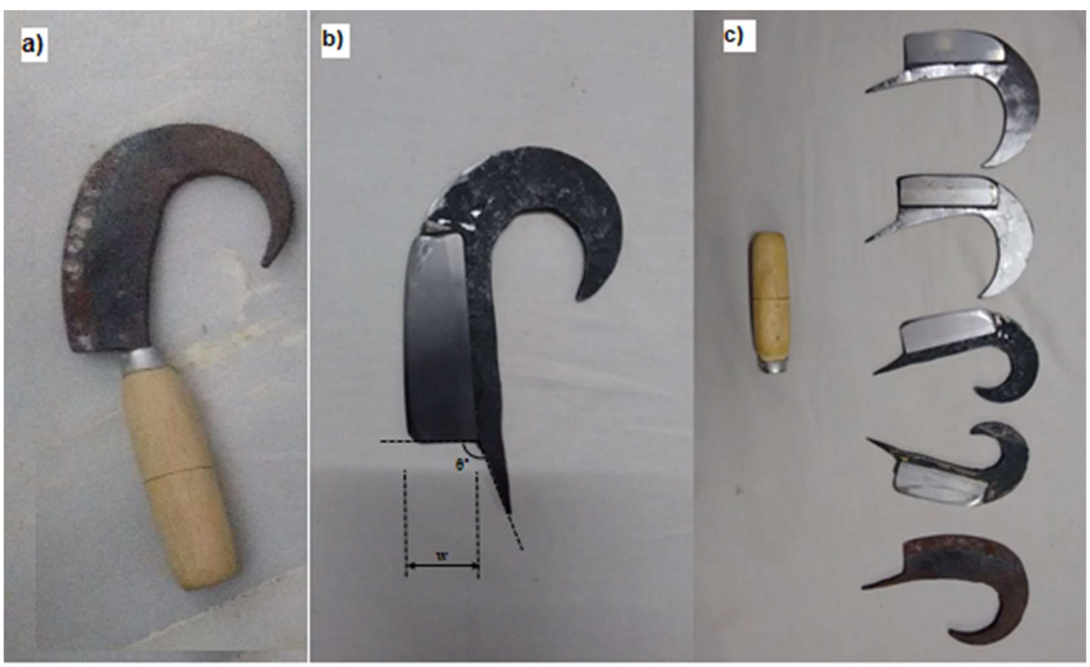

Figure 5.1.1. a) Conventional weaving knife; (b) Evaluation criteria for prototype intervention of knife blade and (c) pairs of knife blades used in the study.

Note. θ˚ = angle between the cutting edge and the axis parallel to the tool handle; w = blade width.

5.1.2.4. EMG Measurement

Selection of muscle under study

Surface EMG electrodes recorded the activities of four muscles. As we were using surface EMG sensors, flexor/extensors muscles (ECRB, FCR, FCU and ECU) are responsible for the wrist movements (flexion/extension/deviation) and are nearest to the outer skin. The placement of the electrode on the anatomical landmarks were done when the participant was standing with arms resting along sides and palm facing upwards (Konrad, 2006). The electrode location for the muscle of interest was used based on previous research. The electrodes on ECRB muscle was located over the posterior base of the third metacarpal (Farooq and Khan, 2014; Yang and Chen, 2016) and FCR was located approximately 3 cm from the lateral epicondyle to the medial distal epicondyle (Yang and Chen, 2016; Ghapanchizadeh et al., 2015). The location of surface electrodes on FCU muscle was positioned approximately 4 cm from the lateral epicondyle to the palmaris longus (Ghapanchizadeh et al., 2015) and ECU was located over the anterior base of the fifth metacarpal via groove by ulnar styloid (Yang and Chen, 2016; Zipp, 1982; Konrad, 2006).

Electrode placement/Subject preparation

The skin preparation was done before positioning the electrode by removing the hair and rubbing alcohol swabs on the selected muscle locations. The placement of electrodes was made parallel to the direction of muscle fibres. In Figure 5.1.2, the location of the wireless EMG and electrogoniometer sensors on the weaver's hand is presented in the flexion/extension plane.

5.1.2.5. EMG recording and analysis

EMG signals were acquired using the wireless sensor (27.6 x 24.1 x 12.7 mm) having bipolar bar surface electrodes with fixed 1 cm inter-electrode spacing (Trigno, Delsys Inc., USA) (Trigno Lab, n.d.). The raw signals were differentially amplified using Butterworth 2nd order band-pass filter (20-450 Hz), sampled at 1000 Hz with the input impedance of 10,000,000 MΩ. The Trigno wireless system was interfaced to the Trigno personal monitor control utility v2.6.11 (Trigno, Delsys Inc., USA) using a connecting lead. The analysis of recorded signals was performed in Lab Chart v8.1.9 software (ADInstruments, Bella Vista, New South Wales 2153, Australia) (Manuals, n.d.) (Figure 5.1.3).

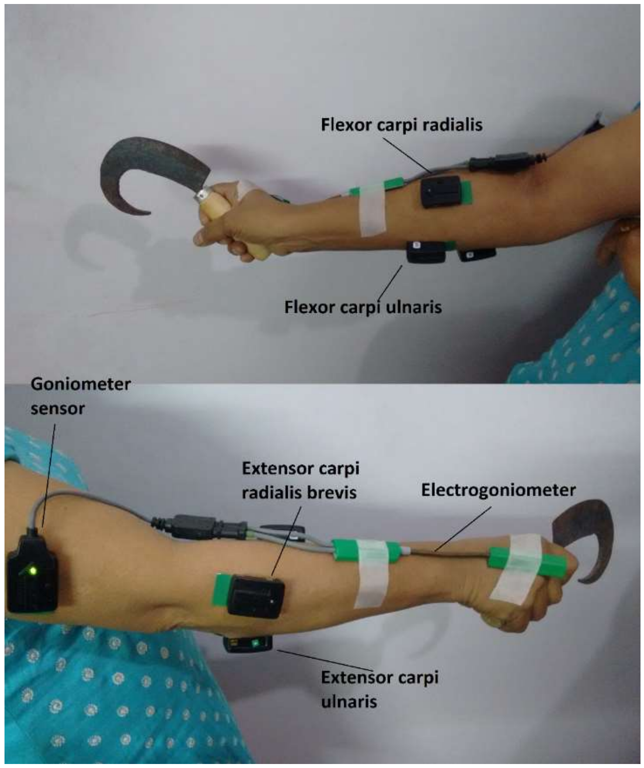

Figure 5.1.2. The location of EMG and electrogoniometer sensors over the forearm muscles (flexor and extensor) and wrist.

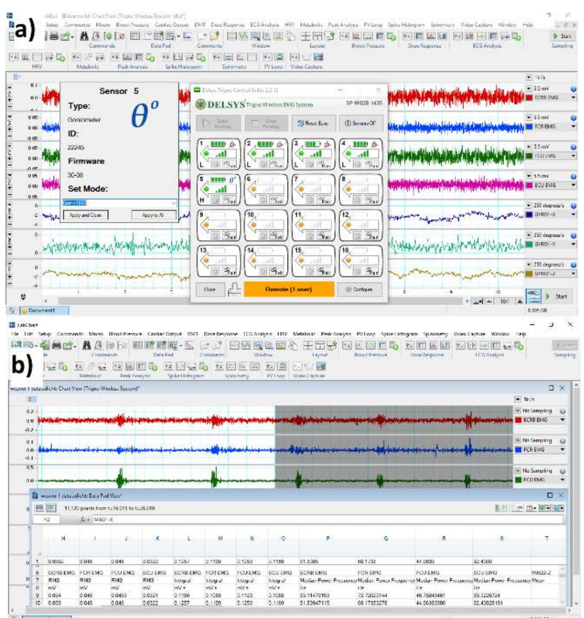

Figure 5.1.3. Photographs of an experimental session. a) Snapshot of Lab Chart software version 8.1.9 and Trigno personal monitor control utility v2.6.11 virtual instrument for the EMG and electrogoniometry testing. b) The graph between the EMG activity of ECRB, FCR, FCU and

ECU muscle (mV) and time (s) during weaving activity and readings of RMS within the data pad.

The analysis includes the recorded EMG data during work and rest. The variables such as root mean square (RMS) of the selected data points were computed from the data pad setup within the Lab Chart software. However, before commencing the actual weaving task, the participants underwent two maximum voluntary isometric contraction (MVIC) exercises, viz., maximum handgrip strength (Bano et al., 2016; Bhardwaj and Khan, 2018) and forearm supported manual resistance test (Konrad, 2006; Rota et al., 2013; Souza et al., 2017). These exercises activate forearm flexors/extensors muscles. Baseline® hydraulic hand dynamometer (Model Number: UPC-714905013552, Fabrication Enterprises Inc., US) was used to undertake the handgrip exercise. The participants were given a 5 min rest before engaging in the MVIC exercises. They were asked to stand straight with their arms hanging along the side of the body. The time-base for EMG RMS during rest was the last 1 min. The participants were tested with the same handgrip posture mentioned by Singh et al., (2018, in press (a)) except for the elbow rest was provided. The participant, using their dominant hand, applied as much grip pressure as possible on the dynamometer for 5 s. A 2 kg barbell was attached to the wrist of the subject using straps and was asked to resist the load for 10 s. The stable forearm support was provided during both exercises to minimize the effect due to gravity. The readings of both MVIC exercises were recorded three times, and the participant was given a recovery break for 120 s in between the trials. The average value from three replications was used to calculate the subsequent normalization.

Unfortunately, there is no consensus as to a single best technique which produces maximal activation in any given muscle as well as the best method for normalization of EMG data (Halaki and Ginn, 2012). It was recognized that though the peak and mean dynamic methods are the most feasible ways of normalizing EMG signal; the MVIC method could reveal the percentage of the maximum activation capacity of the muscle performing a specific task (Yang and Winter, 1984). Furthermore, Knutson et al. (1994) during their investigation found that the normalized EMG provided more reproducible results based on the variance ratio and intra-class coefficient (ICC) of variance when compared to the mean dynamic and peak dynamic methods. Therefore, the EMG data were normalized to the value during the maximum voluntary contraction (Ball and Scurr, 2013). The EMG raw RMS data was transformed into useful normalized EMG (NEMG) data using the formula (Bano et al., 2016) given below.

$$Normalized\ EMG\ (\%) = \frac{(RMS_{EMG})_i - (RMS_{EMG})_{min}}{(RMS_{EMG})_{max} - (RMS_{EMG})_{min}} \times 100$$

where, EMG = electromyography; $(RMS_{EMG})_i$ = EMG RMS of the participant i during the task; $(RMS_{EMG})_{min}$ = EMG RMS during rest; $(RMS_{EMG})_{max}$ = maximum EMG RMS during isometric muscle contraction exercise.

5.1.2.6. Joint Angles

The twin-axis electrogoniometer (Model SG75; Biometrics, UK) was used for the measurement of joint trajectories over the wrist joints in multiple planes. The accuracy and repeatability of these strain gauge type electrogoniometers were ± 2º and 1º measured over a range of ± 90º. A biaxial goniometer adapter (Trigno, Delsys Inc., USA) (Trigno Goniometer Adapter, n.d.) was connected to the goniometer, and the streamed raw data was synchronized to angle values in Lab Chart v8.1.9 software.

Wrist joint angle

Wrist joint angle is the angle between the lower arm and hand along the ellipsoidal (condyloid) type synovial joint, allowing for movement along two axes (Maity et al., 2016). The movement of wrist includes flexion, extension, radial, and ulnar deviation. The electrogoniometer was placed over the radiocarpal joint to measure palmar/dorsal flexion and radial/ulnar deviation on the back of the wrist. Before the actual field trial, the channels of the twin-axis electrogoniometer was calibrated in two anatomical axes for both flexion/extension and radial/ulnar deviation for each participant. The positive angular values denoted flexion and radial deviation, while negative values were referred to as extension and ulnar deviation. The study reports the average, 10th and 90th percentile values of joint angle induced during weaving tasks for all the ten subjects (Table 5.1.1). Since knot cutting requires wrist flexion/extension and deviation, 10th and 90th percentile . Each angle values represent the two extreme positions is the average of values for each joint during the last 60s of knot cutting cycles. Due care has been taken to navigate the extreme points on the plot by using cursor plot function in the waveform graph.

5.1.2.7. Experimental Design

The control factors for designing knife blade considered in this study include its width and angle (Figure 5.1.1a). It was observed that these factors might affect the wrist joint trajectory, in turn, muscle activity. Though many direct or indirect parameters may change the goniometric measurements, the critical process uncontrollable (noise) variables influencing it include width and angle of the knife blade. A 3 (blade width levels) x 3 (blade angle levels) were considered as independent variables for conducting the full factorial design of experiments (DOEs). In this study, three levels of process parameters were considered, and nine conditions were formed for each participant. These levels of knife blade parameters were selected by referring to the preliminary pilot study conducted and general observation. In this study, the goal of multivariate DOEs is to determine if the combination of the independent variables alters the response variables (wrist flexion/deviation, NEMG).

5.1.2.8. Task Assigned for Experiment/Procedure for Measurement

Since the workshops were situated at different locations and the institute's ergonomics laboratory has no loom installed within; it was not possible to invite all the workers at the institute laboratory. The surface EMG and electrogoniometry tests of the experimental cohort were collected at their respective work locations. The study was designed in a way that every participant's data was recorded in a similar way. Repeated surveys were done over one month to obtain the data. The data were collected from 10 AM to 1 PM at workshops.

All the participants were asked to weave 9 x 14 ft^2 sized carpet having 14 counts (14x14 knots/inch), and the same type of carpet was used for experimenting. A few carpets with the same design patterns (silk/wool for knots and cotton base) were selected for the operation to prevent any discrepancy in muscle activity due to pile strength. The participants were instructed using their typical working posture and grip force as they would during usual work. Weaving height 20 cm above elbow height was maintained. This factor was considered based on the guidelines from the previous studies (Choobineh et al., 2004b; Choobineh et al., 2007) which stated that weaving height of +20 cm above elbow height resulted in better postural comfort and the wrist closer to neutral. The testing sequence for each participant was randomized, and each measurement of EMG and goniometry started after beginning the weaving task. Each reading was taken of at least 5 minutes for all prototype interventions. The data were collected for the last 60s of each testing session. The participant took at least a 5 min break before experimenting with each condition (set of weaving knife).

After selecting the combination of knife parameters, the next step in DOE is experimenting. A total of 90 experimental (9 experiment x 10 subjects) runs were performed for the response outputs, and the corresponding performance data were collected. Three response variables (wrist flexion/extension, wrist deviation, NEMG) were obtained from the experiments. The experimental runs were in a random sequence to eliminate any other invisible factors that might contribute to the effect of control factors or bias in the subject performances. MANOVA, post-hoc and graphical analyses were carried out using SPSS version 22.0. Post-hoc comparisons were applied to test the significant difference in the effects of the levels of each independent variable on the dependent variables.

5.1.3. Results

5.1.3.1. Descriptive Data Analysis

Goniometry analysis

Table 5.1.1 presents the summary of mean and percentile values of wrist joint angles (both flexion/extension and deviation) acquired from electro-goniometer under different experimental conditions. From these results, it was evident that the average deviation of wrist flexion/extension from normal erect posture was highest in the 3rd (35.57˚) experiment followed by 6th (33.77˚) experiment and minimum in the 8th (14.75˚) experiment. Whereas, the highest variation in wrist deviation was more or less similar to experiment 3, 6 and 9. The minimum deviation from normal erect posture was noted in the 7th (-17.44˚) experiment followed by 4th (-19.87˚). Therefore, it could be inferred from the results that the blade angle with 120˚ trajectory shows an increase in deviation from the normal erect posture.

Table 5.1.1. Descriptive summary of the data acquired from electro-goniometer and electromyography w.r.t process parameters/test conditions.

Experiment	Process Parameters Levels		Wrist Angles, degrees						Muscle activity (NEMG, %)											
			Flexion (+ve)/Extension (-ve)			Radial(+ve)/Ulnar(-ve)deviation			ECRB			FCR			FCU			ECU		
	Blade Width	Blade Angle	Mean(SD)	90th %tile (SD)	10th %tile (SD)	Mean(SD)	90th %tile (SD)	10th %tile (SD)	10th %tile (SD)	50th %tile (SD)	90th %tile (SD)	10th %tile (SD)	50th %tile(SD)	90th %tile (SD)	10th %tile (SD)	50th %tile (SD)	90th %tile (SD)	10th %tile (SD)	50th %tile (SD)	90th %tile (SD)
1	20	100˚	23.67 (6.20)	30.87 (6.59)	16.18 (7.43)	-23.61 (6.95)	-15.78 (6.61)	-32.10 (6.89)	9.86 (3.29)	15.64 (4.56)	20.67 (6.11)	6.57 (2.63)	12.42 (4.15)	17.95 (5.22)	11.27 (3.62)	14.03 (3.93)	23.38 (5.16)	5.44 (2.23)	10.49 (2.23)	14.06 (3.06)
2	20	110˚	25.06 (5.67)	31.94 (6.05)	16.65 (6.63)	-26.08 (4.40)	-21.29 (5.05)	-31.45 (4.93)	11.53 (3.38)	18.61 (4.91)	24.80 (5.80)	11.87 (3.08)	20.36 (5.23)	23.59 (6.27)	10.83 (3.18)	14.31 (4.21)	24.06 (5.27)	8.71 (2.87)	12.37 (3.22)	18.50 (3.99)
3	20	120˚	35.57 (8.54)	45.10 (8.43)	24.71 (9.18)	-29.92 (5.21)	-25.49 (5.61)	-37.51 (5.76)	15.50 (4.12)	22.21 (6.03)	29.74 (6.03)	12.47 (3.31)	20.47 (4.87)	26.06 (6.65)	13.23 (4.73)	15.36 (4.63)	23.61 (6.11)	10.33 (3.03)	15.40 (3.74)	20.37 (4.71)
4	25	100˚	18.76 (6.07)	25.45 (6.53)	11.08 (6.92)	-19.87 (6.23)	-14.65 (6.87)	-28.40 (6.19)	6.89 (2.89)	8.49 (3.14)	14.27 (3.15)	5.75 (2.69)	9.28 (2.95)	15.96 (4.83)	10.14 (3.54)	12.48 (4.02)	21.30 (5.39)	4.17 (1.91)	7.63 (2.71)	10.49 (2.89)
5	25	110˚	22.18 (5.51)	30.22 (5.06)	17.19 (5.81)	-24.22 (6.96)	-17.63 (7.04)	-32.82 (6.88)	9.21 (2.96)	13.12 (4.15)	19.04 (4.98)	8.98 (3.34)	13.63 (3.63)	20.09 (6.14)	10.79 (4.21)	14.70 (4.15)	23.83 (5.10)	5.78 (2.22)	11.13 (2.94)	14.69 (3.99)
6	25	120˚	33.77 (9.78)	44.39 (9.96)	23.08 (8.77)	-31.02 (5.43)	-25.91 (5.62)	-38.82 (7.13)	15.47 (4.48)	22.68 (5.87)	29.93 (6.69)	12.55 (4.17)	20.77 (4.19)	25.90 (5.73)	12.32 (4.13)	15.62 (4.69)	23.02 (6.36)	11.13 (3.15)	17.68 (4.26)	22.88 (5.32)
7	30	100˚	16.23 (7.30)	24.42 (6.83)	6.74 (6.98)	-17.44 (5.93)	-11.39 (6.08)	-26.23 (6.33)	4.73 (2.03)	12.19 (3.33)	14.65 (4.29)	3.97 (1.68)	8.76 (3.67)	12.33 (4.07)	10.22 (3.06)	12.83 (3.34)	21.97 (4.44)	4.63 (1.96)	9.63 (3.01)	12.69 (2.75)
8	30	110˚	14.75 (5.11)	19.89 (5.49)	7.82 (7.10)	-20.86 (5.67)	-15.95 (5.63)	-27.43 (5.82)	7.15 (2.88)	10.26 (3.12)	18.12 (5.15)	4.37 (2.09)	9.32 (3.14)	13.07 (3.58)	10.82 (2.51)	13.54 (3.91)	22.39 (5.08)	9.84 (2.58)	12.63 (2.89)	20.02 (4.72)
9	30	120˚	29.80 (6.73)	37.50 (6.62)	20.09 (6.66)	-29.73 (5.77)	-23.99 (6.21)	-38.72 (6.09)	12.71 (4.45)	19.32 (5.81)	26.96 (6.72)	10.85 (3.16)	21.97 (5.44)	25.17 (6.34)	12.59 (3.95)	15.64 (4.34)	24.17 (6.16)	10.44 (3.06)	16.02 (4.04)	20.61 (4.85)

Note. NEMG = normalized electromyography; ECRB = extensor carpi radialis brevis; FCR = flexor carpi radialis; FCU = flexor carpi ulnaris; ECU = extensor carpi ulnaris.

Electromyography results

The mean NEMG recordings of the dominant hand ECRB, FCR, FCU and ECU muscles are summarized in the graphical form (Figure 5.1.4). Also, Table 5.1.1 elaborates the 10th, 50th and 90th percentile values of the muscle activity for the four muscles for each knife conditions. From these results, it was evident that the data values of NEMG for the extensor muscles (ECRB and ECU) was maximum for 25x120˚ and minimum for 25x100˚. Whereas, these values for flexor muscles (FCR and FCU) was maximum for 20x120˚ and minimum for 30x100˚. The FCU muscles have shown the least variation among different configurations. On the contrary, the other flexor muscle (FCR) shown visible fluctuations. Overall, 25x100˚ and 30x100˚ presented the least NEMG scores. However, the EMG readings for 30x110˚ knife combination in FCR and ECU is more or less similar to them. Therefore, the summary illustrates no specific details that may conclude about the best alternative among the two experimental settings since the lowest values of NEMG were different for experiments among each muscle. The analysis of variance of these EMG parameters to obtain the best combination of knife configuration has been discussed in the coming section.

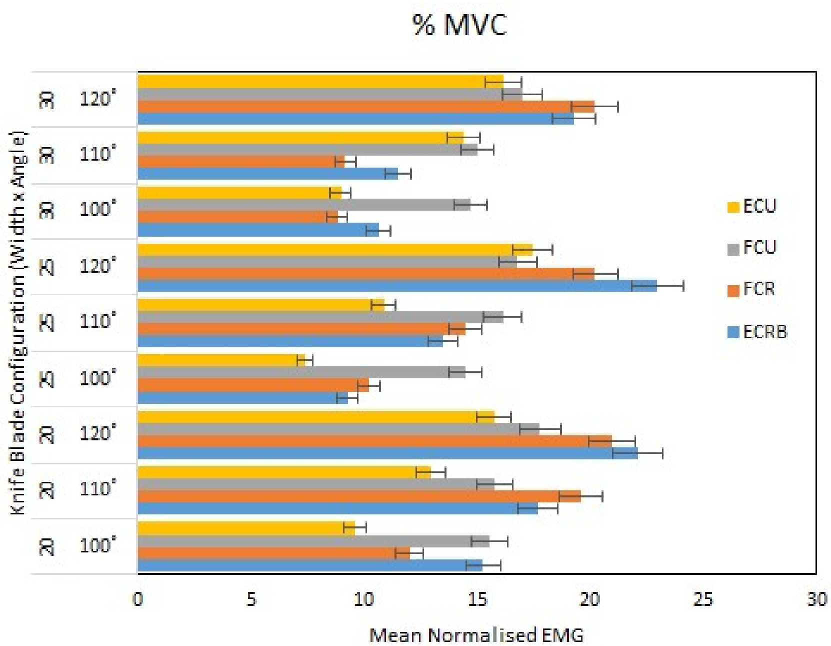

Figure 5.1.4. Mean normalized EMG recordings for ECRB, FCR, FCU and ECU muscles (dominant hand) in nine configurations of weaving knife.

Note. ECRB = extensor carpi radialis brevis; FCR = flexor carpi radialis; FCU = flexor carpi ulnaris; ECU = extensor carpi ulnaris.

5.1.3.2. MANOVA Analysis

Multivariate analysis of variance (MANOVA) is a parametric alternative to ANOVA tests with several dependent variables, and post-hoc comparisons help to protect against inflated cumulative type-1 error rate (Hair et al., 1998). In order to test the MANOVA assumption, a series of Pearson correlations were performed between all of the dependent variables. It was observed that most of the dependent variables were correlated in the moderate range (0.20 to 0.60) which suggests that MANOVAs distributional assumptions are met (Meyers et al., 2006). Furthermore, the Box's M value for the two independent variables (blade width and blade angle) was 218.89 with an associated p-value of 0.314. Thus, it can be interpreted as the covariance matrices between the groups were assumed to be equal (for $p < 0.001$) for the purposes of the MANOVA (Huberty and Petoskey, 2000).

In the present analyses, a two-way MANOVA was conducted to understand if there is an interaction between the two independent variables (blade width and angle) on the dependent variables. The hypothesis that there would be one or more mean differences between 3 (blade width) x 3 (blade angle) levels and response variables was tested for significance. The summary showed that the multivariate effects for both blade width and angle (combining all dependent variables) were statistically significant with values of Pillai's trace = 0.327 and 0.686, F(8, 81) = 2.506 and 6.704, $p<0.001$. The estimated effect size, η^2= 0.263 and 0.343 implies that 26.3% and 34.3% of the variance in the dependent variables was accounted for by the three levels of blade width and blade angle.

Before conducting a series of ANOVA and post-hoc analyses, the assumptions of homogeneity of variance was tested for all six dependent variables. Levene's F test was used to test the null hypothesis that the error variance of the dependent variable is equal across groups. The insignificance among variables suggests that the variances associated with dependent variables were homogeneous (Table 5.1.2). Thus, the homogeneity of variance assumption could be considered satisfied. As can be seen in Table 5.1.2, two-way MANOVA on six dependent variables was conducted before post-hoc analysis. The results showed that the effect of both blade width and blade angle were significant at wrist angles (both flexion/extension and deviation) ($p<0.05$). However, the effect of blade angle alone was also highly significant on NEMG values of ECRB and FCR muscles ($p<0.01$). The influence of blade width on NEMG showed no significance on either muscle activity. The interaction effect of blade width with blade angle was not significant on either of the dependent variables. The magnitude of a treatment effect or the effect size (partial η^2) on both blade width and blade angle was highest for the wrist angles. It may be concluded that the most important criteria are wrist flexion/extension and wrist deviation having the most substantial effect. This was the reason for assigning highest weights by the Analytic Hierarchy Process (AHP) method which has been discussed later in the text (section 5.2)

5.1.3.3. Post-MANOVA Analyses

A series of post-hoc analyses (Tukey's HSD) were performed to compare of all pairs of means (Kao and Green, 2008) across all three levels of blade width and blade angle and all fourteen response variables. The graphical analyses of interaction plots were performed, and the means of the data were presented in Figure 5.1.5 and 5.1.6.

Goniometer data

The results showed that the effect of blade width on wrist flexion/extension was significantly different for 20, 25 and 30mm but wrist deviation was different for 20, 30mm. The effect of blade angle on wrist flexion/extension as well as deviation was significant ($p<0.05$) for all combination of angular levels considered in the present study (100˚, 110˚ and 120˚).

This research showed that wrist angle is directly associated with blade angle, and the wrist angle decreases (deviate more from neutral) with the increase of blade angle, at three blade width levels (20, 25 and 30mm) (Figure 5.4.5). It was noticed that when 30mm blade width was used, the lowest wrist flexion/extension was obtained at a blade angle of level 2 (110˚). Although, for the same blade width, the minimum wrist deviation was obtained at a blade angle of level 1 (100˚). It was also observed that the highest deviation from wrist neutral position (0˚) was found at a blade angle of level 3 (120˚) for 20 and 25 mm blade width. This suggests the influence of blade angles on wrist posture, which means 100˚ and 110˚ are the two blade angle conditions that yielded the best near neutral wrist posture.

Table 5.1.2. Results of Levene's test and MANOVA showing the effects of blade width and blade angles on dependent variables ($ANGLE_{WF}$, $ANGLE_{WD}$, $NEMG_{ECRB}$, $NEMG_{FCR}$, $NEMG_{FCU}$, $NEMG_{ECU}$)

Variables/Test	Levene's		MANOVA														
			Blade Width					Blade Angle					Blade Width*Blade Angle				
	$F_{(8, 81)}$	p	Type III sum of squares	Mean square	$F_{(2, 81)}$	p	η^2	Type III sum of squares	Mean square	$F_{(2, 81)}$	p	η^2	Type III sum of squares	Mean square	$F_{(4, 81)}$	p	η^2
$ANGLE_{WF}$	1.335	0.238	931.847	465.923	9.727	0.000**	0.194	3367.420	1683.710	35.150	0.000**	0.465	93.905	23.476	0.490	0.743	0.024
$ANGLE_{WD}$	0.128	0.998	227.655	113.828	3.283	0.043*	0.075	1522.188	761.094	21.951	0.000**	0.351	115.625	28.906	0.834	0.508	0.040
$NEMG_{ECRB}$	0.365	0.936	320.398	160.199	0.550	0.579	0.013	1531.305	765.653	2.627	0.008**	0.061	144.472	72.236	0.124	0.973	0.006
$NEMG_{FCR}$	0.179	0.993	343.605	171.803	1.128	0.329	0.027	1552.386	776.193	5.098	0.004**	0.112	253.113	126.557	0.416	0.797	0.020
$NEMG_{FCU}$	1.344	0.215	10.084	5.042	0.029	0.971	0.001	80.590	40.295	0.234	0.712	0.006	8.055	4.028	0.012	0.998	0.001
$NEMG_{ECU}$	0.762	0.637	25.394	12.697	0.076	0.927	0.002	910.281	455.141	2.735	$0.059^{\dagger}$	0.063	78.709	39.355	0.118	0.976	0.006

* *(p<0.05)*
** *(p<0.01)*
† *(slight but not significant)*
Note. N=90; η^2= partial eta square; MANOVA = Multivariate analysis of variance; $ANGLE_{WF}$ = Wrist flexion/extension angle; $ANGLE_{WD}$ = Wrist deviation angle; $NEMG_{ECRB}$ = normalized EMG (extensor carpi radialis brevis); $NEMG_{FCR}$ = normalized EMG (flexor carpi radialis); $NEMG_{FCU}$ = normalized EMG (flexor carpi ulnaris); $NEMG_{ECU}$ = normalized EMG (extensor carpi ulnaris).

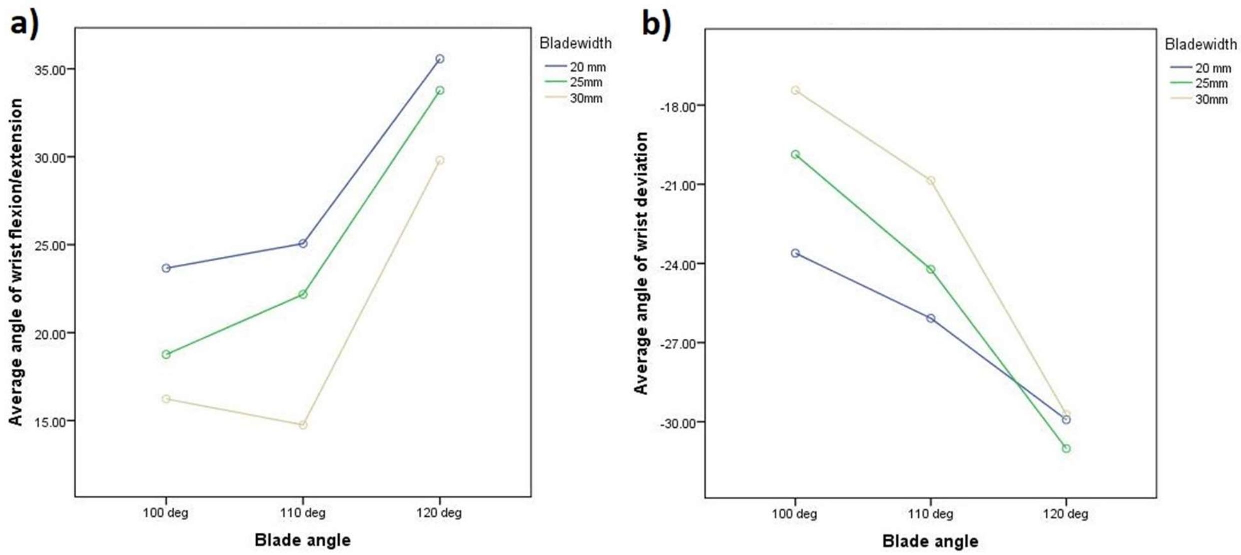

Figure 5.1.5. Variation of wrist flexion/extension with blade angle at different blade width levels.

EMG data

The results of Tukey's HSD post-hoc multiple comparisons showed that there was no effect of blade width on any of the NEMG scores. The effect of blade angle on NEMG values was significant *($p<0.01$)* in ECRB, FCR and ECU muscles for 100˚ and 120˚. Therefore, for better understanding and visualization, interaction plots were charted for the further analyses.

Figure 5.1.6 charting the mean of NEMG values vs. blade angle at different levels of blade width, indicated that normalized values were positively associated with blade angle in most cases. For 25 and 30 mm blade width conditions, the NEMG values at the two lower levels of blade angle (100˚) were found smaller yet close to each other.

Overall, the results from the analyses translate that blade angle with 100, and 110 levels and blade width with 25 and 30 mm contributes to near neutral wrist position as well as smaller values of NEMG. An apparent decrease in blade angle and increase in blade width may result in the ergonomically efficient knife blade. MANOVA analysis alone with interaction plots showed no sufficient evidence to select an optimum solution for the blade configuration. To find the best knife blade configuration from the multiple response variables with respect to the change of control factors, some optimization approach should be taken into account.

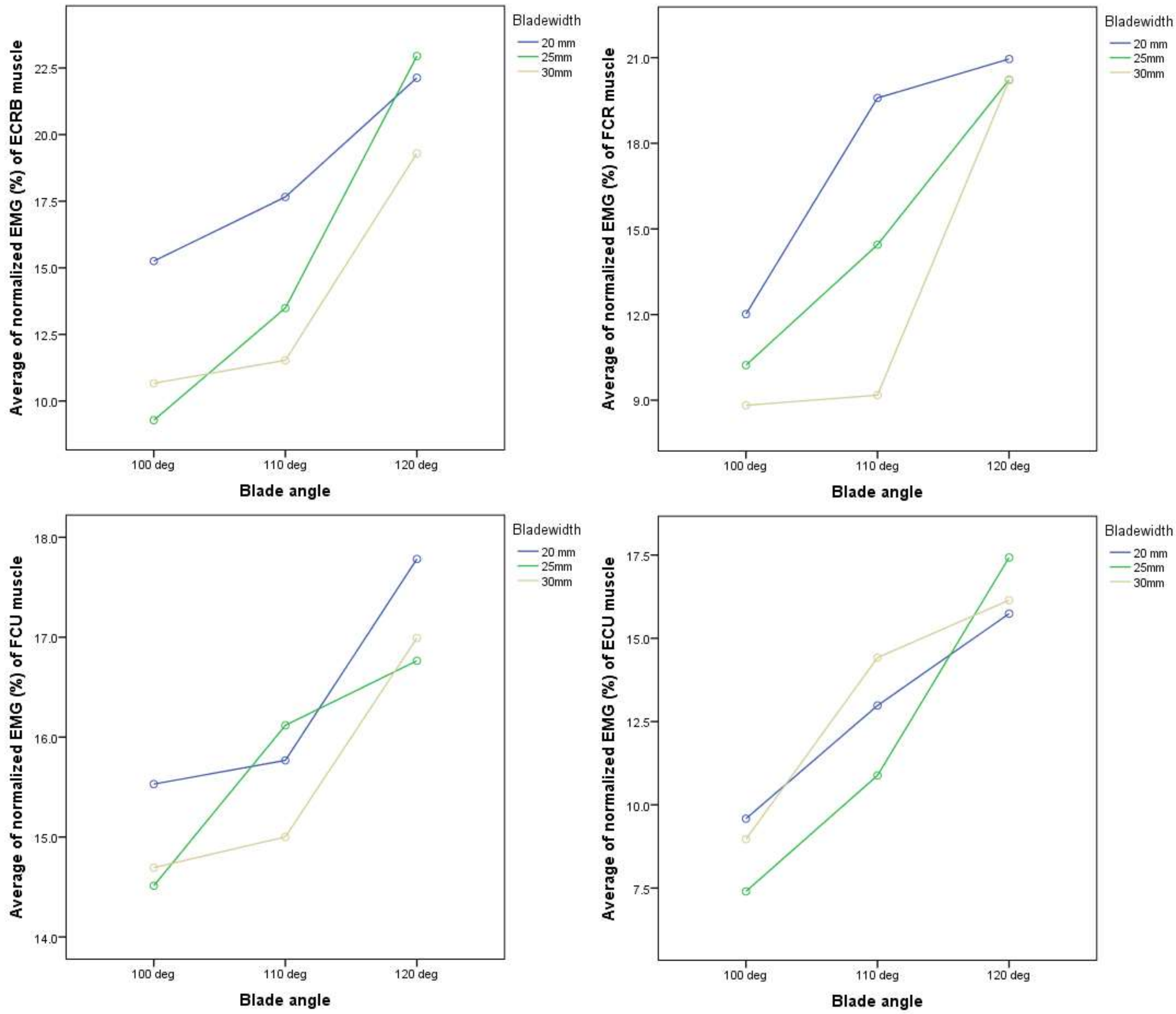

Figure 5.1.6. Variation of normalized EMG values (ECRB, FCR, FCU, and ECU muscles) with blade angle at different blade width levels.

5.1.4. Discussion

This section presents the possible explanations of the findings discussed in the result section. The results of the present study present the evidence that the wrist flexion/extension/deviation and EMG activity may be influenced by the ergonomic design of the knife blade. The MSDs are highly prevalent among the weavers. In reviewed literature, there was extensive evidence that has shown that the major locations of discomfort among weavers were lower back, neck, wrist, elbow, and shoulders (Choobineh et al. 2004a; Chaman et al., 2015; Nazari et al., 2012). Singh et al. (2018a) investigated the prevalence of CTDs among female weavers in India and reported that apart from body discomfort, the weavers were exposed to discomfort in palmar regions. In their continued cross-sectional study, loss of grip strength was also reported among female operatives (Singh et al., in press (a)).

Musculoskeletal pain is widespread among the weavers and most of the upper and lower limb MSDs might be related to the poor postures (Afshari et al. 2014). However, wrist and elbow discomfort could be due to un-ergonomic use of hand tools that may also lead to CTS (Radjabi, 1983; Singh et al., 2018a). Pal and Dhara (2017) in their cross-sectional study investigated the postural patterns of jari workers and found significant wrist deviations between normal standing angles and working angles, which is in line with the findings of the present work. These studies, however, have been limited to postural assessment among handicraft workers.

Studies have shown that the angular improvement in tool handle configuration resulted in better-perceived discomfort ratings (Bhardwaj and Khan, 2018; Haque and Khan, 2010). Schoenmarklin and Marras (1989a) opined that the hammers with bent handles resulted in less total ulnar deviation than straight hammers which may decrease the risk of hand/wrist disorders. In their continued study (Schoenmarklin and Marras, 1989b), they found that small change in bent angle in the handle does not show a significant difference in subjective rating of discomfort. Therefore, we have not used any perceived discomfort ratings in our study since the variation of independent variables (blade width and angle) were quite small and the weavers may not feel any change due to little change in width and angle of the knife.

During knot cutting, the wrist acts as a fulcrum, and the cutting force (by weaving knife) has a turning effect (moment) about the fulcrum as the knife swings to cut the knot (Singh et al., 2018a). The smaller blade angle makes the cutting edge tending perpendicular to the knife handle (Figure 1a), reducing the range of motion about the wrist. The higher blade width even further make the cutting edge closer to the knot while cutting, hence, letting the weaver cut the knot with minimal effort. Unlike the other muscles, ECRB and FCR showed a noticeable difference in EMG activity while using higher blade widths (25mm and 30mm).

The muscles of the posterior forearm extend to the medial digits of the hand, and responsible for gripping actions and wrist flexion/extension (Dianat et al., 2012). In an experimental study by Oikawa et al. (2011), they opined that the FCU and ECRB muscle activities for the dorsiflexion and palmar flexion wrist positions were significantly different than neutral position during piano playing. However, the ECRB muscle showed a more significant effect on wrist flexion/extension and acted as a persistent stabilizer of the wrist and finger joints. Also, Khan et al. (2009) reported that ulnar deviation has a significant effect on the ECRB muscle. Moreover, their experimental results demonstrated that for the EMG activity for ECRB muscle was higher in ulnar deviation than in radial deviation. The findings of their study are consistent with the findings of the present study stating the drop of ECRB muscle activity with the reduction in the wrist angle deviation due to the variation in weaving knife configuration.

FCR located on the anterior part of the forearm that resists the scaphoid from rotating into flexion, thus, activates as the wrist comes into flexion and supination (Salvà-Coll et al., 2011). During weaving, the knot cutting involves coupling between wrist flexion and ulnar deviation simultaneously. The cumulative effect of this type of movement leads to prono-supination of the forearm which is similar to a dart thrower's motion, hair combing, washcloth wringing, shoe tying, and can-opening (Li et al., 2005). Perhaps, this type of coupling movement may be responsible for the activating FCR muscle. A recent study of Shah et al. (2018) provided the pieces of evidence that in the absence of FCR, the forces of ECRB and ECU were significantly lower throughout the multiple cycles of 50˚ flexion and 30˚ extension. Altogether, this finding suggests that ECRB and FCR are related to each other, albeit to some extent. In fact, in our results, the two muscles (ECRB and FCR) were most affected (decreased EMG values) while weaving using higher blade widths since it requires minimum effort.

Previous longitudinal studies have presented different designs, and guidelines of hand tool handle that may prevent extension and ulnar deviation of the wrist (Lewis and Narayan, 1993; Johnson, 1990; Singh et al., 2018a). Motamedzade et al. (2007) developed few weaving hand tools including weaving knife. These tools were designed based on anthropometric data of weavers in Iran, and basic ergonomics principles and guidelines were followed. However, to the author's knowledge, no literature has considered the angle and width of the of the knife blade, which was provided to prevent extension/deviation of the wrist in hand tools.

One reason for conducting this study was to perform a preliminary investigation of whether the independent variables (width and angle) between knife blades affect the weaver's performance with respect to goniometry. Beyond goniometric measurements, EMG responses have been used to describe weaving knife characteristics. The small number of experiment limits the extent of inferences drawn from the finding of higher performance characteristics by 30 x 100 and 25 x 100 configuration, but for all conditions, they achieved a higher rank. Furthermore, the results indicate that these variables minimized the undesirable postural deviations and EMG parameters. Therefore, the results do suggest that altering small changes in the knife blade have positive benefits and there were sufficient reasons that optimum results obtained from this study should be implemented which may ease the efforts of the weavers.

In low-middle income countries like India, contractors are not willing to take-up expensive measures to mitigate occupational risks. Therefore, it is challenging to find cheaper ways to explore the better ergonomic interventions (Singh and Khan, 2014; Singh et al., in press (b)). It was recognized from the present study that the suggested modification in the knife blade could be a lost-cost but practical solution that may prevail these occupation related problems.

Measurements reflective of muscle activities have also rarely been included during the use of any non-powered hand tool, despite that there may be a highly interconnected relationship between the muscle activities and postural positions during the use of such hand tools. Limited published research, however, has objectively quantified muscle activities among carpet weavers during the recent decades (Mahdavi et al., 2016; Motamedzade et al., 2014; Allahyari et al., 2016), but none of them have measured the responses during actual working conditions. The artificial laboratory settings might affect muscle activity than in field study. Furthermore, all of them investigated the EMG activities in upper trapezius muscles. On the contrary, we have assessed lower arm EMG activities in flexor and extensor muscles for different hand tool combinations in anticipation that the results could provide inferences about the optimum design. The above said words are in support of the present findings showing that NEMG values were positively associated with blade angle.

5.2. Application of multiple-response optimization methods for the ergonomic evaluation of carpet weaving knife

5.2.1. Introduction

The optimum selection of the alternatives is an very imporatnt aspect in design and development phase. To solve the optimization issues, several decision-making approaches have been developed and widely used. TOPSIS (Çalışkan et al., 2013; Behzadian et al., 2012), VIKOR (Opricovic and Tzeng, 2004; Çalışkan et al., 2013), ELECTRE (Shanian and Savadogo, 2006), PROMETHEE (Chatterjee and Chakraborty, 2012) are such multi-criteria decision making (MCDM) techniques. The TLF approach has been proved to be an effective optimization methodology for multiple responses. We have compared two MCDM methods and TLF in order to reveal and to compare the procedural basis of these the three optimization methods.

This is a longitudinal part of the section 5.1 concerned with evaluating the flexors/extensors muscles which might be responsible for causing discomfort in the forearm regions using surface EMG. In this part of the chapter, a methodology is presented for tackling multiple output responses in designing the best alternative for weaving knife. It will make use of MCDM techniques (TOPSIS and VIKOR) and Taguchi's loss function (TLF) for determining the optimum configuration of the weaving knife. This experimental study was aimed to test the intended modification of existing weaving knife blade at least possible cost in response to electrogoniometry and EMG activity. Also, based on the mentioned background in section 5.1, we report on the novel methodological contributions of three different multiple-response decision-making approaches to determine the best knife properties for the task.

5.2.2. Methods

5.2.2.1. Multi-response Optimization Methods

Multiple-criteria decision making

MCDM is an advanced field of operation research that is used to solve multi-objective optimization problems. For at least the past three decades, MCDM has been an active research area and gained the attention of decision-makers and analysts (Greco et al., 2005). Among several methods developed to solve real-world decision-making problems, the TOPSIS proposed by Hwang and Yoon (1981) has exponentially grown to work across different application areas

(Behzadian et al., 2012). The TOPSIS method consists of the several steps (Çalışkan et al., 2013; Behzadian et al., 2012) as summarized below:

Step 1: Constructing the normalized decision matrix using the following equation:

$$n_{ij} = x_{ij} \Big/ \sqrt{\sum_{i=1}^{m} x_{ij}^2} \qquad i = 1,2, \ldots\ldots, m; j = 1,2, \ldots\ldots, n \tag{1}$$

where, x_{ij} and n_{ij} are the initial and normalized score of the decision matrix.

Step 2: Constructing the weighted normalized decision matrix by multiplying the columns by associated weights obtained by AHP method.

$$V_{ij} = n_{ij} w_j \quad i = 1,2, \ldots\ldots, m; j = 1,2, \ldots\ldots, n \tag{2}$$

where, w_j is the weight assigned to the j^{th} criterion.

Step 3: The positive and negative ideal solutions were obtained using equations:

$$\{V_1^+, V_2^+, \ldots\ldots, V_n^+\} = \{\max(V_{ij})\ if\ j \in B; min(V_{ij})\ if j \in C\} \qquad i = 1,2, \ldots\ldots, m \tag{3}$$

$$\{V_1^-, V_2^-, \ldots\ldots, V_n^-\} = \{\min(V_{ij})\ if\ j \in B; max(V_{ij})\ if j \in C\} \qquad i = 1,2, \ldots\ldots, m \tag{4}$$

where, B and C is the index set of benefit and cost criteria.

Step 4: The two Euclidean distances for positive and negative ideal alternative are computed:

$$S_i^+ = \sqrt{\left\{\sum_{j=1}^{n} \left(V_{ij} - V_j^+\right)^2\right\}} \qquad i = 1,2, \ldots\ldots, m; j = 1,2, \ldots\ldots, n \tag{5}$$

$$S_i^- = \sqrt{\left\{\sum_{j=1}^{n} \left(V_{ij} - V_j^-\right)^2\right\}} \qquad i = 1,2, \ldots\ldots, m; j = 1,2, \ldots\ldots, n \tag{6}$$

Step 5: The relative closeness to the ideal solution is calculated using equation:

$$C_i = {S_i^-} \Big/ {S_i^- + S_i^+} \qquad i = 1,2, \ldots\ldots, m; 0 \le C_i \le 1 \tag{7}$$

The goniometer angles (wrist flexion/extension and deviation) were considered as beneficial attribute since higher values are desired for neutral posture. Here, 180º was taken as a neutral reference to get all positive values of flexion/extension and deviation angles (e.g., 35.57º and -29.92º are 144.43º and 150.08º for the third alternative). On the contrary, for EMG parameters (NEMG), the low values of which are desired in order to lower the muscle activity during the weaving task. Therefore, they were among non-beneficial attributes. The weighing criteria provide the relative importance to the beneficial and non-beneficial attributes. The criteria weights were calculated on Expert Choice software package (version 11.1) implementing the Analytic Hierarchy Process (AHP) method (Ishizaka and Labib, 2009). The pairwise comparisons were made from the subjective perceptions of the author, co-author's and expert officials (including site supervisor and knife fabricator) of the carpet manufacturer. The consistency index (CI) and the consistency ratio (CR) were calculated to ensure the consistency of the subjective perception and the accuracy of the relative weights (Çalışkan et al., 2013).

After generating the outputs from the alternatives, another MCDM method (VIKOR) was applied to rank those alternatives and propose a compromised ranking list to the decision maker. In VIKOR, linear normalization is used to eliminate the units of criterion functions (Opricovic and Tzeng, 2004). The development of the VIKOR method starts with the several steps as shown below:

Step 1: Determination of the best $(x_{ij})_{max}$ and the worst values $(x_{ij})_{min}$ of all criterion functions from the normalized decision matrix.

$$(x_{ij})_{max} = \{\max(x_{ij})\ if\ j \in B; min(x_{ij})\ ifj \in C\} \quad i = 1,2,\ldots\ldots, m \tag{8}$$

$$(x_{ij})_{min} = \{\min(x_{ij})\ if\ j \in B; max(x_{ij})\ ifj \in C\} \quad i = 1,2,\ldots\ldots, m \tag{9}$$

where, x_{ij} is the normalized score of the decision matrix, B and C is the index set of benefit and cost criteria.

Step 2: Computing the values of utility measure (E_i) and the regret measure (F_i) for each non-dominated solution by the following relations:

$$E_i = \sum_{j=1}^{n} w_j \left[\left((x_{ij})_{max} - (x_{ij})\right)/\left((x_{ij})_{max} - (x_{ij})_{min}\right)\right]; \tag{10}$$

$i = 1,2,\ldots\ldots, m; j = 1,2,\ldots\ldots, n$

$$F_i = max\left[w_j \left[\left((x_{ij})_{max} - (x_{ij})\right)/\left((x_{ij})_{max} - (x_{ij})_{min}\right)\right]\right] \tag{11}$$

where, w_j is the weight assigned to the j^{th} criterion.

Step 3: The VIKOR index (P_i) can be obtained using equations:

$$P_i = \alpha[E_i - E_{i-min}/E_{i-max} - E_{i-min}] + (1-\alpha)[F_i - F_{i-min}/F_{i-max} - F_{i-min}] \tag{12}$$

$where,\ E_{i-max} = jmax\ E_i\ ; E_{i-min} = jmin\ E_i\ ;\ F_{i-max} = jmax\ F_i\ ; F_{i-min} = jmin\ F_i\ and\ \alpha \in$ $[0,1]$ is a weighting factor and is usually selected to be 0.5

Step 4: Rank the alternatives, sorting by the values E_i, F_i and P_i. The results are three ranking lists.

Step 5: The compromised ranking having alternative (a') with the smallest VIKOR index (P_i) is the best solution for a given α, if conditions 1 and 2 are satisfied:

C1 - ‘‘Acceptable advantage’’: $P(a'') - P(a') \geq (1/j - 1),\ where,\ a''\ is\ the\ second - best\ alternative\ and\ j\ is\ the\ number\ of alternatives.$

C2 - ‘‘Acceptable stability in decision making’’: The alternative a' was also the best in the ranking made according to E_i and/or F_i. If one of the conditions is not satisfied, then a set of compromise solutions are proposed.

The best and the worst values from all the criteria’s were determined from the normalized decision matrix as per the benefit and cost criteria. The same compromised weighting method, AHP, was used to estimate the criteria weights of the output characteristics. The alternatives were ranked by the values of P_i, E_i, and F_i, in decreasing order. The compromised ranking was obtained according to Pi measures for a chosen value of α (0.5). The best alternative was proposed subjected to the two conditions showed in step 5. We have compared the compromised ranking with TOPSIS ranking list. However, the best alternative was confirmed by comparing the VIKOR index (P_i) on the basis of levels of two factors blade width (20, 25, 30) and blade angle (100, 110, 120) separately. These computations were done for obtaining the least P_i.

Taguchi’s loss function

Taguchi parameter design methodology uses a loss function to calculate the variation between the experimental response values, and this loss function is further transformed into a signal-to-noise (S/N) ratio. There are three quality characteristics available for Taguchi’s experiments which are the most commonly used, viz. lower the better, higher the better, and nominal the best (Antony, 2001). The loss function calculated, summarized in the steps below, is responsible for evaluating the changes in the response variable with respect to the change of control factors and noise factors.

To solve this type of complicated optimization with multiple performance characteristics, a normalization procedure is performed as shown in Step 2. The normalized decision matrix with i^{th} quality characteristic at j^{th} trial is calculated before computing the weighted S/N ratio (Gaitonde et al., 2006). It is important to note that the values of N_{ij} vary from zero to one.

Step 1: The quality loss function for the i^{th} quality characteristic at the j^{th} trial in the orthogonal array for lower-the-better performance characteristic is given as

$$L_{ij} = y_{ij}^2 \qquad (13)$$

The loss function of the higher-the-better performance characteristic can be expressed as

$$L_{ij} = {}^{1}\!/_{y_{ij}^2} \qquad (14)$$

where, y_{ij} is the i^{th} performance response value in the j^{th} trial.

Step 2: Constructing the normalized decision matrix using the following equation:

$$N_{ij} = {}^{L_{ij}}\!/_{\overline{L_i}} \qquad (15)$$

where, $\overline{L_i} = \frac{1}{n}\sum_{j=1}^{n} L_{ij}$ is the average loss function of the i^{th} performance characteristic due to n trials.

Step 3: Total quality loss function (T_j) in the j^{th} experiment can be obtained using equations:

$$T_j = \sum_{i=1}^{n} w_i N_{ij} \qquad (16)$$

$where$, w_i is the scalar weighing factor for the i^{th} performance characteristic.

Step 4: Taguchi loss function for multi-response optimization requires the maximization of response signal-to-noise ratio. The S/N ratio (η_j) that includes the multiple characteristics for the j^{th} experimental run can be expressed as:.

$$\eta_j = -10log(T_j) \qquad (17)$$

5.2.3. Results

5.2.3.1. Multiple-response Optimization

Several MCDA/MCDM methods are available that can be used to solve multi-objective optimization problems. We opted the TOPSIS and VIKOR approach to evaluate possible alternative for knife blade configuration and rank them. Further, we have compared the ranking from MCDM methods with TLF approach to help the decision-makers in terms of user requirements.

Optimization of knife blade parameters

The nine combinations were used for designing the experiment. The decision hierarchy composed of a 3x3 combination of input parameters namely blade width and blade angle and output parameters such as goniometer responses (wrist flexion/extension and wrist deviation) and NEMG values (in ECRB, FCR, FCU and ECU muscles) were considered. These output responses represent the performance characteristic associated with knife blade configuration.

TOPSIS method

The procedure of TOPSIS for the selection of the best alternative from among the available choices involves several steps. At first, the subjective weights of different evaluation criteria for the knife blade were obtained by the AHP method in expert choice software. It was observed that the most important criteria are wrist flexion/extension and wrist deviation (highest effect size, Table 2, Section 5.2), were given equal weights of 0.23. The EMG parameters, which is the non-beneficial attributes, were given the equal weights of 0.159 each for radial muscles (ECRB and FCR) and 0.111 each for ulnar muscles (ECU and FCU). These weighing criteria were agreed by the institute's departmental research committee experts and practicing authors. The random matrix consistency index (RI) for a 6 x 6 matrix is 1.25. Also, the consistency index (CI) and consistency ratio (CR) was found to be 0.004 and 0.0032 which were lower than 0.1, indicating that our proportion of subjective weights was reasonably consistent and reliable (Saaty, 1990; Mu and Pereyra-Rojas, 2018).

The quantitative response values (goniometer and NEMG values) of the different knife blade configurations, which are given in Table 5.1.1 and Figure 5.1.3 (Section 5.1), are normalized using equation (1) shown in TOPSIS steps. The normalized decision matrix was shown in Table 5.2.1. These elements (beneficial and non-beneficial attributes) of the normalized decision matrix was then multiplied by the corresponding weights obtained. The weighted and normalized decision matrix, $V_{ij} = R_{ij} \times W_j$ (equation 2 in TOPSIS steps), is presented in Table 5.2.2. The positive and negative ideal solutions, determined by equations 3 and 4, are presented in Table 5.2.3. The final step was to compute the two Euclidean distances for positive (S_i^+) and negative (S_i^-) ideal solutions and the relative closeness (C_i) to the ideal solution using equation 5-7, are shown in Table 5.2.4. According to descending order of their closeness by the TOPSIS method, the ranking of the experimental conditions was 4-6-8-1-5-9-2-3-7 which indicates that the 25 x 100˚ was the best alternative for optimizing output responses of electro-goniometer and EMG parameters. 25 x 120˚ and 20 x 120˚ were the two worst solutions during weaving.

Table 5.2.1. Normalized decision matrix.

Experiment	$ANGLE_{WF}$	$ANGLE_{WD}$	$NEMG_{ECRB}$	$NEMG_{FCR}$	$NEMG_{FCU}$	$NEMG_{ECU}$
1	0.3346	0.3356	0.3083	0.2527	0.3247	0.2447
2	0.3316	0.3303	0.3569	0.4121	0.3297	0.3315
3	0.3091	0.3221	0.4473	0.4408	0.3718	0.4019
4	0.3451	0.3437	0.1875	0.2151	0.3034	0.1890
5	0.3378	0.3343	0.2726	0.3039	0.3370	0.2778
6	0.3130	0.3197	0.4638	0.4254	0.3505	0.4449
7	0.3505	0.3489	0.2156	0.1856	0.3072	0.2290
8	0.3537	0.3415	0.2330	0.1931	0.3137	0.3682
9	0.3215	0.3225	0.3900	0.4251	0.3553	0.4122

Table 5.2.2. Weighted and normalized decision matrix, $V_{ij} = R_{ij} \times W_j$.

Experiment	$ANGLE_{WF}$	$ANGLE_{WD}$	$NEMG_{ECRB}$	$NEMG_{FCR}$	$NEMG_{FCU}$	$NEMG_{ECU}$
1	0.0770	0.0772	0.0490	0.0402	0.0360	0.0272
2	0.0763	0.0760	0.0567	0.0655	0.0366	0.0368
3	0.0711	0.0741	0.0711	0.0701	0.0413	0.0446
4	0.0794	0.0790	0.0298	0.0342	0.0337	0.0210
5	0.0777	0.0769	0.0433	0.0483	0.0374	0.0308
6	0.0720	0.0735	0.0737	0.0676	0.0389	0.0494
7	0.0806	0.0802	0.0343	0.0295	0.0341	0.0254
8	0.0813	0.0786	0.0371	0.0307	0.0348	0.0409
9	0.0739	0.0742	0.0620	0.0676	0.0394	0.0458

Table 5.2.3. The positive ideal (best) and negative ideal (worst) solution.

Ideal Solution	$ANGLE_{WF}$	$ANGLE_{WD}$	$NEMG_{ECRB}$	$NEMG_{FCR}$	$NEMG_{FCU}$	$NEMG_{ECU}$
$\boldsymbol{V}^{+}$	0.0813	0.0802	0.0298	0.0295	0.0337	0.0210
$\boldsymbol{V}^{-}$	0.0711	0.0735	0.0737	0.0701	0.0413	0.0494

Note. V^{+}= positive ideal solution; V^{-}= negative ideal solution.

Table 5.2.4. The separation measures, relative closeness of a particular alternative to the ideal solution and corresponding rank.

Experiment	S_i^+	S_i^-	C_i	Rank
1	0.0236	0.0455	0.659142544	4
2	0.0482	0.0229	0.321742311	6
3	0.0641	0.0055	0.078727758	8
4	0.0052	0.0647	0.925073869	1
5	0.0259	0.0426	0.621290062	5
6	0.0660	0.0035	0.050509464	9
7	0.0063	0.0630	0.908414263	2
8	0.0213	0.0561	0.724678318	3
9	0.0568	0.0130	0.186299742	7

Note. S^+= Euclidean distances for positive solution; S^-= Euclidean distances for negative solution; C_i= relative closeness to the ideal solution.

VIKOR method

The best and the worst of all criteria were determined from the same decision matrix shown in Table 5.2.1. Further, the values of E_i, F_i, and P_i were calculated using equations as shown in VIKOR steps (equation 8-12) in the methodology section. These values and their corresponding ranks are depicted in Table 5.2.5. The ranking of the knife configurations is 4-6-9-2-5-8-1-3-7 which indicates that the 30 x 100° is the best knife blade alternative for the weavers, and the 20 x 120° is the worst.

Table 5.2.5. The values of E_i, F_i and P_i and corresponding rank.

Experiment	E_i	F_i	P_i	Rank
1	0.37307	0.104564	0.381766	4
2	0.603277	0.146376	0.60835	6
3	0.953287	0.23	1	9
4	0.103819	0.044263	0.089954	2
5	0.412691	0.114932	0.428222	5
6	0.936024	0.23	0.990381	8
7	0.055964	0.017346	0	1
8	0.183049	0.077713	0.21275	3
9	0.821118	0.208145	0.874968	7

TLF method

In order to solve the discrepancy among the best alternative selection by the TOPSIS and VIKOR, the TLF method was employed to find a certain solution. The measured responses of the goniometer and NEMG were used to compute values of loss functions (step 1, equation 13, 14). They were first normalized using equations 15. In this computation, the usual criterion was chosen using the same weights (obtained from AHP). The calculated values of loss functions, normalized loss functions, total loss function and corresponding multi-response signal-to-noise ratios for each trial of the L9 array are presented in Table 5.2.6. The final ranking of the alternative knife blade configurations is also given in Table 5.2.6. This ranking indicates that the 25 x 100˚ is the best knife blade alternative, and the 25 x 120˚ is the worst.

5.2.3.2. Comparison of the TOPSIS, VIKOR and TLF methods

Figure 5.2.1 shows the ranking of all the knife blade configurations derived using the three multiple response optimization ranking methods. Even though the weighing criteria's' were the same for all the methods, the rankings of both MCDM techniques differ, albeit to a moderate degree. Although, 30 mm blade width conditions yielded the best near neutral wrist posture (Figure 5.2.4 and 5.2.5, Section 5.1), but, 25 x 100 obtains the first rank in the TOPSIS and TLF methods. On the other hand, 30 x 100 tops the list in the VIKOR method. Also from correlation analysis, it was evident that there is a high similarity between all the three optimization approaches with a high correlation coefficient (>0.90) significant at the 0.01 level. Moreover, Pearson correlation coefficient indicates the largest agreement between ranking results of TOPSIS and TLF as the perfect correlation (value of 1.00) was obtained between these pairs.

Table 5.2.6. The values of loss function, normalized loss function, total loss function, S/N ratio and corresponding rank.

Loss Functions, L_{ij}						Normalized Loss Functions, N_{ij}						Total Loss Function	Signal-to-noise ratio, η_j	Rank
WF	WD	ECRB	FCR	FCU	ECU	WF	WD	ECRB	FCR	FCU	ECU	TL_j	S/N ratio	
4.09E-05	4.09E-05	232.6233	144.3489	241.1787	91.84544	0.984281	0.982973	0.855207	0.574873	0.949105	0.538857	0.845015	0.731357	4
4.17E-05	4.22E-05	311.8356	383.72	248.6028	168.5255	1.002124	1.014748	1.14642	1.528173	0.978321	0.988738	1.107484	-0.44338	6
4.79E-05	4.44E-05	489.7959	439.0181	316.2089	247.7643	1.153218	1.067368	1.800666	1.748399	1.244369	1.453632	1.374514	-1.38149	8
3.85E-05	3.9E-05	86.10345	104.5993	210.5906	54.78054	0.925296	0.937545	0.316547	0.416569	0.828732	0.321397	0.672683	1.721894	1
4.01E-05	4.12E-05	181.9659	208.7423	259.7834	118.4255	0.965772	0.990711	0.668972	0.831321	1.02232	0.694802	0.879138	0.559428	5
4.68E-05	4.51E-05	526.6784	409.0085	281.0226	303.667	1.125048	1.0831	1.936259	1.628885	1.105902	1.781613	1.395246	-1.44651	9
3.73E-05	3.78E-05	113.7871	77.82634	215.8877	80.42371	0.896939	0.909748	0.418322	0.309945	0.849578	0.471845	0.67801	1.687636	2
3.66E-05	3.95E-05	132.9426	84.24563	225.0337	207.93	0.880976	0.949222	0.488745	0.33551	0.88557	1.219924	0.785712	1.047366	3
4.43E-05	4.43E-05	372.3418	408.3654	288.6971	260.643	1.066345	1.064585	1.368862	1.626324	1.136103	1.529191	1.262196	-1.01127	7

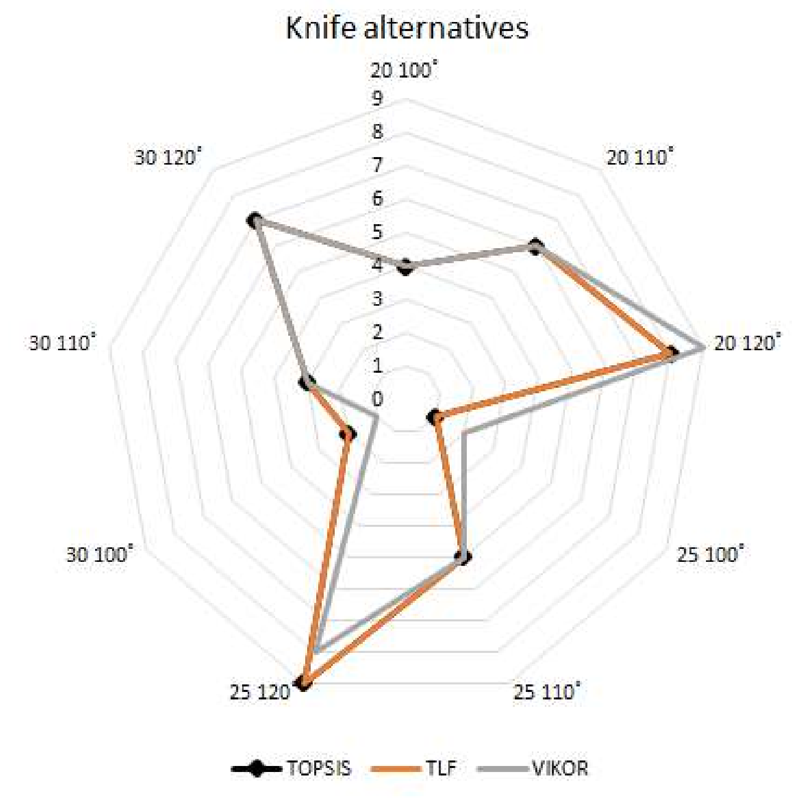

Figure 5.2.1. The plot for the comparison of rankings obtained with the multiple response optimization methods and relative closeness to ideal solution for knife blade configurations.

5.2.4. Discussion

Much investigations in the recent past have reported fuzzy multi-criteria framework in occupational health and safety risk assessment which provides more consistency in decision-making process and ranking of the quantitative and qualitative risk of accidents and workplace conditions (Gul et al., 2017; Gul, 2018; Djapan et al., 2015). Though almost no study has been reported in the literature related to the design intervention in a weaving knife blade, the results are in line with other similar studies (Motamedzade et al., 2007; Das et al., 2005; Hsiang et al., 1997). The ergonomically designed hand tools should be introduced that curtail the pain and fatigue by maintaining the neutral posture whenever possible (Lewis and Narayan, 1993; Johnson, 1990). To maintain a straight wrist, bent handles or angulations of handles should be necessary for hand tools (Das et al., 2005; Patkin, 2001). It can be inferred from our results that the wrist deviation tends to neutral while changing the width and angle of the knife blade.

A few studies from the literature reported regarding the effect of knife blade parameters on wrist posture, gripping forces and cutting moments (Fogleman et al., 1993; McGorry et al., 2003; McGorry, 2001). Hsiang et al. (1997) developed a framework for knife selection, using Taguchi's method of partial factorial design. They investigated the interaction effect of the knife handle, blade length, and height on cutting performance. MCDM approach related to ergonomics have, however, come under scrutiny, particularly in the past few years (Albayrak and Erensal, 2004; Fazlollahtabar, 2010; Behzadian et al., 2012; Gul et al., 2017; Gul, 2018). This makes it difficult to assess risk and evaluate ergonomic interventions on a broader scale where multiple responses play an important role. The lack of methodological standardization is most apparent in terms of hand tool design.

This is the first study to systematically classify the multiple criteria optimization methods in designing hand tool intervention. During the present research, three multiple optimization techniques (TOPSIS, VIKOR, and TLF) were used to rank the alternatives. In line with the visualization results, the knife blade configuration used for reducing the EMG activity showed promising results in curtailing NEMG values incurred during weaving in four different lower arm muscles. On the basis of muscle activities due to redesigning weaving knife, it could be concluded that the change in blade angle and width certainly curtailed the NEMG magnitudes to an extent. Our results have identified and classified the effects of goniometry and EMG activities on variation in ranking nine weaving knife alternatives. We recommended a low-cost solution in the present research. These optimization approaches could also be incorporated into designing other work system interventions. The effectiveness and practicality of the proposed solutions were tested and verified by a confirmation test in a carpet workshop.

5.2.5. Concluding Remarks

This part of the study connects to comparative structure of multiple-response optimization tools, TOPSIS, VIKOR and TLF under an application of weaving knife selection. Nine different configurations using blade angle and width as selection criteria are investigated. The study revealed that the knife blade size and orientation affect not only the wrist posture but also the muscular activity during repetitive working. The crux of the study indicates the strong evidence of the statistical significance of both blade width and blade angle at wrist angles. It signifies that as the blade width and angle changes, the flexion/extension and deviation also tend to vary. Based on the results from the present study, it could be seen that the smaller blade angle (100˚) resulted in lower wrist angle deviation (near neutral posture) as well as EMG values, while higher blade widths (25mm and 30mm) contributed to drop in EMG values of ECRB and FCR muscles. However, it should be noted that the weavers experienced the lowest EMG values in all the four muscles from 25mm and 30mm blade widths having 100˚ blade angle. Multi-criteria decision making methods revealed that 25mm x 100˚ knife configuration outperformed 30mm x 100˚ by a marginal difference. This study demonstrated a heuristic method to quantify knife parameters based on its blade configuration rather than about conventional guidelines for matching geographic anthropometry to handle. In general, according to the results of this study, TOPSIS and TLF are the methods which can offer suitable ergonomics designs. However, when the number of criteria and sample size is increased, the process of optimized designs could become very complicated. While the future research directions remain open to discussion, in the next phase of the study, the authors are intended to investigate and optimize knife blade alternatives beyond the outer border of the alteration levels used for this study.

5.3. Hand tool intervention for workers exposed to hand-arm vibration

5.3.1. General Introduction

Occupational use of powered or non-powered hand tools often leads to awkward posture, forceful gripping, HAV and noise exposure among the industrial workers (Atroshi, 2009; Armstrong, 1983; Mital and Kilbom, 1992; Nandi and Dhatrak, 2008). 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 of handgrip strength, vibration white finger, and CTS (HSE, 2003; 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 most pretentious regions using low-frequency impact tools whereas, the wrist symptoms were more prominent using high-frequency impact tools. Collectively, hand vibration propagates from the direct point of contact of the vibrating surface resulting in HAV exposure symptoms.

There remains a need for assessing exposure to hand-transmitted vibration among the workers involved in handicrafts manufacturing. Therefore, we sought useful to take up this research which was aimed to determine the transmissibility of HAV among the workers.

5.3.2. Material and Methods

5.3.2.1. Selection of Participants and Study design

Thirty male respondents, aged between 20 and 46 (mean 32.80; SD 8.27) took part in the study. The experiments were carried out from April 2017 to September 2017, and all male subjects were selected for the survey from the handicraft workshops. These workshops were situated within the urban and rural areas of Jaipur region. Minimum three year of work experience in the same job and right-hand dominance was the inclusion criteria for this study. Only dominant right-hand workers were selected for the survey for minimizing any discrepancy in the overall statistical significance or familywise error rate due to the hand dominance. The left-handed subjects may differ in grip strength to the right-handers due to handedness and from natural hypertrophy (Incel et al., 2002). The difference in spatial function was also observed in previous studies (Bareham et al., 2015). All of them have no history of upper extremity disorders and permanent hearing impairment. The flowchart in Figure 5.3.1 depicts the adopted strategy of experimental design for this study.

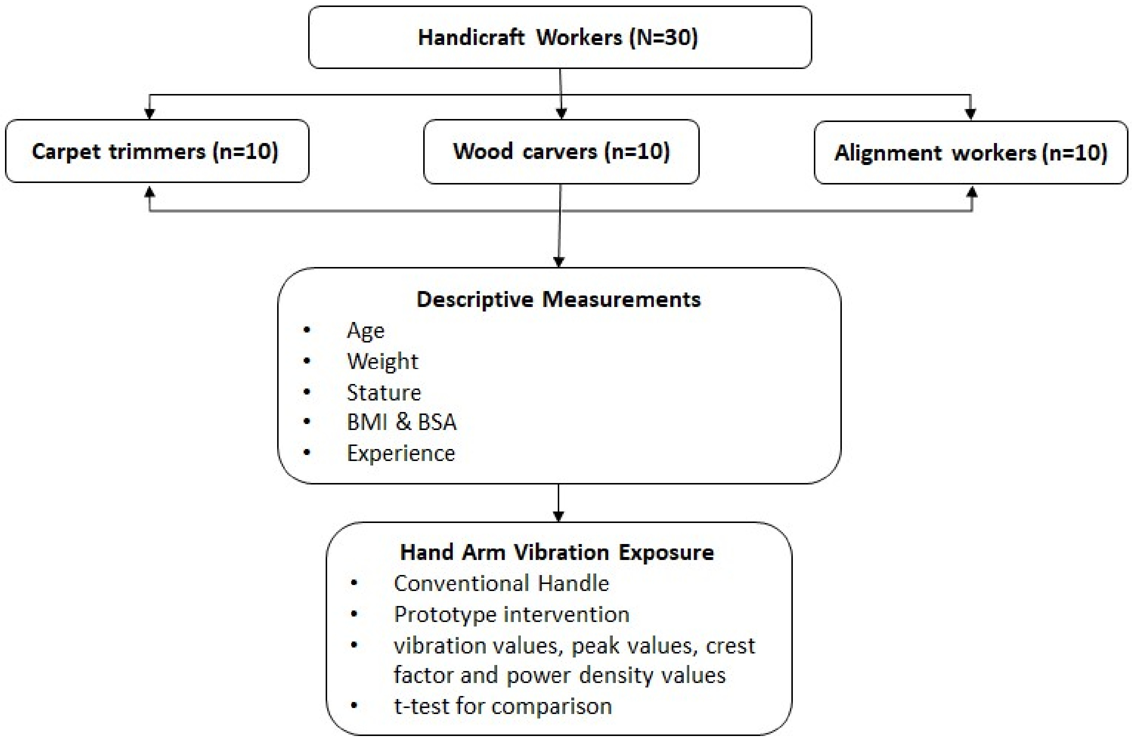

Figure 5.3.1. The adopted strategy of experimental design for this study.

Table 5.3.1 shows the demographic description and general information of participants related to work. The description of the mean BMI was 21.99 ± 1.99 (normal) (WHO, 2000); mean BSA was 1.62 ± 0.11 m^2 (normal). The daily hours spent by the participants was 9.35 ± 0.44 hours with rest of 45-60 minutes each day, and weekly workload was 67.20 ± 3.49 hours (7 days working).

Table 5.3.1. Demographic characteristics of exposed group of workers.

Variable	Carpet trimming worker	Wood carver	Alignment worker	Overall	Kruskal Wallis *p* value
Age (years)	33.20 (8.85)	33.1 (7.1)	32.2 (9.53)	32.8 (8.27)	0.605
Weight (Kg)	58.66 (6.86)	59.1 (6.9)	57.65 (5.95)	58.48 (6.38)	0.228
Stature (cm)	163.35 (5.09)	163.1 (4.8)	162.45 (5.12)	162.97 (4.84)	0.358
BMI (Kg/m^2)	21.96 (2.18)	22.2 (1.8)	21.85 (2.14)	21.99 (1.99)	0.797
BSA (m^2)	1.63 (0.11)	1.63 (0.13)	1.61 (0.10)	1.62 (0.11)	0.172
Experience (years)	12.10 (8.60)	11.4 (7.1)	11.8 (8.94)	11.77 (7.98)	0.249
Weekly Workload (hours)	67.90 (3.38)	67.2 (3.6)	66.5 (3.69)	67.2 (3.49)	0.154

5.3.2.2. *Vibration exposure*

In this study, the HAV was tested using the equipment's described in Chapter 3. 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. 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 has dependencies on 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:

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

where,

W_{hi}; is the weighting factor for the i^{th} one-third-octave band;

a_{hi} is the 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:

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

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:

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

where,

a_{hvi} is the vibration total value for the i^{th} operation;

n is the number of individual vibration exposures;

T_i is the duration of the i^{th} operation.

T_o is the 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):

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

Crest factor and power in band were calculated from the acquired signals. The harmful content and high impulsiveness in the vibration data could be represented by the crest factor (Morioka and Maeda, 1998). The power density is the measure of total power within a specific range of frequency band. The range considered was 6.3 to 12.5 kHz as lower and upper bound of the frequency band.

5.3.2.3. Task assigned for Experiment/Procedure for measurement:

Carpet trimming

A locally fabricated carpet trimming machine using an assembly of different components was used in the study. The motor rated 1.32 kW, pile cutter speed 8000 rpm (approx.), and 8 x 14 ft^2 sized carpet having 14 counts (14x14 knots/inch) was used for experimenting. The depth of cut for the cutter was kept constant at 3 mm. A few carpets with the same design patterns (silk/wool for knots and cotton base) were selected for the operation to prevent any discrepancy due to pile size. The participants were instructed using their typical working posture and grip force as they would during usual work.

Wood Carving

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 routine work. The carving was done on a cylindrically shaped sandalwood block with diameter 3 cm and length 12 cm dimension.

Carpet Alignment

Each of the subjects was provided with an intermittent alignment task using the conventional and the prototype tools. The alignment was done on 9 x 12 ft2 sized carpet having 14 counts (14x14 knots/inch) using their typical working posture and grip force as they would during normal work.

The testing sequence for each participant was randomized, and each measurement of vibration started after beginning the task. Three readings were taken for tool handles and each record at least 60s. The un-weighted vibration data were collected for the last 10s of each testing session. These vibration data were then filtered using 2nd order Butterworth bandpass filter to obtain filtered RMS of frequency-weighted acceleration.

According to IS/IS0 5349-1: 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 equations discussed in section 5.3.2.2.

5.3.2.4. Prototype tools

The prototype tools handles were constructed for the three occupations as mentioned below:

Carpet Alignment Tools

One prototype intervention of hammering rod and chisel were constructed by modifying the conventional tools adopted by the alignment workers. Heat treated plain carbon steel from the leaf springs of scraped vehicles was utilized 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 customized digital human model followed the anthropometric and range of motion data of Indian female (Chakrabarti, 1997). The criteria such as tool weight, 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 0.1mm 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.

Based on the anthropometric considerations (Table 5.3.2), 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.

Table 5.3.2. Hand anthropometric data of participants in the study (n=10)

Dimensions	Mean (SD)		5th		50th		95th	
	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

Conversely, the dimensions of the conventional tools measured was 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 5.3.2 and Figure 5.3.3).

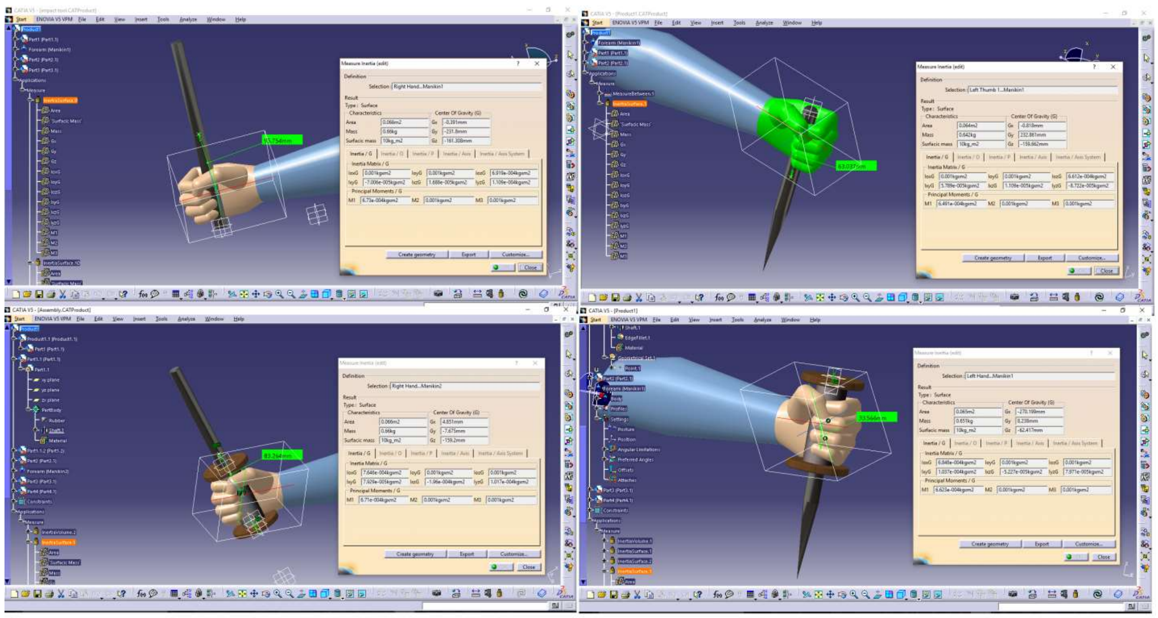

Figure 5.3.2. Dimensional structures of carpet aligning tools in virtual environment using CATIA v5 (conventional and prototypes)

Figure 5.3.3. Overall process of intervention for alignment tool handle.

Carpet Trimmer Handle

The physical structure of the traditional and prototype trimming machine handles are shown in Figure 5.3.4, and their technical characteristics are presented in Table 1 (Appendix-III). A prototype intervention of plastic handle was utilized from the scrapped stone cutting machine (BOSCH GDC 34 M/ GDC 120) and fastened over the metallic strip as shown in Figure 5.3.4b and Figure 5.3.4c. Holes (4mm, diameter) were drilled on the plastic handle and the metal strip and fastened using nut and bolts. The handle was already provided with ovality (filleted on edges) in shape. The shore hardness value (Type D) of the plastic handle was measured using shore durometer (flat cone point (0.79 mm) 35º included angle) and found to be 65HA. That means the plastic used in the study comes under polyurethanes (also called “urethanes”) family of elastomers (Hardness Comparison Chart, n.d.). Furthermore, the ON/OFF switch was also provided for the ease of usability.

Figure 5.3.4. Overall process of intervention for trimming machine handle.

Wood Carving Handle modification

The physical structures of the traditional wood carving tooling arrangement are shown in Figure 5.3.5, and their technical characteristics are presented in Table 2 (Appendix-III). A prototype intervention of carving handle was constructed as per ergonomic design principles. Nitrile Polyvinyl Chloride (NPVC) foam rubber grip was used on the tool handle as a low-cost solution to prevail HAV. Since, 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) 35º 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; Dewangan et al., 2008; Das et al., 2005). 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).

5.3.2.5. Statistical Analysis

Tool handles (conventional and prototype) 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 there is a difference in the vibration values, peak values, crest factor and power in band values in dominant directions before and after the prototype interventions.

Figure 5.3.5. 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) Overall process of intervention for carving tool handle.

5.3.3. Results and Discussion

5.3.3.1. Descriptive statistics for vibration levels

Table 5.3.3 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 occupations considered in the study. The peak and crest value corresponding to un-weighted acceleration magnitudes were assessed to document the effect of handle material on them. The RMS frequency-weighted acceleration magnitudes recorded in the case of carpet trimming and wood carving tool handles was dominant in the *z*-direction, whereas, for carpet alignment tool, the dominant direction was on the *y-axis*. The results indicated that minimum vibrations were found in the *x*-direction for all the tool handles in each group (Figure 5.3.6).

A box plot plotted for the comparative study shows that the total value (a_{hv}) for the tool handles was found larger among the carpet trimmers and wood carvers as compared to alignment workers (Figure 5.3.7). For a vibration value of 3.30 m/s^2 among the carpet trimmers, the time to reach Exposure Action Value (EAV) of estimated daily exposure, A(8) value of 2.5 m/s^2 is 4 hours and 35 minutes (HAV calculator, n.d). Woodcarvers were exposed to a mean vibration value of 2.98, with a time to reach EAV of 5 hours and 38 minutes. Whereas, for alignment workers (1.31 m/s^2), the time to reach EAV has been increased to more than 20 hours which was certainly higher than their daily working hours. Thus, the estimated EAV value, for the carpet trimmers and wood carvers was notably larger as compared to permissible limits, and these workers were at significant risk of developing the HAVS.

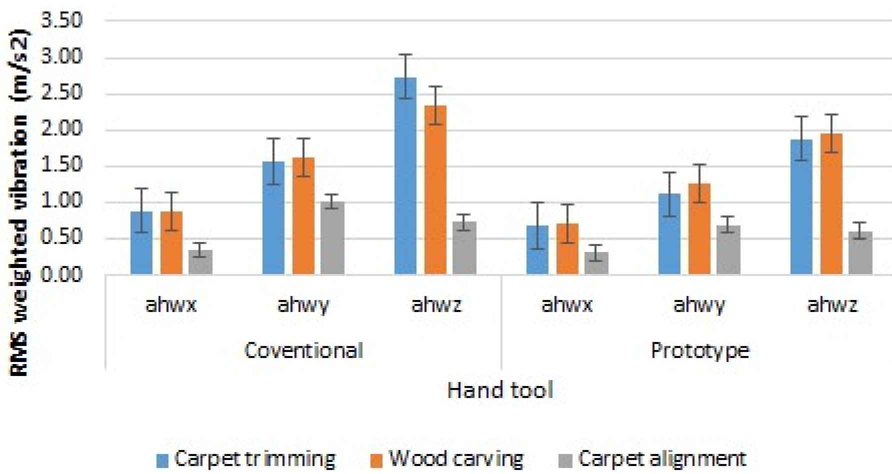

Figure 5.3.6. The mean values of RMS vibrations (m/s^2) with error bar recorded for right hand in tool handles among different occupations.

Note: a_{hwx}, a_{hwy}, a_{hwz}: weighted acceleration in x, y, and z-direction. Error bars (95% CI) indicates the range of values that contains the true mean of the whole possible set of results due to random fluctuation or chance.

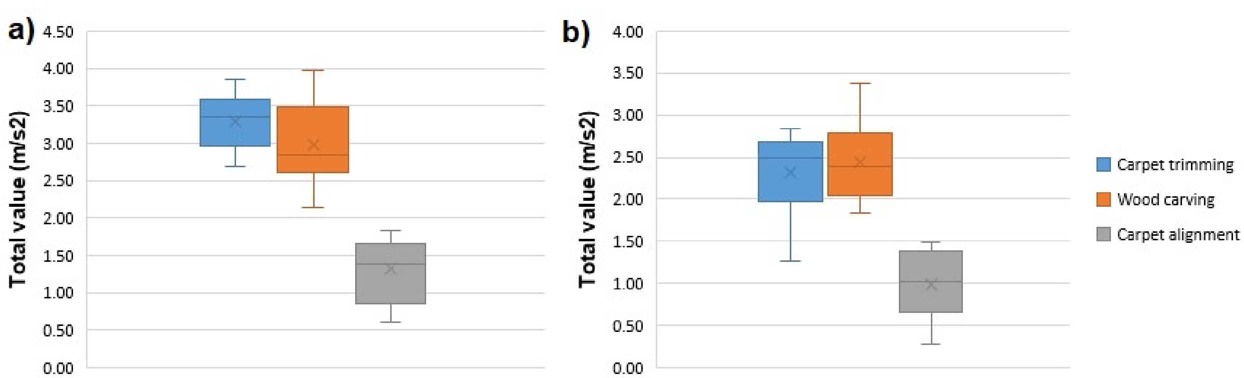

Figure 5.3.7. Box plot showing total RMS value of hand vibration (m/s^2) for right hand in a) conventional and b) prototype tool handles among different occupations.

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

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

The acceleration magnitudes and frequency levels were dominant in the *y* and *z*-direction. Therefore, equivalent vibration magnitudes, peak value, crest value and power in band at hand in *y* and *z*-direction were tested for significance as per ISO5349-1: 2001 (ISO, 2001). Table 5.3.4 and 5.3.5 summarize the results of the vibration transmitted, peak value, crest factor and power density in *y* and *z* directions. As evident, alignment workers were least exposed to RMS frequency-weighted acceleration magnitudes in the dominant directions. It was quite surprising that although the peak values were higher among carpet trimmers and wood carvers, alignment workers showed higher crest factor.

The reduced RMS frequency-weighted acceleration magnitudes could be obtained by using hand tool interventions which may have vibration damping properties and effective in reducing the vibration transmissibility (Dale et al., 2011). However, the present hand tools were deficient in reducing peak values and in turn crest factor to minimize the harmful impulsiveness incurred during handicraft tasks. Therefore, it is advisable that different kind of materials should be explored that may curtail the peak values. Application of anti-vibration gloves should be tested for reducing the impact during the process (Dale et al., 2011). It is also advisable to introduced job rotation to reduce the exposure time (Pettersson, 2013).

It is recommended 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 transmissibility at the surface of handle due to damping properties of wood (Singh and Khan, 2014). Since, besides aesthetic advantages, they also protect the metal from rust, scratches, vibration, impacts, and cracks (Fellows and Freivalds, 1991). However, it was also seen that the wooden handle show no significant reduction over the existing plastic handle (Bhardwaj and Khan, 2018). Therefore, using scrapped plastic handles as an alternative method of vibration isolation seems more cost effective than manufacturing the wooden handles. Perhaps, it leads to effective environmental sustainability and the improvement in the quality of work life among the craft workers.

Table 5.3.3. Descriptive statistics for mean (SD) root mean square (RMS) vibration acceleration magnitudes for the dominant hand at the three axes for hand tools used in different handicraft occupations.

Occupation	Hand tool	Axis	RMS unweighted acceleration, ah (m/s2)	Peak value	Crest Factor	RMS frequency-weighted acceleration, ahw (m/s2)	Total value, ahv (m/s2)
Carpet trimming	Conventional	x	11.65 (2.28)	118.80 (38.76)	10.41 (3.55)	0.88 (0.13)	3.30 (0.40)
		y	20.97 (3.05)	194.51 (45.01)	9.35 (2.29)	1.57 (0.30)	
		z	25.38 (3.37)	202.14 (60.29)	7.94 (2.05)	2.74 (0.44)	
	Prototype	x	9.46 (2.34)	98.92 (22.55)	10.81 (2.92)	0.68 (0.25)	2.32 (0.55)
		y	16.42 (3.52)	152.34 (41.72)	9.62 (3.32)	1.11 (0.33)	
		z	20.43 (4.60)	167.19 (42.90)	8.44 (2.55)	1.88 (0.56)	
Wood carving	Conventional	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)	
	Prototype	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)	
Carpet alignment	Conventional	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)	
	Prototype	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)	

Table 5.3.4. Vibration transmitted, peak value, crest factor and power density in *y* direction.

Occupation	RMS frequency-weighted acceleration, ahwy (m/s2)		*p value*	Peak Value		*p value*	Crest Factor		*p value*	Power in band		*p value*
	Conventional	Prototype		Conventional	Prototype		Conventional	Prototype		Conventional	Prototype	
Carpet trimming	1.57 (0.30)	1.11 (0.33)	0.004 **	194.51 (45.01)	152.34 (41.72)	0.043 *	9.35 (2.29)	9.62 (3.32)	0.837	3.635135 (0.729766)	2.561587 (0.574840)	0.000 **
Wood carving	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)	1.598665 (0.509515)	0.000 **
Carpet alignment	1.01 (0.29)	0.69 (0.32)	0.038 *	17.38 (7.75)	13.68 (5.67)	0.199	16.02 (3.10)	16.46 (4.52)	0.762	0.217849 (0.188713)	0.08303525 (0.0419461)	0.005 **

Table 5.3.5. Vibration transmitted, peak value, crest factor and power density in *z* direction.

Occupation	RMS frequency-weighted acceleration, ahwy (m/s2)		*p value*	Peak Value		*p value*	Crest Factor		*p value*	Power in band		*p value*
	Conventional	Prototype		Conventional	Prototype		Conventional	Prototype		Conventional	Prototype	
Carpet trimming	2.74 (0.44)	1.88 (0.56)	0.001 **	202.14 (60.29)	167.19 (42.90)	0.153	7.94 (2.05)	8.44 (2.55)	0.635	8.713260 (1.842113)	5.766042 (1.341714)	0.000 **
Wood carving	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 **
Carpet alignment	1.42 (0.40)	0.96 (0.43)	0.045 *	48.11 (23.63)	40.92 (21.91)	0.45	19.24 (4.44)	18.81 (4.48)	0.88	0.620855 (0.478785)	0.192641222 (0.114110461)	0.008 **

*(p<0.05)
**(p<0.01)
† (slight but not significant)

Previous studies have shown that HAV exposure affects blood flow in digits leading to CTS (Bovenzi et al., 2004; Bovenzi et al., 2000; Stoyneva et al., 2003). Furthermore, the effect of HAV is also associated with a loss of the muscle strength (Haward and Griffin, 2002; Bovenzi et al., 1991; Radwin et al., 1987; Azmir et al., 2015). Though no attempt was made in this regard during the present study, it will be interesting to assess grip strength association with HAV in later research.

5.3.3.3. Acceleration time-history and frequency spectra

Carpet Trimming

Frequency-dependent vibration magnitudes are transmitted to hand from the tool handle during carpet trimming. The frequency profiles from the data obtained were investigated, and the peak frequency spectrum (from the FFT computations) were examined graphically (Figure 3, Appendix-IV). The results revealed that the peak frequency values ranged from 103 to 110 Hz in the y-direction, 115 to 130 Hz in the z-direction and less than 50 Hz for all recordings in x-direction respectively. These values were in line with the results obtained for vibration magnitudes reported earlier in the text.

Woodcarvers

Vibrations are transmitted to hand from the tool handle. The handle of the hand tool absorbed some of the vibrations. 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 ranged 93 to 115 Hz in the y-direction, 101 to 122 Hz in the z-direction and less than 25 Hz for all recordings in x-direction respectively.

Carpet Alignment

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 the right hand (y-axis), the dominant frequency was in the range of 25-30 Hz. However, it seems minimal magnitude of vibration in x-direction, and the peak frequency ranged 20-25 Hz respectively.

The risk from hand vibration depends on the magnitude, frequency and total duration of the vibration. It seems higher frequencies (>100 Hz) of vibration tend to be involved during carpet trimming and wood carving. Several studies also suggested that the high-frequency vibrations (>100Hz) were associated with vascular symptoms that include primarily hand and wrist regions (Kihlberg and Hagberg, 1997) which may cause dysfunction of the neurovascular system (Krajnak et al., 2010). While low-frequency vibrations (<100Hz) are also undesirable and affects the elbow, upper arm, and shoulder regions (Dale et al., 2011; Kihlberg and Hagberg, 1997). The findings in our study showed that carpet trimming and wood carving workers were exposed to high-frequency vibrations, whereas, alignment workers suffered low-frequency vibrations.

5.3.4. Concluding Remarks

This is one of the first attempts that quantitatively evaluated the hand-transmitted vibration among handicraft workers. HAV reduces work productivity and contribute to workplace accidents. Overall, it was evident that the workers are significantly influenced by the use of improperly designed hand tools. The following conclusions have been drawn from the present study:

- The workers are significantly influenced by the use of improperly designed hand tools. Therefore, it is necessary for the employers within the informal sectors to take responsibility for the occupational health and safety of the handicraft workers.
- The conventional work practices were promptly associated with the HAV. It is preferable to introduce some low-cost workstation interventions which could damp vibrations effectively.
- The crux of the 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.

CHAPTER 6

SUMMARY AND CONCLUSION

6.1. Concluding Remarks

This is a comprehensive study which discusses the work in the area of ergonomic development and hand-tool interventions among handicraft operatives. The study was tailored into two major sections. The first section (chapter IV) of this thesis concluded that the handicraft workers are significantly influenced by the use of ineptly designed workstation and hand tools. The research also points the prevalence of MSDs were promptly associated with poor working posture. This is one of the first attempts to quantitatively evaluate the level of grip strength that female handicraft workers acquire due to the occupational stress. This may be due to poorly designed hand tools and workstations that they are exposed to in their professional life. Although the majority of tasks performed by the handicraft operatives were relatively similar (repetitive hand/finger movement, etc.), their physical workload (frequency and duration of exposure) was different which may be attributed to the difference in static muscle strength. It was observed that there was a significant association of the perceived exertion at higher age and greater experience. The results of the questionnaire revealed that the frequency of most commonly affected body regions among the handicraft workers in the past 12 months were wrist, lower back, shoulders, and elbows. Also, the most commonly affected palmar surface regions among the handicraft operatives in the past 12 months were metacarpal, thenar eminence, and hypothenar.

The occupational problems cannot be eliminated entirely, but they can be minimized with the implementation of some ergonomic work system interventions and guidelines, which eventually enhance the health conditions and productivity of the workers. The other contributions of the thesis were recommending guidelines for work system design that may reduce the symptoms of MSDs, leading improvement in working posture and efficiency of the workers. This provides the answer of the first objective of this research which says "to assess the ergonomic aspects (work related health problems) in handicraft occupations." It leads us to explore interventions that could help reducing problems among the handicraft workers.

The second part (chapter V) of this research was directed to develop and validate designed prototype interventions which could help reducing the major work system related risk factors among the workers. It is divided into two subparts which include the research work in the area of EMG and goniometry and, the development of low-cost interventions to curtail the hand-transmitted vibration in hand tools.

Nine different configurations using weaving knife blade angle and width as selection criteria were investigated. The study revealed that the knife blade size and orientation affect not only the wrist posture but also the muscular activity during repetitive working. The crux of the study indicates the strong evidence of the statistical significance of both blade width and blade angle at wrist angles. It signifies that as the blade width and angle changes, the flexion/extension and deviation also tend to vary. Based on the results from the present study, it could be seen that the smaller blade angle (100˚) resulted in lower wrist angle deviation (near neutral posture) as well as EMG values, while higher blade widths (25mm and 30mm) contributed to drop in EMG values of ECRB and FCR muscles. However, it should be noted that the weavers experienced the lowest EMG values in all the four muscles from 25mm and 30mm blade widths having 100˚ blade angle. Multi-criteria decision making methods revealed that 25mm x 100˚ knife configuration outperformed 30mm x 100˚ by a marginal difference. This study demonstrated a heuristic method to quantify knife parameters based on its blade configuration rather than about conventional guidelines for matching geographic anthropometry to handle. In general, according to the results of this study, TOPSIS and TLF are the methods which can offer suitable ergonomics designs. However, when the number of criteria and sample size is increased, the process of optimized designs could become very complicated. While the future research directions remain open to discussion, in the next phase of the study, the authors are intended to investigate and optimize knife blade alternatives beyond the outer border of the alteration levels used for this study.

HAV syndrome is a widespread symptom that affects a lot of industrial workers worldwide. This is one of the first attempts that quantitatively evaluated the hand-transmitted vibration among handicraft workers. HAV reduces work productivity and contribute to workplace discomfort as well as HAV syndrome. Overall, it was evident that the workers are significantly influenced by the use of improperly designed hand tools. The following conclusions have been drawn from the present study:

- The workers are significantly influenced by the use of improperly designed hand tools. Therefore, it is necessary for the employers within the informal sectors to take responsibility for the occupational health and safety of the handicraft workers.
- The conventional work practices were promptly associated with the HAV and noise exposure. It is preferable to introduce some low-cost workstation interventions which could damp vibrations and noise effectively.
- Despite new effort to diagnose HAV and noise, it needs more research to develop interventions that could curtail them. We devised an intervention to prevail HAV, however, constructing noise damping solutions remained open-ended for future.

The section of this chapter of the study fulfill the second and third objective of the study which revealed "to design and develop ergonomically efficient hand-tool interventions to improve occupational health of the workers." and "to validate the ergonomically designed hand-tool interventions." Both the sections/phases include plans for future research in the respective areas.

6.2. Major Findings and Contribution

1. This study evaluated that the handicraft workers engaged in hand intensive and highly repetitive jobs are suffering from work-related MSDs. Poor working posture, repetitiveness and long duration of exposure were identified as the major occupational risk factors.
2. Several low-cost yet effective hand tool interventions were developed. This study presents the evidence these interventions are cost-effective as well as ergonomically efficient solutions.
3. This study made a contribution in providing a methodology to design, validate and rank intervention alternatives. The design alternatives were compared by the application of multiple-response optimization methods (TOPSIS, VIKOR and Taguchi Loss Function).
4. In general, according to the results, the use of multiple-response optimization methods can offer suitable ergonomics design selection when multivariate analysis alone could not provide accurate inferences. This research is the first attempt which could help ergonomists and other researchers to discover common threads between the ergonomics approach and optimization techniques.

6.3. Limitations of the study

The findings of any study cannot be without limitations. In this case, the study limitations existed due to constraints on research design or methodology. During the assessment phase, we have tried to limit the "sample bias" or "selection bias", there would be some probability of sampling errors which a sample could not reflects for the whole population. Further, it must be borne in mind that the intervention study was only conducted on a small group of workers due to lack of time and resources. No generalized conclusion could be drawn from the assessment before further studies, but output response was directing towards the provision of a better low-cost design.

Lack of previous research studies on the topic could be another limitation. This study is first of its kind to assess the goniometry, EMG and HAV responses for validating the hand tools used in handicraft occupation. Lack of funding caused difficulty in purchasing expensive hand tools (carpet trimming machine and wood carving set-up) for laboratory research. Therefore, the design work (prototype development) was conducted mainly with fabricators workshop.

During the EMG measurements, the weight and sharpness in cutting edge of the weaving knifes may cause some changes in the muscle activity. Secondly, due to the limited sensors, we have restricted our study assessing only four muscles. While conducting HAV measurements, it should be noted though; the daily exposure may increase or decrease with relatively longer or shorter duration of hand tool usage. The research also points out that further longitudinal work is needed to explore postural assessment among the handicraft workers.

6.4. Recommendations and scope for future work

Engineering innovations and designs in the context of social entrepreneurship and impact to the society that we live in are important factors. The outcomes of the work need to go beyond the walls of the university to serve the handicraft workers. The implementation of the developed intervention among the handicraft workers is the biggest challenge. The contractors in the unorganized market are not willing to take-up expensive measures, therefore, we took up the challenge to find cheaper ways to explore the better ergonomic interventions and proposed few solutions with an anticipation that it may be helpful for the workers of the industry. Nevertheless, we believe that the future scope of the work should be making these solutions within the reach of the intended users. Moreover, out of the seven occupations, we have only proposed hand-tool interventions for four occupations.

The rest three occupations (carpet washing, imitation jewelry and block printing) will be looked after in future.

The focus of the present study was development of hand-tools, however, there is a lot scope in designing the whole workstation. We intend to work on developing carpet looms for curtailing postural risks and MSDs during prolonged sitting in squat posture. Although no attempt was made, it will be interesting to investigate the change in EMG activity with change in knife blade material. Furthermore, investigation and optimization of knife blade alternatives by reducing the angle beyond 100° and increasing the width beyond 30 mm will be the future scope of the study. As a result, the best weaving knife was identified, and the procedure used in our study may help ergonomists to find out the alternative ways which could lead them to enhance or improve hand tool designs.

Several investigators in the past have found that the HAV and noise exposure from hand-held power tools have a combined effect on risk in hearing loss that may cause shift in hearing threshold (SHT) among the workers (Pettersson, 2013; Zhu et al., 1997; Hamernik et al., 1989; Starck et al., 1988). The present study requires longitudinal studies that could demonstrate the agreement between HAV, and noise exposure which could influence SHT among the workers. Future directions include assessment of grades of hearing handicap due to the occupational use of these hand tools, implementation of hearing conservation programmes and practice of personal protective equipment's.

Despite having diversified products, some part of Indian market are still untapped and there is lack of awareness about new traditions and among craftsmen and there is need of technological support and training. Although, we might not be able to make the economic conditions better for artisans but efforts in development of better ergonomic condition can make a substantial difference in their living.

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Appendix-I

Questionnaire

General Information:

Name :

Gender : Male/Female **Age :**

Marital Status : Married/Un-married **Qualification :**

Height (cms) : **Weight (Kg) :**

How long have you been doing this job?

On average, how many hours do you work each day?

How many days do you work each week?

Hand dominance: Right handed ( ) Left handed ( )

Level of smoking: NONE ( ) Light ( ) Medium ( ) Heavy ( )

Level of drinking: NONE ( ) Light ( ) Medium ( ) Heavy ( )

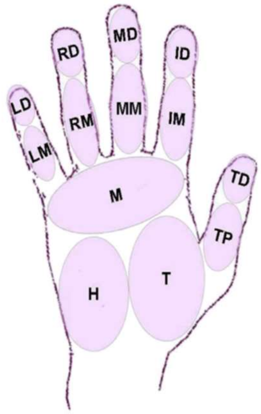
Level of dissatisfaction with hand-tools: Very Low 1 2 3 4 5 6 7 8 9 10 Very High

Adequate illumination*: Very Poor 1 2 3 4 5 6 7 8 9 10 Excellent

Body part Discomfort Interview:

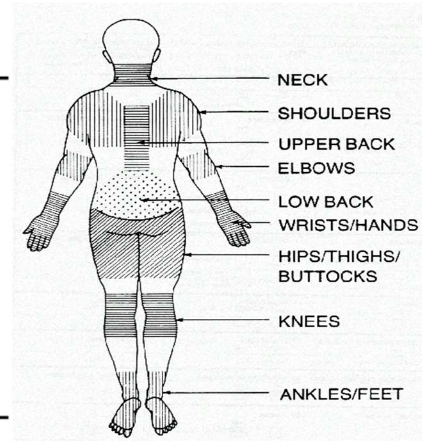
Body part	Have you at any time during the last 12 months had trouble (ache, pain, discomfort) in:	Have you at any time during the last 12 months received medical treatment for trouble in:	Have you had trouble at any time during the last 7 days?
Neck	No ( ) Yes ( )	No ( ) Yes ( )	No ( ) Yes ( )
Shoulder	No ( ) Yes, right shoulder ( ) Yes, left shoulder ( ) Yes, both shoulders ( )	No ( ) Yes ( )	No ( ) Yes ( )
Elbow	No ( ) Yes, right elbow ( ) Yes, left elbow ( ) Yes, both elbows ( )	No ( ) Yes ( )	No ( ) Yes ( )
Wrist/Hand	No ( ) Yes, right wrist/hand ( ) Yes, left wrist/hand ( ) Yes, both wrists/hand ( )	No ( ) Yes ( )	No ( ) Yes ( )
Upper Back	No ( ) Yes ( )	No ( ) Yes ( )	No ( ) Yes ( )
Lower Back	No ( ) Yes ( )	No ( ) Yes ( )	No ( ) Yes ( )
One or Both Hips/Thighs	No ( ) Yes ( )	No ( ) Yes ( )	No ( ) Yes ( )
One or Both Knees	No ( ) Yes ( )	No ( ) Yes ( )	No ( ) Yes ( )
One or Both Ankles/Feet	No ( ) Yes ( )	No ( ) Yes ( )	No ( ) Yes ( )

Tick (✓) the region(s) where you feel pain/deformity/loss of tissues:



Hand and finger areas

T	Thenar area
M	Metacarpal area
H	Hypothenar area
TP	Thumb proximal phalanx
TD	Thumb distal phalanx
IM	Index finger middle and proximal phalanges
ID	Index finger distal phalanx
MM	Middle finger middle and proximal phalanges
MD	Middle finger distal phalanx
RM	Ring finger middle and proximal phalanges
RD	Ring finger distal phalanx
LM	Little finger middle and proximal phalanges
LD	Little finger distal phalanx



Physical Strength Data:

1.	Hand grip strength Dominant Hand (lb)	
2.	Hand grip strength Non-Dominant Hand (lb)	
3.	Tip Pinch Strength Dominant Hand (lb)	
4.	Key Pinch Strength Dominant Hand (lb)	
5.	Palmar Pinch Strength Dominant Hand (lb)	
6.	Tip Pinch Strength Non-Dominant Hand (lb)	
7.	Key Pinch Strength Non-Dominant Hand (lb)	
8.	Palmar Pinch Strength Non-Dominant Hand (lb)	

Frequency of repetitiveness: 1-3 times a week ( ); Everyday ( ); 1-3 times a day ( ); More than 3 times a day

Have you been medically diagnosed or having any serious disease/injury of the following:

Joints No ( ) Yes ( )

Nerves No ( ) Yes ( )

Muscles No ( ) Yes ( )

Other (If any)

Please give details of any issue regarding discomfort/pain that has not been discussed by the questionnaire: ____

Thank you for your participation; your effort may help in improving the working environment and develop new tool for better performance with comfort. If you would be prepared to participate in future research, it would be greatly appreciated:

Address: ________________________________, Site Name:________________________________

Signature

***Note. Results not included in the thesis**

Appendix-II

Figure 1. Digital pinch and hand grip dynamometers used in this study.

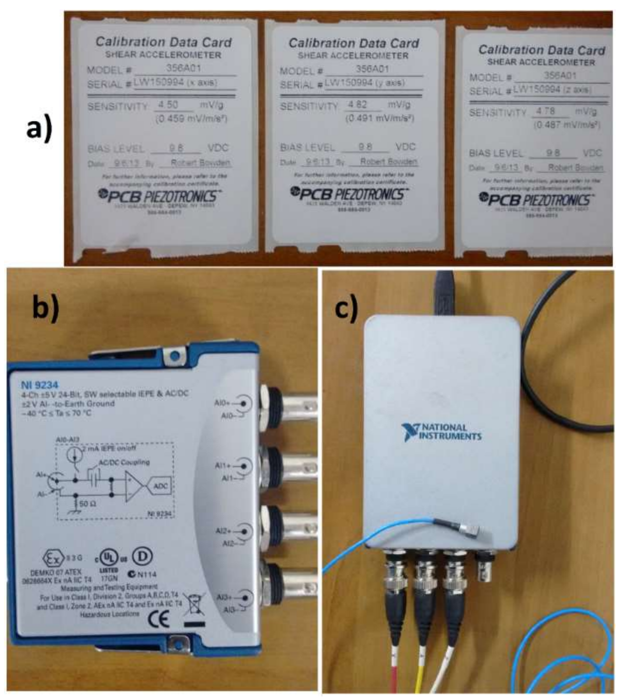


Figure 2. a) Accelerometer sensitivity details; b) NI-DAQmx, programmable Data Acquisition Unit, Model No. NI 9234; c) PCB Piezotronics accelerometers

Appendix-III

Table 1. Technical characteristics of carpet trimming tooling arrangement (with and without prototype intervention)

Parameters	Driving motor	Conventional	Prototype
Power, kW	1.32	-	-
Voltage, V	415/3-phase	-	-
Max speed, min-1	8000-10000	-	-
Handle Material	-	Steel	Plastic
Make	Swipfe Engineering Pvt. Ltd	Local	BOSCH GDC 34 M/ GDC 120 (scrapped)
Length, mm	-	95-100	115
Width, mm	-	35	30
Thickness, mm	-	5	30

Table 2. Technical characteristics of conventional wood carving tools

Parameters	Driving motor	Tool handle	Cutter
Power, kW	1.12	-	-
Voltage, V	220-240	-	-
Max speed, min^{-1}	1740-2200	-	2500-3000
Length, cm	-	12	-
Max Diameter, cm	-	2.5	4.2
No. of teeth	-	-	26
Material	-	Steel	Heat treated steel

Appendix-IV

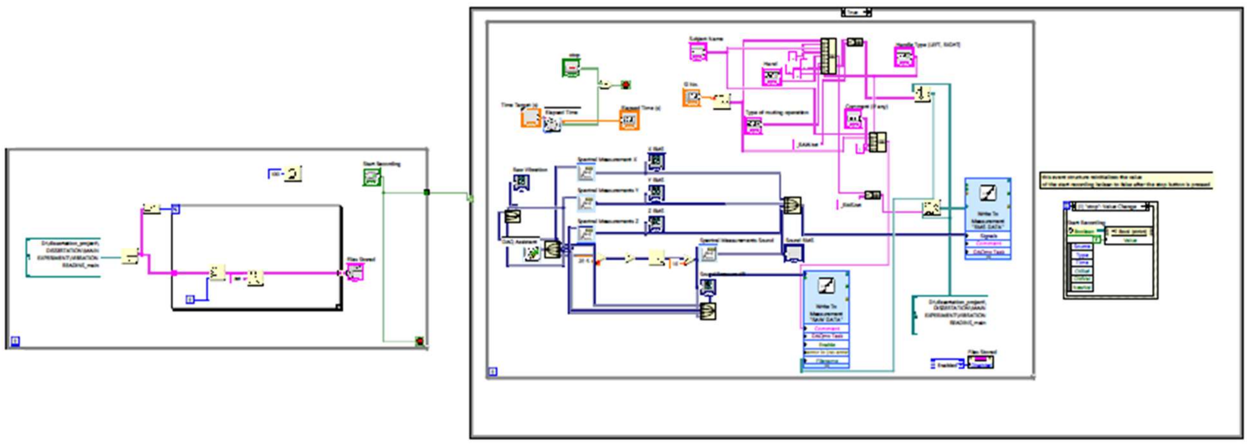


Figure 1. LabVIEW code written in version 13 at a chosen sampling rate (1.5k samples per channel per second) for acquiring the acceleration values along each of the directions (x, y, and z).

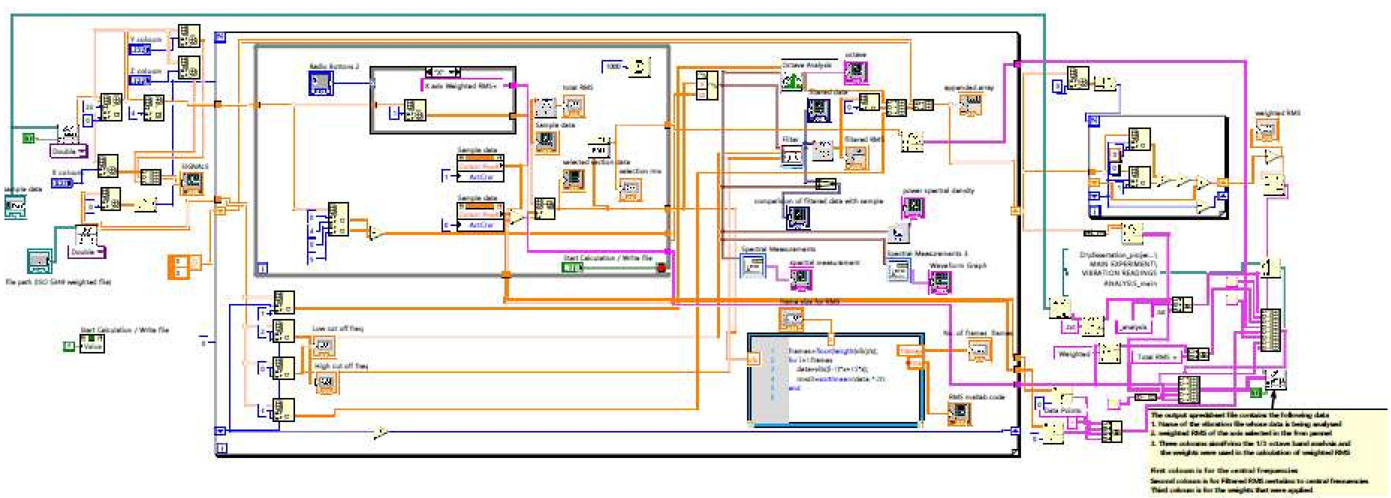


Figure 2. A secondary LabVIEW based code developed to filter the selected portion of unweighted acceleration data into frequency-weighted acceleration (between 6.3 Hz and 1250 Hz) using 2nd order bandpass filter (IIR Butterworth) related to the center frequencies of the one-third octave bands.

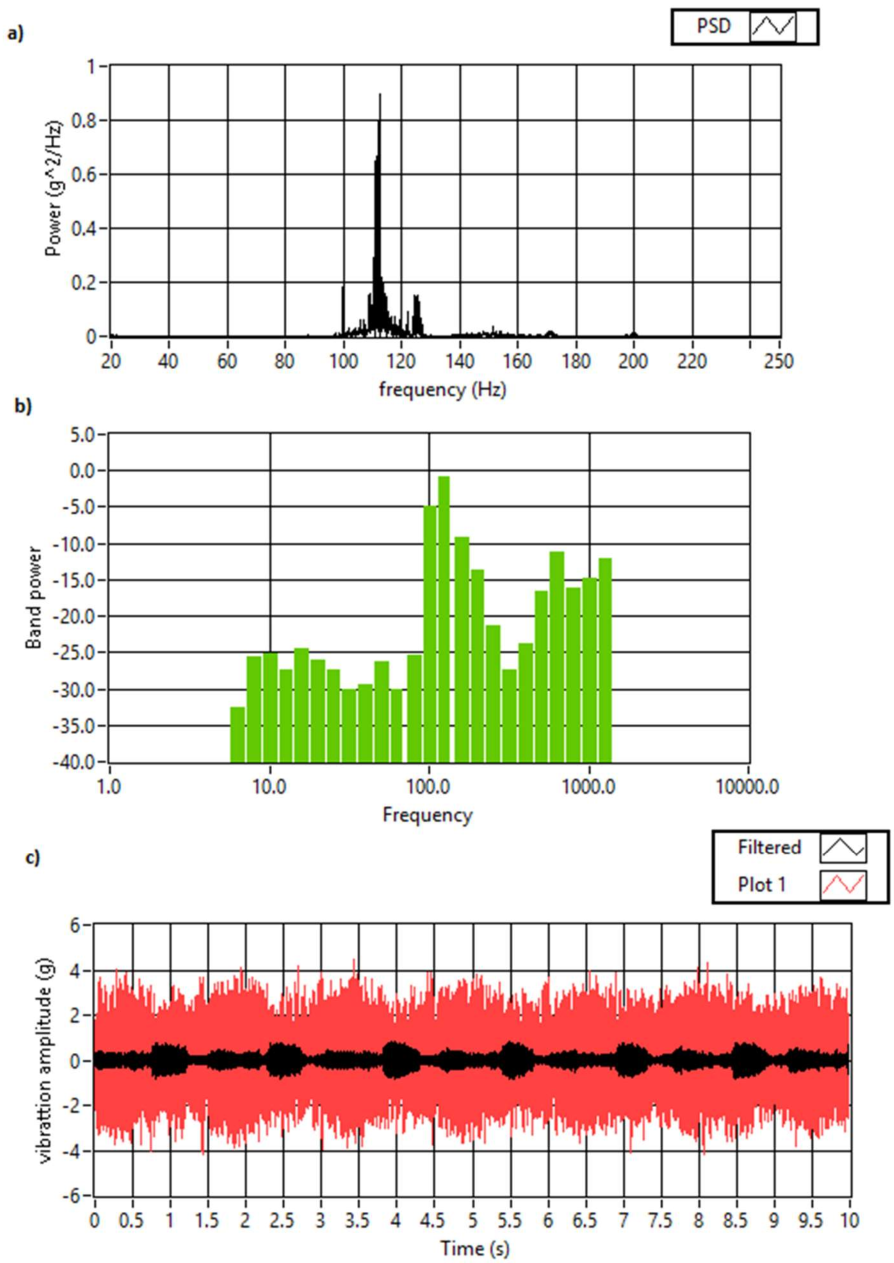


Figure 3. a) Sample graph between power spectral density and frequency; b) Sample graph between 1/3 octave band and frequency; c) Sample graph between original amplitude and filtered amplitude of most dominant frequency.

Note: Sample graphs were obtained as a snapshot of the LabVIEW code written in version 13.

Brief Bio-data of Ashish Kumar Singh

1986 Born in New Delhi, India on the 19th of May

Research

2019 Presently, working as a postdoctoral research fellow at IIT Guwahati, India.

Academics

2019 Currently a candidate (registered in January 2016) for the degree of Doctor of Philosophy at MNIT Jaipur, India.

2014 Post-Graduated from BITS Pilani, India with a Master of Science in Industrial Engineering (Quality Management).

2004 Graduated from Swami Keshvanand Institute of Technology (SKIT), University of Rajasthan, Jaipur, India with a Bachelor's degree in Mechanical Engineering.

Experience

Research 2019 – to date

Pursuing postdoctoral research work at IIT Guwahati, India.

Research 2016 – 2019

Academic 2014 to 2015.

Two year teaching experience at Global Institute of Technology and SKIT Jaipur, India.

Industrial 2008 to 2013.

About 5 years of industry experience at C&S Electric Limited, Suzlon Energy Limited and Macawber Beekay Pvt. Ltd.

Publications

More than 15 first-authored papers published in several peer-reviewed Journals and Conferences which includes popular journals like, "International Journal of Occupational Safety and Ergonomics", "Human Factors and Ergonomics in Manufacturing & Service Industries", "Noise & Vibration Worldwide", "Ergonomics" and "International Journal of Human Factors and Ergonomics". All the papers were published with renowned publishers like "Wiley", "Taylor and Francis", "Sage" and "Inderscience".

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Publications from Ph.D. Work

Refereed Articles in Scientific Journals (Published/Accepted)

1. **A. K. Singh***, M. L. Meena, H. Chaudhary (2019) "Application of multiple-response optimization methods for the ergonomic evaluation of carpet weaving knife", Human Factors and Ergonomics in Manufacturing & Service Industries, Vol. 29, No. 4, pp. 293-311 (**SCI/SSCI**) (DOI: 10.1002/hfm.20785) (**John Wiley & Sons, US**)

2. **A. K. Singh***, M. L. Meena, H. Chaudhary (2019) "Measuring static muscular strength among female operatives': a cross-sectional comparison in different handicraft occupations", International Journal of Occupational Safety and Ergonomics (JOSE) (**SCI/SSCI**) (accepted, in press) (DOI: 10.1080/10803548.2018.1506537) (**Taylor & Francis, UK**)

3. **A. K. Singh***, M. L. Meena, H. Chaudhary, S. Karmakar (2019) "Assessment of low-cost intervention (foam rubber) among wood carvers exposed to hand-arm vibration and noise", Drewno-wood, Vol. 62, No. 203, (**SCI/SCIE**) (DOI: 10.12841/wood.1644-3985.298.04) (**Wood Technology Institute, Poland**)

4. **A. K. Singh***, M. L. Meena, H. Chaudhary, G.S. Dangayach, (2019) "A comparative assessment of static muscular strength among female operatives' working in different handicraft occupations in India", Health Care for Women International, Vol. 40, No. 4, pp. 459-478 (**SCI/SSCI**) (DOI: 10.1080/07399332.2018.1484468) (**Taylor & Francis, UK**)

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6. **A. K. Singh***, M. L. Meena, H. Chaudhary (2018) "Assessment of low cost tool intervention among carpet alignment workers exposed to hand-arm vibration and shift in hearing threshold", International Journal of Human Factors and Ergonomics, Vol. 5, No. 3, pp. 189-209 (**Scopus**) (DOI: 10.1504/IJHFE.2018.10016992) (**Inderscience, UK**)

7. **A. K. Singh***, M. L. Meena, H. Chaudhary, G.S. Dangayach (2018) "Ergonomic evaluation of cumulative trauma disorders among female carpet weavers in India: guidelines to an effective sustainability in work system design", International Journal of Human Factors and Ergonomics, Vol. 5, No. 2, pp. 129-150 (**Scopus**) (DOI: 10.1504/IJHFE.2018.092228) (**Inderscience, UK**)

8. **A. K. Singh***, M. L. Meena, H. Chaudhary, G.S. Dangayach (2017) "Ergonomic assessment and prevalence of musculoskeletal disorders among washer-men during carpet washing: guidelines to an effective sustainability in workstation design", International Journal of Human Factors and Ergonomics, Vol. 5, No. 1, pp. 22-43 (**Scopus**) (DOI: 10.1504/IJHFE.2017.10009436) (**Inderscience, UK**)

Research outside Ph.D.

1. **A. K. Singh*** (2019) "Comparative assessment of shift in hearing threshold among handicraft operatives' in India", Ergonomics, Vol. 62, No. 1, pp. 88-102 (**SCI/SSCI**) (DOI:10.1080/00140139.2018.1519121) (IF-2.181) (**Taylor & Francis, UK**)

2. **A. K. Singh***, M. L. Meena, H. Chaudhary, G.S. Dangayach (2019) "Development and evaluation of wearable electro-goniometer for the assessment of repetitive efforts and measurement of joint trajectories during carpet weaving", International Journal of Business and Systems Research (**Scopus**) (accepted, in press) (Available from: http://www.inderscience.com/info/ingeneral/forthcoming.php?jcode=ijbsr) (**Inderscience, UK**)

3. A Chaudhary, M. L. Meena, **A. K. Singh*** (2019) "Productivity improvement of an electrical appliance industry by implementing lean manufacturing tools and a low-cost intervention (A case study)", International Journal of Productivity and Quality Management (**Scopus**) (accepted, in press) (**Inderscience, UK**)

4. **A. K. Singh***, M. L. Meena, H. Chaudhary, "Ergonomic risk and postural assessment during metallographic specimen polishing in virtual environment" Elsevier: Materials Today Proceedings (**Scopus**) (accepted, issue awaiting) (**Elsevier, US**)

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Publications in International Conferences (Peer-Reviewed)

1. **A. K. Singh***, M. L. Meena, H. Chaudhary, “Musculoskeletal risk assessment among the male workers engaged in craft sectors of Jaipur, India”, Proceedings of the International Conference on Industrial Engineering and Operations Management (IEOM), Bangkok, Thailand on March 5-7, 2019, pp. 763-770, (ISBN: 978-1-5323-5948-4 (**Scopus**)

2. **A. K. Singh***, M. L. Meena, H. Chaudhary, “Ergonomic risk and postural assessment during metallographic specimen polishing in virtual environment” Proceedings of the International Conference on Hybrid and Composite Materials, Chemical Processing: HCMCP-2016 by Elsevier: Materials Today Proceedings at St. Peter’s Engineering College, Hyderabad, 141-147, 25th to 27th October, 2016.

3. **A. K. Singh***, M. L. Meena, H. Chaudhary, “Ergonomic assessment and prevalence of cumulative trauma disorders among female carpet weavers: proposed guidelines for hand tool design” Proceedings of the 14th International Conference on Humanizing Work and Work Environment (HWWE 2016) by India Society of Ergonomics at NIT, Jalandhar, 268-273, 8th to 11th December, 2016. (ISBN Number: 978-93-83006-81-6)

4. M. L. Meena*, **A. K. Singh**, H. Chaudhary, "Measuring quality of work life among female weavers in carpet industries”, 21st International Conference on “Engineering & Technology, Computer, Basic & Applied Sciences” (ECBA- 2017) March 6-7, 2017, Hong Kong, Vol. 3(21). (ISBN 978-969-683-357-4)

5. **A. K. Singh***, M.K. Sain, M.L. Meena and H. Chaudhary “Comparative assessment of static muscular strength among female carpet weavers’” Proceedings of the 15th International Conference on Humanizing Work and Work Environment (HWWE 2017) by India Society of Ergonomics at AMU, Aligarh, pp. 252, 8th to 10th December, 2017. (ISBN Number: 978-938-672-425-0)

6. **A. K. Singh***, R. Jain, B. S. Sirvee and M.L. Meena “Ergonomic evaluation and work table design for wood furniture manufacturing industry” Proceedings of the 15th International Conference on Humanizing Work and Work Environment (HWWE 2017) by India Society of Ergonomics at AMU, Aligarh, pp. 20, 8th to 10th December, 2017. (ISBN Number: 978-938-672-425-0)