ERGONOMIC INTERVENTIONS FOR IMPROVING HEALTH OF BRICK KILN INDUSTRY WORKERS

Ph.D. Thesis

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Ergonomic Interventions for Improving Health of Brick Kiln Industry Workers

Submitted in

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by

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Under the supervision of

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June 2019

DECLARATION

I, **Manoj Kumar Sain**, declare that this thesis titled, **“Ergonomic Interventions for Improving Health of Brick Kiln Industry Workers”** and the work presented in it, are my own. I confirm that:

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- 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 Interventions for Improving Health of Brick Kiln Industry Workers”** being submitted by **Manoj Kumar Sain (2014RME9054)** is a bonafide research work carried out under my supervision and guidance in fulfillment of the requirement for the award of the degree of **Doctor of Philosophy** in the Department of Mechanical Engineering Engineering, Malaviya National Institute of Technology Jaipur, India. The matter embodied in this thesis is original and has not been submitted to any other University or Institute for the award of any other degree.

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(Manoj Kumar Sain)

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ABSTRACT

In India, fired clay bricks are produced in traditional kilns which fall under the category of unorganised small–scale industries. The Indian unorganised sector employs approximately 458 million workers including around 10 million people in fired clay brick kilns. India is the world's second largest brick producer and has more than 140 thousand brick kilns. Despite its economic importance, the Indian clay brick manufacturing sector is not as modern as it should be, and about 99% of clay brick production work is done manually with traditional methods. The clay brick making process requires a large number of repetitive manual activities. Prolonged working in repetitive and awkward postures with traditional ways result in musculoskeletal issues among brick kiln workers doing manual labour. Unlike other labour–intensive sectors, workers in this particular sector have a lack of awareness about musculoskeletal problems. The work–related musculoskeletal problems within brick kiln workers can be minimised by properly designed ergonomic interventions. Various studies have reported the effectiveness of ergonomic interventions in different sectors. However, limited work has been reported on the investigation of musculoskeletal symptoms and postural risks among the workers involved in various manual tasks of clay brick manufacturing. In this sector, ergonomic intervention studies are hardly seen in the literature. Hence, the present research was taken up for preventing musculoskeletal issues of manual brick kiln workers through ergonomic interventions.

Most labour–intensive among the tasks involved in clay brick manufacturing are spading, clot cutting and mould filling, mould evacuating and carrying. These are the tasks that can be attributed to the use of most repetitive and awkward postures.

The present study was carried out mainly in two steps. In the first step, musculoskeletal health of workers was analysed. Association of musculoskeletal issues and various risk factors was also analysed under this step. The musculoskeletal health was analysed using a modified Nordic questionnaire and handgrip strength measurement. The postural risk was analysed by rapid upper limb assessment (RULA) and rapid entire body assessment (REBA) methods. All statistical analyses were performed using SPSS software (version 22). As per the results of the study, musculoskeletal issues in the wrist (51.5%) and lower back (50%) regions were reported most frequently. For the mould evacuating task, wrist (76.2%) and lower back (56%) issues were the most frequently reported musculoskeletal problems, while in the spading task, lower back (62.4%) and shoulder (57.7%) problems were prominent. Postural analysis showed that kiln workers are exposed to very high risks in spading and mould filling tasks. Hand grip strength analysis revealed that the hand musculoskeletal system of brick moulders get affected by prolonged strenuous tasks.

In the second step of research, ergonomic interventions were designed and validated to address the musculoskeletal problems of brick kiln workers. A study was conducted to analyse the effect of the lumbar belt and stretching exercises on lower back issues among 125 workers, and the intervention was found to be significantly effective in reducing lower back issues among workers. To address the hand musculoskeletal issues, the design of moulding box was modified and a clot cutting/mud pulling hand tool was designed ergonomically. Firstly, these hand tools were designed and tested on software like ANSYS and CATIA, and then physical prototypes were fabricated. The prototypes were tested and evaluated by 30 workers for validation. The postural assessment and usability test proved that newly designed hand tools reduces the work–related musculoskeletal problems and improves work comfort.

Musculoskeletal health of workers is an important concern, especially in developing as well as under–developed economies. In this context, the present work makes a significant contribution to the research currently going on in this field. Not only does the present research provide evidence of the prevalence of musculoskeletal symptoms experienced by brick kiln workers; it also provides statistics of specific musculoskeletal problems and ways to address them.

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List of Abbreviations

ATA	Actual technical actions
BLS	Bureau of labour standards
BMI	Body mass index
CI	Confidence interval
CQH	Comfort questionnaire for hand tools
CTDs	Carpal tunnel disorders
FEA	Finite element analysis
FIOH	Finnish institute of occupational health
GS	Grip strength
HAL	Hand activity level
IEA	International ergonomics association
ILO	International labour organization
JSI	Job strain index
LBP	Lower back pain
MSDs	Musculoskeletal disorders
OCRA	Occupational repetitive actions
OR	Odds ratio
QEC	Quick exposure check
REBA	Rapid entire body assessment
RTA	Reference technical actions
RULA	Rapid upper limb assessment
SD	Standard deviation
SEM	Standard error of mean
SNQ	Standard Nordic questionnaire

Chapter 1

Introduction

1.1 Background

Being an important material for construction, clay bricks are widely used worldwide. Clay brick manufacturing is one of the oldest and traditional industries. Excavations of ancient civilizations such as Harappa and Mohenjodaro have shown that sun–dried clay bricks were in use, even 5000 years ago (Verma and Uppal, 2013). Developing economies, increasing population and urbanisation have caused a faster growth in infrastructure and construction sector worldwide. The government of India initiatives like “Pradhan Mantri Awas Yojana” and “Smart City Projects” are expected to be major growth drivers for the brick industry of the country. In India fired clay bricks are produced in traditional and unorganised small scale industries (Bandyopadhyay and Sen, 2016; Sett and Sahu, 2014). The unorganised sector in India provides employment to approximately 4575 lac workers (NCEUS, 2007) including employment to about 100 lac peoples by fired clay brick kilns. India is world’s second largest brick producer having more than 1.40 lac brick kilns (Das, 2014; Kamyotra, 2015; Mukhopadhyay, 2008), out of which 25,000 brick kilns are situated in North Indian states of Rajasthan, Haryana, Punjab and Uttar Pradesh (Verma and Uppal, 2013).

The comparative view of clay brick industry in India and other Asian countries is shown in Figure 1.1. About 13% share of clay bricks produced worldwide, comes from India. Despite its importance, the Indian clay brick manufacturing sector is not as modern as it should be. About 99% of brick production work in India is done manually, and only one percent of work is done through machines (Kamyotra, 2015). Whereas, in developed and high income countries mechanized and fully automated processes are used for various brick making activities. The clay brick making process includes a number of manual activities which are repetitive and are continuously performed in awkward postures with traditional methods and hand tools (Das, 2014; Trevelyan and Haslam, 2001).

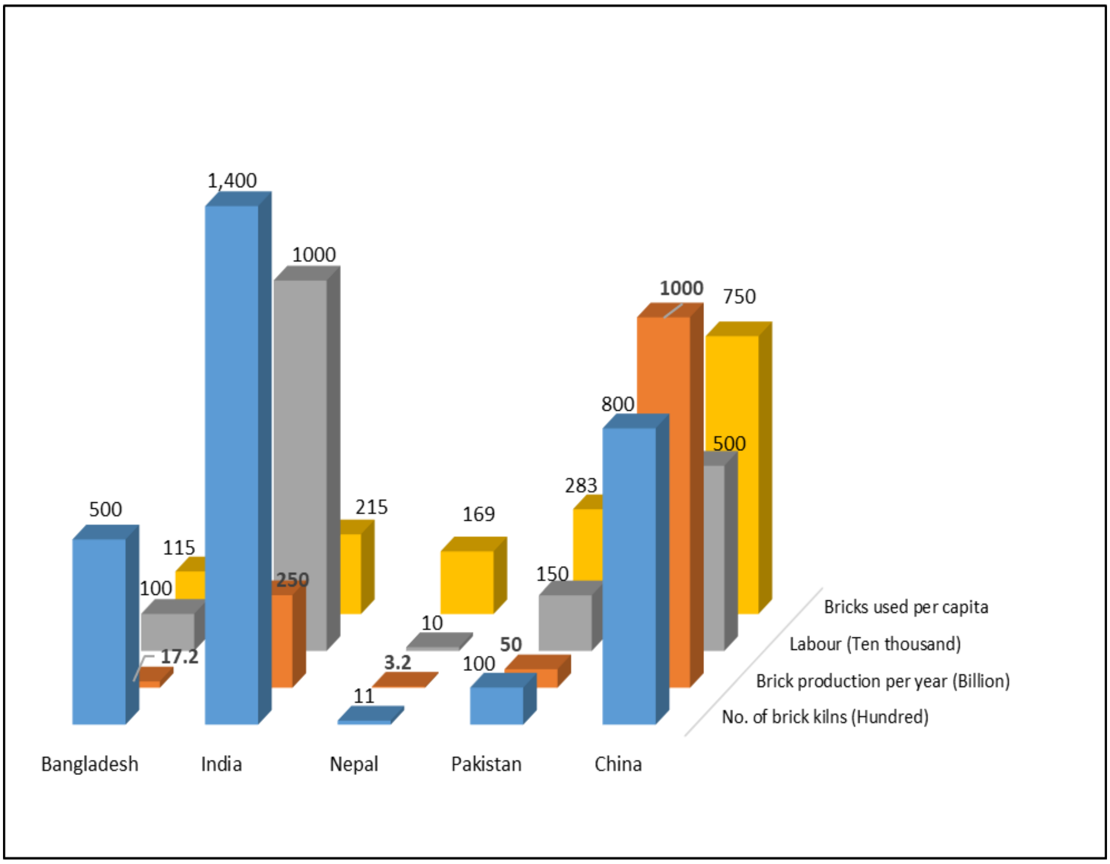


Figure 1.1: Comparative view of the clay brick industry in various Asian countries *(Source: Kamyotra, 2015)*

Various tasks manually performed during clay brick manufacturing with the relevant working conditions are presented in Figure 1.2. In the first step, clay is quarried using some manual digging tools such as spade, mattock, etc. Clay is then broken into small pieces with the help of a mallet. In the second step, clay is prepared by wetting and then mixing with the help of a spade or manually. The prepared clay is then cut into clots by hands. Sometimes coal dust covering is also provided on prepared clots to avoid sticking of clay on moulding box as well as to improve the burning of brick. In the next step, the clot is filled into the moulding box, and green brick is evacuated on the ground. After some days bricks are stacked to dry and then dried bricks are carried to the kiln and arranged for firing. After some days, fired bricks become ready and are loaded in vehicles for transportation to market.

Thus, the brick kiln workers have to perform various manual tasks in awkward and repetitive postures for 8–10 hours every day. In this industry, the maximum number of workers are uneducated or very less educated, and they are not trained in safe and healthy working practices.

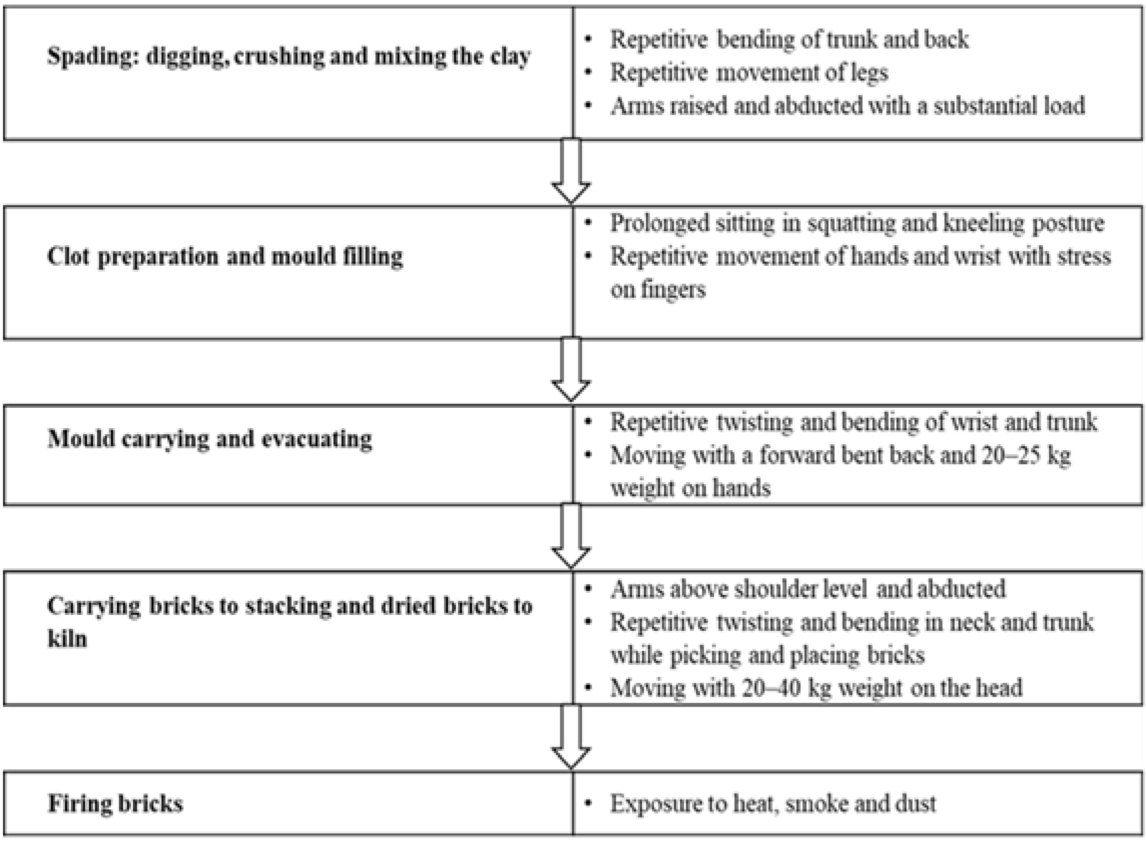


Figure 1.2: Major activities in clay brick making process

Working in continued repetitive and awkward postures has been recognized as a significant occupational risk factor emergent in various manual small scale industries (i.e., handicraft, apparel, furniture, agriculture, construction, etc.) worldwide (Capodaglio, 2016; Choobineh et al., 2004; Dianat et al., 2015; Jain et al., 2017; Nejad et al., 2013). Repetitive work in prolonged awkward postures is associated with discomfort, fatigue, health problems and musculoskeletal disorder (MSDs) among workers (Cooper and Kleiner, 2001; McGaha et al. 2014; Meena et al., 2014). Work–related problems are the physical and sensitive reactions that occur when the conditions of work do not meet the capabilities, resources or the requirements of the workers (Saiyed and Tiwari, 2004). Presently, work–related MSDs are the most critical issues worldwide.

The ergonomic interventions like work system and hand–tool redesign, job rotation, exercise, and training on ergonomics are the best solutions to work–related MSDs. These ensure that workers can work safely for a longer period with improved productivity (Gangopadhyay et al., 2014; Meena et al., 2014a; Bandyopadhyay and Sen, 2016; Robertson et al. 2013).

Ergonomic studies on clay brick manufacturing sector conducted so far in India has mainly been focused on the nutrition level of female workers (Sett and Sahu, 2016), heat exposure (Sett and Sahu, 2014), respiratory symptoms (Monga et al. 2012), lower back pain(Das 2015) and physical stress (Das 2014). Very few studies have investigated the MSDs in different body regions and associated factors within the workers involved in various manual activities of clay brick manufacturing. Exploration of occupational health issues and associated factors is the first stage towards designing the work environment ergonomically (Meena et al., 2014a; Sain and Meena, 2016). Hence, the current research was carried out to assess the musculoskeletal health of brick kiln workers and to develop some ergonomic interventions to solve these issues.

1.2 Motivation of research

In today's scenario wellbeing of workers has emerged as a crucial issue in most of the developed and developing countries. In most of the organised sectors, safety at work and workers' comfort is considered as a key factor in improving the productivity and quality of products. Musculoskeletal issues can be minimised by managing the biomechanical and psychosocial load at work. Although a lot of research on managing the occupational health issues has been done in various sectors, this particular sector has received very less attention in the form of ergonomic studies targeting minimization of relevant problems. In India, some studies in the brick manufacturing sector have been conducted, and most of the studies were focussed on testing the nutrition level of female workers, heat exposure (Sett and Sahu, 2014; 2016), respiratory symptoms (Monga et al., 2012), lower back pain (Das, 2015) and physical stress (Das, 2014). After conducting an extensive literature review, it was observed that exploratory research on ergonomic interventions in the brick kiln sector that need to be addressed include the following issues:

- Very few studies have investigated musculoskeletal symptoms in different body regions among kiln workers.
- The literature lacks significant research related to the association of the prevalence of musculoskeletal issues and risk factors.

- Applications of ergonomic interventions in the brick kiln sector have also not been satisfactorily addressed so far.

1.3 Objectives of research

The present research focuses on the identification of prevalence of occupational health issues particularly MSDs and associated risk factors that could be helpful for design, development and evaluation of ergonomic intervention for workers in traditional brick kilns. The specific objectives are as follows:

- To assess occupational health and identify the prevalence of musculoskeletal issues and associated risk factors among brick kiln workers.
- To perform the postural analysis of workers within the existing work environment.
- To design and validate ergonomic interventions for brick kiln workers.
- To highlight areas of future study for the continuance of present research.

1.4 Research hypotheses

During the initial review of literature, various work–related health issues and MSDs were observed among the workers employed in various unorganised small scale industries. Fired clay brick manufacturing is also a traditional and unorganised small scale sector in India. Literature barely describes any research on musculoskeletal issues and ergonomic interventions to minimise these problems. During the initial visits of brick kilns it was seen that brick kiln workers generally use traditional methods and hand tools during various manual activities.

Hence, following hypotheses were synthesized to work upon:

H_1: Work–related musculoskeletal issues are prevalent among clay brick manufacturing workers in India.

H_2: Musculoskeletal issues among clay brick kiln workers are associated with personal and work related factors.

H_3: A planned ergonomic intervention reduces the musculoskeletal issues among workers involved in manual brick making activities.

1.5 Organization of thesis

For the chronological presentation of work done throughout the research, the thesis is organised into six chapters as follows:

Chapter 1 includes a detailed introduction, with background, motivation and the objectives of the current work.

Chapter 2 contains a comprehensive literature review related to ergonomics, musculoskeletal symptoms, human hand tool design variables and research work done on brick kiln industry in the context of musculoskeletal health and ergonomic assessment. The chapter summarises the previous research findings as a basis for finding out research gaps and builds up a framework to attain the objectives set on the basis of these research gaps.

Chapter 3 is devoted to the broad research methodology adopted in the present study. This chapter deals with the research framework, study area and sampling, methods of data collection and statistical analysis.

Chapter 4 presents the identification of prevalence of musculoskeletal issues and risk factors among workers involved in selected manual brick making tasks. The association between prevalence of musculoskeletal problems and risk–factors is also described in this chapter. The chapter also focuses on posture analysis using the rapid upper limb assessment (RULA) and rapid entire body assessment (REBA) methods, and hand grip strength analysis. On the basis of questionnaire survey and posture analysis outcomes, critical activities were identified for further design of ergonomic interventions.

Chapter 5 discusses the design, development and testing of ergonomic interventions.

Chapter 6 presents the summary, findings, limitations of the current research and scope for future work.

Chapter 2

Literature Review

This chapter sketches the findings of literature review on various aspects of ergonomics and musculoskeletal issues among workers involved in manual activities like those of brick kiln workers and intervention designs for prevention of musculoskeletal problems. The main purpose of the literature review was to explore the current area of research in the field of ergonomics and to determine the gap for research in the area. The articles were searched from various databases (PubMed, EBSCOhost, ScienceDirect) and e–publishers (Elsevier, Taylor & Francis, Emerald, Inderscience, SAGE, Wiley, J–Stage, etc.). The Scopus Analysis Tool was used for search and analysis of literature. Data was also gathered from some government reports and websites of various organizations and agencies.

The search for relevant literature was started with a quite broad outlook. Initially, literature on ergonomic researches in various sectors was explored. Keywords like "ergonomics", "anthropometry", "occupational health", "safety", "accidents", "risk", "hazard", "work environment", "musculoskeletal" and "MSDs" were searched in different combinations. In addition, the search was limited to English language. Then the search was confined to musculoskeletal issues and ergonomic interventions in small scale industries in India, and then clay brick manufacturing sector together with other unorganized sectors. Research work related to ergonomic design of hand tools and other ergonomic interventions were also reviewed to find out the necessary points considered during intervention design and implementation. The search scheme and its outcomes in different phases are depicted in Figure 2.1. A total of 49642 articles were found with keyword "ergonomics", and the final search was confined to 112 articles after applying filters and exclusion criteria as mentioned in the search scheme.

A total of 168 articles from journals, books, websites, reports, etc. were referred during the writing of the thesis.

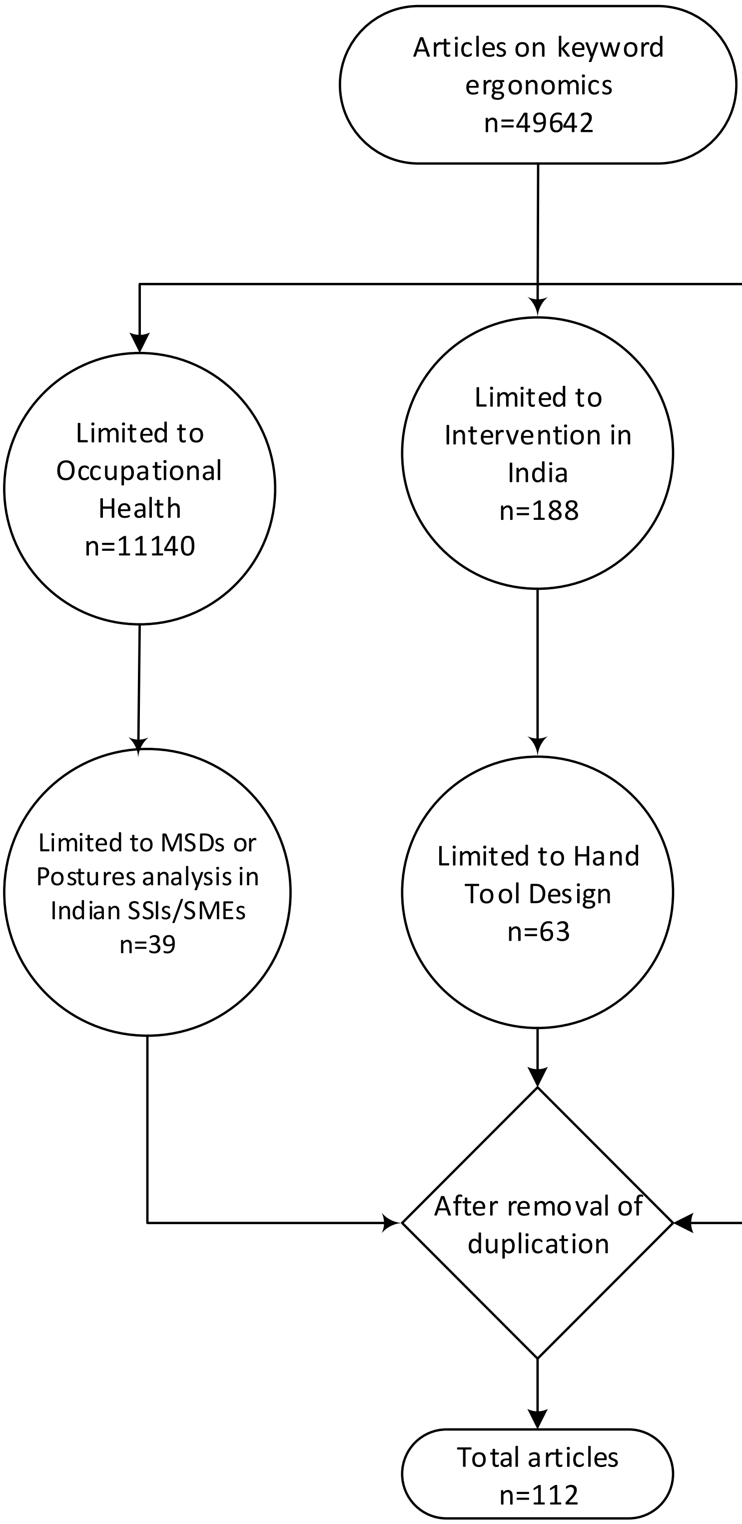


Figure 2.1: Literature search scheme

2.1 Ergonomics

The word 'Ergonomics' is derived from two Greek words 'ergon' (work) and 'nomos' (laws) to denote the science of work. According to the International Ergonomics Association (IEA, 2000)

"Ergonomics is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well–being and overall system performance."

Ergonomics is also considered as a science which offers fundamental understanding as well as a technology applying that understanding to work–system design in their widest sense. According to this view, ergonomics problem place contains all the elements of the total human–environment system, including hardware, software, space and interaction of people with individual and social groups along with others (Shackel, 1996).

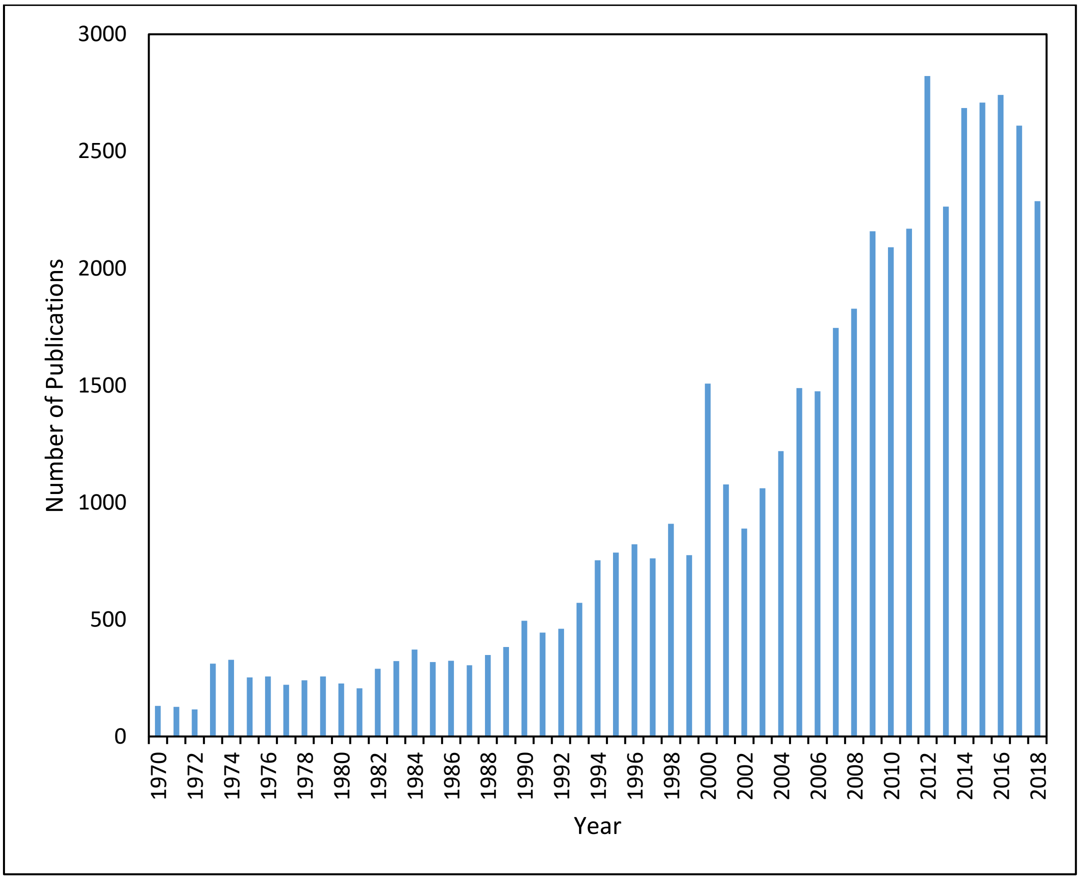


Figure 2.2: Global research trend on ergonomic issues *(Source: Scopus)*

Wickins et al. (1998) states that the purpose of human factors is to take care of human characteristics in the design of work systems. On the contrary, they consider engineering psychology as the ultimate goal of understanding the human mind with emphasis on discovering general principles and the theory.

Ergonomics has become popular among the general public, with its use by marketing personnel to denote the quality of design and ease of use of products. In the present scenario, comfort, safety and wellbeing of workers have emerged as areas of concern worldwide. Hence, the research in the field of ergonomics is also growing up rapidly. Figure 2.2 shows the increasing worldwide publications on ergonomic issues. The research growth in this field has been exponential in the past few decades. Research growth in the field of ergonomics in India has been very slow. However, in the past decade, a substantial rise in publications was observed (Figure 2.3).

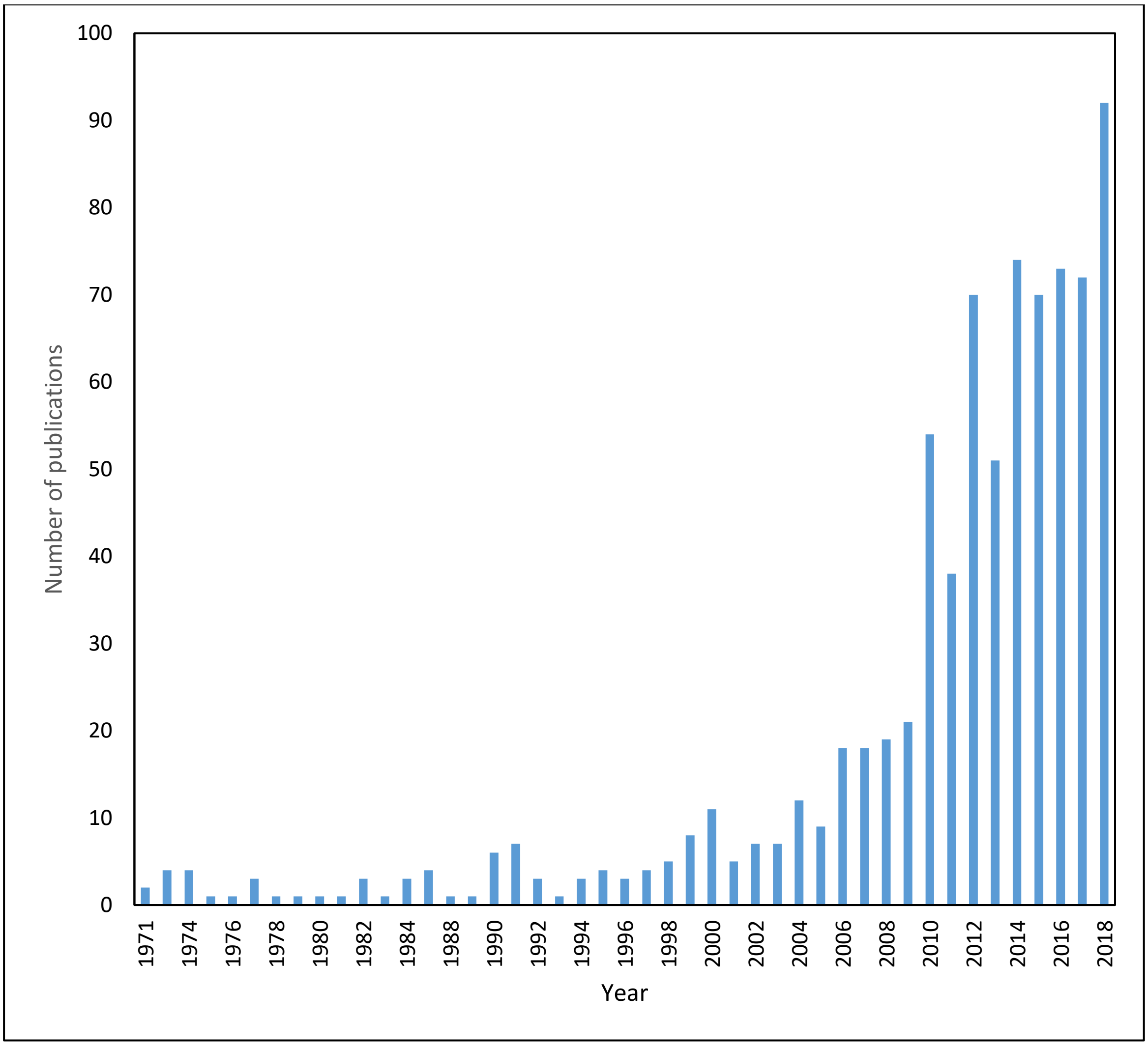


Figure 2.3: Growth of publications on ergonomic issues in India *(Source: Scopus)*

Most of the high–income and middle–income countries (i.e., United States, Germany, Canada, Sweden, Japan, Italy, India, etc.) emphasize on ergonomic research to enhance the comfort, safety and health of workers.

A comparative view of research publications in various countries on ergonomic issues is depicted in Figure 2.4. It can be observed that India is far behind developed countries like US, Germany, Canada, etc. as far as publications in this field are concerned. Hence, research in this field requires urgent attention.

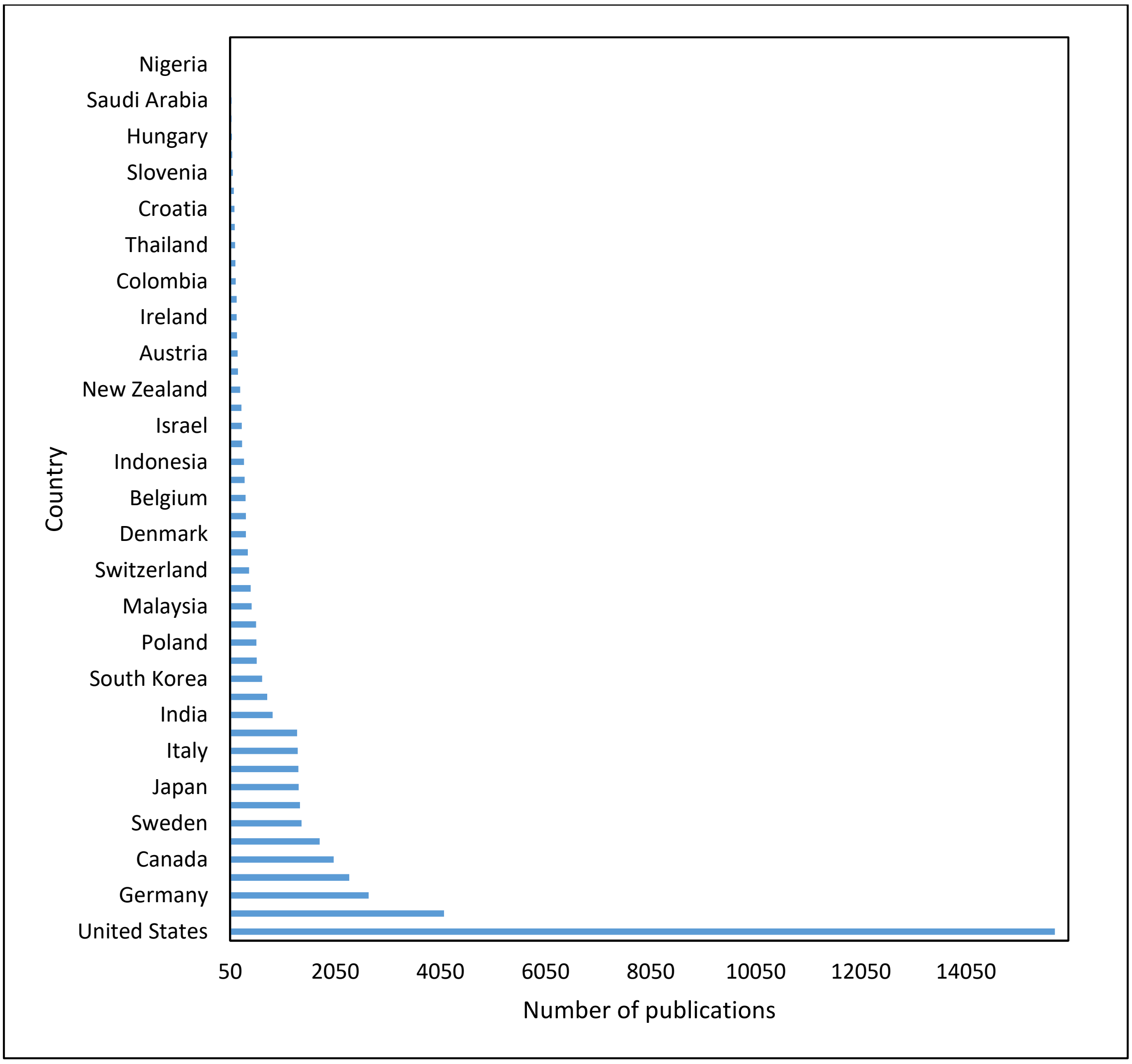


Figure 2.4: Country-wise research publications on ergonomic issues *(Source: Scopus)*

Figure 2.5 shows worldwide publication of research articles on ergonomics in various journals subject–wise. The pie chart shows that the majority of articles are published in journals related to “social sciences”, “engineering” and “medical, nursing and health”. Some work has also been reported in psychology and neuroscience related journals.

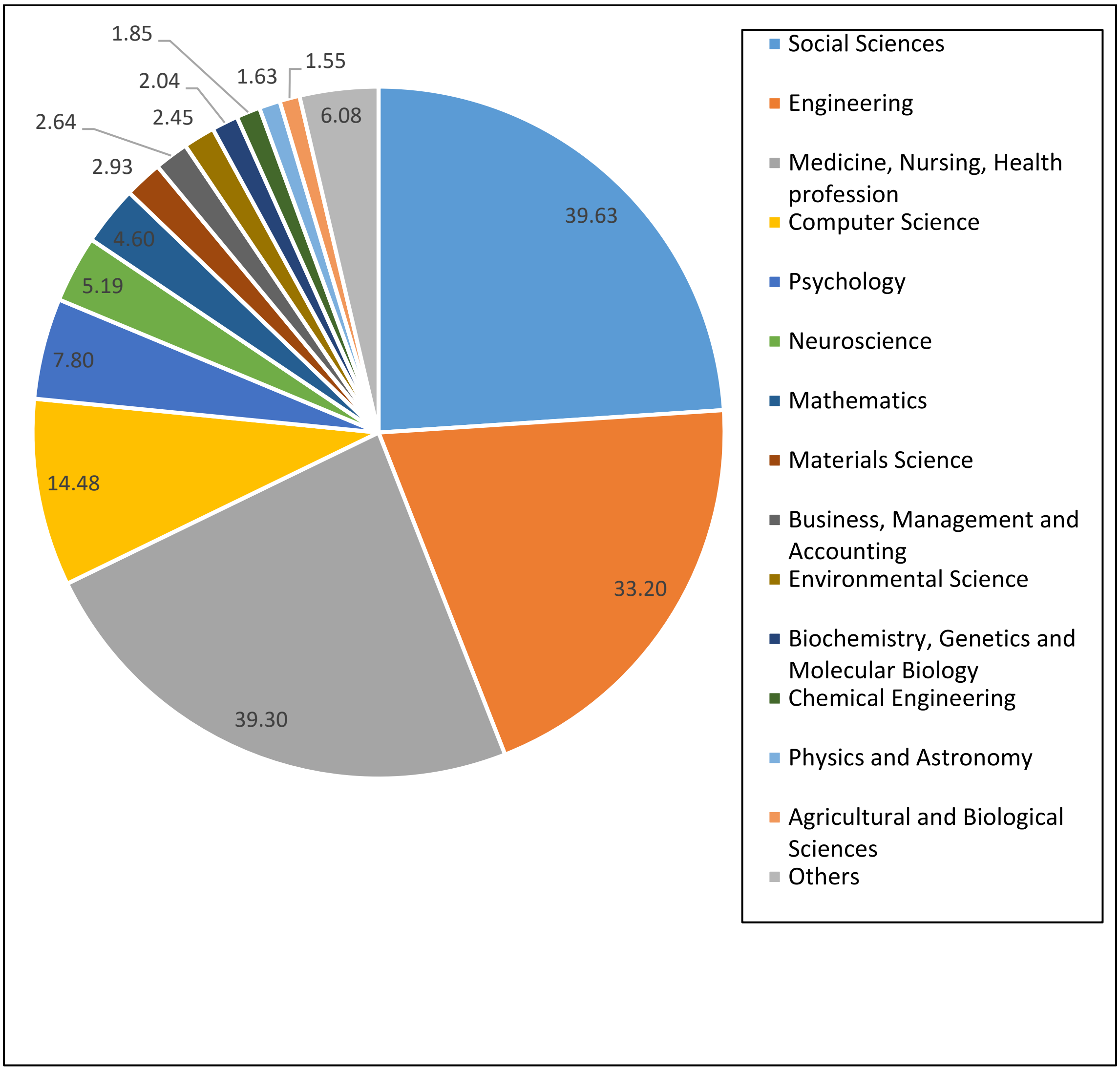


Figure 2.5: Subject–wise worldwide publications on ergonomics *(Source: Scopus)*

Ergonomic studies can broadly be categorised in three domains, namely physical ergonomics, organizational ergonomics and cognitive ergonomics as shown in Figure 2.6. Physical ergonomics deals with the physical load on the human body when performing activities like work, sports, jobs at home or dealing with products. Heavy, repetitive, static and sedentary work are four major types of physical loads. Cognitive ergonomics is the discipline that deals with making human–system interactions compatible with human cognitive abilities and limitations, particularly at work. Cognitive ergonomics applies the knowledge emerging from cognitive sciences on mental processes such as perception, attention, memory, decision making, and learning.

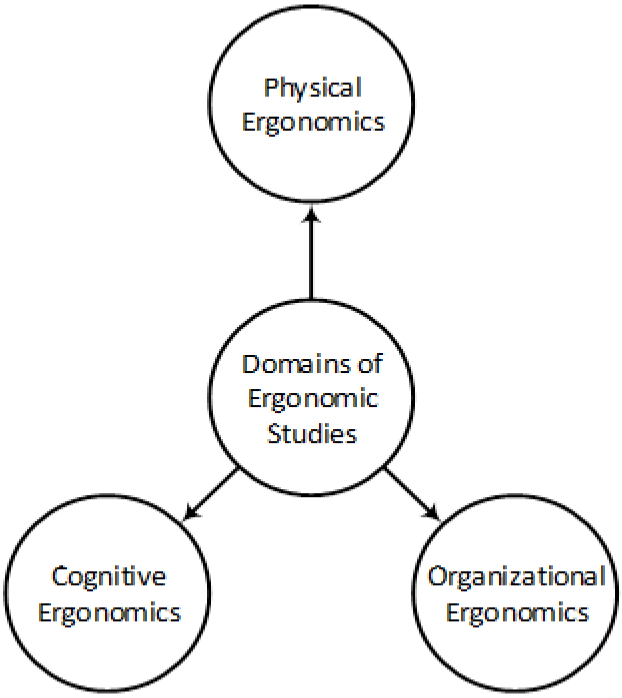


Figure 2.6: Types of ergonomic studies

Organizational ergonomics deals with the optimization of social–technical systems, including their organizational structures, policies and processes. The relevant topics include communications, management of resources, work projects, temporal organization of work, team work, participative project, new work paradigms, cooperative work, organizational culture, network organizations and quality management (IEA, 2000).

2.2 Musculoskeletal issues

Musculoskeletal issues are injuries, discomfort and pain that affect the musculoskeletal system (i.e., muscles, tendons, ligaments, nerves, discs, blood vessels, etc.) of the human body. These issues develop over time as chronic diseases called musculoskeletal disorders (MSDs). Pain, numbness, tingling, difficulty in moving, muscle loss, cramping, paralysis, inflammation and redness in eyes, etc. are the symptoms of musculoskeletal problems. Work–related musculoskeletal problems are the most significant difficulties found in various sectors worldwide. These musculoskeletal issues are leading causes of dissatisfaction among workers (Jain et al., 2017; Sain and Meena, 2016; Punnett and Wegman, 2004). Musculoskeletal and other occupational health issues result in increased absenteeism, lost working time, adverse effects on labour relations, increased probability of accidents and errors, job transfers, higher turnover of workers, decreased productivity, low–quality of work and high administrative and personnel costs (Cardinali, 1998; Miller, 1995; Niu, 2010; Widanarko et al., 2012). The financial damage caused by these problems affects the overall harmony of individual work as well as companies and society on the whole too.

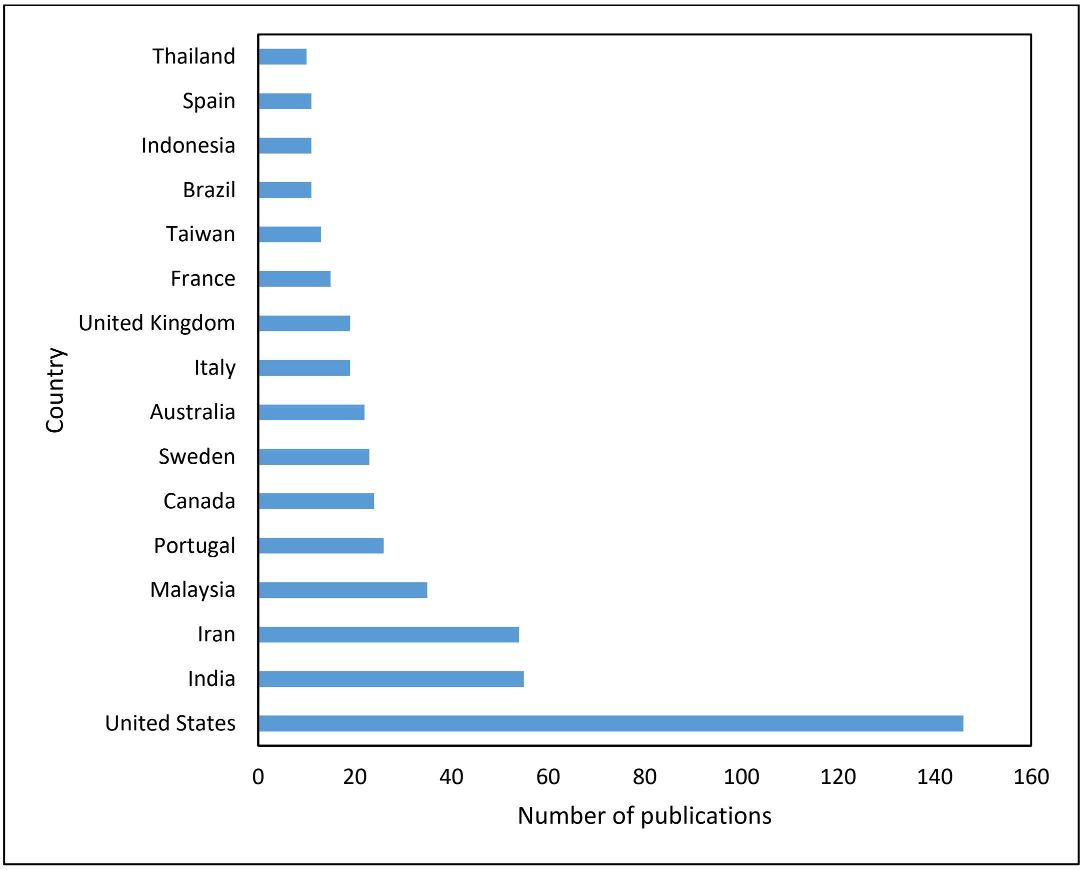


Figure 2.7: Country–wise publications on musculoskeletal issues *(Source: Scopus)*

As mentioned earlier, the wellbeing of workers has emerged as a crucial issue in most of the developed and developing countries. This is evident from the significant number of research articles on musculoskeletal issues that have been published over the years. The statistics of these publications are shown in Figure 2.7. In most of the organised sectors, safety at work and workers' comfort are considered as important factors in improving the productivity and quality of products. Long back, Bernardo Ramazzini (1633–1714), an Italian physician and a pioneer in the field of occupational–health, advocated that poor working conditions are responsible for numerous risk factors of MSDs (Najarkola, 2005). The intensity of risk changes according to the period a worker is subjected to risk factors, the incidence to which they are subjected, and the level of the risk.

Musculoskeletal issues can be minimized by ergonomic interventions which will create better quality of life for workers and reduce the tremendous financial losses and medical costs. (Roper and Yeh, 2007; Ahasan and Imbeau, 2003). The musculoskeletal issues can be minimised by reducing the biomechanical and psychosocial load and proper work system design (Ahasan and Imbeau, 2003; Niu, 2010; Roper and Yeh, 2007; Shariat et al. 2017). Healthy workers can be nearly three times more productive than those in poor health (Niu, 2010). In labour–intensive industries, salary paid to workers is likely to be more than 70 percent of the total expenditure. This can be considered as an investment with the underlying assumption that the workers perform with full efficiency. This requires the workers to be in the best of their health with no degradation arising due to work–related factors including body harm (Miller 1995). This can be achieved by ergonomic interventions. Moreover, many researchers have reported productivity enhancement and cost benefits as the result of ergonomic interventions. Govindraju et al. (2001) reported 23% increment in operator's productivity and 19% reduction in injuries as the result of improved workplace illumination in circuit board manufacturing companies. In another case study of a plant making flashlights and lanterns, significant reduction in rejection rate and almost a 50% increase in output were achieved after ergonomic interventions.

According to Megeid et al. (2011), the garment industry in Egypt suffers from poor performance of workers, as a result of inappropriate design of workplace. Yeow and Sen (2006) studied manual component insertion lines in a printed circuit assembly factory, and found that there was an improvement of 50.1% in labor productivity with the application of ergonomic principles. Also, there was a 59.8 percent increment in the total revenue in the MCI lines. Guimarães et al. (2012) conducted ergonomic intervention in a Brazilian footwear company and found that the pilot line productivity increased by 3%, and rework was reduced by 85%. The cost of the intervention was US $ 70,132 while annual savings were US $ 503,479. Tompa et al. (2012) performed economic analysis of a participatory ergonomics process at a clothing manufacturer in South–western Ontario, Canada and found that the benefit–to–cost ratio was 5.5.

Lahiri et al. (2005) performed net–cost estimation for wood processing and found that after applying appropriate ergonomic interventions, productivity was increased by 10 percent with a benefit to cost ratio of 84.9.

2.3 Assessment methods for musculoskeletal risks

As mentioned earlier ergonomic interventions are important in reducing various musculoskeletal issues, hence, the risk factors for musculoskeletal problems must be identified and assessed at workplace. The musculoskeletal risk factor assessment methods can be divided into three categories: (i) subjective judgment through questionnaire survey or personal interview; (ii) observational methods or posture assessment methods; (iii) and measurement of biomechanical (i.e., grip strength, pinch force, etc.) or physiological parameters (heartbeat, oxygen consumption, etc.). Direct measurement methods are more precise and reliable; however, these methods need large investment and proper training. Direct observation methods are among the most commonly used techniques by researchers and practitioners. These methods are easier to use, less costly and more flexible when it comes to collecting field data (Chiasson et al., 2012; David, 2005). The number of posture assessment techniques has increased rapidly in recent years, and a variety of assessment methods are available in the literature.

2.3.1 Quick exposure check (QEC)

The quick exposure check (QEC) is a posture assessment technique developed by David et al. (2003) and again modified by David et al. (2008). This method combines the observer’s assessment with the worker’s response to closed questions. QEC assesses musculoskeletal risk for back, arms, neck and upper extremities during the work. In addition to a grand score for the whole body, this method also gives a risk index for each targeted body part (back, shoulders, arms, wrist–hand and neck). The assessment includes working postures, frequency of movement, force, exposure to vibration, shift duration as well as psychosocial risk factors. In this method, assessment may be biased due to the inclusion of worker’s perception. However, this method can be used only for upper extremities.

2.3.2 Finnish institute of occupational health (FIOH) method

FIOH is the ergonomic workplace analysis method, developed by the Finnish Institute of Occupational Health (Ahonen et al., 1989). This method provides an ergonomic investigation on 14 attributes viz. workstation design, physical workload, lifting, work posture and movements of multiple body parts, accidental risk, task content, task restrictions, inter–personal contact and communication, decision–making, worker’s attention, repetitiveness, lighting, thermal environment and noise. The observer allots each item a score on a scale of either four or five levels. Each level relates to a detailed condition described by the method. For example, a score of 5 indicates a severe risk to the worker’s health, while a score of 1 indicates no risk condition.

2.3.3 Occupational repetitive actions (OCRA)

The occupational repetitive actions (OCRA) is an index that describes the risk factors of repetitive tasks at work (Colombini, 1998; Occhipinti, 1998). This index is calculated by obtaining the ratio of actual technical actions (ATA) of the task to be analysed, to the reference technical actions (RTA). The RTA value is obtained by taking into account the frequency of movements, use of force, type of posture, recovery period distribution and additional factors like vibration and localized tissue compression. The OCRA method provides two separate indices for left and right shoulders and elbow/wrist/hand. This method is good for initial screening due to its capability of rapid use. However, consideration of worker’s perception in this method may result in bias.

2.3.4 Job strain index (JSI)

The job strain index (JSI) was developed by Garg and Moore (1995) as a means to assess jobs for risk of musculoskeletal symptoms of the distal upper extremities (i.e., hand, wrist and elbow). It provides an index that includes the level of perceived exertion, percentage effort duration out of total cycle time, frequency of efforts, hand and wrist posture, work speed and shift duration. This method is useful for identifying the root causes of the most severe risk factors and the tasks that are most difficult for the worker. JSI offers a basis for exploring work place strengths and weaknesses along with workers. This method is suitable for assessing work with short cycle time. However, it is difficult to assess the precise posture categories by this method.

2.3.5 Hand activity level (HAL)

HAL was developed by American Conference of Governmental Industrial Hygienists (ACGIH), 2002. This technique has three levels of risk. The risk level is obtained by the normalized peak force (NPF)/HAL ratio. If the ratio is lower than the action limit (AL), the risk is acceptable; whereas if the score exceeds the threshold limit value, the risk is not acceptable. In this method, the perception of workers is taken into account for risk assessment, which may result in bias.

2.3.6 Rapid upper limb assessment method (RULA)

The RULA was developed by McAtamney and Nigle Corlett, (1993). This method provides an overall score taking into account postural loading on the whole body with particular attention to the upper limb (i.e., neck, trunk, shoulders, arms and wrists). The overall score also takes into account the duration for which the posture is held, the force used, and the repetitiveness of the movement. This method can be used for work profiles composed of several different tasks. However, it does not give a separate score for different body parts, and the observer plays an important role in the selection of tasks to assess if the work is variable.

2.3.7 Rapid entire body assessment method (REBA)

The (REBA) method (Hignett and McAtamney, 2000) provides an overall risk score considering all the body parts (i.e., trunk, legs, neck, shoulders, arms and wrists). The overall score takes into consideration the same additional factors as RULA as well as the quality of the hand–coupling. This method takes into account a large number of work characteristics, hence, it cannot be used as a screening tool.

Some other methods have also been developed over the years by various researches. These methods are: Ovako Working Posture Analysis System (OWAS) by Karhu et al. (1981), Loading on the Upper Body Assessment (LUBA) by Kee and Karwowski (2001), Key Item Method (KIM) by Steinberg et al. (2005) and Upper Limb Risk Assessment (ULRA) by Roman–Liu (2007). Comparison among all the postural assessment techniques has shown that there are differences between the methods and it remains difficult to identify the best method for estimating musculoskeletal risks. However, the RULA and REBA methods seem to be most appropriate in analysing brick making tasks, as these methods consider most of the characteristics of the work.

2.4 Anthropometry

Human beings perform their regular tasks with the help of a variety of equipment and hand tools. Such tools should be compatible with the physical dimensions, mobility and strength of the workers. Mismatches between human characteristics and equipment dimensions are known to be contributing factors in low productivity, discomfort, accidents, fatigue, injuries, and MSDs. The use of hand tools that fit workers' characteristics is crucial for task productivity and prevention of MSDs. Anthropometry is the science that deals with the measurement of various human characteristics such as size, movement of body parts and strength. The anthropometric data is used to design hand tools, equipment, workplace, and clothing to improve the productivity, safety, and comfort as well as in reducing occupational health issues of the workers. Anthropometric data vary considerably with factors such as gender, race, age and work culture. The application of anthropometric data, therefore, depends on the anticipated user population.

2.4.1 Availability of anthropometric data

In developed countries like USA, UK, France, etc., a large amount of anthropometric data is collected by various agencies and is available for reference. The anthropometric data collected and maintained by the Aerospace Medical Research Laboratories, Dayton, Ohio (USA) is the biggest single repository of its kind in the world. It contains data on US army and air force personnel as well as civilians. Some data for foreign populations are also available in the NASA data bank. ERGODATA is another data bank located at anthropology laboratory of Paris, University of France. It mostly contains European anthropometric data. Journal publications in the field of anthropometry are limited to India as shown in Figure 2.8. Although, some government agencies in India have worked in this field, but the studies were limited to measurement of very few body parameters.

In India, the anthropological survey of India has been involved in anthropometric data collection since 1945. The main aim of these surveys has been to collect data on morphological characteristics of various population groups for anthropological studies. A pan India anthropometric survey was initiated by Archaeological Survey of India (ASI) in 1961 and continued till 1969. During this period, data on 60,000 male participants of about 300 different castes/tribes/communities throughout the country were collected. The body dimensions in this survey included stature, sitting height, weight and few other dimensions.

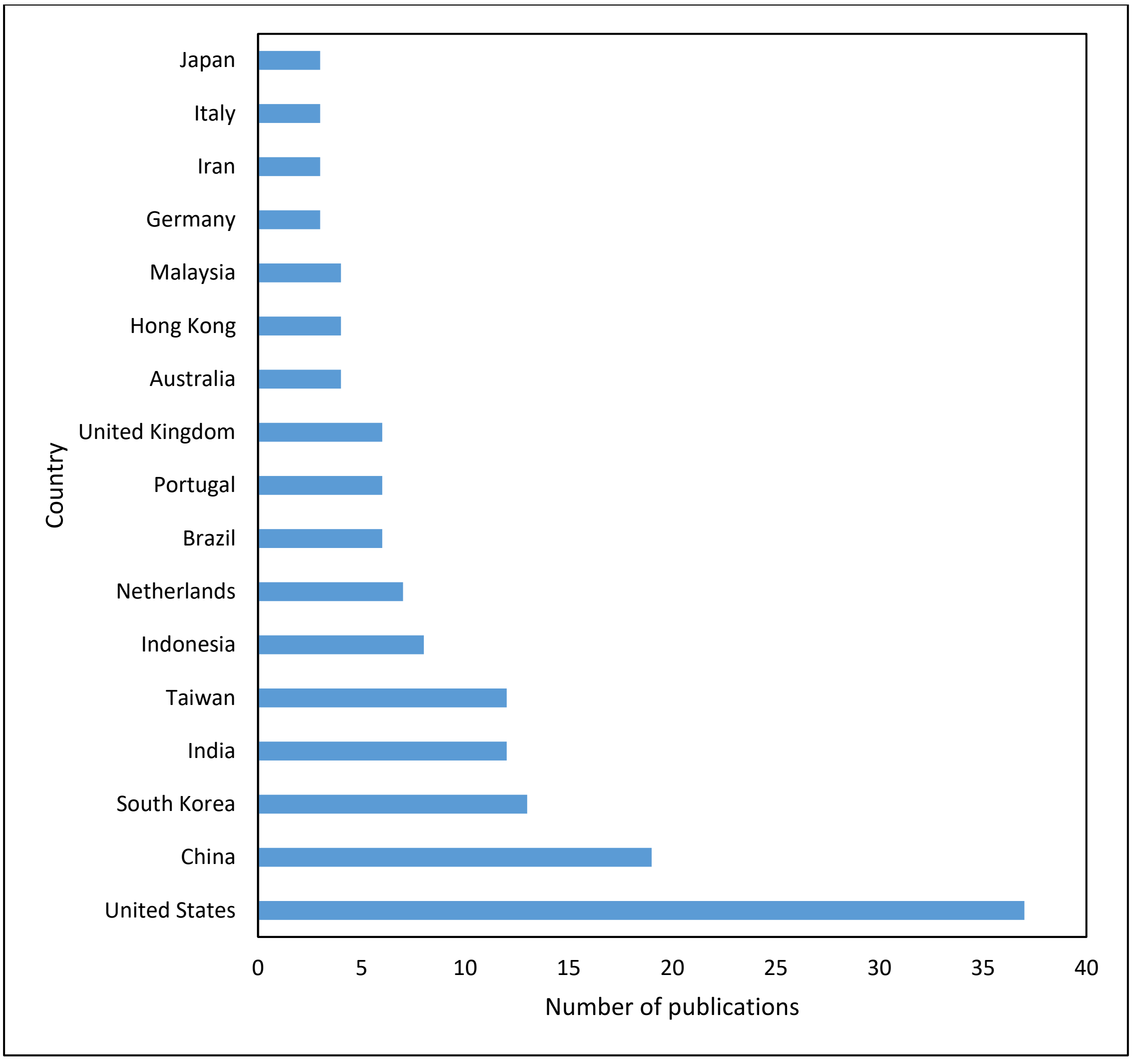


Figure 2.8: Research publications on anthropometry in various countries

(Source: Scopus)

During 1972–1980, an All India Bio–Anthropological survey was carried out by ASI to get baseline information of Indian population in terms of their body, disabilities, diseases, abnormalities, demography and food habits. However, only three body dimensions i.e., stature, weight and chest circumference were included in this survey. About 35,000 participants were covered from 351 locations across the country. Under the eighth five–year plan (1992–1997) of Government of India, the ASI undertook anthropological survey on Indian women. The survey work has been completed in nine states and is still under progress for the rest of the states. Some anthropometric data are available at Defence Institute of Physiology and Allied Sciences, Delhi. However, these data are on personnel from armed forces and dimensions covered are few. Recently, National Institute of Design, Ahmedabad has published a monogram on anthropometric data of Indians. They have given data on 1,000 participants from all over the country.

However, most of the participants here are from student communities or other occupational groups. There are very few studies available on anthropometric data on Indian workers, and most of the studies belong to the agriculture sector only (Pandey, 1970; Sen et al., 1977; Gupta et al., 1983; Gite and Yadav, 1989; Gite, 1996; Yadav et al., 1997).

A study was conducted by Dewangan et al. (2005) to collect the anthropometric measurements of male farm workers aged between 20 to 30 years in the north–eastern region of India. Thirty–three body dimensions of 280 farmers from seven states were measured. The study revealed that the farm youth from north–eastern India had significantly lower values of body measurements compared to other regions except southern and eastern regions of India. It was also found that all the anthropometric dimensions were lower than those from China, Japan, Taiwan, Korea, Germany, Britain and the USA.

An anthropometric study was carried out by Dewangan et al. (2008) among female agriculture workers from three tribes of two north–eastern Indian states, Arunachal Pradesh and Mizoram. The study was conducted among 400 subjects for the measurement of 76 body dimensions. The study revealed that values of body dimensions of tribal female agricultural workers from these states of India were lesser than those of American, British, Chinese, Egyptian, Japanese, Korean, Mexican and Taiwanese female workers.

Dewangan and Datta (2010) conducted a study on 801 male agricultural workers from four major and fourteen minor tribes of north–eastern (NE) region of India. They measured a set of 76 body dimensions including age and body weight. The mean stature of the total population was found to be 162 cm and body weight was 56.1 kg. A significant difference in most of the body dimensions was found among workers from four major tribes. The study proved that the anthropometry also depends on the race.

The literature shows that most of the work in the field of anthropometry in the Indian context has been carried out in the agriculture sector (mostly for north–eastern regions). To design hand tools for brick kiln worker belonging to Rajasthan state, the desired hand anthropometric data is not readily available in the literature. The major factors to take into account while designing a hand tool would be age, race, gender and occupation. As there is a large difference among the body dimensions, it is not economical or sometimes practically feasible to design hand tools and workplaces to suit all the users. Therefore, generally, the design is made to satisfy the majority of the users. This can be achieved through the use of 5th percentile and 95th percentile values of dimensions. The users who fall outside these limits will obviously find the designed hand tools incompatible for use.

2.5 Ergonomic Interventions

It might be in the economic interest of management to take a more active role to prevent musculoskeletal issues and other occupational health problems among workers involved in manual activities by using ergonomic interventions. Ergonomic interventions refer to the manipulation of the tools, techniques and processes using ergonomic principles that will reduce exposure to physical hazards. It also focuses on workers' training and use of personal protective equipment for safety and hygiene. Ergonomic interventions improve the occupational health of the workers, so they can work safely for a longer period (Gangopadhyay et al., 2014; Bandyopadhyay and Sen, 2016). Design teams can play an important role for meeting ergonomic goals jointly with productivity goals (Neumann et al., 2006). In order to reduce musculoskeletal issues and symptoms, many interventions are used. According to work reported by various researchers, ergonomic interventions can be categorized as follows:

i. Work place improvements
ii. Hand tool improvements
iii. Workers' and managers' training
iv. Physical exercise
v. Design and use of personal protection, etc.

A number of researchers have worked on workplace improvements through redesign (Choobineh et al., 2007; Ikhar and Deshpande, 2011; Mahmoud et al.,2004; Megeid et al., 2011; Wani et al., 2012) and improvement of ambience (Al–Yassen, 2009; Ali et al., 2013; Jones and Kumar, 2010; Wang and Lin, 2011) to enhance the workers' health and comfort. Some other studies (Dianat et al., 2015; Jain et al., 2018; Khidiya and Bhardwaj, 2012) have reported interventions related to hand tool improvement to target musculoskeletal health. Training of workers and managers is also reported (Mirmohammadi et al., 2012; Bau et al., 2012) as an effective intervention towards the wellbeing of workers. Workplace exercises are also reported to be effective in reducing

MSDs among workers (Andersen et al., 2008a; 2008b; Jakobsen et al., 2015; Shariat et al., 2018). Use of personal protection aids is also reported as an important intervention by researchers (Nazari et al., 2012; Nag et al., 2010). Table 2.1 summarizes the occupational health problems studied in various industries and their proposed solutions.

2.6 Ergonomic design of hand tools

Hand tools have been in use for thousands of years. Even prehistoric man made use of hand tools in some way or the other (Fraser, 1980). As the demands of human beings grew in number, hand tools have been improved or created with the assistance of evolving technology. Hand tools, with a slight modification in terms of external design and materials, are still being used in our daily lives and industrial jobs.

Working with un–ergonomically designed hand tools induces work stress on upper extremities such as the elbows, wrists, palms, and fingers. These problems in turn, give rise to a variety of issues such as cumulative trauma disorders, reducing productivity, and disabling of individuals (Aghazadeh and Mital, 1987; Cederqvit and Lindberg, 1993; Freivalds, 1996).

According to surveys from the bureau of labour standards (BLS, 2014) hand tools have been involved in 4.6% of occupational injuries and illnesses in the US. Over the past four decades, proper design, evaluation, selection, and use of hand tools have been a major ergonomic concern.

Basic ergonomic design principles and recommendations involved in tool design, ergonomic evaluation process for tools, checklists for ergonomic evaluation, and attributes desirable for specific hand tools have been extensively developed by numerous ergonomists (Mital and Kilbom, 1992a; 1992b; Dababneh et al., 2004). While the role of ergonomists in the course of product design is mainly focused on ergonomics as a scientific system; it has yielded remarkable benefits to users of products in terms of safety, comfort, productivity, and ease–of–use (Wickens et al., 1998).

Table 2.1: Occupational health problems in various SSIs and their solutions

Reference	**Industry**	**Occupational health problem**	**Ergonomic intervention**
Choobineh et al., 2007; Wani et al., 2012; Pandit et al., 2013; Meena et al., 2012; Nazari et al., 2012; Nag et al., 2010	Carpet, Handicraft and Handloom	MSDs, respiratory disorders, eyesight problems, and skin problems	Adjustable vertical seat and weaving heights ,use of protecting equipment e.g. face masks, first aid facility, gloves and proper uniform
Ikhar and Deshpande, 2011; Mahmoud et al.,2004	Cotton spinning	MSDs like low back pain, neck pain and knee pain, eye and ear diseases	Improved working posture by developing a new workstation
Wang and Lin, 2011; Al–Yassen, 2009; Moghaddasi et al., 2014; Jekayinfa, 2008	Food and bakery industry	MSD in the ankle, wrist, neck and shoulder respiratory, allergic like asthma and pulmonary disease	Improved ventilation, air flow, and number of inlets and outlets and using ergonomically designed tools.
Megeid et al., 2011; Sarder et al.,2006; Parimalam et al., 2006	Garment industry	Back pain ,neck pain , shoulder pain, wrist pains , other pains in the upper body, visual discomforts and dehydration	Proposed use of backrests, floor mats for standing tasks (e.g. cutting), tilting the worktables, training programs with work safety awareness.
Guimarães et al., 2012; Roquelaure et al., 2001	Footwear industry	MSDs, eye strain and noise–related problems	Proposed replacement and maintenance of machines to reduce noise and work postures improvement and use of sit–stand seats to reduce MSDs.
Ali et al., 2013; Jones and Kumar, 2010	Saw Mills	Respiratory, allergic like asthma, overexertion , MSDs and organ loss due to accidents	Proposed proper ventilation and safety equipment use.

The articles on hand tool improvements in different sectors reported by various researchers from different countries are shown in Table 2.2.

Majority of hand tool improvements have taken place in the manufacturing and agriculture sectors. However, construction, fishing, food processing, food services, forestry, furniture, health, construction, process and services sector have also been reported in the literature.

Decreasing musculoskeletal risks and tool related problems, and improving productivity & performance are the reasons that have motivated most of the hand tool improvement studies. Reducing musculoskeletal issues and MSDs, including problems of carpal tunnel disorders (CTDs), upper extremities and ulnar deviation were the most frequently reported reasons for the initiation of hand tool improvement. Many researchers also reported various tool related problems as a cause for initiation of development which includes issues in grip, length, diameter, height, handle orientation and material properties. Productivity and performance issues including those related to efficiency, satisfaction and comfort were also reported as major issues for initiation of hand tool design studies.

Table 2.2: Country–wise and sector wise ergonomic studies on hand tool design

Sector	**Country**	**Task**	**Reference**
Agriculture	Brazil	Sugarcane harvesting	Abrahao et al., 2012
	India	Harvesting	Nag et al., 1988; Gite, 1991; Mehta et al., 2012
		Land preparation	Borah and Kalita, 2012; Khidiya and Bhardwaj, 2012; Kishtwaria and Rana, 2012
	Indonesia	Harvesting	Sutjana, 2000
	South Africa	Land preparation	Vanderwal et al., 2011
	Thailand	Rice harvesting	Swangnetr et al., 2014
Food Services	Taiwan	Food–serving in the restaurants	Hsu and Wu, 1991; Chan, 1999;
		Food cooking	Wu and Hsieh, 2002
	USA	Ice cream serving	Dempsey et al., 2000

Sector	**Country**	**Task**	**Reference**
Food Processing	European countries	Vegetable cutting	Marsot, 2005
	England	Meat cutting operations	McGorry, 2001
	India	Fish Processing	Nag and Nag, 2007
	New Zealand	Meat cutting operations	McGorry et al., 2003
	USA	Poultry and meat processing operations	Szabo et al., 2001
		Meat packing	Cochran and Wiley, 1985; Dempsey and McGorry, 2004
Forestry	USA	Gardening	Fellows and Freivalds, 1991; Chang et al., 1999
		Cutting and pruning	Mirka et al., 2009
	South Africa	Slicing and Chipping root and tuber crops.	McNeill and Westby, 1999
	Europe	Wood cutting	Paivinen and Heinimaa, 2003
	Finland	Cutting wood	Paivinen and Heinimaa, 2009
Handicraft	USA	Stretching fabric or leather over a wood frame.	Smith et al., 2000
Furniture making	Iran	Furniture making	Nejad et al., 2013
	Sweden	Metal roof cutting	Oster et al., 1994
Construction	Germany	Brickwork or stonework for leveling	Strasser et al., 1996
	Netherlands	Painting	Eikhout et al., 2001
		Installation work in a ceiling	Groenesteijn et al., 2004
	Canada	Painting	Rosati et al., 2014
	Iran	Wall construction	Dianat et al., 2015
Health, Services	Finland	Chemical testing	Sormunen and Nevala, 2013
Health	Japan	Surgical work	Shimomura et al., 2015

Sector	Country	Task	Reference
Manufacturing	Canada	Sawing steel	Das et al., 2005
	Iran	Various industrial processes	Dababneh et al., 2004
		Carpet weaving	Motamedzade et al., 2007
	Netherlands	Maintenance tasks	Kuijt–Evers et al., 2004; Vink and Eijk, 2007
	South Africa	Metal wire–tying	Bridger et al., 1997
	Sweden	Maintenance tasks	Kadefors et al., 1993; Hall, 1997
		Cutting the plates	Kilbom et al., 1993
	Taiwan	Filing operations	Hsu and Wu, 1999
		Wire–tying task	Li, 2002
	USA	Maintenance tasks	Mital, 1986; Mital and Sanghvi, 1986; Mital and Channaveeraiah, 1988; Mital et al., 1994; Habes and Grant, 1997
		Wire cutting	Leamon and Dempsey,1995
		Wire twisting task	Dempsey et al., 2002
		Railway works (Spike–mauling)	Marras and Rockwell, 1986
		Clamping	Jung and Hallbeck, 2005
		Metal cutting	You et al., 2005
		Machining work	Dempsey et al., 2004
		Sheet metal operation	Anton et al., 2007
	West Indies	Industrial operations	Lewis and Narayan, 1993
Process	Nigeria	Tailoring work	Adeleye and Akanbi, 2015
Service	USA	Hair dressing	Boyles et al., 2003

2.6.1 Hand tool improvement studies

Numerous hand tool improvement design studies have been conducted to increase the workers' comfort in various manual tasks. Important hand tool design studies for different tasks that have been conducted in the past are presented in Table 2.3. The maximum number of studies were reported for specialized scissors which include nippers, pruning and plate shear, shear tools, trimming tools and snip tools. Studies for screwdrivers and various types of knives that include blade knife, razor knife, carpet knife, stationery knife were also reported in large numbers. Some studies were also reported for other hand tools like shovel, wrench, handsaw, hoes, scissors, trowel, sickle, chisel, hammer, rake, axe, chopstick, scrapper and animal–drawn mould board plough. However, studies related to tools like scooping tool, spike maul, pipettes, clamping tool, hacksaw, weaving comb and file were limited.

Table 2.3: Different types of hand tool improvement studies

Reference	Hand tool	Application
Fellows and Freivalds, 1991; Kilbom et al., 1993; Lewis and Narayan, 1993; Oster et al., 1994; Leamon and Dempsey,1995; Hall, 1997;Dempsey et al., 2002; Li, 2002; Dababneh et al., 2004; Groenesteijn et al., 2004; Kuijt–Evers et al.,2004; You et al., 2005; Anton et al., 2007; Motamedzade et al., 2007	Specialized Scissors (Nippers, Pruning and Plate sear, Shear tool, trimming tool, Snip)	Used for trimming, cutting, harvesting etc.
Mital, 1986; Mital and Sanghvi, 1986; Mital and Channaveeraiah, 1988; Kadefors et al., 1993; Mital et al., 1994; Habes and Grant, 1997; Hall, 1997; Dababneh et al., 2004; Dempsey et al., 2004; Kuijt–Evers et al.,2004; Vink and van Eijk, 2007	Screwdriver	Used for turning (driving or removing) screws.
Cochran and Wiley, 1986; McGorry, 2001; Szabo et al., 2001; McGorry et al., 2003; Dababneh et al., 2004; Dempsey and	Knife (blade knife, razor knife, carpet knife, pen knife, stationery knife)	Some of these names refer to a different kind of knife operations depending on the

Reference	**Hand tool**	**Application**
McGorry, 2004; Marsot, 2005; Nag and Nag, 2007; Motamedzade et al., 2007		sector and all used for cutting.
Fellows and Freivalds, 1991; Bridger et al., 1997; Chang et al., 1999; Wu and Hsieh, 2002	Shovel	Used for various operations like digging, lifting, and moving bulk materials.
Mital, 1986; Mital and Sanghvi, 1986; Mital and Channaveeraiah, 1988; Mital et al., 1994	Wrench	Used to turn objects usually rotary fasteners, such as nuts and bolts or keep them from turning.
Dababneh et al., 2004; Mirka et al., 2009; Nejad et al., 2013	Handsaw	Used for trimming, cutting wood and various furniture operations
Fellows and Freivalds, 1991; Chang et al., 1999; Vanderwal et al., 2011	Hoes	Used in farming to prepare the soil, control weeds, clear soil, and harvest crops. It is also used to mix things like concrete and digging holes.
Boyles et al., 2003; Adeleye and Akanbi, 2015; Shimomura et al., 2015	Scissor	Used to cut several thin materials, such as paper, cardboard, metal foil, thin plastic, cloth, rope, and wire, and also used to cut hair.
Strasser et al., 1996; Khidiya and Bhardwaj, 2012; Dianat et al., 2015	Trowel	Used for breaking up clay, digging small holes, especially for planting and weeding, mixing in fertilizer or other additives, and transferring plants to pots.
Nag et al., 1988; Sutjana, 2000; Mehta et al., 2012	Sickle	Used for harvesting grain crops or cutting succulent forage primarily for feeding livestock

Reference	**Hand tool**	**Application**
Lewis and Narayan, 1993; Nejad et al., 2013	Chisel	Used to force the blade into some material to cut it.
Dababneh et al., 2004; Nejad et al., 2013	Hammer	Commonly used for drive nails, fit parts, forge metal, and break apart objects.
Fellows and Freivalds, 1991; Chang et al., 1999	Rake	Used to collect leaves, hay, grass, etc., and, in gardening, for loosening the soil, light weeding and leveling.
Paivinen and Heinimaa, 2003; Paivinen and Heinimaa, 2009	Axe	Used for split and cut wood; to harvest timber.
Hsu and Wu, 1991; Chan, 1999	Chopstick	Used to pick up pieces of food.
Eikhout et al., 2001; Rosati et al., 2014	Scrapper	Used for removing old paint on a wood surface or removing roughness from walls.
Gite, 1991; Kishtwaria and Rana, 2012	Animal–drawn mould board plough	In Indian agriculture, it is used for various field operations.
Dempsey et al., 2000	Scooping tool	Used for scooping ice–cream and put it into cup
Marras and Rockwell, 1986	Spike Maul	Used to drive railroad spikes in railroad track work. It is also known as a spiking hammer.
Sormunen and Nevala, 2013	Pipettes	Used in chemistry, biology and medicine to transport a measured volume of liquid
Jung and Hallbeck, 2005	Clamping tool	To hold objects tightly together to prevent movement or separation through the inward pressure.

Reference	Hand tool	Application
Das et al., 2005	Hacksaw	Used for cutting metal.
Motamedzade et al., 2007	Weaving comb	Comb is an instrument to hammering carpet weaving
Hsu and Wu, 1999	File	Used for finishing operation on various metals.

2.6.2 Hand tool design attributes

The design variables for various types of hand tools can be broadly classified into four categories, namely: user variables, product variables, task variables and qualitative variables as shown in Figure 2.9.

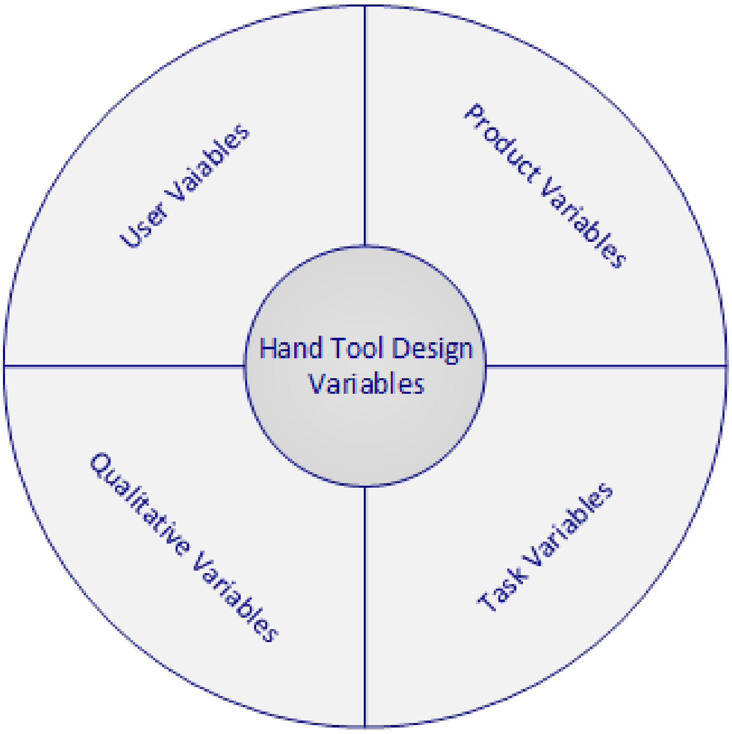


Figure 2.9: Variables considered in hand tool design

The review of literature shows that the product, task and qualitative variables have been received more attention as compared to human variables for ergonomic design of hand tools. Table 2.4 shows the various studies with the hand tool design attributes targeted in research. Muscular effort and other wrist problems were mainly reported measures under the human variables that need to be considered before designing.

Table 2.4: Hand tool design attributes reported in literature

Design attributes	**Criteria**	**Reference**
User variable	Biomechanical stress; muscular load, strain, effort, activity	Nag et al., 1988; Kadefors et al., 1993; Lewis and Narayan, 1993; Oster et al., 1994; Strasser el al., 1996; Bridger et al., 1997; Chang et al., 1999; Li, 2002; Kuijt–Evers et al.,2004; Das et al., 2005; Borah and Kalita, 2012; Khidiya and Bhardwaj, 2012; Sormunen and Nevala, 2013
	Blisters; high force exertions; pressure points; wrist movements	Fellows and Freivalds, 1991; Oster et al., 1994; McGorry, 2001; McGorry et al., 2003; Groenesteijn et al., 2004; Sormunen and Nevala, 2013
	Applied force; torque; pinch force and efficiency	Mital and Channaveeraiah, 1988; Hsu and Wu, 1991; Mital et al., 1994; Hall, 1997; Habes and Grant, 1997; Chan, 1999; Eikhout et al., 2001
	Age, gender, isometric strengths, anthropometric variables	Mital and Sanghvi, 1986; Rosati et al., 2014
Product variable	Tool properties (length, diameter, height, sharpness, weight etc.)	Cochran and Wiley, 1986; Marras and Rockwell, 1986; Mital and Sanghvi, 1986 ; Strasser et al., 1996; Chan, 1999; Dempsey et al., 2000; Sutjana, 2000; McGorry et al., 2003; Dababneh et al., 2004; Dempsey and McGorry, 2004; Hsu and Wu, 1991; Nejad et al., 2013; Sormunen and Nevala, 2013
	Cost and material of tool	Strasser et al., 1996; Chang et al., 1999; Chan, 1999; Szabo et al., 2001; McGorry et al., 2003; Dababneh et al., 2004; You et al., 2005
	Grip properties (gripping capability, size, force, span, length, strength)	Mital and Channaveeraiah, 1988; Gite, 1991; Kadefors et al., 1993; Kilbom et al., 1993; Lewis and Narayan, 1993; Mital et al., 1994; Hall, 1997; Chang et al., 1999; Hsu and Wu, 1999; Dempsey et al., 2000; Smith et al., 2000; Eikhout et al., 2001; Boyles et al., 2003; Dempsey and McGorry, 2004; Dababneh et al., 2004; Kuijt–Evers et al.,2004; Jung and Hallbeck, 2005; You et al., 2005; Motamedzade et al., 2007; Mirka et al., 2009; Khidiya and Bhardwaj, 2012; Swangnetr et al., 2014; Adeleye and Akanbi, 2015; Dianat et al., 2015

Design attributes	Criteria	Reference
	Handle properties (sharp edges, length, weight, cross section, diameter, slipperiness, shape,)	Cochran and Wiley, 1986; Mital and Channaveeraiah, 1988; Gite, 1991; Lewis and Narayan, 1993; Habes and Grant, 1997; Chang et al., 1999; Wu and Hsieh, 2002; Szabo et al., 2001; Dababneh et al., 2004; Dempsey et al., 2004; Kuijt–Evers et al.,2004; Das et al., 2005; Jung and Hallbeck, 2005; You et al., 2005; Motamedzade et al., 2007; Paivinen and Heinimaa, 2009; Vanderwal et al., 2011; Khidiya and Bhardwaj, 2012; Dianat et al., 2015; Shimomura et al., 2015
	Blade properties (coatings, length, height, thickness, stiffness, curvature, sharpness, life, shape, length, diameter, grip, hardness)	Paivinen and Heinimaa, 2003; Marsot, 2005; Paivinen and Heinimaa, 2009; Vanderwal et al., 2011
Task variable	Working posture, awkward wrist postures	Hsu and Wu, 1999; McNeill and Westby, 1999; Eikhout et al., 2001; Wu and Hsieh, 2002; McGorry, 2001; McGorry et al., 2003; Kuijt–Evers et al.,2004; Vink and van Eijk, 2007; Nejad et al., 2013; Swangnetr et al., 2014
	Repetitive motions; wrist and finger strain	Mital and Sanghvi, 1986; Leamon and Dempsey,1995; Smith et al., 2000; Eikhout et al., 2001; Szabo et al., 2001; Boyles et al., 2003; McGorry et al., 2003; Mirka et al., 2009
	Tool opening angle, orientation	Oster et al., 1994; Das et al., 2005; Dababneh et al., 2004; Khidiya and Bhardwaj, 2012
	Working stress or area	Marras and Rockwell, 1986; Dempsey et al., 2000
	Lifting angle, surface angle, work height	Mital and Sanghvi, 1986; Strasser el al., 1996; Wu and Hsieh, 2002; Boyles et al., 2003; Marsot, 2005; You et al., 2005; Anton et al., 2007; Rosati et al., 2014
	Physical workload	Nag et al., 1988; Sutjana, 2000; Eikhout et al., 2001; Borah and Kalita, 2012; Kishtwaria and Rana, 2012
	Cutting velocity	Khidiya and Bhardwaj, 2012

Design attributes	**Criteria**	**Reference**
Qualitative variable	Comfort, discomfort, satisfaction	Gite, 1991; Oster et al., 1994; Bridger et al., 1997; Hall, 1997; Chan, 1999; Dempsey et al., 2002; Groenesteijn et al., 2004; Kuijt–Evers et al.,2004; Das et al., 2005; Jung and Hallbeck, 2005; Marsot, 2005; You et al., 2005; Anton et al., 2007; Motamedzade et al., 2007; Vink and van Eijk, 2007; Paivinen and Heinimaa, 2009; Abrahao et al., 2012; Swangnetr et al., 2014; Dianat et al., 2015
	Functional, fit, usability	Marras and Rockwell, 1986; Mital, 1986; Oster et al., 1994; Chan, 1999; Boyles et al., 2003; Kuijt–Evers et al.,2004; Jung and Hallbeck, 2005; Motamedzade et al., 2007; Sormunen and Nevala, 2013; Dianat et al., 2015
	Boredom, fatigue, rest	Kilbom et al., 1993; Oster et al., 1994; Bridger et al., 1997; Hsu and Wu, 1999; Smith et al., 2000; McGorry, 2001; Nag and Nag, 2007; Khidiya and Bhardwaj, 2012; Nejad et al., 2013
	Efficiency, performance, productivity	Mital, 1986; Kilbom et al., 1993; Hsu and Wu, 1999; McNeill and Westby, 1999; Dempsey et al., 2000; Sutjana, 2000; Dempsey et al., 2004; Paivinen and Heinimaa, 2009; Abrahao et al., 2012; Khidiya and Bhardwaj, 2012; Kishtwaria and Rana, 2012; Mehta et al., 2012; Adeleye and Akanbi, 2015
	Incentive, income, maintenance, training, working hour	Nag and Nag, 2007; Mehta et al., 2012; Adeleye and Akanbi, 2015
	Vibration	Mital et al., 1994; Smith et al., 2000; McGorry, 2001; Mirka et al., 2009; Nejad et al., 2013
	Climate, noise, illumination	Nejad et al., 2013
	Tactile feel, ease in use	Mital, 1986; Strasser el al., 1996; Chang et al., 1999; Eikhout et al., 2001; Dempsey et al., 2002; Li, 2002; Kuijt–Evers et al.,2004
	Workload	Chang et al., 1999
	Appearance, colour, dullness	Szabo et al., 2001; Dababneh et al., 2004; Kuijt–Evers et al.,2004; Jung and Hallbeck, 2005

Although anthropometric variables play an important role in hand tool design, very few articles reported these as important criteria. However, many articles have used anthropometric data for hand tool design to some extent.

For hand tools, grip, handle and blade properties play an important role in design. This is apparent from the fact that these were the most reported attributes under the product variable. On the other hand, cost and material criteria have been reported in a lesser number of articles, showing lesser importance of these criteria compared to other relevant criteria. Working posture and way of tool handling are the maximum reported measures under the task variable.

It shows that workers were not aware of the proper use of hand tools, so there was a need for training of employees and monitoring of tasks for safe and proper use of hand tools. Qualitative variables have also been reported in many articles indicating their relative importance. Comfort, discomfort, satisfaction, functionality, ease of use, fatigue, performance, training, incentive and maintenance are the maximum reported criteria under the qualitative variable. Some more variables in this category like vibration, workload, climate, noise and illumination were reported in lesser numbers.

2.7 Ergonomic studies in brick kiln industry

As mentioned in previous sections, the clay brick industry in India is very large in terms of production labour and number of brick units. Regardless of its importance, the clay brick industry is traditional and still unorganized in India. The clay brick manufacturing includes a number of repetitive manual tasks continuously performed in awkward postures with traditional ways and hand tools (Das, 2014; Trevelyan and Haslam, 2001). In Indian unorganised sector, most of the research work related to occupational health and ergonomic intervention has been carried out in the agriculture sector (Borah and Kalita, 2012; Gite, 1991; Jain et al., 2018a; Khidiya and Bhardwaj, 2012; Kishtwaria and Rana, 2012; Mehta et al., 2012; Nag et al., 1988). Some work has also been reported in the handicraft sector (Meena et al., 2014a; 2014b; Mukhopadhyay and Srivastava, 2010). In other unorganised industries, very little work has been reported.

Very few studies have been found in the literature on brick kiln industry in context of ergonomics and occupational health of workers. Table 2.5 shows the ergonomic studies in brick kiln industry reported in literature.

Table 2.5: Summary of ergonomic studies in brick kiln industry

Reference	**Country/state**	**Task**	**Sample size**	**Problem targeted**
Das, 2018	India (West Bengal)	Moulding, stacking and carrying	112 F	Effect of thermal and cardiac stress on productivity
Sett and Sahu, 2016	India (West Bengal)	Moulding and carrying	162 F (77 +55)	Nutritional status using hand grip strength and body composition
Bandyopadhyay and Sen, 2016	India (West Bengal)	Brick making	62 F	Physiological load and workers' energy requirements
Noor et al., 2015	Indonesia	Brick making	37	Prevalence of musculoskeletal complaints
Maity et al., 2015	India (West Bengal)	Brick making	111 (52 M + 59 F)	Prevalence of musculoskeletal disorders
Das, 2015	India (West Bengal)	Brick making	148 F	Prevalence of lower back pain
Hajizadeh et al., 2014	Iran	Brick firing	184	Effect of heat stress on productivity
Das, 2014	India (West Bengal)	Brick making	220 M	Work comfort, hand grip strength and pulmonary function
Qutubuddin et al., 2013	India (Karnataka)	Brick making	60 (30 M +30 F)	Prevalence of musculoskeletal disorders
Pandey and Vats, 2013	India (UP)	Brick making	40 (20M + 20 F)	Prevalence of musculoskeletal disorders
Monga et al., 2012	India (Punjab)	Brick making	W 80 CG 180	Prevalence of respiratory symptoms
Pandey and Vats, 2012	India (UP)	Brick making	41 (20M + 20 F)	Identification of musculoskeletal risk factor
Trevelyan and Haslam, 2001	UK	Moulding and carrying bricks	Main 14 Follow up 11	Prevalence of musculoskeletal disorders
Chung and Kee, 2000	South Korea	lifting tasks	37	Prevalence of lower back issues

Note: M– Male; F– Female

Ergonomic studies on the Indian clay brick manufacturing sector conducted so far have been focused on the investigation of nutrition level of workers, heat exposure (Sett and Sahu, 2014; 2016), respiratory symptoms (Monga et al., 2012), lower back pain (Das, 2015) and physical stress (Das, 2014; Sain and Meena, 2017).

2.8 Summary of literature review and research gaps

From the review of literature, it can be summarized that musculoskeletal problems and MSDs are major sources of workers' dissatisfaction as well as loss of productivity and product quality in various sectors worldwide. These issues can be reduced by proper ergonomic interventions. The literature also shows that small scale industries, especially the unorganised sector in India need attention towards studies for ergonomic interventions for the wellbeing of workers. In the Indian unorganised sector, most of the research work related to musculoskeletal health issues and ergonomic interventions have been carried out in the agriculture sector (Borah and Kalita, 2012; Gite, 1991; Jain et al., 2018a; Khidiya and Bhardwaj, 2012; Kishtwaria and Rana, 2012; Mehta et al., 2012; Nag et al., 1988). Some work has also been reported in the handicraft sector (Meena et al., 2014a; 2014b; Mukhopadhyay and Srivastava, 2010). In other unorganised industries, very little work has been reported. Ergonomic studies on the Indian brick manufacturing sector conducted so far have been focused on the investigation of nutrition level of workers, heat exposure (Sett and Sahu, 2014; 2016), respiratory symptoms (Monga et al., 2012), lower back pain (Das, 2015) and physical stress (Das, 2014). After conducting an extensive literature review, the following gaps were identified to prepare the base for further research:

- To date, limited studies have investigated the prevalence of musculoskeletal issues in different body parts and associated factors among the workers involved in various manual clay brick manufacturing tasks.
- Studies on posture analysis and anthropometry of Indian brick kiln workers are hardly seen in literature.
- Existing ergonomic studies are lacking in designing ergonomic interventions and hand tools for brick kiln workers.

Chapter 3

Methodology of Research Work

The review of literature was presented in Chapter 2, where the research gaps in current knowledge in context of ergonomic studies in clay brick kiln industry were identified. Various research approaches adopted by numerous researchers were also discussed in the literature review. On the basis of reported studies and opinions of experts, the research methodology for the present work was established, which is elaborated in this chapter.

3.1 Framework of research

The present research is proposed for discovering solutions to musculoskeletal and occupational health problems among Indian manual clay brick kiln industry workers. Various steps included in the ergonomic analysis of existing work environment and design of interventions for improving musculoskeletal health are depicted in Figure 3.1. The initial steps considered in the framework are literature review and identification of research area followed by preliminary studies and identification of research gaps. The next step consists of ergonomic analysis of existing work environment using various techniques such as questionnaire survey, postural assessment techniques, musculoskeletal strength measurement tools, etc. This step provides critical tasks and risk factors for further improvements. After ergonomic assessment, the next step is to develop some ergonomic interventions to improve musculoskeletal health of the workers and then validate the interventions. For design of interventions, various design software were used, and the designed interventions were tested in virtual as well as real field conditions. The current study was performed mostly in the field; however, some work was also performed in the laboratory and on software. The detailed methods and materials adopted in various steps of the present study are described in concerned chapters separately.

3.2 Study area and selection of subjects

The present study was conducted among workers employed in 32 traditional fired clay brick manufacturing units (kilns) situated in the Rajasthan state of India. The total number of subjects (kiln workers) who participated in various steps of the study was

486. Convenient and random sampling methods were adopted for the selection of study subjects. This exploratory study was conducted from January 2016 to October 2018. In Rajasthan, brick manufacturing is generally done from November to June.

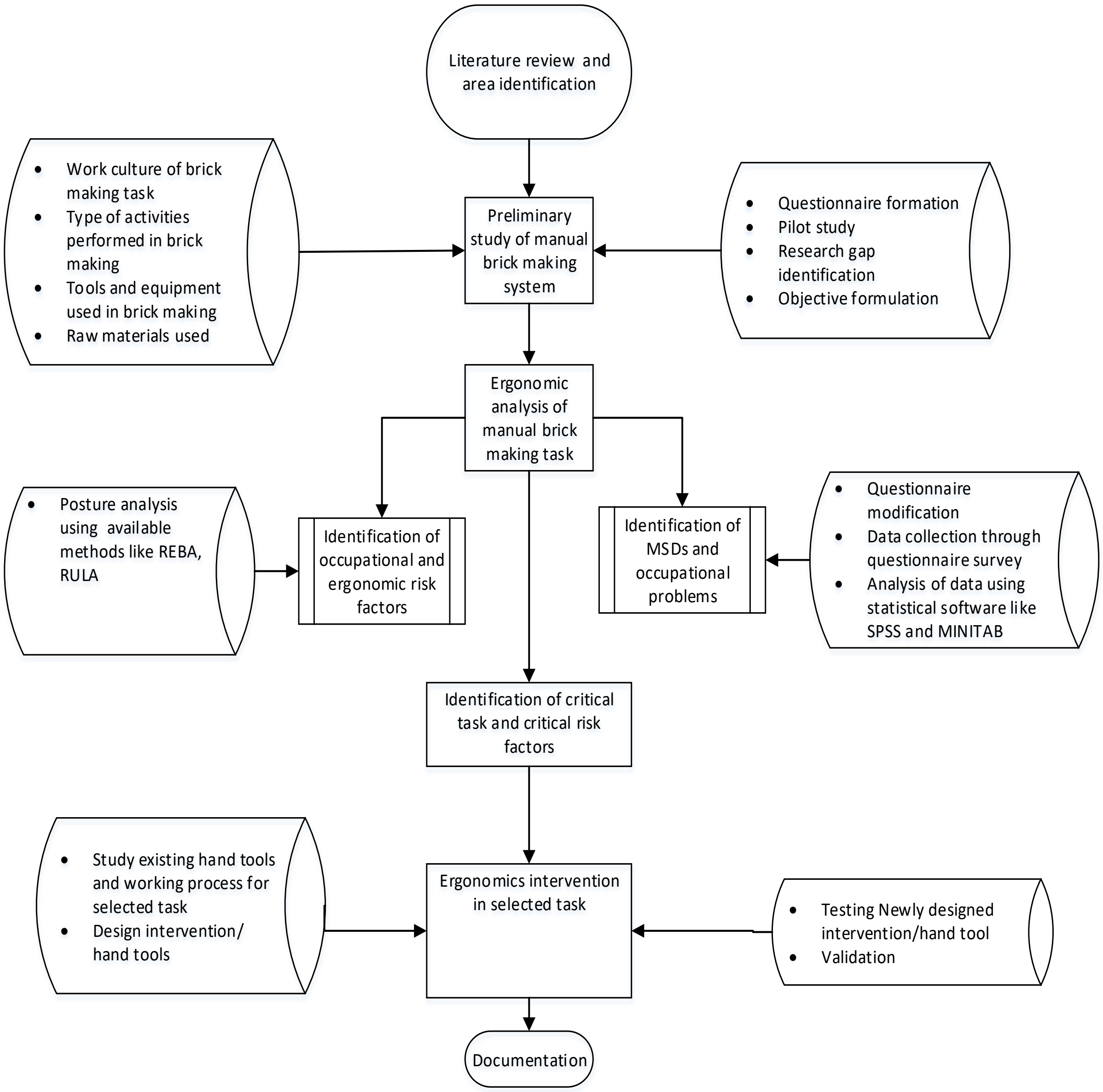


Figure 3.1: Research framework

During this period, the possibility of rain remains low, and hence most of the research work was carried out during winter and summer seasons. Consent from workers and kiln managers/owners were taken before the study. Prior approval from the departmental research committee of Malviya National Institute of Technology, Jaipur, (Rajasthan) was taken for this study, and it was ensured that no aspect of the study was in any way in violation of the World Medical Association Declaration of Helsinki

(2001) and National Ethical Guidelines for Biomedical and Health Research Involving Human Participants of Indian Council of Medical Research (2016).

Before listing the participants, brick kilns were visited, and all the steps of brick manufacturing process were observed carefully. The clay brick manufacturing process includes various manual tasks such as excavation of clay using some digging tools, breaking clay into small pieces, mixing clay using a spade or by hands, clot cutting, filling clots into moulding boxes, mould evacuation, stacking bricks for drying, carrying bricks and arranging bricks in kiln for firing. During the initial visits, it was observed that the workers involved in spading, clot cutting and mould filling, mould evacuating and carrying tasks were the ones who had to subject themselves to the most awkward postures. The workers involved in these tasks were selected randomly for further study. Various clay brick manufacturing tasks are shown in Figure 3.2.

Digging and crushing clay

Preparing clay by wetting and mixing

Clot preparation

Mould filling

Mould evacuation

Stacking bricks to dry

Carrying brics to kiln and loading

Setting bricks in the kiln

Figure 3.2: Various manual activities performed during clay brick manufacturing

In the first step, clay is excavated or mined by using some digging tools. After digging, clay is converted into small pieces if required. In the second step, clay is prepared by wetting and mixing, either manually or using a spade. The prepared clay is then converted into clots, and sometimes coal dust is also mixed with prepared clay. In the next step, clots are filled into moulding boxes and green bricks are evacuated on the ground. After some days, bricks are stacked to dry, and then dry bricks are carried to the kiln and arranged for firing. After some days, fired bricks become ready and are loaded in vehicles. After observation of various tasks, four tasks namely spading, clot preparation and mould filling, mould evacuating and brick carrying were selected for further studies.

3.3 Data collection and analysis

The data was collected with the help of modified Nordic questionnaire for identification of prevalence of musculoskeletal issues and associated factors among workers. Digital hand grip dynamometer was used to record the hand grip strength of workers while using various hand tools. To analyse the postural risk among workers, REBA and RULA score sheets were employed. The prevalence of lower back pain was measured on a Likert scale of 1–5 using a structured questionnaire. Comfort questionnaire for hand tools (CQH) was used to assess the usability of hand tools. Anthropometric data was recorded with the help of anthropometric kit and weighing machine. For the representation of data, bar charts, pie charts and tables were used. Descriptive statistics were shown in the tables. Statistical tests like logistic regression and paired t–test were applied to analyse the collected data.

3.4 Software used

IBM SPSS software (version 22) was used for data analysis. For hand tool design and analysis, ANSYS 16.0 and CATIA V5R18 were used. Human hand tool modelling was also done in CATIA V5R18. Microsoft Visio was used for preparing flow charts and schematics.

In the upcoming chapters (chapters 4 and 5) the ergonomic analysis and design of interventions by adopting the above–mentioned research methodology are explained.

Chapter 4

Prevalence of Musculoskeletal Issues and Risk Factors

4.1 Introduction

Work–related musculoskeletal problems need urgent attention in various sectors worldwide. The musculoskeletal disorders are causally related to occupational ergonomic stressors, such as repetitive and stereotyped motions, forceful exertions, awkward postures, vibration, and combinations of these exposures. (Jain et al. 2017; Sain and Meena, 2016; Punnett and Wegman, 2004). Musculoskeletal issues include injuries, discomfort and pain that affect the human body's musculoskeletal system. These issues develop over time as chronic diseases called MSDs. Pain, numbness, tingling, difficulty in moving, muscle loss, cramping, paralysis, inflammation and redness in eyes, etc. are the symptoms of musculoskeletal problems. Some common MSDs include tendon inflammations (i.e., tenosynovitis, epicondylitis, bursitis, etc.), nerve compression disorders such as carpal tunnel syndrome and sciatica and osteoarthrosis, and conditions such as myalgia, lower back pain and other regional pain syndromes. Musculoskeletal and other occupational health issues result in increased absenteeism and lost working time, adverse effects on labour relations, increased probability of accidents and errors, job transfers, higher turnover of workers, decreased productivity, low–quality of work and high administrative and personnel costs (Cardinali, 1998; Miller, 1995; Niu, 2010; Widanarko et al., 2012). The financial damage caused by these problems not only disturbs individual working, but also the concerned companies and the whole society as well.

The manual clay brick making process includes various activities of repetitive nature which are continuously performed in awkward postures with traditional hand tools. The ergonomic stressors result in various musculoskeletal issues among brick kiln workers. In the present chapter, the prevalence of musculoskeletal issues including handgrip analysis and posture analysis is described. Association between musculoskeletal disorders and various risk factors is also described in this chapter.

4.2 Materials and methods

To study the prevalence of musculoskeletal issues among brick kiln workers, various methods and materials were adopted which are described in upcoming sections.

4.2.1 Study area and sampling design

The prevalence of musculoskeletal issues among brick kiln workers was studied using a modified Nordic questionnaire. The selection procedure of participants is depicted in Figure 4.1. Initially, 490 workers from 32 brick kilns were approached to participate in the study through the brick kiln owners and managers. From among the approached brick kiln units, the owners of 10 brick kilns refused to participate, and a total of 400 participants from 22 kilns were finally enlisted for the study.

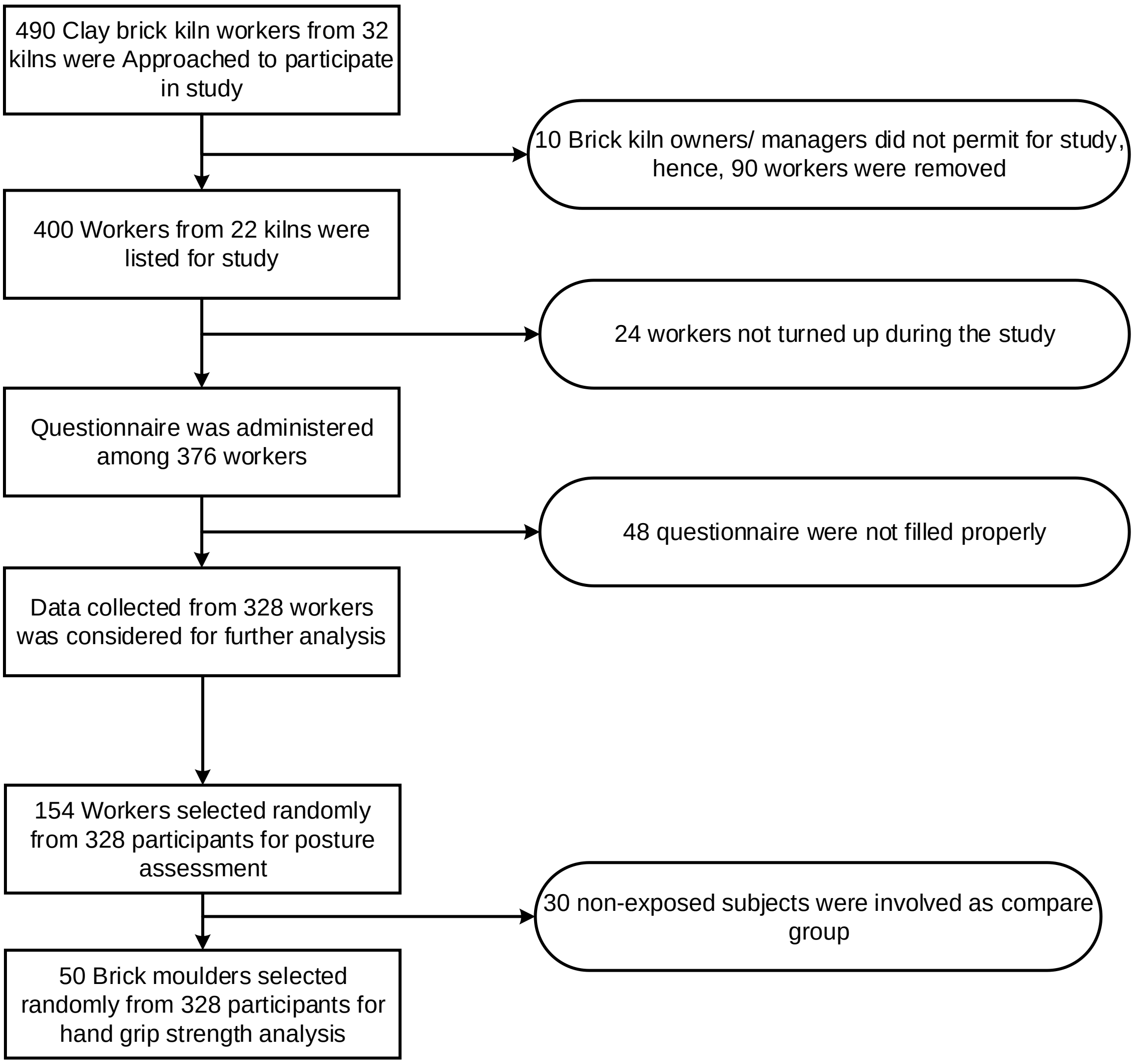


Figure 4.1: Selection of participants

Out of these listed workers, 24 did not turn up to fill the questionnaire. Remaining 376 participants agreed to fill out the questionnaire. Out of the filled questionnaires, 48 were not filled completely. Finally, data obtained from 328 workers were considered for further analysis. The workers involved in spading, mould filling, mould evacuating and brick carrying tasks were selected randomly after careful observation of these tasks during the initial visits to the kilns. Out of 328 workers involved in spading (excavating clay and preparing mud), clot cutting and mould filling, mould evacuating and brick carrying tasks, 154 workers were randomly selected for postural analysis.

To analyse the effects of these tasks on hand musculoskeletal system, the hand grip strength of workers was measured and compared with that of the non–exposed group (employees not involved in manual labour). A total of 50 (32 males and 18 females) brick moulders aged between 18–53 years and having at least one year of working experience were randomly picked from the same population for which the questionnaire survey was conducted. In the non–exposed group comprising of 30 subjects (21 males and 9 female) from the age group of 18–52 years, were involved in various managerial activities such as taking attendance, selling the prepared bricks and some other tasks like drinking water supply, etc. were selected.

4.2.2 Questionnaire development

A structured, modified Nordic Questionnaire was used to collect the demographic and musculoskeletal health–related data of the workers. To modify the questionnaire, a pilot study among 50 brick kiln workers was conducted using Standard Nordic Questionnaire (Kourinka et al., 1987). Some additional space for comments was provided in the SNQ. Body parts like elbows, hips, thighs and ankles were removed from the modified questionnaire as the issues in these body parts were reported by a few (≤5%) workers only.

On the other hand, body parts like upper arm, lower arm and fingers were included in the questionnaire as more than 20% of workers reported musculoskeletal symptoms in these body regions. In most of the clay brick manufacturing activities (like spading, clot cutting, mould filling, mould evacuating, etc.) both hands are used simultaneously. Majority of workers (96%) included in the pilot survey reported similar issues on both right and left sides. Hence, the provision of issues in right and left sides was removed from the questionnaire. Provisions for personal and work–related factors were also modified with the consultation of experts. The questionnaire was finalised after consultation with three experts. The modified questionnaire was divided into three portions: (i) demographic variables (i.e., age, height, weight, gender, qualification, smoking habits, etc.), (ii) work–related characteristics (i.e., type of task, experience, working hours, rest duration, etc.) and (iii) body parts having musculoskeletal symptoms including pain and/or discomfort. In the third portion, the workers were asked whether they felt pain or discomfort in one or more body parts, and the responses were recorded in the form of '0' (no) or '1' (yes). As the majority of workers were less educated, the questionnaire was translated into the Hindi language, and the workers were also helped by the surveyor in filling the questionnaire.

4.2.3 Postural assessment techniques

During the initial study, it was observed that the workers used both upper and lower extremities during different brick making tasks. Therefore, Rapid Upper Limb Assessment (RULA) 30) as well as Rapid Entire Body Assessment (REBA) methods were used to analyse the postures. These techniques are inexpensive and easy to conduct compared to other observational techniques. Hence these methods are widely used by professionals for postural analysis in manual working (Ma et al., 2009; Singh et al. 2012). The postures were observed carefully during work sessions, and scores were entered in the RULA and REBA score sheets.

4.2.4 Data analysis

The demographic characteristics (age, weight, height, body mass index (BMI), gender, work experience, etc.) and work variables (working hours, work experience, the task performed, etc.) were categorised and tabulated. The BMI was calculated using weight and height of workers as per the following relation:

$$\mathrm{BMI} = \frac{\text{Weight in kg}}{(\text{Height in meters})^2}$$

For data analysis, IBM SPSS software (version 22) was used. To explore the factors causing musculoskeletal problems, binary and multinomial logistic regressions were used. The significance level was checked at $p<0.05$ and odds ratios (OR) with confidence intervals (CI) were calculated. Age, gender, BMI, work experience, and tasks were considered as independent variables. Musculoskeletal symptoms in the neck, shoulders, upper arms, lower arms, wrists, fingers, upper back, lower back and knee regions were considered as dependent variables. The risk factors found significantly associated with musculoskeletal symptoms in the binary logistic regression analysis were again analysed by multinomial logistic regression method at $p<0.05$. The reference response level for the regression model was taken as '1', indicating presence of musculoskeletal symptoms. Hosmer–Lemeshow test for goodness of fit was used for checking the correctness of the binary logistic regression model.

4.3 Characteristics of survey population

Table 4.1 shows the demographic and work-related characteristics of the brick kiln workers (N=328). Most of the workers (57.62%) were in the age group of 21–30, while some workers (8.55%) were below 20 years of age.

Table 4.1: Characteristics of brick kiln workers (N = 328)

		Number of workers					
Characteristics	**Category**	**Spading** ***(n = 85)***	**Mould filling** ***(n = 95)***	**Mould evacuating** ***(n = 84)***	**Carrying** ***(n = 64)***	**Total**	**Percentage (%)**
Age (years)	≤ 20	05	07	13	03	28	8.6
	21 – 30	55	61	31	42	189	57.6
	31 – 40	15	14	23	10	62	18.9
	41 – 50	07	12	15	06	40	12.2
	≥ 51	03	01	02	03	09	2.7
Weight (kg)	≤ 45	00	01	01	01	03	0.9
	46 – 55	23	22	36	12	93	28.4
	56 – 65	43	43	26	36	148	45.1
	66–75	18	28	20	14	80	24.4
	>75	01	01	01	01	04	1.2
Height (m)	< 1.60	03	01	03	01	08	2.4
	1.60 – 170	36	41	38	21	136	41.5
	170.10 – 180	46	49	33	41	169	51.5
	>180	00	04	10	01	15	4.6
Body Mass Index (BMI)	<18.50	14	14	14	10	52	15.9
	18.50–24.99	69	76	70	54	269	82.0
	25–29.99	02	05	00	00	07	2.1

		Number of workers					
Characteristics	**Category**	**Spading** *(n = 85)*	**Mould filling** *(n = 95)*	**Mould evacuating** *(n = 84)*	**Carrying** *(n = 64)*	**Total**	**Percentage (%)**
Gender	Male	58	60	48	51	217	66.2
	Female	27	35	36	13	111	33.8
Work experience (years)	<5	43	55	37	29	164	50.0
	5–10	42	38	45	34	159	48.5
	>10	00	02	02	01	05	1.5
Smoking habit	Smokers	21	30	26	18	95	28.96
	Nonsmokers	64	65	58	46	233	71.04

Body mass index (BMI) data showed that most of the workers (82.01%) were healthy. 15.85% workers were found underweight, and a few (2.14%) were overweight. Statistics also showed that 50% of the workers had less than five years of experience and only 1.52% workers had more than ten years of experience. From these facts, it could be inferred that the workers do not stay in this job for a long time. The number of male respondents (66.16%) considered in the study was more than female respondents (33.84%).

4.4 Prevalence of musculoskeletal issues among workers

The most commonly affected body parts were wrists, lower back and shoulders. Figure 4.2 shows the prevalence of musculoskeletal symptoms in different body parts of workers. Musculoskeletal issues in the wrist region were reported by maximum number (51.52%) of workers. The workers with pain and discomfort in lower back and shoulder were found to be 50% and 47.87% respectively.

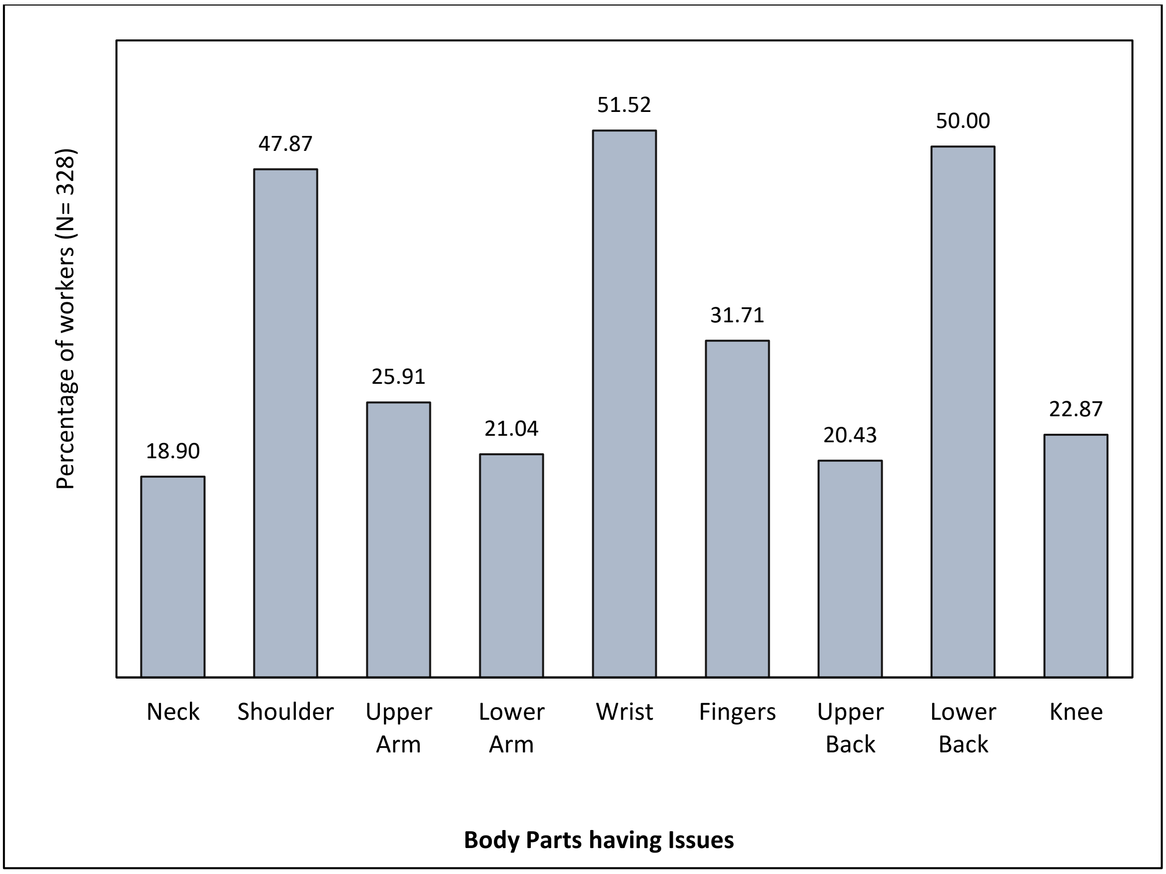


Figure 4.2: Frequency of musculoskeletal symptoms

4.4.1 Task–wise musculoskeletal problems

To gain more insight into musculoskeletal difficulties, the data was analysed for different tasks (i.e. spading, mould filling, evacuating and carrying) separately. The results of the task–wise analysis are given in Figure 4.3. Problems in the lower back region were reported by the maximum number of workers (62.35%) performing the spading task. About 57.65% of workers were found with shoulder problems, whereas 42.35% of workers reported issues in wrist regions. Among the workers involved in mould filling task, maximum number of workers (55.79%) reported finger related problems. Wrist related issues were found in 53.68% of workers while 42.11% workers reported shoulder problems. Majority of workers (76.19%) involved in mould evacuating task reported symptoms related to wrist regions followed by musculoskeletal issues in the lower back region (55.95%). Musculoskeletal problems in shoulder area were found in 53.13% of the brick carriers, whereas upper back issues were mentioned by 45.31% of the workers.

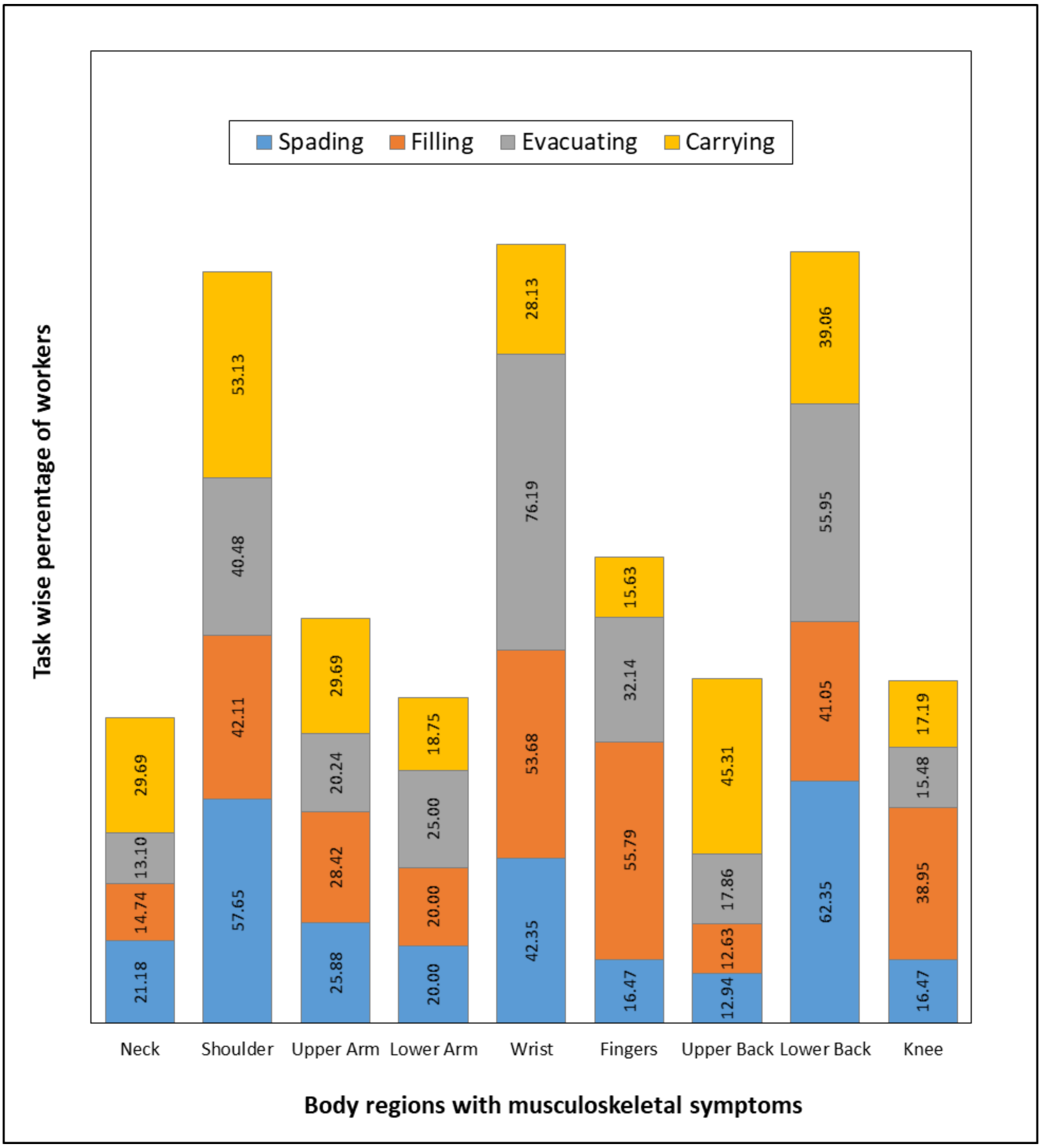


Figure 4.3: Task–wise occurrence of musculoskeletal issues

4.5 Association between risk factors and prevalence of musculoskeletal issues

To identify the factors causing musculoskeletal problems, binary and multinomial logistic regressions were used. The significance level was checked at $p<0.05$, and odds ratios (OR) with confidence intervals (CI) were calculated.

4.5.1 Binary logistic regression

Binary logistic regression was applied to identify the significance of the relationship between musculoskeletal issues and personal and work–related factors. The details of association between musculoskeletal symptoms in different body parts with demographic and occupational factors are shown in Table 4.2 and Table 4.3. Age was found to be substantially associated with the musculoskeletal problems in all body regions except for upper back region. Gender was observed as a significant contributing factor for the occurrence of MSDs in fingers and lower back. Finger issues were lesser in males (OR = 0.26, 95% CI: 0.09 – 0.73, p = 0.01) while lower back problems were more in males (OR = 3.71, 95% CI: 1.51 – 9.11, p = 0.00) compared to females. The underweight workers (i.e., BMI<18.5) were more prone to shoulder–related issues (OR = 23.37, 95% CI: 1.81– 301.36, p = 0.02) as compared to overweight workers (i.e., BMI >25).

The type of task performed by the workers was also a causal factor for the generation of MSDs. Spading task showed significant association with wrist (OR = 2.42, 95% CI: 1.03 –5.66, p = 0.04), upper back (OR = 0.16, 95% CI: 0.06 – 0.40, p = 0.00) and lower back (OR = 3.97, 95% CI: 1.75 – 8.98, p = 0.00) problems. Mould filling task was recognised as a substantial contributing factor for musculoskeletal issues in wrist (OR = 4.27, 95% CI: 1.81 – 10.09, p = 0.00), finger (OR = 17.56, 95% CI: 5.90 – 52.31, p = 0.00), and knee (OR = 6.88, 95% CI: 2.40 – 19.70, p = 0.00) regions. Prevalence of MSDs in wrists (OR = 12.22, 95% CI: 4.82 – 30.98, p = 0.00), fingers (OR = 3.57, 95% CI: 1.23 – 10.36, p = 0.02) and lower back (OR = 2.62, 95% CI: 1.14 – 6.00, p = 0.02) were significant in mould evacuating task workers.

The workers having less than five years of experience were less prone to musculoskeletal symptoms in neck (OR = 0.03, 95% CI: 0.00– 0.72, p = 0.03) and upper back regions (OR = 0.08, 95% CI: 0.01 – 0.76, p = 0.03) compared to the workers having 10 years or more of experience.

Table 4.2: Association between risk–factors and musculoskeletal issues in neck, shoulder, arm and wrist regions

Factor	**Neck (n = 62)**			**Shoulder (n = 157)**			**Upper arm (n = 85)**			**Lower arm (n = 69)**			**Wrist (n = 169)**		
	χ^2 = 2.42			χ^2 = 11.94			χ^2 = 12.33			χ^2 = 14.57			χ^2 = 5.88		
	p	**OR**	**95% CI**	**p**	**OR**	**95% CI**	**p**	**OR**	**95% CI**	**p**	**OR**	**95% CI**	**p**	**OR**	**95% CI**
Age	**0.00****	1.19	1.11–1.29	**0.00****	1.18	1.11–1.25	**0.00****	1.12	1.06– 1.19	**0.02***	1.06	1.01–1.12	.02*	1.066	1.01 –1.12
Gender[a]															
Male	0.82	0.83	.18 – 3.84	0.28	1.64	.67– 3.98	0.60	1.33	.47 – 3.77	0.50	1.42	.51 – 3.99	0.17	0.53	.22 – 1.31
Weight	0.78	1.01	.92– 1.12	0.06	1.07	1.00 – 1.14	0.16	1.05	.98 – 1.13	0.15	0.95	.88 – 1.02	0.36	1.03	.97 – 1.10
Height	0.14	0.99	.97 – 1.00	0.24	0.99	.99 – 1.00	0.23	0.99	.98 – 1.00	0.91	1.00	.99 – 1.01	0.94	1.00	.99 –1.01
BMI[b]															
< 18.5	0.08	0.03	.00– 1.59	0.**02***	23.37	1.81– 301.36	0.42	3.03	.20 – 45.21	1.00	82902256.34	0.00	0.58	0.55	.06 – 4.63
18.5 –**24.99**	0.21	0.11	.00– 3.47	0.09	7.73	.75– 79.93	0.56	2.06	.19 – 22.75	1.00	109320361.57	0.00	0.92	0.91	.15 – 5.67
Task[c]															
Spading	0.57	0.72	.23 – 2.22	0.17	1.74	.79– 3.85	0.77	1.15	.46– 2.85	0.66	1.24	.47 – 3.22	**0.04***	2.42	1.03 –5.66
Filling	0.13	0.40	.12– 1.30	0.92	0.96	.43– 2.13	0.21	1.79	.72 – 4.42	0.44	1.46	.56 – 3.81	**0.00****	4.27	1.81 – 10.09
Evacuating	**0.00****	0.15	.04– .55	0.26	0.62	.27– 1.42	0.34	0.63	.24 – 1.63	0.46	1.44	.55 – 3.73	**0.00****	12.22	4.82 – 30.98
Experience[d]															
< 5 years	**0.03***	0.03	.00– .72	1.00	0.00	0.00	0.44	0.40	.04 – 4.20	0.07	0.10	.01 – 1.19	0.60	0.44	.02 – 8.09
5 – 10 years	0.68	0.61	.05– 6.73	1.00	0.00	0.00	0.84	1.25	.15 – 10.47	0.28	0.28	.03 – 2.84	0.80	1.37	.09 – 21.60
Smoking															
Smoker[e]	0.62	1.27	.49 – 3.28	0.70	1.15	.58 – 2.28	0.05	2.19	.998 – 4.792	0.80	1.10	.54 – 2.26	0.05	0.49	.240 – 1.01

Note: – n: Number of workers having musculoskeletal issues

CI: Confidence interval, p: Significance value

* Significant at p<0.05, ** Significant at p<0.01

[a] With reference to females, [b] With reference to BMI 25 – 29.99, [c] With reference to carrying, [d] With reference to experience >10 years, [e] With reference to non–smokers

Table 4.3: Association between risk–factors and musculoskeletal issues in the finger, back and knee regions

Factor	Finger (n = 104)			Upper back (n = 67)			Lower back (n = 164)			Knee (n = 75)		
	$\chi 2 = 15.11$			$\chi 2 = 9.03$			$\chi 2 = 4.90$			$\chi 2 = 9.45$		
	p	**OR**	**95% CI**	**p**	**OR**	**95% CI**	**p**	**OR**	**95% CI**	**p**	**OR**	**95% CI**
Age	**0.03***	1.06	1.01 – 1.12	0.94	1.00	.95–1.05	**0.04***	1.06	1.00 –1.11	**0.00****	1.11	1.04 – 1.17
Gender^{a}												
Male	**0.01***	0.26	0.09 – 0.73	0.20	0.49	0.17 – 1.44	**0.00****	3.71	1.51 – 9.11	0.06	0.34	0.11 – 1.06
Weight	**0.00****	1.15	1.07 – 1.24	0.63	1.02	.95 – 1.10	**0.02***	.92	.86 – .98	0.09	1.07	.99 – 1.16
Height	0.14	0.99	.980 – 1.00	0.67	1.00	.99 – 1.01	0.92	1.00	.99 – 1.01	0.87	1.00	.99 – 1.02
BMI^{b}												
BMI < 18.5	0.83	0.77	.07 – 9.08	0.34	0.26	.02 – 4.25	0.95	1.09	.09 – 14.02	0.67	2.03	.08 – 50.54
BMI 18.5 –24.99	0.37	0.38	.04 – 3.21	0.69	0.60	.05 – 7.05	0.79	1.37	.13 – 14.11	0.33	4.13	.24 – 70.98
Task^{c}												
Spading	0.54	1.42	.46 – 4.37	**0.00****	0.16	.06 – .40	**0.00****	3.97	1.75 – 8.98	0.96	1.03	.35 – 3.04
Filling	**0.00****	17.56	5.90 – 52.31	**0.00****	0.14	.06 – .36	.17	1.78	.79 – 4.00	**0.00****	6.88	2.40 – 19.70
Evacuating	**0.02***	3.57	1.23 – 10.36	**0.00****	0.20	.08 – .48	**0.02***	2.62	1.14 – 6.00	0.43	0.64	.21 – 1.94
Experience^{d}												
<5 years	0.09	0.09	.01 – 1.49	**0.03***	0.08	.01 – .76	1.00	0.00	0.00	0.06	0.07	.01 – 1.13
5 – 10 years	0.50	0.47	.03 – 5.39	0.17	0.25	.03 – 1.86	1.00	0.00	0.00	0.41	0.35	.03 – 4.19
Smoking												
Smoker^{e}	0.76	0.90	.44 – 1.83	0.15	0.58	.28 – 1.21	0.66	1.16	.59 – 2.31	0.33	1.48	.67 – 3.25

Note: – n: Number of workers having musculoskeletal issues

CI: Confidence interval, p: Significance value

* Significant at p<0.05, ** Significant at p<0.01

^{a} With reference to females, ^{b} With reference to BMI 25 – 29.99, ^{c} With reference to carrying, ^{d} With reference to experience >10 years, ^{e} With reference to non–smokers

4.5.2 Multinomial logistic regression

Multinomial logistic regression analysis was performed to further analyse the association of musculoskeletal symptoms and the risk factors that were found to have a significant association in binary logistic regression. The analysis results are shown in Table 4.4.

Table 4.4: Association of musculoskeletal problems in body parts with risk–factors (multinomial logistic regression)

Body part	**Factor**	**p**	**OR**	**95% CI**
Neck	Age	0.00**	0.85	0.80 – 0.90
	Task (*referent carrying*)			
	Mould Filling	0.03*	3.20	1.09 – 9.40
	Mould evacuating	0.00**	7.82	2.50 – 24.68
	Experience (*referent >10 years*)			
	<5 years	0.03*	35.78	1.43 – 893.02
Shoulder	Age	0.00**	0.86	0.83 – 0.90
Upper arm	Age	0.00**	0.88	0.85 – 0.91
Lower arm	Age	0.00**	0.91	0.88 – 0.94
Wrist	Age	0.00**	0.88	0.84 – 0.91
	Task (*referent carrying*)			
	Spading	0.03*	0.43	0.20 – 0.94
	Mould filling	0.00**	0.22	0.10 – 0.48
	Mould evacuating	0.00**	0.08	0.04 – 0.19
Fingers	Age	0.00**	0.88	0.86 – 0.92
	Weight	0.00**	0.90	0.85 – 0.96
	Task (*referent carrying*)			
	Mould filling	0.00**	0.09	0.04 – 0.22
	Mould evacuating	0.03*	0.36	0.14 – 0.92
	Gender (*referent female*)			
	Male	0.02*	2.88	1.17 – 7.07
Upper back	Task (*referent carrying*)			
	Spading	0.00**	5.75	2.51 – 13.20
	Mould filling	0.00**	5.77	2.55 – 13.04
	Mould evacuating	0.00**	4.42	2.02 – 9.68
	Experience (*referent >10 years*)			

Body part	Factor	p	OR	95% CI
	<5 years	0.01*	14.35	2.05 –100.26
Lower back	Age	0.00**	0.89	0.86 – 0.92
	Weight	0.00**	1.09	1.03 – 1.16
	Task (*referent carrying*)			
	Spading	0.00**	0.28	0.13 – 0.59
	Mould evacuating	0.01*	0.39	0.18 – 0.81
	Gender (*referent female*)			
	Male	0.00**	0.20	0.09 – 0.46
Knee	Age	0.00**	0.86	0.82 – 0.89
	Task (*referent carrying*)			
	Mould filling	0.00**	0.17	0.07 – 0.44

Note: The reference response is 1

* Significant at p<0.05, ** Significant at p<0.01

The association of workers' age with the musculoskeletal issues in all body regions were found comparable with the issues found in binary logistic regression. The spading task was significantly associated with wrist (OR = 0.43, 95% CI: 0.20 – 0.94, p = 0.03) and upper back (OR = 5.75, 95% CI: 0.01 – 2.51 – 13.20, p = 0.00) regions. This is also similar to the results obtained through binary logistic regression. The mould filling task was found to be significantly associated with issues in most of the body parts (i.e., neck, wrist, fingers, upper back and knees). The mould evacuating task was considerably associated with musculoskeletal problems in neck, wrist, upper back, fingers, upper back and lower back. The association of musculoskeletal problems in various body parts with other risk factors was also found somewhat similar to the results of binary logistic regression.

4.6 Postural assessment

The body postures acquired by workers during spading, mould filling, mould evacuating and brick carrying tasks were analysed by direct observational techniques, i.e., REBA and RULA. The various postures acquired by the workers are shown in the Figure 4.4.

The average REBA scores for spading, mould filling, mould evacuating and brick carrying tasks were 11.71±.80, 11.10±.82, 10.50±.72 and 10.00±.81 respectively. The REBA scores for spading and mould filling tasks were found to lie in the category of 'very high risk' (i.e. REBA score > 11). Table 4.5 shows the description of body postures adopted during selected tasks and their corresponding REBA and RULA scores.


Body postures during spading task


Body postures during mould filling


Body postures during mould evacuating

Body postures during brick carrying

Figure 4.4: Body postures during different brick making tasks

Table 4.5: Postural details and corresponding scores

Task	**Postural detail**	**REBA**		**RULA**	
		Score (*M* ± *SD*)	**Action level**	**Score (*M* ± *SD*)**	**Action level**
Spading	Repetitive bending in the trunk, lower back and legs, arms raised and abducted with a substantial load	11.71±.80	Very high	6.40±.64	Very high
Mould filling	Prolonged sitting in squatting and kneeling posture, repetitive movements of hands, wrist and stress on fingers.	11.10±.82	Very high	6.05±.76,	Very high
Mould Evacuating	Repetitive twisting and bending of wrist and trunk while picking and evacuating, moving with a forward bent back and about 20–25 kg weight on hands.	10.50±.72	High	5.24±.74	High
Brick carrying	Arms above shoulder level and abducted, repetitive twisting and bending in neck and trunk while picking and placing bricks, moving with about 20–40 kg weight on the head.	10.00±.81	High	5.00±.85	High

***Note:** – M: mean, SD: standard deviation*

The average RULA scores also showed similar severity of occupational risks as found in REBA assessment. The RULA scores for spading, mould filling, mould evacuating and carrying tasks were 6.40±.64, 6.05±.76, 5.24±.74 and 5.00±.85 respectively. The scores for spading and mould filling tasks lie in the high–risk category (6–7). The average REBA and RULA scores for different tasks are depicted in Figure 4.5.

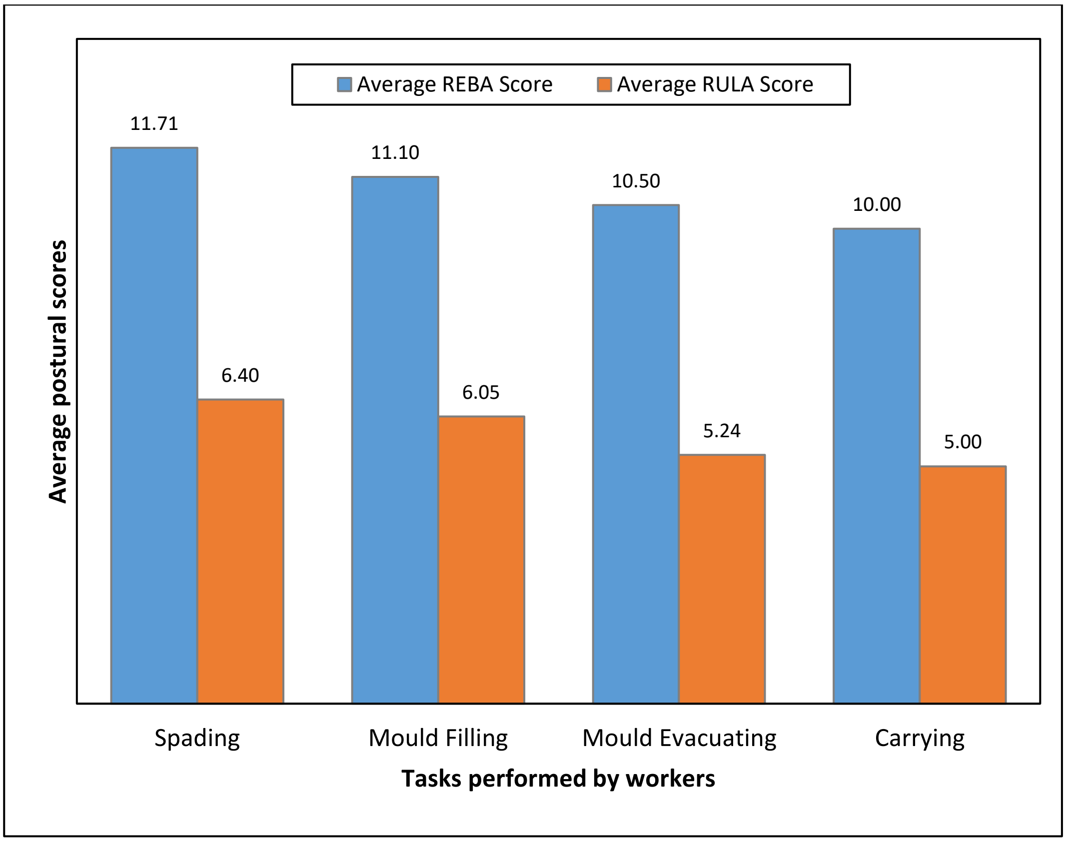


Figure 4.5: Comparative view of average REBA and RULA scores

The REBA and RULA scores clearly indicate that there is an immediate requirement of intervention in the related tasks. From the scores obtained for mould evacuating and carrying tasks, it was concluded that further investigation and ergonomic changes were needed.

4.7 Hand grip strength analysis

As shown in previous sections, wrist and finger issues were most frequent among brick moulders (viz. clot cutting, mould filling and mould evacuating workers). To analyse the effect of these tasks on hand musculoskeletal system, the hand grip strength of workers was measured and compared with that of the non–exposed group. A total of 50 brick moulders aged between 18–53 years and having at least one year of working experience were randomly picked from the same population that was used for the questionnaire survey. Hand grip strength was measured by using a digital hand grip dynamometer.

All the hand grip measurements were taken with the upper limb straight, i.e., at 0° elbow–angle (horizontal level) as shown in Figure 4.6. Three measurements, before starting the work (GS1), at lunch time (GS2) and the end of the work shift (GS3) were recorded.

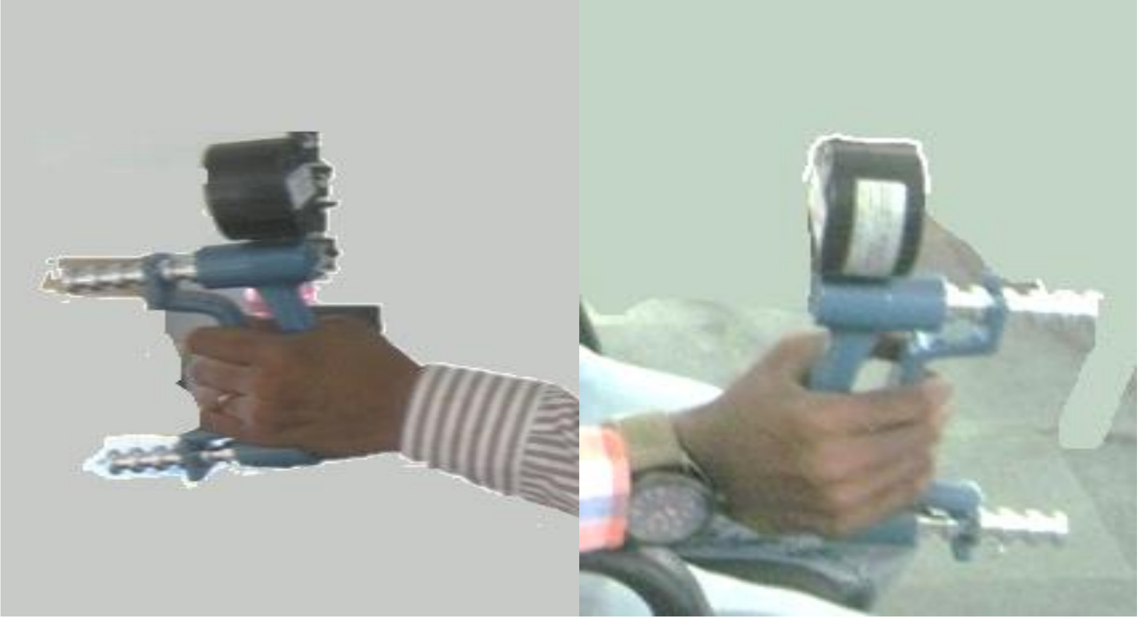


Figure 4.6: Left and right hand grip strength measurement

The average grip strengths of female brick moulders were found to be 33.59 kg and 27.91 kg for right and left hand respectively. Whereas the average grip strengths of male brick moulders were found to be 34.75 kg and 29.73 kg for right and left hand respectively. This hand grip strength was the average of the hand grip strength taken throughout the day. The hand grip strength of non–exposed females was found to be 30.74 kg and 24.53 kg for right and left hands respectively. The hand grip strength of non–exposed males were found to be 32.7 kg and 26.85 kg for right and left hands respectively. The average hand grips strength for exposed and non–exposed groups are depicted in Figure 4.7.

The hand grip strength was recorded in intervals of three hours throughout the work shift. It should be noted that all the positions of the hands are frequently in use in brick moulding task. The brick moulders cut clots, fill these clots into the moulding boxes and evacuate moulding boxes on the ground. The brick moulders use both the hands simultaneously during clot cutting, mould filling and evacuating. The hand grip strength recorded throughout the duration (after every three hours) of work shift is depicted graphically in Figure 4.8. At the start of the work shift, the grip strength was fairly high for both male and female workers, and considerably decreased with the passage of work duration. At the starting of the work shift, the grip strength of male moulders was 36.95 kg for the right hand and 34.75 kg for left hand which decreased to 32.58 kg and 29.83 kg for the right hand and left hand respectively by the end of the work shift.

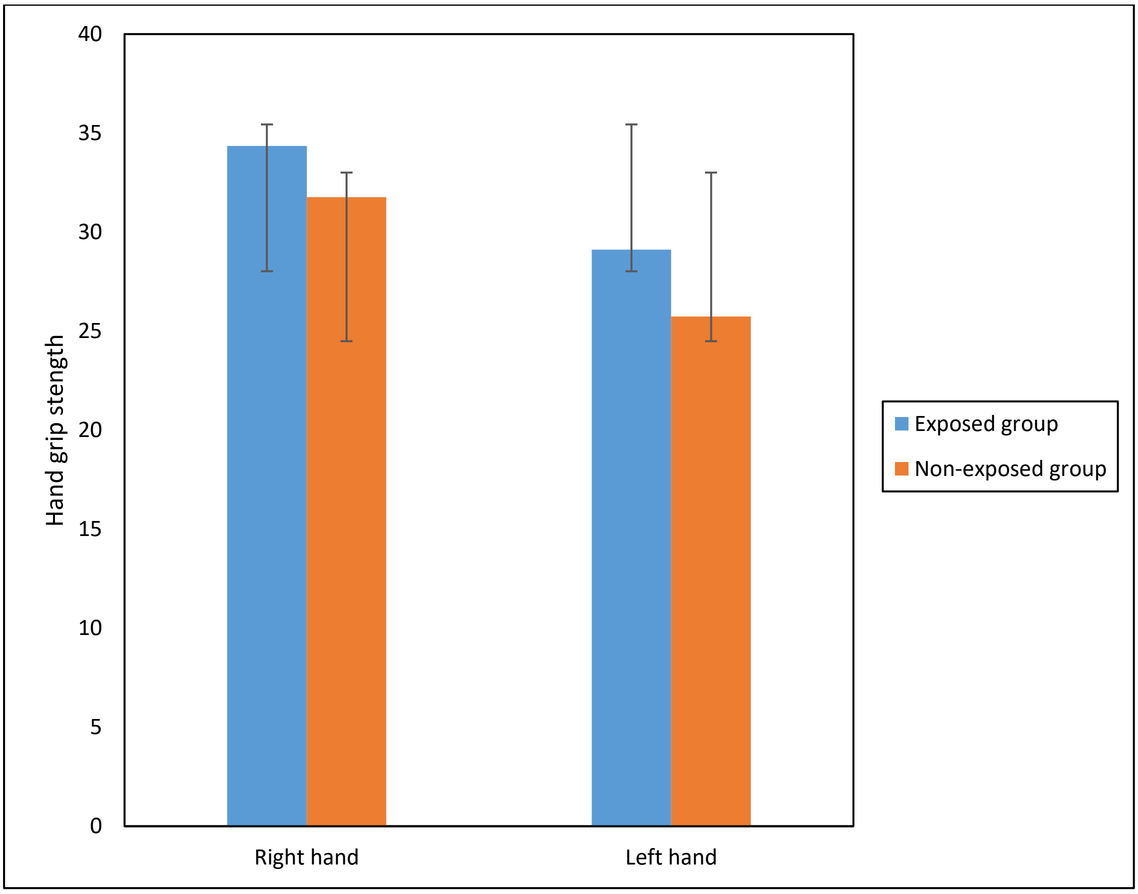


Figure 4.7: Comparative view of hand grip strength for exposed and non–exposed groups

For female moulders, the grip strength was recorded to be 35.56 kg and 33.59 kg for the right hand and left hand respectively at the starting of the work shift. By the end of the work shift, the hand grip strength of females decreased to 31.56 kg for right hand and 27.82 kg for left hand. Pared t–test statistics showed that the difference between GS1 and GS2, GS2 and GS3; and GS1 and GS3 were significant ($p = 0.00$). The reduction in hand grip strength of both male and female brick moulders clearly gave an indication of hand musculoskeletal risk among workers, which can potentially result in chronic hand MSDs afterwards.

Higher hand grip strength of the brick moulders compared to non–exposed group (control group) maybe due to the strengthening of hand musculoskeletal system of workers resulting from heavier manual labour.

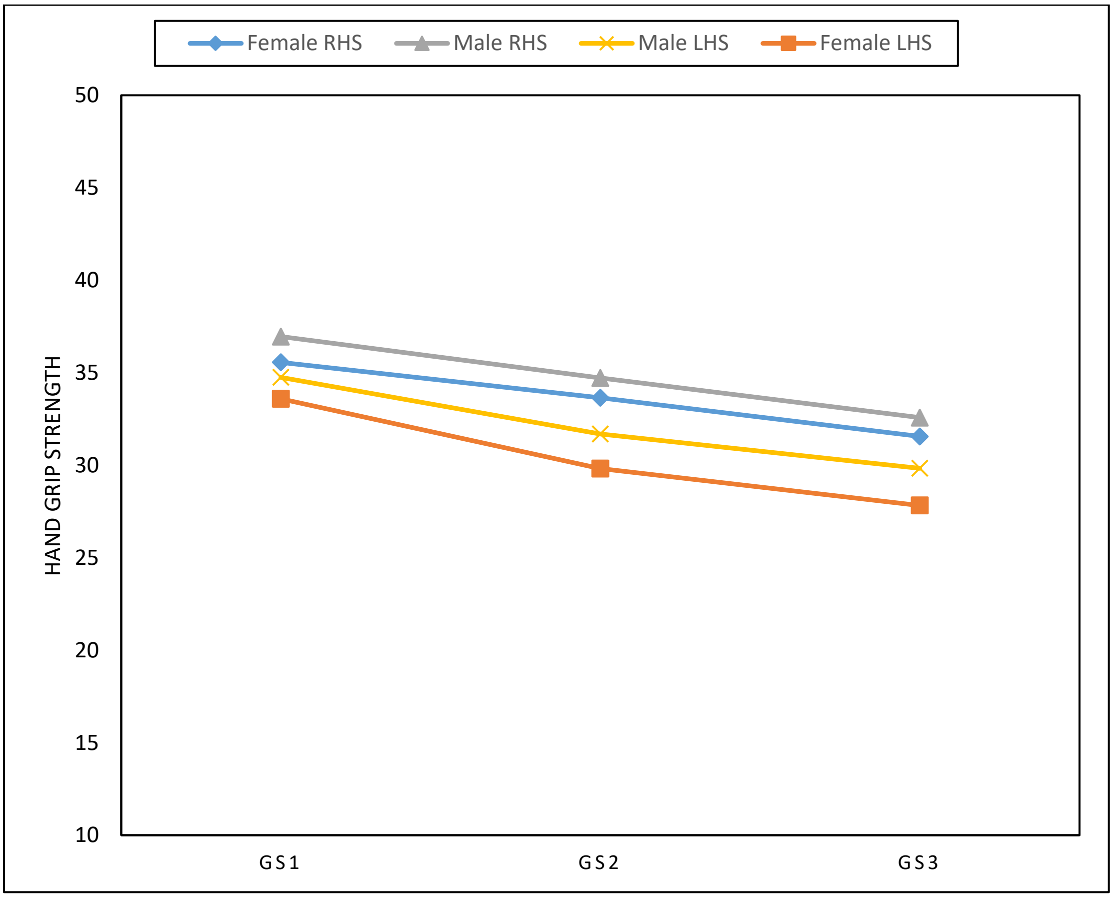


Figure 4.8: Effect of exposure time on hand grip strength

4.8 Summary

Findings of the present study showed that most of the labourers belonged to the age group of 21–30 years, which is almost similar to the results of previously published studies (Bandyopadhyay and Sen, 2016; Das, 2014; Das, 2015; Sett and Sahu, 2014; 2016). Therefore, it seems that the workers of higher age group find it hard to be in this profession. In contradiction to these studies, majority of workers were found with normal BMI which shows better nutritional condition of brick workers in Rajasthan compared to some other Indian studies (Bandyopadhyay and Sen, 2016; Das, 2014; Sett and Sahu, 2016).

Shoulder related problems among workers doing spading and brick carrying tasks were found to be higher than average in the present study. These numbers are also higher compared to another previously reported work (Inbaraj et al., 2013) in the same field (23.5%). Some other Indian researchers (Chandra et al., 2011; Jain et al., 2018a; Ray et al., 2015) have reported a larger number of shoulder issues (56.7%, 87. 8% and 84.4%) in similar tasks compared to present study. It could be the result of repetitive awkward movement (beyond 90^o, raised and abducted positions) of shoulders during these activities. Musculoskeletal problems in the wrist regions were very high among workers performing the evacuating task, which is also higher than wrist problems reported by Inbaraj et al. (2013). The probable reason of large number of wrist issues could be repetitive twisting and bending of the wrist while reversing the moulding box that has an improperly designed handle size and orientation.

Pain and discomfort in fingers were very high among workers involved in mould filling task. However, the issues were lower in comparison to one previous research (Das, 2014), which reported finger related issues among 93% brick workers. Excessive strain during clot cutting, pulling and mould filling could be the reason behind this. The occurrence of lower back pain and discomfort was very high among workers performing spading and mould evacuating tasks. Inbaraj et al. (2013), Das (2014) and Das (2015) have also reported lower back pain among 59%, 70% and 93% brick workers respectively. Prolonged squatting posture and repetitive bending during these tasks could be the possible causes of lower back issues.

The postural analysis gave very high values of both REBA and RULA scores for spading and mould filling tasks. The use of un–ergonomically designed traditional hand tools with awkward postures and lack of awareness of ergonomic principles might be the probable reasons behind high postural risks (Jain et al., 2018). Studies related to postural analysis in brick kiln industry are limited. However, similar results were obtained in previous studies on Indian manual farming sector (Das et al., 2013; Jain et al., 2018a) where spading and working in squatting posture are almost similar to those in the brick industry.

Binomial and multinomial logistic regressions showed that age was significantly associated with musculoskeletal symptoms in most of the body parts; which is understandable and even resonates with some of the other Indian studies (Das, 2014;

Inbaraj et al., 2013; Jain et al., 2018a). Type of task was also found as an important contributing factor in causing discomfort in different body regions. Prevalence of lower back issues in males was higher as compared to females which might be due to work–related factors, and physiological and anatomical differences between males and females (Rosati et al., 2014). Underweight workers were more prone to shoulder related MSDs; which seems apparent as these workers have comparatively lesser strength (Bandyopadhyay and Sen, 2016; Dianat et al., 2015).

The results of hand grip assessment indicated that brick moulders are exposed to hand muscle fatigue; which may eventually result in hand MSDs. As mentioned earlier, workers lose their hand grip strength after repetitive and strenuous tasks performed over long intervals of time.

To address the aforesaid musculoskeletal issues among brick kiln workers, there is a need for ergonomic interventions. The ergonomic interventions for improving musculoskeletal health of brick kiln workers are described in Chapter 5.

Chapter 5

Design and Validation of Ergonomic Interventions

5.1 Introduction

The results of questionnaire survey for prevalence of musculoskeletal symptoms, hand grip analysis and postural assessment described in Chapter 4 showed that most of the brick kiln workers suffered from musculoskeletal problems in the wrist, lower back, shoulder, finger, upper arm and knee regions due to prolonged working in a specific task with a load, repetition and awkward postures. It was also observed that kiln workers are exposed to very high risks in spading and mould filling tasks. The risk levels were found high in mould evacuating and carrying tasks too. The hand grip strength of brick moulders was also found affected by strenuous tasks. These musculoskeletal problems among manual brick kiln workers can be managed by properly designed ergonomic interventions. Ergonomic interventions refer to the manipulation of tools, techniques and processes using ergonomic principles that have the potential of reducing exposure to physical hazards. In order to reduce musculoskeletal issues and symptoms, various interventions such as work place improvements, hand tool improvements, workers' and managers' training, physical exercises, and design and use of personal protection equipment are proposed in literature.

There is a severe shortage of the literature related to ergonomic interventions for improving the health of clay brick kiln workers. Therefore, efforts have been made to develop some ergonomic interventions for improving health of brick kiln workers in India. Further, these interventions have been tested in the field through an ergonomic point of view for its effectiveness. In this chapter, the development procedure and validation of three ergonomic interventions namely, the effect of lumbar belt on lower back issues, design of moulding box, and design of clot cutter/mud puller is described.

5.2 Effect of lumbar belt on lower back issues

Among the various musculoskeletal issues, lower back pain (LBP) is the most frequent reported problem throughout the world (Das, 2015; Wynne, 2014). Higher rate of lower back musculoskeletal symptoms has been found to occur among manual workers, specifically the workers who regularly perform most of the work in a bent posture and make repetitive movements with upper body parts. Bending and twisting positions, in addition to load, could be major causes of LBP among workers (Driscoll et al., 2014; Sterud and Tynes, 2013). In some previous studies, lower back problems were reported as a frequent issue among brick kiln workers (Das, 2014; Das, 2015). Also, in the present study, lower back issues were found to be most frequent among spading and mould evacuating workers. Various approaches have been proposed for LBP prevention and treatment, such as ergonomic design of workplace, exercises, workers training and lumbar supports. The lumbar belt supports the spine by preventing flexo– extension and lateral bending, and decreases the load on the trunk (Ammendolia, 2005; Van Poppel, 2000).

The aim of present study was to investigate the effect of the flexible lumbar belt on lower back issues among brick kiln workers who reported these issues in the questionnaire survey.

5.2.1 Materials and methods

To address the lower back issues, a study on effect of lumbar belt along with some light exercises was designed and conducted. In the questionnaire survey described in previous chapter, 125 workers involved in spading, mould evacuating and brick carrying tasks reported lower back issues. These workers were further asked to give their responses about lower back pain/discomfort on a Likert scale of 1–5 (1: Pain not noticeable, 2: Low pain, 3: Moderate pain, 4: High pain, 5: Very High pain).

An adjustable lumbar belt was used on 72 workers who had moderate to very high lower back pain (3–5 score). Workers selected for intervention group wore a flexible lumbar belt as shown in Figure 5.1 (Tynor made) for 15 days, 3 hours/day. After 15 days, participants were again asked to give their response on lower back pain. Workers having moderate or high lower back pain were also advised to perform some light exercises (i.e., hamstring stretch, hip rolls, knee bends, extension exercises, knee to chest, etc.) after every two hours. The total intervention period was of three months. The mean and standard deviation of characteristics of workers were calculated, and the paired t–test was applied in order to study the differences between lower back pain before and after the intervention.

Figure 5.1: Lumbar belt used in the study

5.2.2 Study results

A total of 125 workers with a mean age of 32.82 years participated in the study. All the subjects had reported lower back issues in the questionnaire survey. The number of subjects involved in intervention study groups was 72. The characteristics of the workers involved in the study are shown in Table 5.1.

Table 5.1: Characteristics of participants (N = 125, male = 87, female = 38)

Characteristics	**(*Mean* ± *SD*)**
Age (year)	32.82 ± 8.26
Weight (kg)	59.26 ± 6.66
Height (cm)	170.67 ± 5.58
Body mass index	20.30 ± 1.60
Work experience	5.50 ± 2.02
Pain score before intervention	2.29 ± 1.15
Pain score after intervention	1.52 ± 0.70

Note: SD is standard deviation

It was observed that the level of pain and discomfort in lower back area was decreased significantly after the interventions were introduced. The number of workers reporting medium, high and very high levels of issues were very less, while the frequency of negligible pain was increased after the intervention. The frequency of workers having lower back problems before and after intervention is depicted in Figure 5.2.

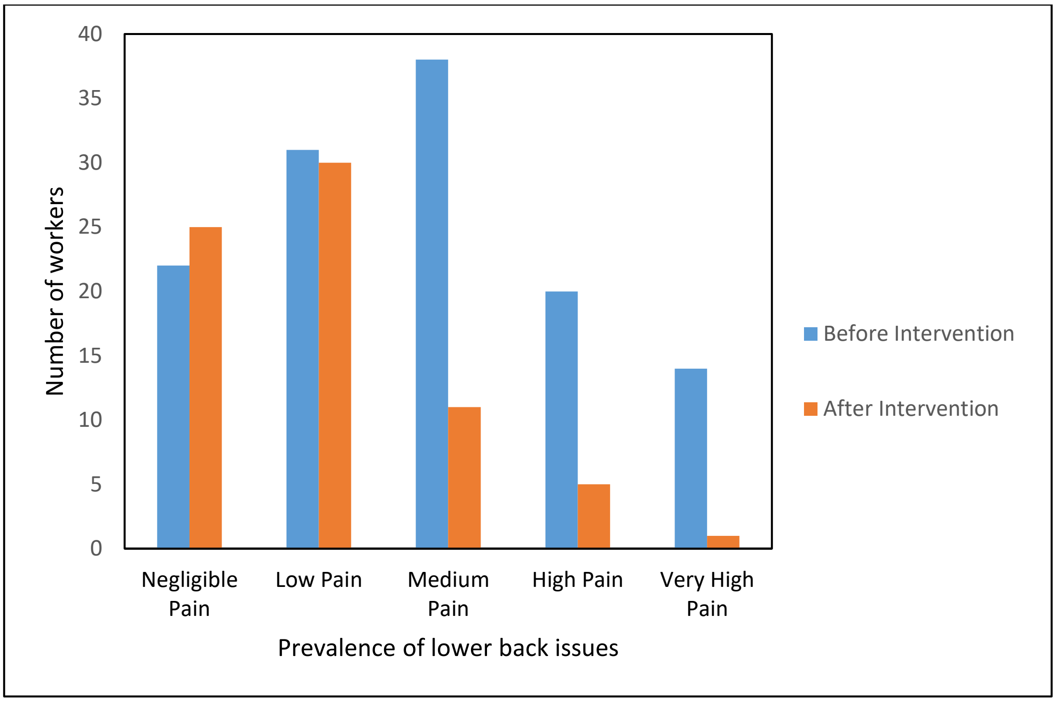


Figure 5.2: Prevalence of lower back issues before and after intervention

Paired t–test was used to analyse the effect of interventions on lower back pain among worker. A value of $p<0.05$ was considered as statistically significant. It was found that the lower back pain level was reduced significantly after the introduction of interventions as shown in Table 5.2.

Table 5.2: Paired t–test statistics

	Mean	N	SD	SEM	p
Before intervention	3.67	72	.79	.093	.000
After intervention	1.99	72	.96	.113	

The purpose of the present study was to examine the effectiveness of flexible lumbar belt on LBP symptoms. Study results show that the use of lumbar belt is beneficial for reducing the LBP symptoms among workers to some extent. Some previous studies have also proved that using lumbar belt helps people to continue their daily activities with substantially low levels of discomfort and reduced pain. These belts can restrict the lumbar motion by decreasing the load on certain parts of the spine. However, some previous studies have stated that there might be some adverse biomechanical effects of wearing lumbar belts over a long time. It is speculated that the use of lumbar support for a long time could weaken the trunk muscles.

Nevertheless, results in the previous studies are contradictory and do not seem to confirm this thought (Ammendolia, 2005; Van Poppel, 2000). The subjective nature of assessment in these studies might be the reason for such inconclusive results. Long term electromyography studies along with subjective responses may prove to be much effective in arriving at a valid conclusion.

5.3 Design of hand tools

Hand tools have been in use for thousands of years, initially for hunting and gathering food. These have been the primary means to extend the capabilities of the hand (Mital, 1991).

In a country like India, hand tools are used in various small scale industries including the unorganised sector. A major part of manual clay brick manufacturing work is still performed using hand tools despite the ongoing automation in other sectors. Therefore, proper design of hand tools can play an important role in preventing musculoskeletal issues, such as carpal tunnel syndrome, tendonitis, etc. Ergonomically designed hand tools can improve workers’ comfort and reduce biomechanical stresses and risk factors for musculoskeletal problems. In the present study, in order to reduce wrist and finger issues, the design of moulding box was improved, and a new hand tool for clot cutting/mud pulling was designed according to ergonomic principles.

Before designing the hand tool for brick kiln workers, current working practices and various hand tools commonly used in the brick kiln industry were analysed critically. The various hand tools used by brick kiln workers are depicted in Figure 5.3. During the analysis of hand tools, it was observed that the design of moulding box was very poor as per ergonomic principles. The size, shape and orientation of handles in moulding boxes were found to be inappropriate, and these were mainly responsible for wrist and finger issues as mentioned in Chapter 4. It was also observed that the clot cutting task is performed by hands without any hand tool. The fingers and wrists are exposed to repetitive strain during clot cutting task, as mentioned previously in hand grip strength analysis. Hence, modification in the design of moulding box and design of a clot cutting/mud pulling tool were taken up.

Figure 5.3: Hand tools used in brick kiln industry

5.3.1 Materials and methods

To reduce the prevalence of wrist and finger issues among brick moulders, two hand tools, moulding box, and clot cutter/ mud puller were designed ergonomically. The existing moulding box design was not found to be proper and the clot cutting was done by hands without using any hand tool. These issues resulted in biomechanical stress on fingers, wrists and lower arms. To design the tools, anthropometric data of 102 randomly selected workers were collected and used. For mechanical design, ANSYS 16 and CATIA V5R18 software were used. For human hand tool modelling and postural analysis, CATIA V5R18 was used. A usability test was performed to test the quality of existing and newly designed hand tools. Figure 5.4 shows the procedure of hand tool development. The first step in hand tool design was identification of musculoskeletal issues. The second step was the study of existing practices and hand tools. After analysis of existing hand tools and work practices, the new hand tools were designed as per ergonomic principles. The design was first tested in a virtual environment; then physical prototypes were fabricated. The hand tools were tested with 32 workers in field environment, and the design was validated after successful feedback.

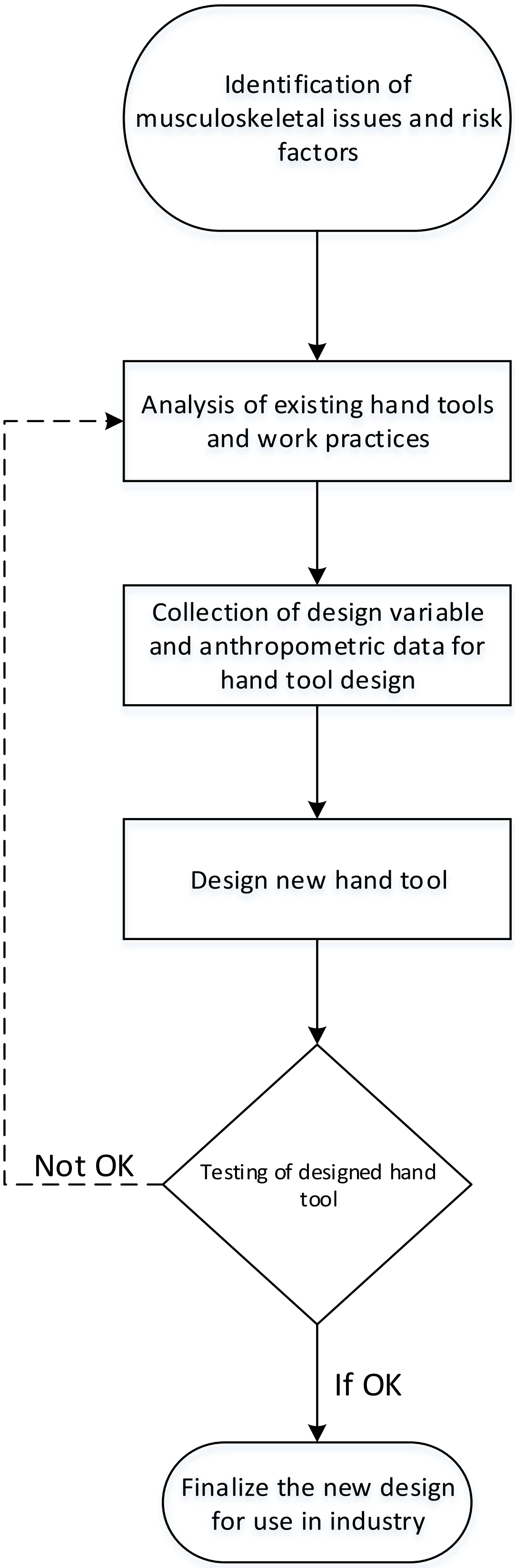


Figure 5.4: Hand tool development procedure

While designing the handle length, shape, diameter and orientation, the anthropometric dimensions, strength data and working conditions were taken into consideration. According to ergonomic design principles, it is advised that the handle of hand tools should be designed in such a way that the hand and forearm accompany each other for better comfort and minimum stress in usage. The contour of the handle also influences the posture; therefore the contour of handle is another main aspect which can be utilized to decrease or reduce exhaustion faced by the workers.

The main muscles, which bend the fingers and produce grip are found in the forearm. The wrist joint is expanded by long tendons of these muscles. Hence, the gripping ability of the fingers is affected by the wrist position. Regular usage of manual hand tools in awkward positions of the wrist can cause musculoskeletal disorders to both parts of wrist (i.e., synovial coverings for guarding the tendons and median nerve crossing over the wrist). The cross–section of the tool handle also influences workers' operating performance and comfort. The power produced in usage should be spread over the large pressure areas of the palm. If the designed hand tool has a small handle that does not create space between the coverage of the palm, a large pressure is generated at the midpoint of the palm (Lewis and Narayan, 1993).

Hence, the handle should be designed such that it is as far away as possible from the hand when gripped. Sharp ends and curves may produce scratches, damages, or wear/tear. Therefore, the design should be preferably modified by turning sharp ends and replacing steep curves by large radius curves. All aforesaid points were considered, and 5th percentile and 95th percentile values of dimensions were used as per requirement to match with majority of workers.

5.3.2 Hand anthropometry of workers

For the ergonomic design of hand tools, anthropometric data is a prerequisite. As revealed from review of literature, anthropometric data of Indian workers is available for specific regions only. Desired anthropometric data of brick kiln workers in Rajasthan is not readily available. Hence several desired hand anthropometric dimensions of brick kiln workers as shown in Table 5.3 were measured in order to create a database.

Table 5.3: Details of hand anthropometric dimensions

S. No.	Anthropometric dimension	Detail
1	Hand length	The distance from the base of the hand to the top of middle finger along the long axis of the hand
2	Middle finger length	The distance from the base of to the top of middle finger along the long axis of the hand
3	Middle finger II–phalanx length	The distance from the II phalanx to the top of middle finger along the long axis of the hand
4	Palm length	The distance from the base of hand to the furrow where the middle finger folds upon the palm.
5	Hand breadth at metacarpal–III	The breadth of the hand measured across the distal ends of the metacarpal bones
6	Hand breadth across thumb	The breadth of the hand measured at the level of the distal end of the 1st metacarpal of thumb
7	Hand thickness at metacarpal–III	The thickness of the hand measured at metacarpal along short axis of the hand
8	Hand grip diameter	The diameter of the widest level of a cone, which the subject can grasp with his thumb and middle finger touching

The pictorial view of measured anthropometric hand dimensions is represented in Figure 5.5.

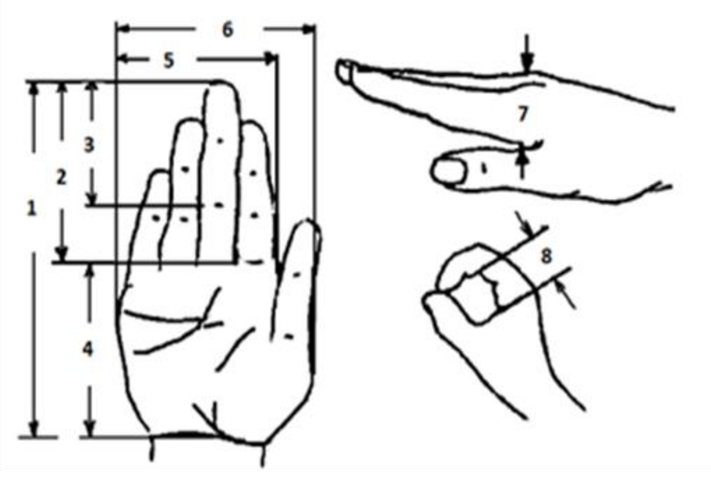


Figure 5.5: Hand anthropometric dimensions

From the collected anthropometric data, the values of minimum, maximum, mean, standard deviation (SD), standard error of mean (SEM), variance, range, 5th, 90th and 95th percentile values of body dimensions, stature, palm length, hand length, hand breadth, hand thickness and middle finger lengths were evaluated. These statistics are presented in Table 5.4. This anthropometric data was used to design hand tools for clay brick kiln workers.

Table 5.4: Anthropometric data of brick kiln workers *(n= 102)*

Statistics	**Mean**	**SEM**	**SD**	**Variance**	**Range**	**Minimum**	**Maximum**	**Percentiles**		
								5	**90**	**95**
Stature (cm)	170.66	0.33	3.33	11.10	14.50	162.00	176.50	163.03	174.78	175.20
Middle finger length	7.63	0.03	0.34	1.17	1.50	6.62	8.12	6.76	8.02	8.05
Hand breadth at MC III	7.76	0.04	0.35	1.25	1.49	6.84	8.33	7.06	8.23	8.26
Hand breadth across thumb	9.96	0.05	0.54	2.90	2.96	7.76	10.72	8.92	10.52	10.62
Hand thickness	3.46	0.05	0.51	2.56	1.99	2.63	4.62	2.73	3.94	4.31
Hand grip diameter	5.05	0.07	0.67	4.45	2.47	3.68	6.15	3.93	5.92	6.02
Middle finger length at II phalanx	4.82	0.02	0.23	0.52	1.00	4.14	5.14	4.24	5.08	5.10
Palm length	8.85	0.04	0.40	1.57	1.74	7.68	9.42	7.85	9.30	9.34
Hand length	16.49	0.07	0.74	5.43	3.24	14.30	17.54	14.60	17.32	17.38

5.3.3 Design of moulding box

Brick moulding is basically a repetitive and continuous task performed in squatting posture in which a load of around 7 to 9.5 kg is handled each time by fingers and wrists of both hands with a frequency of 4 –5 bricks per minute. This leads to a total load handling equivalent to 22.5 to 47.5 kg per minute. A worker on an average makes 1000 –1200 bricks per day. Thus, a worker carries a minimum of 6,000 kg load per day. Due to awkward postures and repetitive loads, the prevalence of wrist and hand issues were more frequent. The prepared clay (mud) is moulded in the form of bricks with the help of a moulding box. Moulding box or mould is an important hand tool used in manual clay brick industry. The Conventional moulding box used by the workers is a hollow rectangular cuboid open from the top and made of wood or aluminium. As investigated through questionnaire survey and hand grip strength analysis, the hand musculoskeletal issues were prevalent among brick moulders. Hence, it was important to modify the existing design of moulding box ergonomically. Before modifications were introduced, existing moulding boxes were analysed critically.

Existing moulding box

The isometric view and 2–D drawing of conventional moulding box is depicted in Figure 5.6. This moulding box is made up of wood, and has an overall weight of 1–1.5 kg. In the conventional moulding box, two small handles are provided at one end. The handles (as can be seen from Figure 5.6) are trapezoidal in shape with a rectangular cross–section.

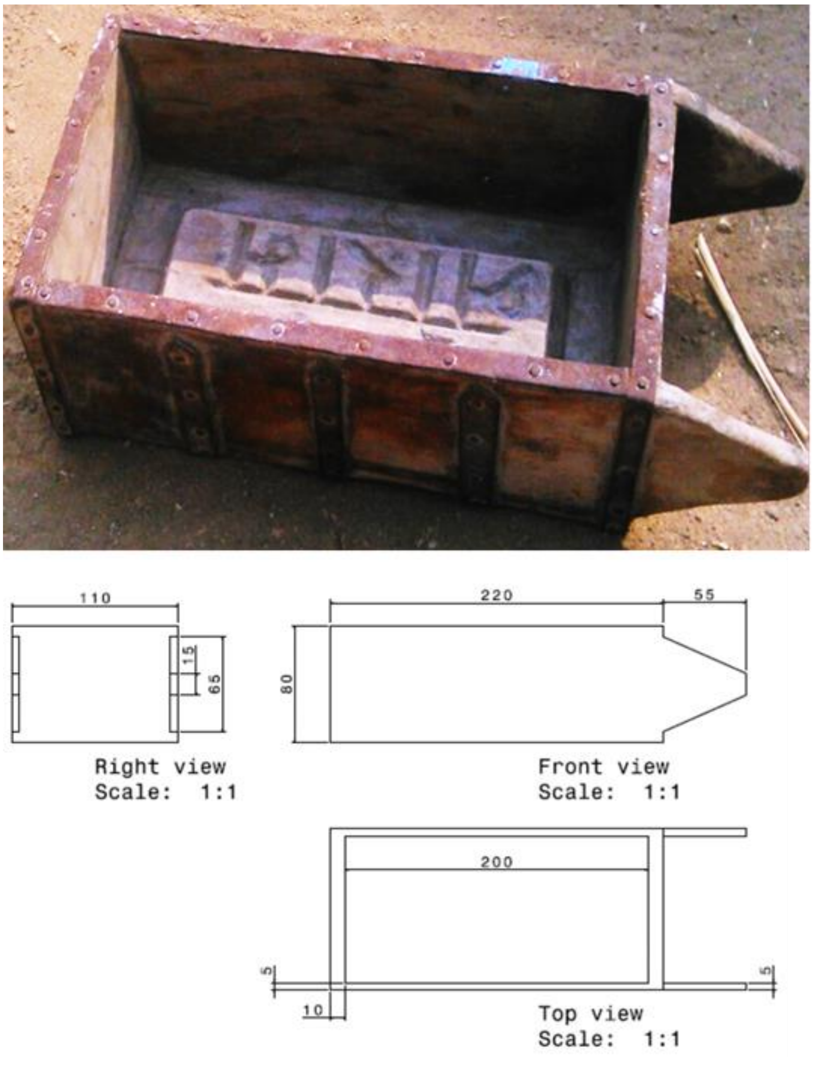


Figure 5.6: Photograph and orthogonal views of conventional moulding box

The size, shape and orientation of handles were not ergonomically designed, and were not according to anthropometric dimensions of workers. This resulted in awkward postures of wrists and arms. To reduce the hand musculoskeletal issues, the moulding box was redesigned considering hand anthropometry of brick kiln workers. In the proposed designs, the hand and wrist postures were improved by altering the handle size, shape and orientation.

Modifications in moulding box design

The design of handle is attributed with the size, shape, orientation, texture and hardness of the grip. The handle should be gripped in such a way so that the fingers and thumb flex around the handle. Based on anthropometric considerations, the handle should accommodate the maximum dimension of hand breadth at thumb. Incorporating the ergonomic principles, two moulding box designs were proposed as shown in Figure 5.7.

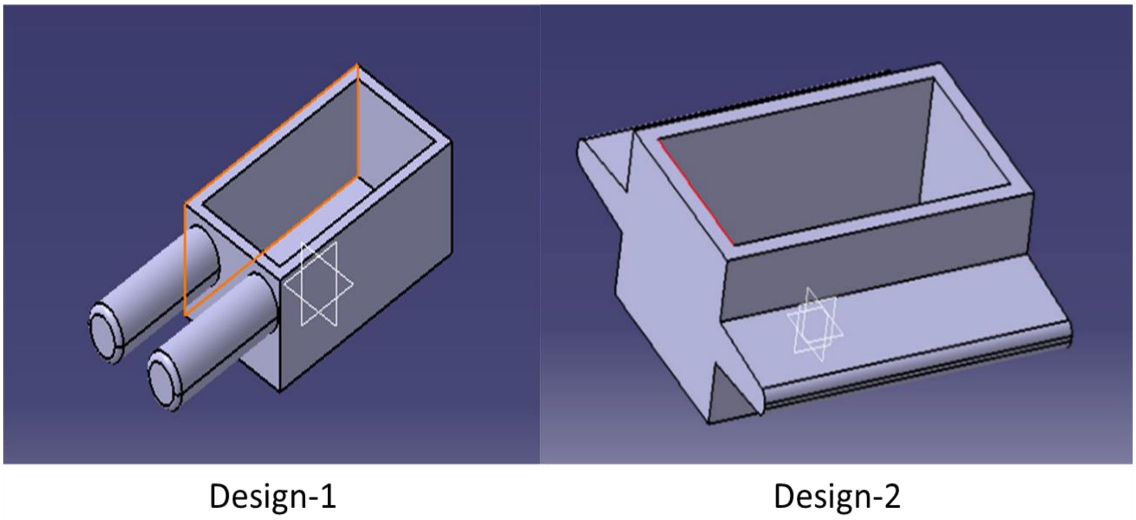


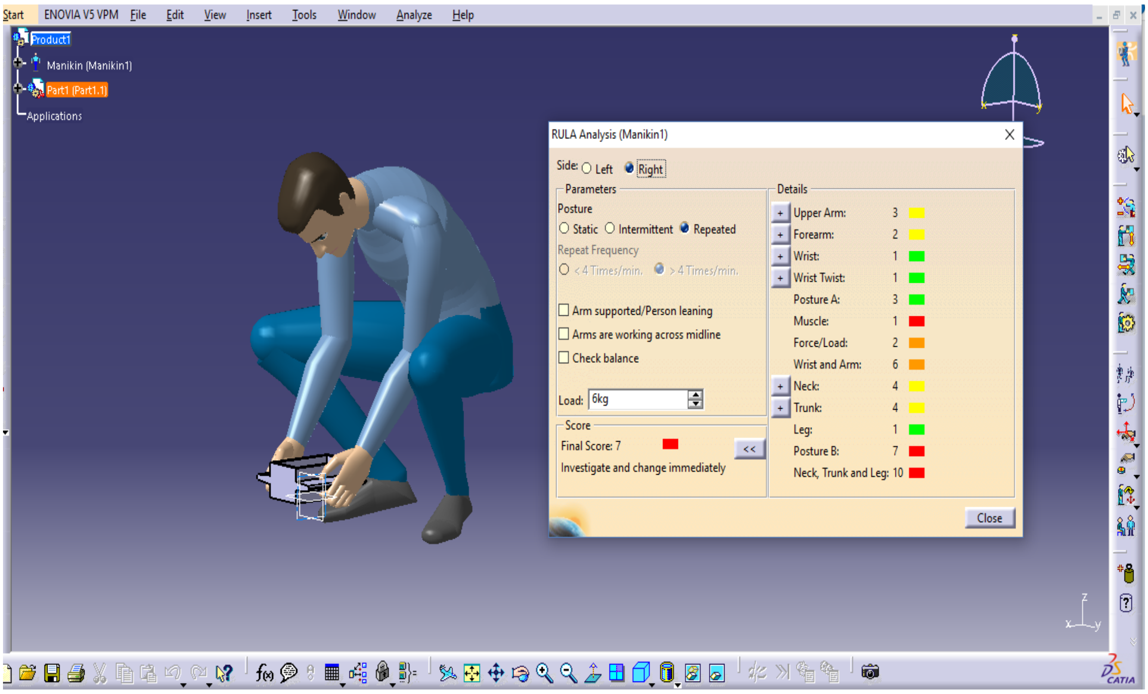
Figure 5.7: Proposed designs of moulding box

In design–1, the length and diameter of handles were modified according to hand anthropometric data of the brick kiln workers.

As per the ergonomic principles, the handle should be designed on the basis of hand breadth at thumb. The 95th percentile value of the hand breadth at thumb for brick kiln workers was found to be 10.62 cm. Considering a clearance of 0.5 cm on each side of the grip, the length of the handle comes to 11.62 cm; and this value was recommended for the length of the handle.

For better grasp, the handle diameter should not go beyond the inside grip diameter of the user's hand. Therefore, the handle diameter should be kept according to the 5th percentile value of the inside grip diameter to cover the larger population group. The value of the inside grip diameter for brick kiln workers was found to be 3.93 cm. However, design–1 had to be discarded due to heavy moment (approximately 91 kg–cm) on the wrist. To reduce this heavy moment and for better hand posture, design–2 was chosen for further consideration. In this design, holding flanges were provided on both sides of the moulding box instead of handles to reduce the moment on wrists. These flanges were also helpful in lifting the vacant moulding boxes while evacuating green bricks on the ground. The moment on the wrists with the flanges was reduced to 75 kg–cm.

The length of flange was taken same as the length of the box. The breadth of flange was taken as 95th percentile of middle finger length up to II Phalanx for the workers, which was found to be 5.10 cm. Firstly, the design was tested in a virtual environment using human hand tool modelling in CATIA as shown in Figure 5.8. The RULA assessment in virtual environment showed that the wrist and hand postures were improved significantly.



RULA Analysis (Manikin1)

Side: ○ Left ● Right

Parameters

Posture

○ Static ○ Intermittent ● Repeated

Repeat Frequency

○ < 4 Times/min. ● > 4 Times/min.

☐ Arm supported/Person leaning

☐ Arms are working across midline

☐ Check balance

Load: 6kg

Score

Final Score: 7 🟥

Investigate and change immediately

Details

Upper Arm:	3	🟨
Forearm:	2	🟨
Wrist:	1	🟩
Wrist Twist:	1	🟩
Posture A:	3	🟩
Muscle:	1	🟥
Force/Load:	2	🟧
Wrist and Arm:	6	🟧
Neck:	4	🟨
Trunk:	4	🟨
Leg:	1	🟩
Posture B:	7	🟥
Neck, Trunk and Leg:	10	🟥

Figure 5.8: Postural analysis of design–2 in CATIA

After testing in a virtual environment, the prototype of the moulding box as shown in design–2 was fabricated. Pine wood was used as the material for the box. The photograph of newly designed moulding box with its specifications is shown in Figure 5.9. The physical prototype was then validated using CQH among the brick kiln workers.

Specifications

Material: Pine wood
Weight: 1.5 kg
Size: 22 cm x 10 cm x 8 cm x .75 cm
Flange width: 5.10 cm
Flange length: 23.5 cm

Figure 5.9: Newly designed moulding box and its specifications

5.3.4 Usability analysis of moulding box

Usability test of moulding box was done using self–reporting comfort questionnaire for hand tools (CQH). The questionnaire was administered among 32 participants aged between 18 to 40 years. The participants were asked to rate the hand tool on a scale of 1(Fully disagree) to 5 (fully agree) for given parameters.

The existing moulding box obtained low scores as compared to newer one for various hand tool parameters. The usability score for existing and newly designed moulding boxes are given in Table 5.5. For existing moulding box, lowest score was given to posture of hand/wrist (1.44). Average usability score was 2.13, while the maximum (3.28) score was given to ease of use. For newly designed moulding box, the usability scores were more than 3 for all parameters. Maximum rating was given to ease of use (4.22) and comfort (4.09). The minimum rating (3.06) was given to the symptoms of blisters. However, the overall ratings were better than that of the conventional moulding box. The average usability score for newly designed tool was 3.42 which shows that the tool is comfortable for use.

Table 5.5: Outcomes of usability test for moulding box

Parameters	**Conventional moulding box**		**Newly designed moulding box**	
	Average Score	SD	Average Score	SD
Ease of use	3.28	0.89	4.22	0.75
Proper handle size	2.22	0.66	3.13	0.79
Proper handle shape	2.06	0.76	3.09	0.86
Good fit of handle	1.88	0.61	3.09	0.89
Proper handle orientation	2.03	0.78	3.91	5.56
No symptoms of blisters	2.22	0.61	3.06	0.80
Good posture of wrist/hand	1.69	0.54	3.22	0.94
Less moment on hand	1.81	0.54	3.16	0.88
Low muscle pain	2.03	0.59	3.19	0.82
Good comfort	2.09	0.69	4.09	0.82
Average Score	**2.13**		**3.42**	

Note:– *1: Fully disagree, 2: Somewhat disagree, 3: Neutral, 4: Somewhat agree, 5: Fully agree*

5.4 Design of clot cutting/mud pulling hand tool

In the current practice, the clot cutting and mud pulling tasks are performed by hands which exerts stress on fingers and wrists. This can be seen from Figure 5.10.

Figure 5.10: Conventional method of clot cutting

Repetitive stress on fingers and wrists results in musculoskeletal issues. To reduce hand musculoskeletal symptoms in fingers and wrists, a clot cutting/mud pulling hand tool was conceptualised. The clot cutting tool is basically a spade–like tool with two handles. The clot cutting tool was firstly designed using ANSYS software and was analysed using finite element analysis (FEA). The finite element analysis of the designed hand tool is shown in Figure 5.11.

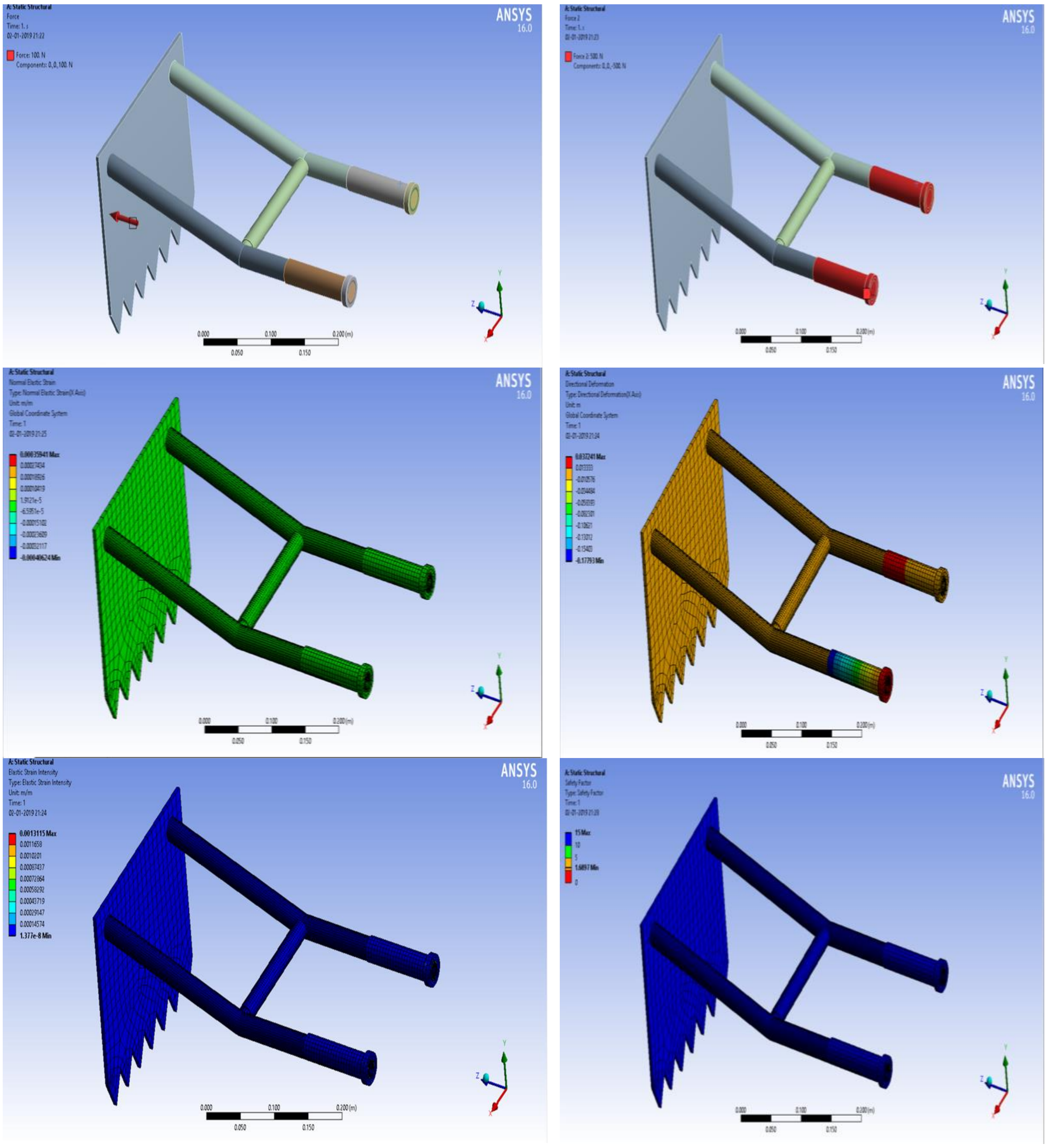
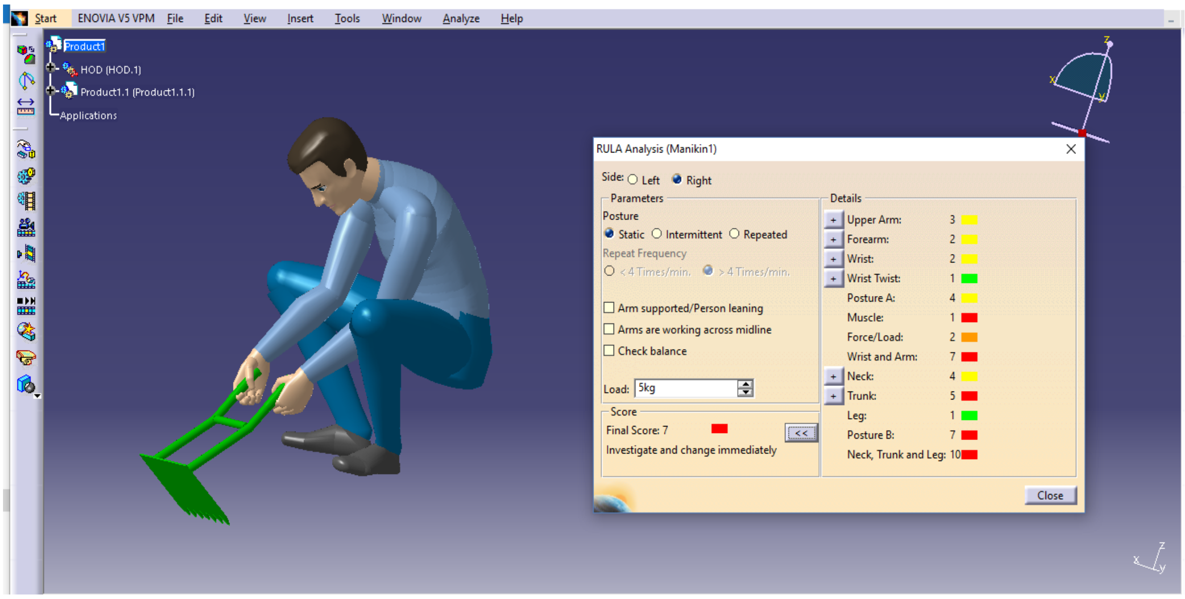


Figure 5.11: Finite element analysis of clot cutter/mud puller

Taking the maximum pull as 500 N and load as 100 N, the values of strain intensity, stress, directional deformation and factor of safety were calculated. The maximum value of factor of safety was obtained as 16 while the minimum value of factor of safety was 1.69. The analysis shows that the design can bear the given load without fail.

The dimensions of the clot cutting tool were taken as per anthropometric data and established principles from literature. The 95th percentile value of the hand breadth at thumb for brick kiln workers was found to be 10.62 cm. Taking a clearance 0.5 cm, the minimum length of hand grip was found to be 11.62 cm. Keeping a proper distance from the worker's body, the total handle length was taken as 40 cm. The 5th percentile value of the inside grip diameter was found to be 3.93 cm. This value was considered for hand grip diameter. The rake angle of 22.5° was provided for better cutting of mud. A shank angle of 15° was also provided to maintain the neutral position of wrists and arms. The size of blade was taken as 25 cm x 20 cm with a serrated end (height of serrations being 1 cm).



RULA Analysis (Manikin1)

Side: ○ Left ● Right

Parameters

Posture

● Static ○ Intermittent ○ Repeated

Repeat Frequency

○ < 4 Times/min. ● > 4 Times/min.

☐ Arm supported/Person leaning

☐ Arms are working across midline

☐ Check balance

Load: 5kg

Score

Final Score: 7 🟥

Investigate and change immediately

Details

Upper Arm:	3	🟨
Forearm:	2	🟨
Wrist:	2	🟨
Wrist Twist:	1	🟩
Posture A:	4	🟨
Muscle:	1	🟥
Force/Load:	2	🟧
Wrist and Arm:	7	🟥
Neck:	4	🟨
Trunk:	5	🟥
Leg:	1	🟩
Posture B:	7	🟥
Neck, Trunk and Leg:	10	🟥

Figure 5.12: Postural assessment with clot cutter

Postural analysis using human hand tool modelling was done in CATIA environment as shown in Figure 5.12. After testing in a virtual environment, the physical prototype of the clot cutting/mud pulling tool was fabricated. Structural steel was used as material for the tool. The photograph of newly designed hand tool with its specifications is shown in Figure 5.13. The physical prototype was then validated using CQH among workers.

Material: Structural steel
Weight: 1.3 kg
Blade Size: 25 cm x 20 cm
Handle length: 40 cm
Handle diameter: 2.5 cm
Grip length: 11.12 cm
Grip diameter: 3.93 cm.
Rake angle: 22.5 degree
Shank angle: 15 degree

Figure 5.13: Newly designed clot cutting/mud pulling hand tool

5.4.1 Usability analysis of clot cutter

Usability test of clot cutter/ mud puller was done using self–reporting comfort questionnaire for hand tools. The questionnaire was administered among 32 participants aged between 18 to 40 years.

Table 5.6: Outcomes of usability test for clot cutter

Parameter	**Score**	
	Average	**SD**
Ease of use	4.25	0.76
Proper handle size	3.34	0.55
Proper handle shape	3.25	0.76
Good fit of handle	3.41	0.67
Proper handle orientation	3.28	0.81
No symptoms of blisters	3.38	0.75
Good posture of wrist/hand	3.38	0.66
Less moment on hand	3.31	0.54
Low muscle pain	3.31	0.82
Good comfort	4.19	0.74
Average Score	**3.51**	

Note:–*1: Fully disagree, 2: Somewhat disagree, 3: Neutral, 4: Somewhat agree, 5: Fully agree*

The participants were asked to rate the hand tool on a scale of 1(Fully disagree) to 5 (fully agree) for given parameters. The usability scores for the newly designed tool are given in Table 5.6. The average usability score was 3.53. The minimum rating (3.25) was given to the handle shape. The average score indicates that the tool was found to be “mostly comfortable”.

5.5 Summary

The use of a lumbar belt with light stretching exercises was found to be significantly effective in reducing lower back issues among workers. The postural assessment and usability test proved that modified moulding box and the newly designed clot cutting/ mud pulling tool reduce the work–related musculoskeletal problems among brick kiln workers and improve the work comfort.

Chapter 6

Concluding Remarks

6.1 Summary of the work done

In the current study, manual clay brick manufacturing activities were ergonomically analysed, and ergonomic interventions were designed to address the musculoskeletal issues. Based on the study, the following conclusions can be made:

- Manual clay brick manufacturing in traditional kilns is a high–risk occupation. Also, the workers in this particular sector have a lack of awareness about use of ergonomic principles and safe work practices. As a result, the brick kiln workers suffer from various occupational health problems especially musculoskeletal health issues and MSDs. Workers prefer this occupation in their young age only and migrate to other sectors due to various issues including MSDs.
- The work–related musculoskeletal problems among brick kiln workers can be minimised by properly designed ergonomic interventions. However, the ergonomic intervention studies in clay brick manufacturing sector are hardly seen in the literature. Hence, the present research was taken up for preventing musculoskeletal issues of manual brick kiln workers through ergonomic interventions.
- The present study was carried out mainly in two steps. In the first step, musculoskeletal health and association of musculoskeletal issues with various risk factors were explored. As per the results of the study, musculoskeletal issues in the wrist and lower back regions were reported most frequently among brick kiln workers. Postural analysis showed that kiln workers are exposed to very high risks in spading and mould filling tasks. Hand grip strength analysis revealed that the hand musculoskeletal system of brick moulders get affected by prolonged strenuous tasks.
- In the second step of research, ergonomic interventions were designed and validated to address the musculoskeletal problems of brick kiln workers. A study was conducted to analyse the effect of the lumbar belt and stretching exercises on lower back issues, and the intervention was found to be

significantly effective in reducing such issues among workers. To address the hand musculoskeletal issues, the design of moulding box was modified and a clot cutting/mud pulling hand tool was ergonomically designed. Firstly, these hand tools were designed and tested on software, and then physical prototypes were fabricated. The postural assessment and usability test proved that newly designed hand tools reduce the work–related musculoskeletal problems and also improve work comfort.

6.2 Research findings

The major research findings in accordance with research objectives and research hypotheses specified in Chapter 2 are as follows:

- Most of the brick kiln workers belonged to the age group of 21–30 years, therefore, it seems that the workers of higher age group find it hard to be in this profession. Majority of workers were found with normal BMI which shows the better nutritional condition of brick workers in Rajasthan.
- More than 50% of brick kiln workers reported lower back, shoulder and wrist related musculoskeletal issues. Problems in the lower back and shoulder regions were reported by 62.35% and 57.65% of workers performing the spading task. From the workers involved in mould filling task, the majority of workers reported finger (55.79%) and wrist (53.68%) related issues. Most of the workers (76.19%) involved in mould evacuating task reported symptoms related to wrist regions followed by musculoskeletal issues in the lower back region (55.95%). Musculoskeletal problems in shoulder area were found in 53.13% of the brick carriers.
- From the logistic regressions results, workers’ age was found to be significantly associated with musculoskeletal symptoms in most of the body parts. Type of task was also found as an important contributing factor in causing MSDs in different body regions. Prevalence of lower back issues in males was found to be higher as compared to females. It was also found that underweight workers were more prone to shoulder related issues. The results of hand grip assessment indicated that brick moulders were exposed to hand muscle fatigue; which may eventually result in hand MSDs. Workers lose their hand grip strength after repetitive and strenuous tasks performed over long intervals of time.

- Study on the effect of lumbar belt with stretching exercises on LBP among brick kiln workers showed that the use of lumbar belt is beneficial for reducing the LBP symptoms among workers to some extent. The modified moulding box designed to minimise hand musculoskeletal issues, and newly designed clot cutting hand tool to address finger and wrist issues were found to be comfortable in usability and postural assessments. The average usability score for both the hand tools was found to be more than 3.

6.3 Limitations and scope for future work

In the current research, ergonomic interventions for reducing the lower back and hand musculoskeletal problems among clay brick kiln worker were successfully designed. However, the current research has some limitations which can steer motivation for future research.

- The present study was limited to only one state of India, i.e., Rajasthan; other regions can also be included in future studies.
- This research was cross–sectional in design, further longitudinal research can be conducted to study long term effects of exposure as well as interventions. In addition, more complex models considering physical and psychological factors can be designed for further investigations.
- In the present study only those workers who were performing specific tasks (i.e., spading, clot cutting and mould filling, mould evacuating, and brick carrying) for the last six months were studied. Effects of task rotation on musculoskeletal symptoms were not taken into consideration which may be studied in further studies.
- Besides musculoskeletal problems, other occupational health issues such as respiratory symptoms, skin and allergic problems may be included in future.
- In the current research, testing was done for short duration among a small group of workers which can be further extended for large population seen in the real work environment.
- To extend the findings of present research work, further study using advanced techniques like electromyography (EMG) and clinical studies may be conducted to identify long–term biomechanical and physiological changes among brick kiln workers.

- As another future research direction, training of workers and managers along with its effect on occupational health issues among brick kiln workers can also be suitably explored.

Musculoskeletal health of workers is an important concern, especially in developing as well as under–developed economies. In this context, the present work establishes a significant contribution to the research currently going on in this field. Not only does the present research provide evidence of the prevalence of musculoskeletal symptoms experienced by brick kiln workers; it also provides statistics of musculoskeletal problems among clay brick kiln and ergonomic solutions to manage them.

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Appendix–I: Modified Nordic questionnaire for prevalence of musculoskeletal issues

The purpose of this survey is to gain an insight into the different health problems among brick kiln workers from a design ergonomics perspective. All data collected would be kept confidential and would be destroyed after analysis.

Please answer the following questions /mark ✓ in appropriate box

Name:

Age (years): Height (cm): Weight (kg):

Gender: Male ☐ Female ☐

Smoking Habit: Yes ☐ No ☐

Qualification: Literate ☐ Secondary ☐ Sr. Secondary ☐

Other (specify):

Nature of work:

1. How long have you been in this work (years):

2. On an average how long do you work daily (tick):

a. less than 8 hours ☐ b. 8 hours ☐

c. more than 8 hours (specify):

3. Specify your normal working hours:

4. What is the duration of rest/break in between working hours?

a. 30 minutes ☐ b. 1 hour ☐ c. 1.5 hour ☐

d. other (specify):

5. Mention the body part that gives you maximum pain/discomfort at the end of a day work. You may select multiple choices.

Neck ☐ Shoulder ☐ Upper arm ☐

Lower arm ☐ Lower back ☐ Upper back ☐

Knee ☐ Wrist ☐ Fingers ☐

Other (specify):

6. Did you ever remain out of work due to severe pain in your body parts or other work related health issue?

a. Yes ☐ b. No ☐

If yes please specify the problem:

7. Any other health problems faced in this profession:

Signature of Worker (optional):

Thank you for your kind cooperation.

Appendix–II: Questionnaire for prevalence of lower back issues

The purpose of this to gain an insight into the lower back problems among brick kiln workers.

Please answer the following questions /mark ✓ in appropriate box

Name:

Age (years): Height (cm): Weight (kg):

Gender: Male ☐ Female ☐

Qualification: Literate ☐ Secondary ☐ Sr. Secondary ☐

Other (specify):

Used lumbar belt: Yes ☐ No ☐

1. Nature/type of work:

2. How long have you been in this work (years):

3. On an average how long do you work daily (tick):

a. less than 8 hours ☐ b. 8 hours ☐

c. more than 8 hours (specify):

4. What is the duration of rest/break in between working hours?

a. 30 minutes ☐ b. 1 hour ☐ c. 1.5 hour ☐

d. other (specify):

5. Do you feel pain/discomfort or any other issue at lower back region after work?

Yes ☐ No ☐

If yes, rate the level of pain/ discomfort

1	**2**	**3**	**4**	**5**
Pain not noticeable	Low pain	Moderate pain	High pain	Very high pain

Thanking You.

Appendix–III: Comfort questionnaire for hand tools

Name: Gender:
Age: Height: Weight:

Tick the number of your best answer; if you are unsure just estimate the level as closely as possible.

1: Fully disagree, 2: Somewhat disagree, 3: Neutral, 4: Somewhat agree, 5: Fully agree

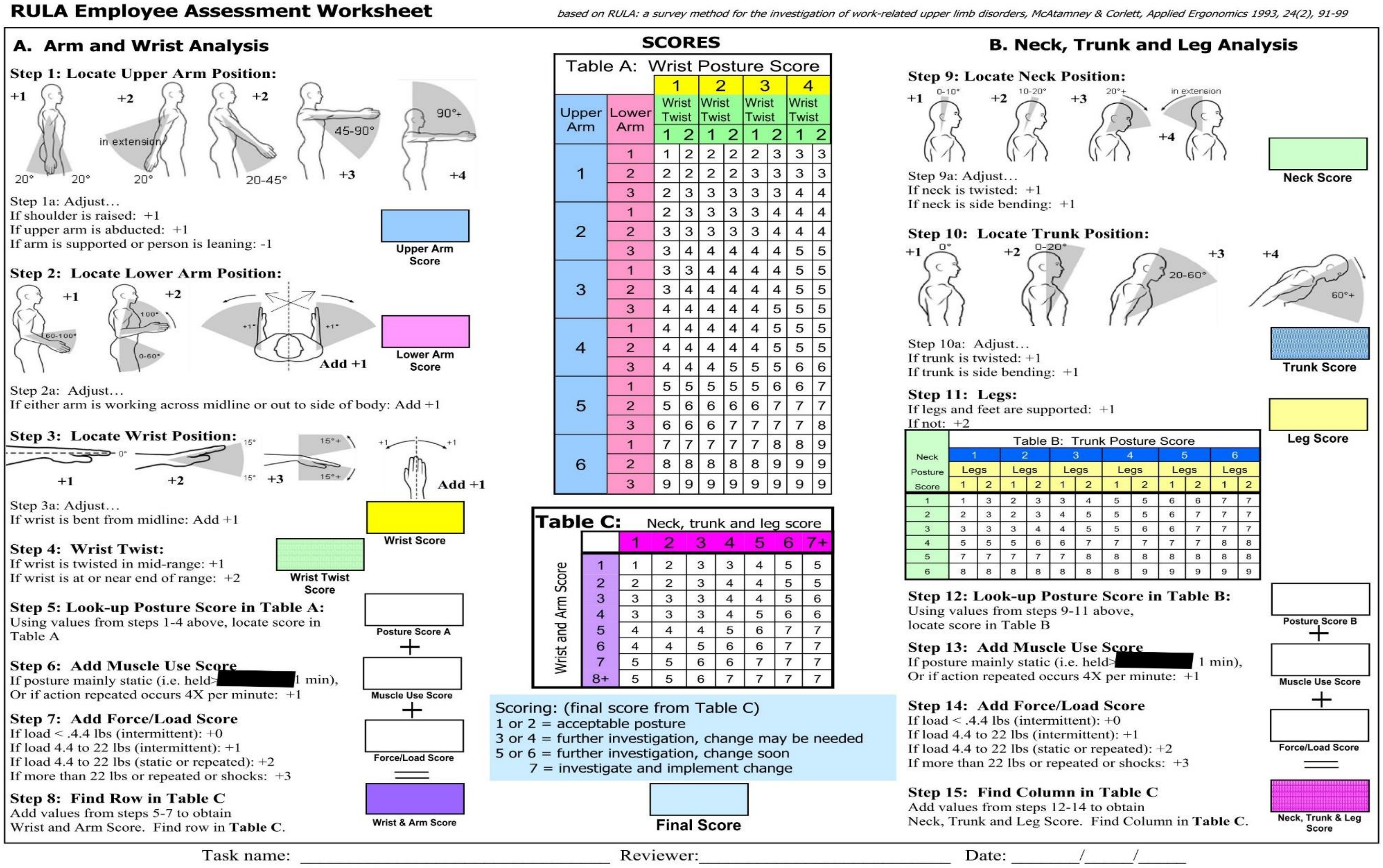
Parameter	**Response**				
Proper handle size	**1**	**2**	**3**	**4**	**5**
Proper handle shape	**1**	**2**	**3**	**4**	**5**
Proper fit of handle	**1**	**2**	**3**	**4**	**5**
Proper handle orientation	**1**	**2**	**3**	**4**	**5**
No symptoms of blisters	**1**	**2**	**3**	**4**	**5**
Proper posture of wrist/hand	**1**	**2**	**3**	**4**	**5**
Less moment on hand	**1**	**2**	**3**	**4**	**5**
Low muscle pain	**1**	**2**	**3**	**4**	**5**
Proper comfort	**1**	**2**	**3**	**4**	**5**

Any additional comments regarding the use or comfort of the tool:

Your cooperation and valuable participation for answering the questions is highly appreciated.

Thanking You.

Appendix–IV: RULA score sheet



RULA Employee Assessment Worksheet

based on RULA: a survey method for the investigation of work-related upper limb disorders, McAtamney & Corlett, Applied Ergonomics 1993, 24(2), 91-99

A. Arm and Wrist Analysis

Step 1: Locate Upper Arm Position:

Step 1a: Adjust…
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score

Step 2: Locate Lower Arm Position:

Lower Arm Score

Step 2a: Adjust…
If either arm is working across midline or out to side of body: Add +1

Step 3: Locate Wrist Position:

Step 3a: Adjust…
If wrist is bent from midline: Add +1

Wrist Score

Step 4: Wrist Twist:
If wrist is twisted in mid-range: +1
If wrist is at or near end of range: +2

Wrist Twist Score

Step 5: Look-up Posture Score in Table A:
Using values from steps 1-4 above, locate score in Table A

Posture Score A

+

Step 6: Add Muscle Use Score
If posture mainly static (i.e. held>[redacted]1 min),
Or if action repeated occurs 4X per minute: +1

Muscle Use Score

+

Step 7: Add Force/Load Score
If load < .4.4 lbs (intermittent): +0
If load 4.4 to 22 lbs (intermittent): +1
If load 4.4 to 22 lbs (static or repeated): +2
If more than 22 lbs or repeated or shocks: +3

Force/Load Score

=

Step 8: Find Row in Table C
Add values from steps 5-7 to obtain Wrist and Arm Score. Find row in **Table C**.

Wrist & Arm Score

SCORES

Table A: Wrist Posture Score

		1		2		3		4	
		Wrist Twist		Wrist Twist		Wrist Twist		Wrist Twist	
Upper Arm	Lower Arm	1	2	1	2	1	2	1	2
1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	3	3	3	4	4	4
	2	3	3	3	3	3	4	4	4
	3	3	4	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5
	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	7	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

Table C: Neck, trunk and leg score

Wrist and Arm Score	1	2	3	4	5	6	7+
1	1	2	3	3	4	5	5
2	2	2	3	4	4	5	5
3	3	3	3	4	4	5	6
4	3	3	3	4	5	6	6
5	4	4	4	5	6	7	7
6	4	4	5	6	6	7	7
7	5	5	6	6	7	7	7
8+	5	5	6	7	7	7	7

Scoring: (final score from Table C)
1 or 2 = acceptable posture
3 or 4 = further investigation, change may be needed
5 or 6 = further investigation, change soon
7 = investigate and implement change

Final Score

B. Neck, Trunk and Leg Analysis

Step 9: Locate Neck Position:

Step 9a: Adjust…
If neck is twisted: +1
If neck is side bending: +1

Neck Score

Step 10: Locate Trunk Position:

Step 10a: Adjust…
If trunk is twisted: +1
If trunk is side bending: +1

Trunk Score

Step 11: Legs:
If legs and feet are supported: +1
If not: +2

Leg Score

Table B: Trunk Posture Score

Neck Posture Score	1		2		3		4		5		6	
	Legs		Legs		Legs		Legs		Legs		Legs	
	1	2	1	2	1	2	1	2	1	2	1	2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	7	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	9	9	9	9	9

Step 12: Look-up Posture Score in Table B:
Using values from steps 9-11 above, locate score in Table B

Posture Score B

+

Step 13: Add Muscle Use Score
If posture mainly static (i.e. held>[redacted]1 min),
Or if action repeated occurs 4X per minute: +1

Muscle Use Score

+

Step 14: Add Force/Load Score
If load < .4.4 lbs (intermittent): +0
If load 4.4 to 22 lbs (intermittent): +1
If load 4.4 to 22 lbs (static or repeated): +2
If more than 22 lbs or repeated or shocks: +3

Force/Load Score

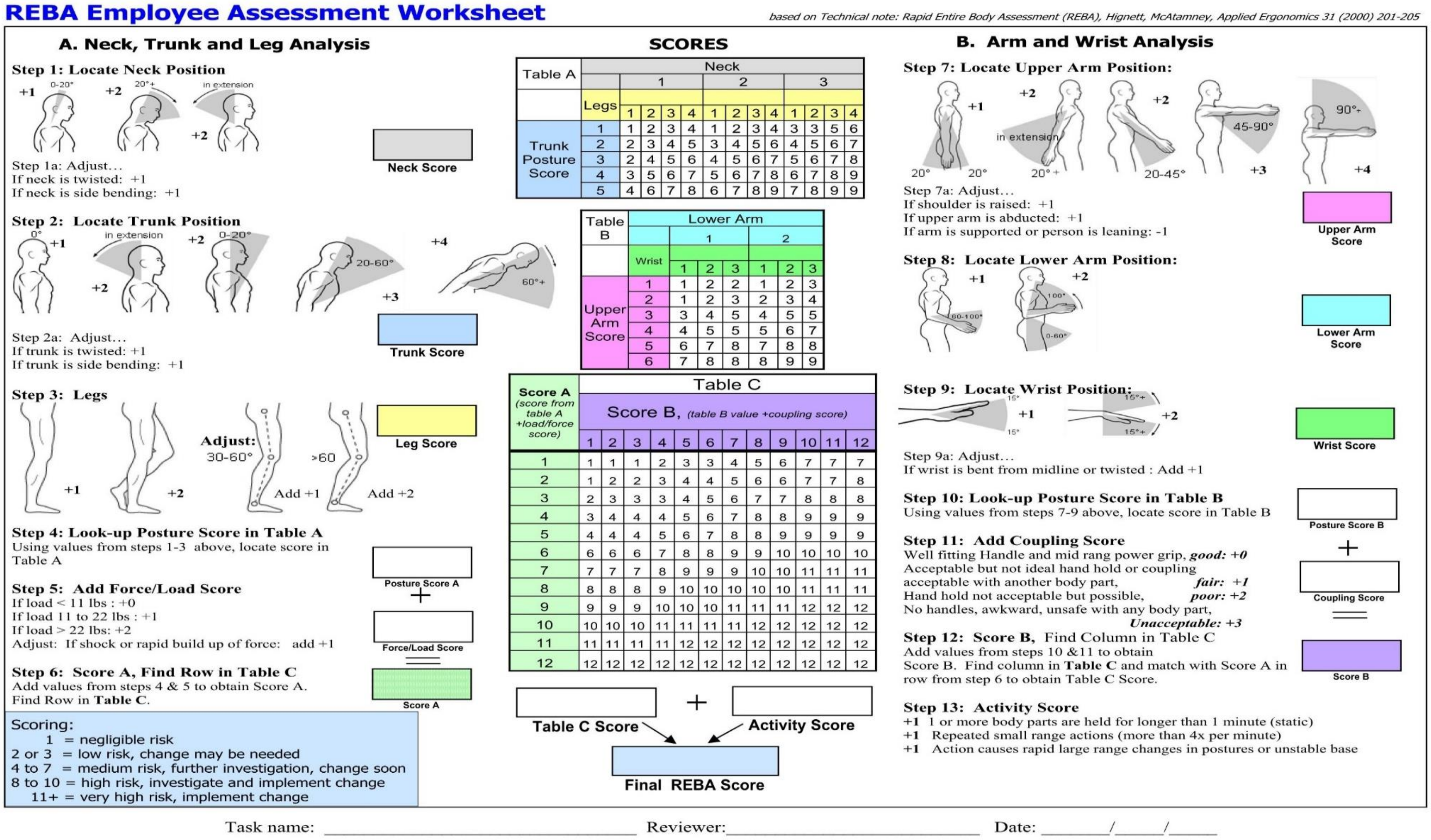
=

Step 15: Find Column in Table C
Add values from steps 12-14 to obtain Neck, Trunk and Leg Score. Find Column in **Table C**.

Neck, Trunk & Leg Score

Task name: ________________________________ Reviewer:__________________________ Date: _______/_____/_____

Appendix–V: REBA score sheet



REBA Employee Assessment Worksheet

based on Technical note: Rapid Entire Body Assessment (REBA), Hignett, McAtamney, Applied Ergonomics 31 (2000) 201-205

A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position

Step 1a: Adjust…
If neck is twisted: +1
If neck is side bending: +1

Neck Score

Step 2: Locate Trunk Position

Step 2a: Adjust…
If trunk is twisted: +1
If trunk is side bending: +1

Trunk Score

Step 3: Legs

Leg Score

Step 4: Look-up Posture Score in Table A
Using values from steps 1-3 above, locate score in Table A

Posture Score A

+

Step 5: Add Force/Load Score
If load < 11 lbs : +0
If load 11 to 22 lbs : +1
If load > 22 lbs: +2
Adjust: If shock or rapid build up of force: add +1

Force/Load Score

=

Step 6: Score A, Find Row in Table C
Add values from steps 4 & 5 to obtain Score A.
Find Row in **Table C**.

Score A

Scoring:
1 = negligible risk
2 or 3 = low risk, change may be needed
4 to 7 = medium risk, further investigation, change soon
8 to 10 = high risk, investigate and implement change
11+ = very high risk, implement change

SCORES

Table A		Neck											
		1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B		Lower Arm					
		1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Score A *(score from table A +load/force score)*	Table C Score B, *(table B value +coupling score)*											
	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score + **Activity Score**

Final REBA Score

B. Arm and Wrist Analysis

Step 7: Locate Upper Arm Position:

Step 7a: Adjust…
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score

Step 8: Locate Lower Arm Position:

Lower Arm Score

Step 9: Locate Wrist Position:

Wrist Score

Step 9a: Adjust…
If wrist is bent from midline or twisted : Add +1

Step 10: Look-up Posture Score in Table B
Using values from steps 7-9 above, locate score in Table B

Posture Score B

+

Step 11: Add Coupling Score
Well fitting Handle and mid rang power grip, ***good: +0***
Acceptable but not ideal hand hold or coupling
acceptable with another body part, ***fair: +1***
Hand hold not acceptable but possible, ***poor: +2***
No handles, awkward, unsafe with any body part,
Unacceptable: +3

Coupling Score

=

Step 12: Score B, Find Column in Table C
Add values from steps 10 &11 to obtain
Score B. Find column in **Table C** and match with Score A in row from step 6 to obtain Table C Score.

Score B

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base

Task name: ______________________________ Reviewer:_________________________ Date: _______/_____/_____

Appendix–VI: REBA and RULA scores for different tasks

S. No.	REBA Score				RULA Score			
	Spading	**Mould filling**	**Mould evacuating**	**Brick carrying**	**Spading**	**Mould filling**	**Mould evacuating**	**Brick carrying**
1	11	12	11	9	7	7	6	6
2	12	10	10	11	7	6	5	3
3	12	12	9	9	7	5	4	4
4	12	11	10	11	7	6	5	5
5	11	10	10	10	7	5	4	3
6	11	11	11	11	6	6	5	6
7	11	12	10	9	6	5	5	5
8	12	11	11	10	6	6	5	4
9	11	11	10	11	6	6	5	5
10	11	11	11	10	6	6	6	4
11	12	12	10	11	7	6	5	5
12	10	10	11	10	6	5	6	5
13	12	12	10	9	7	7	5	5
14	13	11	10	11	7	6	6	5
15	12	10	10	9	7	5	4	6
16	11	10	12	10	6	5	6	5
17	12	9	10	11	6	5	5	6
18	12	11	11	9	7	6	6	5
19	12	12	10	11	7	7	6	6
20	11	10	10	9	6	5	6	4
21	11	11	10	9	6	6	6	6
22	10	10	10	11	5	5	5	5
23	13	11	11	10	6	6	6	6
24	11	11	10	9	6	6	6	6
25	11	11	11	11	6	6	6	5
26	12	10	10	9	7	4	5	4
27	11	11	11	10	6	6	6	5
28	12	12	11	11	7	7	5	4
29	12	11	10	9	7	5	5	5
30	12	11	9	11	7	6	4	4

S. No.	REBA Score				RULA Score			
	Spading	Mould filling	Mould evacuating	Brick carrying	Spading	Mould filling	Mould evacuating	Brick carrying
31	10	10	11	10	5	5	6	5
32	11	11	11	9	6	6	4	5
33	11	12	10	10	6	6	5	6
34	13	11	11	11	6	6	6	5
35	12	11	10	10	7	6	5	6
36	11	12	10	9	5	7	6	5
37	12	10	10	10	7	5	5	6
38	12	11	11	9	7	6	4	4
39	12	12	11	11	7	6	6	6
40	11	12	9	9	6	7	4	6
41	12	11	10	10	7	6	6	5
42	12	11	11	9	7	6	6	4
43	12	12	10	10	7	7	5	5
44	11	10	11	11	6	5	6	4
45	13	11	10	10	6	6	5	5
46	11	11	11	10	6	6	5	5
47	12	12	9	9	7	7	4	4
48	10	11	11	11	5	7	6	5
49	12	11	11	9	7	7	4	6
50	12	12	10	10	6	6	5	5
51	13	12	11	10	7	7	6	6
52	12	12	12	10	7	7	5	5
53	12	11	11	11	6	7	6	6
54	12	11	10	10	7	7	5	4
55	11	12	12	9	6	6	6	6
56	13	10	11	10	7	7	5	5
57	13	11	11	11	6	7	5	3
58	12	12	12	11	6	7	4	5
59	12	12	11	11	6	6	6	6
60	12	11	10	9	7	6	4	6
61	13	13	11	10	5	6	5	4
62	13	12	11	10	7	7	6	5

S. No.	REBA Score				RULA Score			
	Spading	Mould filling	Mould evacuating	Brick carrying	Spading	Mould filling	Mould evacuating	Brick carrying
63	11	12	11	9	7	7	6	6
64	12	10	10	11	7	6	5	3
65	12	12	9	9	7	5	4	4
66	12	11	10	11	7	6	5	5
67	11	10	10	10	7	5	4	3
68	11	11	11	11	6	6	5	6
69	12	12	10	9	6	5	5	5
70	12	11	11	10	6	6	5	4
71	11	11	10	11	6	6	5	5
72	11	11	11	10	6	7	6	4
73	12	12	10	11	7	6	5	5
74	10	10	11	10	6	5	6	5
75	12	12	10	9	7	7	5	5
76	13	12	10	11	7	6	6	5
77	12	10	10	9	7	5	4	6
78	11	10	12	10	6	6	6	5
79	12	9	10	11	6	5	5	6
80	13	11	11	9	7	6	6	5
81	12	12	10	11	7	7	6	6
82	11	10	10	9	6	5	6	4
83	11	11	10	9	6	6	6	6
84	10	10	10	11	5	5	5	5
85	13	11	11	10	6	6	6	6
86	11	11	10	9	6	6	6	6
87	11	11	11	11	6	6	6	5
88	12	10	10	9	7	4	5	4
89	11	11	11	10	6	6	6	5
90	12	12	11	11	7	7	5	4
91	12	11	10	9	7	5	5	5
92	13	11	11	10	6	6	6	6
93	11	11	10	9	6	6	6	6
94	11	11	11	11	6	6	6	5

S. No.	REBA Score				RULA Score			
	Spading	Mould filling	Mould evacuating	Brick carrying	Spading	Mould filling	Mould evacuating	Brick carrying
95	12	10	10	9	7	5	5	4
96	12	11	11	10	6	6	6	5
97	12	12	11	11	7	7	5	4
98	12	11	10	9	7	5	5	5
99	12	11	9	11	7	6	4	4
100	10	10	11	10	5	5	6	5
101	11	11	11	9	6	6	4	5
102	11	12	10	10	6	6	5	6
103	13	11	11	11	6	6	6	5
104	12	11	10	10	7	6	5	6
105	11	12	10	9	5	7	6	5
106	12	10	10	10	7	5	5	6
107	12	11	11	9	7	6	4	4
108	12	12	11	11	7	6	6	6
109	12	12	9	9	6	7	4	6
110	12	10	10	10	7	6	6	5
111	12	11	11	9	7	6	6	4
112	12	12	10	10	7	7	5	5
113	11	10	11	11	6	5	6	4
114	13	11	10	10	6	6	5	5
115	11	11	11	10	6	6	5	5
116	12	12	10	9	7	7	4	4
117	10	11	11	11	5	7	6	5
118	12	11	11	9	7	7	4	6
119	12	12	10	10	6	6	5	5
120	13	12	11	10	7	7	6	6
121	12	12	12	10	6	7	5	5
122	12	11	11	11	6	7	6	6
123	12	11	10	10	7	7	5	4
124	11	12	12	9	6	6	6	6
125	13	10	11	10	7	7	5	5
126	13	11	11	11	6	7	5	3

S. No.	REBA Score				RULA Score			
	Spading	Mould filling	Mould evacuating	Brick carrying	Spading	Mould filling	Mould evacuating	Brick carrying
127	12	12	12	11	6	7	4	5
128	12	12	11	11	6	6	6	6
129	12	10	11	9	7	7	4	6
130	13	13	11	10	5	6	5	4
131	13	12	11	10	7	7	6	5
132	11	12	11	9	7	7	6	6
133	12	11	10	11	7	6	5	4
134	12	12	9	9	7	5	4	4
135	12	11	10	11	7	6	5	5
136	11	10	10	10	7	5	4	3
137	11	11	11	11	6	6	5	6
138	11	12	10	9	6	5	5	5
139	12	11	11	10	6	6	5	4
140	12	11	10	11	6	7	5	5
141	11	11	11	10	6	6	6	4
142	12	12	10	11	7	6	5	5
143	10	10	11	10	6	5	6	5
144	12	12	10	9	7	7	5	5
145	13	11	10	11	6	6	6	5
146	12	10	10	9	7	5	4	6
147	11	11	12	10	6	7	6	5
148	12	10	10	11	6	5	5	6
149	12	11	11	9	7	6	6	5
150	12	12	11	11	7	7	6	6
151	11	10	10	9	6	6	6	4
152	11	11	10	9	6	6	6	6
153	10	10	10	11	5	5	5	5
154	13	11	11	10	6	6	6	6

Appendix–VII: Hand grip strength of brick moulders

S. No.	Right hand				Left hand			
	GS1	**GS2**	**GS3**	**Average**	**GS1**	**GS2**	**GS3**	**Average**
1	35.00	33.50	31.00	33.17	30.00	28.50	26.00	28.17
2	37.00	35.00	32.50	34.83	29.00	27.00	25.50	27.17
3	36.50	33.50	33.00	34.33	30.50	29.00	26.50	28.67
4	34.00	32.00	30.00	32.00	29.00	28.00	25.50	27.50
5	35.00	33.50	31.00	33.17	29.50	27.00	25.00	27.17
6	37.00	35.00	32.50	34.83	30.00	28.50	26.00	28.17
7	36.00	34.00	31.50	33.83	30.00	27.50	26.50	28.00
8	35.00	33.50	31.00	33.17	29.50	27.00	25.00	27.17
9	37.00	36.00	34.00	35.67	32.00	30.50	29.00	30.50
10	37.00	36.00	34.00	35.67	32.00	30.50	29.00	30.50
11	36.00	33.50	32.00	33.83	28.50	25.00	24.00	25.83
12	35.00	33.50	31.00	33.17	29.50	27.00	25.00	27.17
13	34.00	33.00	30.00	32.33	28.50	27.00	25.50	27.00
14	36.50	34.00	32.50	34.33	30.00	29.00	27.00	28.67
15	36.50	34.00	32.00	34.17	29.00	25.00	24.50	26.17
16	37.00	36.00	34.00	35.67	32.00	30.50	29.00	30.50
17	30.00	26.00	24.50	26.83	28.00	26.00	24.50	26.17
18	40.00	37.00	35.00	37.33	33.50	32.00	30.00	31.83
19	37.00	36.00	34.00	35.67	32.00	30.50	29.00	30.50
20	39.00	37.50	35.00	37.17	33.00	31.00	20.00	28.00
21	38.00	35.50	33.00	35.50	34.50	31.00	28.50	31.33
22	38.00	35.50	33.50	35.67	31.50	30.00	28.00	29.83
23	37.00	35.50	32.50	35.00	30.00	29.00	27.00	28.67
24	41.00	38.50	35.00	38.17	33.50	30.00	27.50	30.33
25	30.00	27.50	26.00	27.83	37.00	34.50	32.00	34.50
26	32.00	30.00	28.00	30.00	30.50	28.00	26.00	28.17
27	37.50	36.00	33.50	35.67	30.00	28.00	26.00	28.00

S. No.	**Right hand**				**Left hand**			
	GS1	**GS2**	**GS3**	**Average**	**GS1**	**GS2**	**GS3**	**Average**
28	35.50	34.00	31.00	33.50	30.00	28.50	26.50	28.33
29	30.00	25.00	23.50	26.17	26.00	24.50	24.00	24.83
30	38.00	26.00	24.00	29.33	30.00	27.50	26.00	27.83
31	39.00	37.00	35.00	37.00	32.50	30.00	27.50	30.00
32	37.00	36.00	34.00	35.67	32.00	30.50	29.00	30.50
33	38.50	37.00	35.00	36.83	32.00	30.50	28.00	30.17
34	40.00	37.50	35.00	37.50	34.50	32.00	30.00	32.17
35	37.00	36.00	34.00	35.67	32.00	30.50	29.00	30.50
36	37.00	36.00	34.00	35.67	32.00	30.50	29.00	30.50
37	34.00	32.00	30.00	32.00	29.50	27.00	25.00	27.17
38	36.50	34.00	32.00	34.17	31.00	28.00	27.50	28.83
39	40.00	37.00	35.00	37.33	33.50	32.00	30.00	31.83
40	37.00	36.00	34.00	35.67	32.00	30.50	29.00	30.50
41	30.50	29.00	28.00	29.17	28.00	27.00	26.00	27.00
42	38.50	37.00	35.00	36.83	32.00	30.50	28.00	30.17
43	37.00	35.00	33.00	35.00	31.50	30.00	28.00	29.83
44	38.50	37.00	35.00	36.83	32.00	30.50	28.00	30.17
45	35.50	34.00	31.00	33.50	30.50	29.00	27.50	29.00
46	37.50	36.50	35.00	36.33	32.50	30.00	28.00	30.17
47	40.00	37.00	35.00	37.33	33.50	32.00	30.00	31.83
48	39.00	37.00	35.00	37.00	31.50	30.00	28.00	29.83
49	38.50	37.00	35.00	36.83	32.00	30.50	28.00	30.17
50	35.50	33.50	31.00	33.33	30.00	29.00	26.50	28.50

Appendix–VIII: Anthropometric data of workers

S. No.	Stature (cm)	Middle finger length	Hand breadth at MC III	Hand breadth across thumb	Hand thickness	Hand grip diameter	Middle finger II phalanx	Palm length	Hand length
1	170.2	76.5	77	98.8	30.2	44.5	48.3	88.7	165.2
2	173.2	79.5	80.8	103.9	26.3	56.7	50.3	92.2	171.7
3	169	74.3	75.4	95	28.6	41.2	46.8	86.2	160.5
4	174.9	80.2	81.6	105.2	38.2	58	50.8	93	173.2
5	172	77.5	78	103.9	38	48.5	49.0	89.9	167.4
6	174	79.2	81.1	104.2	31.4	54.2	50.1	91.9	171.1
7	163.2	71	70.4	91.6	34.7	38.9	44.6	82.4	153.4
8	170.2	76.7	77.3	102	38.1	50.1	48.4	89	165.7
9	174.5	80	81.2	103.7	27.3	56.8	50.6	92.8	172.8
10	169.8	75.3	75.1	97	30.2	44.7	47.5	87.3	162.6
11	168.4	73.2	73.6	96.3	37	41	46.1	84.9	158.1
12	173	78.5	80	103.9	28.9	54	49.6	91.1	169.6
13	174.2	81.2	83.1	105.2	34.8	59.2	51.4	94.2	175.4
14	168	73.3	74.1	95	36	46.2	46.2	85	158.3
15	176.5	80.2	82.6	104.2	32.6	58.5	50.8	93	173.2
16	170	76.5	77.2	100.9	35.8	50.4	48.3	88.7	165.2
17	174.5	80.3	82.3	106.2	39.4	59.5	50.8	93.1	173.4
18	171	77	78.4	101.6	38.9	56.3	48.6	89.3	166.3
19	170.4	76.7	78.3	101	43.1	50.1	48.4	89	165.7
20	168	73.6	74.7	95	46.2	47	46.4	85.4	159
21	162	66.2	70.6	89.2	30.2	40.8	41.4	76.8	143
22	171	76.5	77.1	99.9	30.3	49.2	48.3	88.7	165.2
23	166.5	72.7	73.1	95.2	30.1	45.2	45.8	84.3	157
24	162.2	67	68.4	77.6	28.8	39.8	42.0	77.7	144.7
25	170.2	76.7	77.3	99	36.4	49	48.4	89	165.7
26	175.2	80	82.2	104.7	38.1	58	50.6	92.8	172.8
27	169.8	74.3	75.4	97	36	45.9	46.8	86.2	160.5
28	170	76	77.3	100.1	37.1	48.1	48.0	88.2	164.2
29	171	76.3	78.2	98	27.3	49	48.2	88.5	164.8
30	168.1	74.2	75.6	95.2	28.2	44	46.8	86.1	160.3
31	172.5	77.6	77.5	101	35.8	51.4	49.0	90	167.6
32	174	80	81.3	106	39.2	59	50.6	92.8	172.8
33	172	78.1	78.4	102.8	39.2	57.7	49.4	90.6	168.7
34	170.1	76.4	78	100.2	43	51	48.2	88.6	165
35	170.2	76.5	77	98.8	30.2	52.1	48.3	88.7	165.2

S. No.	Stature (cm)	Middle finger length	Hand breadth at MC III	Hand breadth across thumb	Hand thickness	Hand grip diameter	Middle finger II phalanx	Palm length	Hand length
36	174	80	80.8	104.5	28.3	57	50.6	92.8	172.8
37	168	73.9	75	94.8	28.5	43.2	46.6	85.7	159.6
38	175	80.5	81.4	105	38	58.8	51.0	93.4	173.9
39	172.5	77.9	79	104.8	38.8	55.8	49.2	90.4	168.3
40	172.5	79	81	104	31.4	54.2	50.0	91.6	170.6
41	163	70.5	70.8	91.6	34.5	40.4	44.3	81.8	152.3
42	170.4	76.8	77.7	103	38.8	51.1	48.5	89.1	165.9
43	174.5	80	81.2	103.7	27.3	59.1	50.6	92.8	172.8
44	169.8	75.3	75.1	97	30.2	41.7	47.5	87.3	162.6
45	168.4	73.2	73.6	96.3	37	41.1	46.1	84.9	158.1
46	173	78.5	80	103.9	28.9	58.2	49.6	91.1	169.6
47	174.2	81.2	83.1	105.2	34.8	60.2	51.4	94.2	175.4
48	168	73.3	74.1	95	36	46.2	46.2	85	158.3
49	176.5	80.2	82.6	104.2	32.6	61.5	50.8	93	173.2
50	170	76.5	77.2	100.9	35.8	50.4	48.3	88.7	165.2
51	174.5	80.3	82.3	106.2	39.4	59.9	50.8	93.1	173.4
52	171	77	78.4	101.6	38.9	56.3	48.6	89.3	166.3
53	170.4	76.7	78.3	101	43.1	51.1	48.4	89	165.7
54	168	73.3	74.7	95	46.2	47.3	46.2	85	158.3
55	162	66.2	70.6	89.2	30.2	48.8	41.4	76.8	143
56	171	76.5	77.1	99.9	30.3	45.2	48.3	88.7	165.2
57	166.5	72.7	73.1	95.2	30.1	39.2	45.8	84.3	157
58	162.2	67	68.4	77.6	28.8	36.8	42.0	77.7	144.7
59	170.2	76.7	77.3	99	36.4	46.1	48.4	89	165.7
60	175.2	80	82.2	104.7	38.1	58	50.6	92.8	172.8
61	169.8	74.3	75.4	97	36	45.9	46.8	86.2	160.5
62	170	76.7	77.3	100.1	37.1	47.1	48.4	89	165.7
63	171	76.3	78.2	98	26.3	46.2	48.2	88.5	164.8
64	168.1	74.2	75.6	95.2	28.2	44	46.8	86.1	160.3
65	171	76.6	77.3	100.9	35.9	50.4	48.4	88.9	165.5
66	175	81	83.3	107.2	39.4	60.9	51.3	94	175
67	172	78	78.5	102.6	38.9	56.7	49.3	90.5	168.5
68	170.1	76.4	78	100.2	43	51	48.2	88.6	165
69	172.2	77.5	80	102.8	30.2	52.5	49.0	89.9	167.4
70	173.2	79.5	80.8	103.9	26.3	56.7	50.3	92.2	171.7
71	169	74.3	75.4	95	28.6	39.2	46.8	86.2	160.5
72	174.9	80.2	81.6	105.2	38.2	58	50.8	93	173.2

S. No.	Stature (cm)	Middle finger length	Hand breadth at MC III	Hand breadth across thumb	Hand thickness	Hand grip diameter	Middle finger II phalanx	Palm length	Hand length
73	172	77.5	78	103.9	38	50.5	49.0	89.9	167.4
74	174	79.2	81.1	104.2	31.4	57.2	50.1	91.9	171.1
75	165.2	72.8	73.4	94.6	34.7	40.8	45.8	84.4	157.2
76	170.2	76.7	77.3	102	38.1	51.1	48.4	89	165.7
77	174.5	80	81.2	103.7	27.3	59.1	50.6	92.8	172.8
78	169.8	75.3	75.1	97	30.2	41.7	47.5	87.3	162.6
79	168.4	73.2	73.6	96.3	37	41.1	46.1	84.9	158.1
80	173	78.5	80	103.9	28.9	58.2	49.6	91.1	169.6
81	174.2	81.2	83.1	105.2	34.8	60.2	51.4	94.2	175.4
82	168	73.3	74.1	95	36	46.2	46.2	85	158.3
83	176.5	80.2	82.6	104.2	32.6	60.4	50.8	93	173.2
84	170	76.5	77.2	100.9	35.8	50.4	48.3	88.7	165.2
85	174.5	80.3	82.3	106.2	39.4	59.9	50.8	93.1	173.4
86	171	77	78.4	101.6	38.9	51.8	48.6	89.3	166.3
87	170.4	76.7	78.3	101	43.1	51.1	48.4	89	165.7
88	168	73.3	74.7	95	46.2	47.3	46.2	85	158.3
89	163.5	67.2	70.6	89.2	30.2	39.8	42.1	78	145.2
90	171	76.5	77.1	99.9	30.3	49.2	48.3	88.7	165.2
91	166.5	72.7	73.1	95.2	30.1	39.2	45.8	84.3	157
92	168.2	69.8	70.4	88.8	29	40.5	43.8	81	150.8
93	170.2	76.7	77.3	99	36.4	48.9	48.4	89	165.7
94	175.2	80	82.2	104.7	38.1	59	50.6	92.8	172.8
95	169.8	74.3	75.4	97	36	48.9	46.8	86.2	160.5
96	170	76.7	77.3	100.1	37.1	49.1	48.4	89	165.7
97	171	76.3	78.2	98	26.3	48.2	48.2	88.5	164.8
98	168.1	75.2	77.6	96.2	28.8	50	47.4	87.2	162.4
99	171	76.6	77.3	100.9	35.9	50.4	48.4	88.9	165.5
100	174.5	80.3	82.3	106.2	39.4	59.9	50.8	93.1	173.4
101	172	78	78.5	102.6	38.9	56.7	49.3	90.5	168.5
102	170.1	76.4	78	100.2	43	50	48.2	88.6	165

Appendix–IX: Usability test responses for conventional moulding box

S. No.	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
1	2	2	2	2	2	2	1	1	2	2
2	3	2	3	1	1	2	2	2	1	1
3	2	2	1	1	1	3	3	1	2	1
4	3	2	2	2	2	3	2	2	2	2
5	2	2	2	2	3	2	2	2	2	2
6	3	2	2	2	3	3	2	2	2	1
7	2	1	1	1	2	3	1	3	2	3
8	3	1	3	2	1	2	2	2	1	2
9	3	3	1	1	1	2	2	1	3	3
10	3	2	3	1	3	2	2	2	2	3
11	2	3	2	2	2	2	1	2	3	2
12	4	2	2	2	2	1	2	1	2	3
13	3	2	1	3	1	2	2	2	1	1
14	3	2	2	1	1	3	2	1	2	2
15	3	2	1	2	2	2	2	2	2	2
16	5	2	3	2	3	2	1	2	2	2
17	4	2	2	1	3	3	2	3	2	1
18	3	2	1	2	2	3	1	1	2	3
19	3	1	2	1	1	2	2	2	1	2
20	4	2	1	2	2	1	1	1	2	2
21	4	3	2	2	1	2	2	2	3	1
22	3	4	3	3	1	3	1	2	2	2
23	5	3	2	2	2	1	2	2	2	3
24	3	2	4	2	3	2	1	2	2	2
25	4	3	3	2	3	3	2	2	2	3
26	4	2	2	2	2	3	2	2	2	2
27	3	3	2	3	2	2	2	2	2	3
28	5	2	2	2	3	2	1	1	3	2
29	3	3	2	2	3	2	2	2	2	2
30	3	2	2	3	2	2	1	2	3	2
31	5	3	3	2	3	2	2	2	1	2
32	3	2	2	2	2	2	1	2	3	3

Appendix–X: Usability test responses for modified moulding box

S. No.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	3	3	2	2	2	3	3	2	3	3
2	5	4	3	4	4	3	4	4	3	3
3	4	2	4	2	2	3	3	4	2	3
4	4	3	2	3	3	2	3	2	3	3
5	3	3	3	5	4	3	5	4	2	4
6	5	2	3	3	3	3	3	2	2	3
7	3	3	2	2	4	3	5	3	4	4
8	3	2	4	3	3	4	3	3	2	3
9	4	3	3	3	4	2	2	2	2	3
10	4	3	3	3	3	3	3	4	3	3
11	5	4	4	2	34	4	3	3	5	3
12	4	3	2	3	2	3	4	2	3	3
13	5	4	4	2	3	2	4	3	3	4
14	3	2	4	2	2	4	3	4	4	3
15	4	3	3	4	2	2	5	2	2	5
16	5	2	2	3	3	5	3	4	3	4
17	5	4	4	3	5	3	2	4	4	5
18	4	3	2	3	2	3	3	3	4	4
19	4	2	4	3	2	3	3	3	3	4
20	5	3	3	4	4	2	3	3	3	4
21	5	4	3	3	2	4	3	3	3	4
22	5	3	2	3	1	3	3	4	4	5
23	4	2	2	3	2	2	5	3	3	4
24	5	3	4	3	3	2	3	4	3	4
25	4	4	3	5	3	3	2	5	3	5
26	4	3	4	2	2	4	2	3	3	4
27	3	4	5	3	3	3	3	4	4	4
28	5	5	3	4	3	4	3	2	3	4
29	5	4	2	2	3	2	5	2	3	4
30	4	3	3	3	2	4	2	2	3	4
31	3	3	3	3	3	3	2	3	3	4
32	4	3	3	5	3	3	2	4	3	5

Appendix–XI: Usability test responses for clot cutting tool

S. No.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	4	3	3	3	3	3	4	3	3	3
2	4	3	3	4	4	3	3	3	2	4
3	3	3	3	3	3	2	3	3	3	3
4	4	4	3	4	4	3	3	4	4	4
5	3	3	3	3	3	3	3	3	3	4
6	4	3	3	4	2	3	3	3	3	3
7	5	4	3	4	3	4	3	3	3	5
8	3	4	2	3	3	3	3	3	2	3
9	5	3	3	4	4	3	3	3	3	3
10	5	3	3	3	3	3	3	3	2	4
11	4	4	3	3	3	3	3	3	3	3
12	5	3	3	4	3	4	4	3	3	4
13	3	4	3	3	3	3	3	4	5	5
14	5	3	3	4	4	3	4	3	3	4
15	3	4	3	3	3	3	3	3	3	5
16	3	4	2	5	2	2	3	3	4	4
17	5	4	3	4	4	3	3	3	3	5
18	4	3	3	3	2	3	3	3	5	4
19	4	3	3	3	3	4	4	4	3	4
20	3	3	3	4	4	3	4	4	4	4
21	4	3	3	3	3	3	3	3	3	5
22	5	3	3	3	3	3	3	2	4	4
23	4	4	4	4	4	4	3	3	3	4
24	4	3	5	3	2	3	3	3	3	5
25	5	4	3	4	3	4	3	3	4	4
26	3	4	2	2	2	3	3	3	2	3
27	4	3	3	4	4	3	3	3	3	5
28	5	3	4	3	3	3	3	3	3	4
29	5	2	3	2	2	5	3	3	3	5
30	4	3	3	4	4	3	3	3	3	3
31	4	3	4	3	3	3	3	3	3	4
32	4	4	3	3	3	3	4	3	4	5

Publication from PhD work

International Journal Publications:

- Sain, M.K. and Meena, M.L. (2018) "Identifying musculoskeletal issues and associated risk factors among clay brick kiln workers", Industrial Health, Vol. 57 Issue: 3, pp. 381–391 **(SCI, J–Stage)**
- Sain, M.K. and Meena, M.L. (2018) "Exploring the musculoskeletal problems and associated risk–factors among brick kiln workers", International Journal of Workplace Health Management, Vol. 11 Issue: 6, pp.395–410 **(ESCI & Scopus, Emerald)**
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- Sain, M. K. and Meena, M.L. (2016) "Occupational Health and Ergonomic Intervention in Small Scale Industries: A Review", International Journal of Recent advances in Mechanical Engineering, Vol. 5 Issue 1, pp.13–24

Book Chapter

- Sain M. K., Meena M.L. Dangayach G. S. and Bhardwaj, A. (2018) "A brief Procedure for Ergonomic Design of Hand Tool for Small Scale Industries", Ergonomics in Caring for People, pp. 209–214 **(Springer)**

Conference Publications

- Sain, M.K. and Meena, M.L., "Analysing the prevalence of occupational risk among workers involved in traditional clay brick manufacturing task" 15th International Conference on Humanizing Work and Work

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- Sain M. K., Meena M.L. and Dangayach G. S. "Productivity Enhancement and Cost Benefits through Ergonomic Intervention in Small Scale Industries: A Review", 18th Annual International Conference of the Society of Operations Management on December 12–14, 2014 at IIT Roorkee.

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