Assistive design intervention to reduce Occupational Ergonomic stress among Women Handloom Weavers of Assam

A thesis submitted in partial fulfilment of the requirement for the degree of Doctor of Philosophy

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This thesis material presented here in by Ms Sangeeta Pandit was undertaken under my guidance and supervision. The volume of work here in for the degree of Doctor of Philosophy of Indian Institute of Technology, Guwahati was not submitted by her earlier for any other degree or diploma.

She has undergone six specified courses and obtained 9.49 C.P.I. (out of 10), and fulfilled all the requirements as mentioned in the rules and regulations for submitting the thesis for the PhD degree of the Indian Institute of Technology, Guwahati.

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Dedication

I would like to dedicate this thesis to my beloved parent, without their support, love and sacrifices; this thesis would never have been possible.

Preface

Occupational ergonomics is a solution oriented branch of ergonomics. Its goal is to optimize workers well-being and productivity by decreasing work related stressors. Stress is a matter of concern in any organization and to relieve from occupational stress ergonomic principle is very important. To apply ergonomic principles causative factors of stress, its consequences and remedy are to be studied so that a compatible interface may be established between the workers and work environment. In any occupational settings, exposure to occupational stressors for long period will cause loss of work efficiency and development of musculoskeletal injuries which may lead to disability over a period of time.

There is a growing recognition by both management and workers that musculoskeletal injuries reduced human performance. This is result of poorly designed working conditions and manual workforce that exceeds biomechanical capabilities of the workers. The condition that leads to such physical mismatching of job and workers capabilities is complex to deal with. Early identification of problems and application of ergonomic intervention is preventive in nature, before injuries occur, thereby avoiding future medical treatment.

Ergonomic knowledge was mainly concentrated in academic domain in the last three to four decades in India and very few attempts have been initiated in the application of the knowledge in the industry. In India, it may be worth to mention that earlier women were only involved into household activities, but now with economic hike and for financial support of the family more and more women have made headway into economic sectors to earn their livelihood. The requirements of workstation for this working group are different from the male counterpart. As per legendry evidences, North East India is powered with women empowerment. Women are engaged in different economic sectors, like agro based industry such as tea, fruit processing and home based cottage industry like handloom. In recent years there is a rapid transformation of handloom industry towards commercialization with initiatives from Government and different NGO's.

Handloom is the second largest activity in people involvement, after agriculture in India and Assam reports to have the highest number of handlooms in the national scenario as reported in 2009-2010 Census report. The large work force employed in handloom in Assam comprised of 99% women weavers. Mechanization of handloom industry is not much welcomed because a vast rural workforce thrives on this sector to earn their livelihood. Strength of handloom lies in its uniqueness in innovative designs, which requires maintaining the traditional and ethnic values that is not replicable by mechanization. Handloom weaving consists of many potential ergonomic risk factors for development of musculoskeletal problems. The present study looked into ergonomic design intervention by understanding the occupational stress parameters and coming up with engineering control in workstation modification by assistive design reducing work stressors and increasing work efficiency and comfort.

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Sangeeta Pandit

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Summary of the Research

Indian women earlier were only involved into household activities, but with time and economic demands more and more women are becoming self-independent by getting into different economic sectors. They are joining in diverse work sectors, which were once ruled by only men. This results in the use of inappropriate workstation and work equipment's which are not designed for them, resulting increased work related occupational stress, including musculoskeletal health problems. Working class women, undergoes more stress as they had to perform dual role of workplace and family resulting little time for muscle recovery, the situation further deteriorates with poor workstation usage at work places. Study conducted on "Women's Safety and Health Issues At Work", by NIOSH (Publication number 2001-123) revealed that sprains and strains, carpel tunnel syndrome, tendonitis, and other musculoskeletal disorders account for more than half (55%) of the injuries and illnesses suffered by female workers, as compared to 45% male workers.

Due to the poor literacy rate, and household responsibilities, a major population of women workforce in India are involved into small scale and cottage industries to earn their livelihood. Handloom is one of the biggest home based cottage industry accounts to be the second largest industry after agriculture in India, where major workforce is women. North East (NE) of India reports to have the highest no of handlooms and among North Eastern States, Assam have the maximum number of handlooms where 99% weavers are women.

Ergonomic study at different handloom clusters of Assam revealed that women weavers of this industry suffer from musculoskeletal problems. Causative factors for muscular pain among handloom weavers were due to poor loom design, resulting development of biomechanical stress for highly forceful action in executing primary motion along with repetitive nature of weaving task, which all together results less time for muscle recovery. The situation further deteriorates with long attainment of awkward posture for the demand of weaving task. Based on the research findings, it was observed that decreasing force by ergonomic intervention in executing primary motion of weaving can be highly effective in reducing occupational hazards for development of musculoskeletal problems. Technological intervention in lowering effect of force has already been undertaken in two primary motions of weaving, these are picking and beating operation, but there is no such development been found out with shedding motion. Shedding is the first primary motion of weaving, which is done with the help of two pedals. Introduction of Jacquard for commercial production has increased pedalling force. Effective reduction of force for pedalling against Jacquard shedding is very much required in the present work context. Discussion and observation study revealed that pedal operation is highly dependent on seat; modification of one would not be effective without the other.

With advent of commercialization, weaving heavy motif and wide width fabric has changed production scenario. This resulted increase tension load on warp thread against which pedalling is performed. Pedalling is highly repetitive task which get adverse with high force for Jacquard, resulting development of musculoskeletal disorder in the lower limbs, as reported by the weavers involved with commercial production. Ergonomic intervention in pedal modification is the need of the hour so that, it can be operated with much less force. With changing production outlook, aim of the present research was development of low-cost ergonomic design intervention in seat and pedal modification, keeping in mind about rural economy. Participatory approach of skilled weavers and loom experts were used for the design development process. The modified pedal is made of compound lever mechanism where both lever arms follow first class lever principle along with cam profile resulting increased mechanical advantage from existing pedal which follows second class lever principle.

As already mentioned pedalling is highly correlated with plank, which gives body support for movement of the lower limb. Inappropriate seat without considering women anthropometry resulted development of muscle load in the lower limb and back which aggravates with long duration of commercial weaving. Modification of the plank considering women anthropometry and application of ergonomic principles was found to be highly effective in reducing muscle stress as reported by the weavers.

Usability testing of the modified design was found to be highly effective, in decreasing force (modified pedal) and muscle load (modified plank), resulting increased work comfort of the weavers. This, in a way would be effective in reducing muscle fatigue, enhancing productive time.

Chapter 1

Introduction: women occupational wellness; reference handloom industry of Assam

Chapter 1

Abstract: - *In India, as a tradition women were primarily involved into household activities, but with increased economic demands to support family income and with the urge to become self-independent more and more women have made headway into various economic sectors to earn their livelihood. They are joining into the main workforce in increasing numbers which were once ruled by only men. Use of inappropriate workstation and work equipment's, which are not designed for them have resulted in increased work related occupational stress and health hazards including musculoskeletal disorders. Dual role performed by the working class women, combining household chore and work undergoes more stress and the situation further deteriorates with poor workstation usage at work places. Due to the poor literacy rate and household responsibilities, a very small population of the workforce are involved into white collar job, the rest around 96% are involved into small scale industries. It is noticed that women are mostly involved into home based cottage industries as major workforce. Handloom industry, one of the biggest home based cottage industry, accounts to be the second largest industry in India after agriculture and according to National Handloom Census report 77.9% of the workforce in this sector reports to be women. NE reports to have the highest no of handlooms in India, and among North Eastern States, Assam reports to have the maximum number of handlooms where 99% weavers are women. Though a major population of handloom weavers of Assam are women but no gender specific considerations, either anthropometry or physiology, is taken into consideration while handloom design and manufacturing by local entrepreneurs.*

1.1 Workstation and Musculoskeletal problems

General concern among many ergonomists for workstation design is that, the ergonomic issues are often overlooked at the beginning of the design process and are considered when strategic decisions have already been made, where changes increases the cost drastically. Feedback of a poor workstation design are received much later from the users in the form of sick leave, even at times not reported being unaware of the causative factors related to poor performance due to body pains. This makes management unclear about the causes and effects of production loss. Additionally, design team almost never gets this feedback and it is therefore difficult to gain organizational learning (Dul & Neumann, 2009) to take remedial steps. .

Over the years, ergonomist found out a causal relationship between specific health problems (e.g., body pains) and jobs (Van Willy, 1970; Smith et al., 1981). Some of the common work related health problems reported as carpel tunnel syndrome, thoracic outlet syndrome, tendinitis, cumulative trauma disorders, repetitive strain injuries (Putz-Anderson, 1993) etc. Musculoskeletal problems appeared to be common problems and major causes of concern (Bernard, 1997; Smith et al., 2006). Lu and Aghazadeh (1996) in their study have found that working posture is significantly affected by workstation design, which in turn, contributes to various physical symptoms. Normal person without primary anatomical or physiological defects also develop degenerative tissue changes and functional defects on the musculoskeletal system due to stresses induced by long enforced postures, misdistribution of tissue pressure and prolonged static loading on the muscles (Chaffin, 1974; Magora, 1970; Van Wely, 1970). Another study by Wall et al., (1992) found that many cases of shoulder and neck pains are caused by inappropriate use of furniture.

Ergonomic deficiencies in the workstation are significantly indicated by bodily pains, absenteeism and job turnover. Bodily discomfort and pains, tends to be aggravated by tasks carried out in a poor workstation, which is a situation that is accompanied by increasing error rates (Grandjean, 1988; Corlett and Bishop, 1976; Eklund, 1995), leading to decreased production and loss of income, this situation adversely affects workers physiological and mental health as well. The question arises, where both males and females, engaged in a task; required separate work style or work equipment or common inclusive design approach could be suitable with the compatible characteristics of both.

1.2 Need for ergonomic considerations in workstation design for women workforce

Women play dual roles in work areas attaining desired level of production and shouldering household chores, where child upbringing appears to be her sole responsibility (Figure 1.1). Most of the daily work they perform goes unrecognized, because the type of activities they perform does not fit into any specific "occupation". They execute ardours household activities for long hours and add a major contribution to household income, but still, they are not perceived as workers by themselves or by data collecting agencies and government. According to International Labour Organization (ILO), 2/3rd of the working hours around the world are worked by women because of the combination of diverse roles in the workplace, in the family and in the society (Dewan, n.d.). Most often, women's work remains unseen but it bestows a major portion of the world's economy. A study conducted by NIOSH on Women's Safety and Health Issues At Work revealed that women suffer from musculoskeletal problems more than men (NIOSH Publication number 2001-123).

Figure.1.1. Working women of today

In Indian context women were mostly responsible and involved into household activities as per traditional and social norms but with growing economic demands to contribute to overall wellbeing of the family and with the urge to become self-independent more and more women have made headway into economic sectors. They are joining day by day in increasing numbers in different male dominating work sectors. This eventually led them to use workstations and work equipment's which are not designed for them as per anthropometric and physiologic requirements (NIOSH Publication number 2001-123) Figure 1.2. Inappropriate working environment increases bodily discomforts and pains among this working group. Full potential of women workforce is not achieved as some common belief say that they require different treatment suiting to women specific capabilities.

Figure 1.2. Agricultural product designed for men used by females

Workloads of working women are more strenuous, as they perform household and workplace activities, resulting less time for muscle recovery. Women who are already in the risk of muscular pain due to household activity and improper rest period for recovery; inappropriate workstation manifolds the risk of occupational hazards. Ergonomic intervention in the workstation design considering for this vast working group, can prevent them from developing occupational hazards that eventually add to work efficiency.

1.3 Small scale industries in India with reference to women workers

There are many reasons, but apparently it can be said that due to the poor literacy rate and household responsibilities, women are mostly found to be engaged in manual and daily wage earnings. Mostly they were found to be involved in agricultural sectors, health care sectors and traditional cottage industries (Figure 1.3). A very small population of Indian women are associated with white collar jobs, the rest around 96% are involved with small scale industries (Bhowmik, 1998).

Figure 1.3 Women in major occupational sector’s (A) Agriculture; (B) Health care sectors (C) Traditional village and cottage industry

Small scale industries are important production house in India and many other countries. India plays a vital role in Asia's economic growth and listed as world's second largest workforce to some 500 million people (Sharma, 2012). Small scale and cottage industries are the backbone of India's economy. Use of human resource in small scale industry is huge and it is highly labour intensive sector. They offer higher productivity of capital than capital-intensive enterprises due to low investment per worker (Vidya & Shashidhar, 2007). It is the primary source of employment for around 85% of the women workers throughout the world (Chen, n.d.).

Paying attention to occupational health and safety issues for this huge women workforce involved in small scale industries and improving working conditions indubitably have noticeable impact on national production, economy and quality of life. In spite of the importance of occupational health and safety issues, regrettably these issues are practically non-existent or at best minimal (Reverente, 1992) and has been a neglected area in small scale industries (McCann, 1996; Jafry & O.Neill, 2000). Due to lack of strict adherence to work environment standards and legislations, these bulk workforces of small scale industries are subjected to various work hazards. It is seen that though males and females are engaged in similar jobs in this sector but women get less priority in terms of pay and other relevant compensations. They are mostly found to be engaged in jobs which are monotonous and repetitive in actions, generally in traditional as well as family based trades (Figure 1.4)

Figure. 1.4. Women workforce in different small scale industries (a) Bidi making (b) Agarbatti processing (c) Fruit processing (d) Basket making (e) Pottery (f) Fish processing (g) Embroidery knitting (h) Jewellery making (i) Packaging industries

Home based cottage industry comes under small scale industry. As a workforce, home based worker remains largely invisible from legislative point of view. Due to invisibility of their work, contribution of the home based workers to the economy is ignored and they are deprived of social benefits and workers right. Women contribute a considerable man-power to run these home based cottage industries. Previously women used to spend their leisure time into craft activities as a passion or for domestic needs but now, due to the narrow scopes of recruitment under different employment structures, these home based craft activities are taking the shape of commercial outlook under the umbrella of "small scale cottage industry".

Government and NGOs are providing various level of supports by financing different training programs, thus traditional home based practices are gradually getting commercialized and more and more women are getting in, to earn their living, but requirements of work satisfaction not only to earn money, there is a need to look into their work environment and occupational wellbeing. Workstation for these two types of work practices (domestic and commercial) is different. Long usage of domestic workstation for commercial production plays adverse role in the development of different occupation related health problems. The hazards involved are either unknown or underestimated by different government authorities. Inadequate approach to take account of women's health issues constitutes a barrier, to frame effective policies on occupational health and safety issues for this working group.

1.4 Handloom an important small scale cottage industry in India

Handloom industry, is one of the biggest home based cottage industry, accounts to be the second largest industry in India, after agriculture (A brief report on textile industry in India, 2013) and 77.9% of the workforce in this sector reports to be women (Handloom Census of India, 2009-2010). India occupies an important place in the world as far as number of handlooms and varieties of traditional handloom products are concerned. It is estimated today that there are about 4.60 million handlooms in the world, out of which about 3.9 million are in India (Compendium of Textile Statistics, 2004 and Compendium of International Textile Statistics 2005). India produces 85% of the handloom products of the world, other countries having handlooms are Sri Lanka, Nepal, Bangladesh, Norway, West Indies, Indonesia, Afghanistan, Pakistan, Iran etc. (Garg et al., 2012).

Figure 1.5. Women engaged in handloom industry

Handloom sector has the potential to contribute towards export earnings in a big way and has been identified as a "Thrust Area" for the overall development of the sector. India's export of handloom products during 2009-10 was US$ 260 million and increased to US$ 365 million in 2010-11, recording a growth of 38%. The biggest destination of India's export of handloom products is USA followed by EU (Garg et al., 2012).

Handloom is the ancient cottage industry of India. A vast population of the country, directly or indirectly depends upon handloom industry for their livelihood. Strength of the handloom industry lies in its uniqueness, flexibility and versatility, which cannot be replicated by powerloom. This industry encourages experimentation and allows innovation. Each state of India has its own design identity which is different from each other (Figure 1.5). Thus, handloom forms a part of the heritage of India and exemplifies the affluence and diversity of our country and the artistic quality of the weavers. Metgud et al., 2008 in their study have observed that, ergonomic studies in textile industry of India is very rare and particularly with reference to women workforce.

1.5 Women workforce in NE India with special reference to Handloom

As per legendry evidences, NE India is powered with women workforce. Women are engaged in different economic sectors, like agro based industry such as tea, fruit processing and home based cottage industries like handloom (Figure 1.6).

Figure 1.6. Women workforce of North East (A) Handloom (B) Tea garden (C) Fruit processing

NE part of India enjoys a totally different socio-geographical nature than other parts of the country. The products and production scenario is also unique. NE part of India falls under tropical rain forest zone and is very rich in flora and fauna. These plentiful natural resources have got translated into the décor and design in almost all the artefacts and work of the artisans in handloom and handicraft products. Fine artistic sense of the people has made this region rich in handicrafts and handloom. Availability of raw materials and traditional skill has promoted this region reach in crafts and cottage industries on small scale basis with small machineries. The manufacturing of this crafts and cottage items are mostly carried out in dwelling houses, sometimes it is done in outdoor shades near by the houses, of craft artisans forming society or cooperative bodies (Figure 1.7).

Figure 1.7. Women in Craft and Cottage industry (A) Basket weaving, (B) Loin Loom, (C) Bamboo jewellery making

NE has the highest number of handlooms in India, where two types of weaving practices are followed (Figure 1.8), one type of weaving is practiced on frame loom (78%) and another on loin loom (21%) (Handloom Census of India, 2009-2010). Loin loom is a traditional weaving practice followed among Tribal women of hills and plains, where they still retain their traditional method of weaving and concentrates for domestic use. Frame loom, on the other hand is gradually transferring from household industry to commercial industry (Figure 1.9).

Figure 1.8. Women of NE practicing weaving in: (A) Loin Loom, (B) Frame Loom

The data trends have shown that the characteristics of the North-Eastern states are distinctly different from the rest of India, where 99% of the weavers in this industry are women (Handloom Census of India, 2009-2010).

1.6 Motivation of research in Handloom Industry of Assam

Among North Eastern States, Assam reports to have the highest number of handlooms (Handloom Census of India, 2009-2010). It is worthy to mention that almost every household in the rural areas of Assam are connected with weaving. Weaving is a traditional household activity for every women of Assam. The art of weaving is handed down across generation, where the girl learns the weaving skill from their mother from childhood. Whenever women of the households, are free from domestic works, they engage themselves in weaving. But with time, this household industry is gradually transferring to commercial industry being gathered together under specific work shed. Earlier they used to spend their leisure time for these craft activity as a passion or for domestic needs. With commercial effect, both time and competition plays important role giving rise to a new set of occupational issues. Commercialization has taken place, but workers occupational wellbeing relevant documentation on ergonomic study has not been reported on these vast women workforce. This motivates for an ergonomic study in this sector.

Figure. 1.9. Transformation of (A) Home based practice to (B) Commercial practice

1.7 State of the art review on Handloom sector

In available literature, there are very few studies in handloom sectors. Studies carried out on carpet loom of Iran and handloom sectors of India are discussed under 3 following categories.

1. Socio-economic Issues

Non availability of raw materials along with impact of globalization by textile and powerloom industries, increased pressure on job loss among women handloom weavers of Sambalpur district of Orissa, India. These result weavers community to push down to the lower strata of the economic ladder resulting switch over to other sources of income. The study reported that the weavers in this region expressed modernization of the loom, for increasing productivity and functionality (Impact of globalisation of textile industry on position of rural women in handloom sector in Orissa, 2004).

2. Ergonomic evaluation on Occupation related health issues

Some ergonomic evaluation studies carried out in handloom sector are discussed below

Tiwari et al., (1999) found higher rate of respiratory morbidity among handloom weavers of Nagpur, India due to cotton dust exposure.

Banerjee & Gangopadhyay, 2003 in their study have reported that handloom weaving involves highly repetitive task leading to the development of pain in the upper limbs among male handloom weavers of West Bengal, India.

Metgud et al., (2008) in their study on women weavers involved in spinning operation at Karnataka, India found to suffer from musculoskeletal pain of upper limb and back due to constant movement of the upper arm and static upright sitting posture without back support.

Nag et al., (2010) in their study on handloom weavers of Ahmedabad, India reported body pains among weavers due to poor workstation design, constrain posture, high muscle exertion and repetitive nature of the task. In their study, they have found, female weavers reported higher incidence of pain which they assumed, might be due to both household and workplace responsibilities causing reduced physical recovery time.

Mahvish & Ullas, (2012) in their study have found that handloom weavers of Ambedkarnagar District Uttar Pradesh, India suffers from skin related health problems due to use of dye for dying process.

Goel & Tyagi, (2012) in their study on women weavers of Uttarakhand, India have stated that the weavers suffer from pain in the lower limbs and back due to improper seat design and fixed posture. They have also reported upper limb pain due to repetitive movement of the upper limb for loom operation.

Pandit et al., (2013) in their study on women handloom weavers of Assam found higher incidence of back and leg pain due to improper seat design and exertion of more pedal force for operating Jacquard loom. The study further added the need for ergonomic design intervention considering gender specific requirements.

Zahmatkesh et al., (2012) in their study evaluating environmental parameters and general working condition of rug weavers of Iran, revealed that the weavers suffer from eye sight problem and breathing disturbances due to poor environmental conditions. They have also observed musculoskeletal and gynaecological disorders among women weavers due to constrained and awkward postures for performing rug weaving.

Motamedzade & Moghimbeigi, (2012) in their study have also mentioned that, lack of adjustable workstation in traditional vertical loom without considering gender specific anthropometric dimensions for workstation design increases the risk of MSD among women carpet weavers of Iran.

Thus, above studies revealed workstation, work equipment's, nature of weaving and environmental factors influences workers' occupational health, and safety issues in this sector.

3 Design intervention related studies

Application of ergonomic intervention in design modification of workstation and work equipment can be effective in increasing efficiency among the weavers which is discussed in the following design intervention studies in handloom industry of Iran and semi-automatic handloom or pedal loom of India.

Ergonomic study of Choobineh et al., (2004) on carpet menders of Iran found that design intervention in workstation modification from tradition method of mending have improved working posture of the menders.

Motamedzade et al., (2007) in their study have found that ergonomic design intervention in hand tool modification used for carpet weaving, have reduced contact stress on the hand as well as improved wrist posture.

Choobineh et al., (2007) in their study have formulated guidelines for weaving workstation modification and based on the guidelines, prototype of weaving workstation was developed which improved posture of the weavers.

Solanki et al., (1993) in their study on pedal operated or semi-automatic handloom at Ahmedabad, India have found pedal modification from oscillatory to cyclic type reduced physiological load among male weavers.

Literature review in the handloom sector mainly highlights the importance of four groups of risk factors related to the development of occupation related health problems: these are poor environmental issues, repetitive nature of weaving task resulting insufficient muscle recovery time, poor workstation related health problems such as constrain posture, contact stress as well as gender specific problems for development of Musculoskeletal disorders (MSDs). It was also evident from few ergonomic design intervention studies that modification of workstation and work equipment has improved existing work related health problems.

1.8 Research Gap

Ergonomic evaluation studies carried out in different handloom sectors of India have proved existence of occupational health problems among weavers (Tiwari et al., 1999; Banerjee & Gangopadhyay, 2003; Metgud et al., 2008; Nag et al., 2010; Goel & Tyagi, 2012; Pandit et al., 2013). Design intervention studies in workstation and work equipment modification on vertical loom of carpet industry of Iran, witnessed improvement of occupational problems (Choobineh et al., 2004; Motamedzade et al., 2007; Choobineh et al., 2007). Reduction in physiological load on male weavers, was also been observed with pedal modification in semi-automatic handloom at Ahmedabad, India (Solanki et al., 1993).

Previously mentioned ergonomic evaluation studies in horizontal frame loom of India have proved existence of health problems. But there is a lack of ergonomic solution on workstation modification which was not been reported in any of the research findings. A design development approach, based on occupational stress analysis of NE handloom operation is required to be carried out to see, the possible development strategy to improve work efficiency among the weavers.

1.9 Justification of the research

Ergonomic study carried out in the handloom industry of Western India suggests difference in prevailing of Musculoskeletal Disorders (MSD) among male and female weavers (Nag, et al., 2010). Motamedzade & Moghimbeigi, (2012) in their study have also mentioned that, lack of gender specific anthropometric dimensions for loom development increases the risk of MSD among women carpet weavers of Iran. Treaster & Burr (2004) in their study have reported that women are more prone than men for many types of upper extremity MSDs. This supports the need for ergonomic study in handloom sector of Assam that mainly consists of female weavers, as no gender specific considerations, either anthropometric or physiology, is taken into account in the construction of horizontal frame loom. The manufacturers of the loom are all men whereas the users are women, which require women compatibility design approach while constructing the handloom.

1.10 Research questions

The questions which came up while studying the workstation and through interview with the weavers and the owners are:

1. Changing requirements of weaving from home based amateur to professional practice; does it have any occupational ill effect on health and well-being of women weavers and
2. What type of ergonomic intervention is required in the workstation to adopt with the upcoming effect of commercialization retaining the essence of handloom traditional feeling.

1.11 Hypotheses

Research Hypothesis:- Existing commercial work practice among women weavers of Assam leads to multiple occupational risks. Ergonomic design intervention can improve work performance. In order to find out the research hypothesis, three experimental hypotheses were formulated these are:-

1. **H: 1** Workstation related adaptation of awkward posture during weaving process increases risk of muscle pain.

2. **H: 2** Force required and duration of pedaling is directly proportional to lower limb pain.
3. **H: 3** Design intervention in workstation modification is effective in increasing operational easiness and thus comfort and increases work efficiency.

1.12 Aim

The study aims in reducing effect of occupational stressors, towards wellbeing of women weavers through assistive workstation design which can go along with traditional loom practice.

1.13 Objectives

The objectives of the present study are:-

i. To find out occupational stressors prevailed in the existing workstation that influence work performance among women weavers.
ii. To understand scopes, where design intervention could be effective in improving work efficiency retaining traditional method of loom practice.

1.14 Work Plan

To understand potential risk factors of the job for transition from home based free weaving to schedule based commercial weaving work study was carried out. It helped in the understanding of occupational stress in the workstation, which assists in the development of the workstation in later part of the thesis. The present study has the following goals

i. Screening the workstation from the view point of ergonomic checklists

ii. Identifying the problems and shortcomings of the existing workstation

iii. Improving the workstation with ergonomic intervention and finally testing the modified design in the simulated laboratory condition

In-order to establish the goals, the study was carried out in three phases discussed in details below.

1.14.1 Phase I: Exploratory study

A. Location and fields were selected and contacts were established covering both governments sponsored and private organizations in Assam.
B. General assessment of working environment and work process being practiced in loom cluster were studied.
C. Checklist and questionnaire study was conducted on women weavers, managements and owners of different looms, to identify specific problem areas that need in-depth studies in phase II.

1.14.2 Phase II. Occupational exposure risks assessment

D. Work study and process study was carried out through direct observation, and by photography and videography method.
E. Work posture was evaluated using direct measurements and through indirect videography methods along with subjective feeling of body pain through questionnaire

1.14.3 Phase III: Ergonomic design intervention

F. Participatory approach was carried out for design ideation and expert comments was used to execute the design, viewing for improved working condition.
G. Trial and testing was carried out to evaluate efficacy of the new design.

1.15 Outline of the thesis layout

The whole work has been parted into three phases and the flow of the work is covered in the following chapters.

Chapter 1:- Introduction: women occupational wellness; reference handloom industry of Assam

Chapter 1 constitute the current chapter of the thesis, which tries to figure out women involvement in different sectors of India, in diverse economic activities. In India, women are getting into main stream workforce in increasing numbers. This group of workforce are more prone to health hazards, as they play dual role in the society and gets very less time for muscle recovery. With growing economic challenge, home based industries are taking the shape of commercial industry where women are mostly involved. Changing of work practice on same workstation increases occupational hazards among this working group. One such example is the handloom industry of Assam which is gradually getting commercialized. An ergonomic study to identify occupational problems for commercial production on horizontal frame loom, the workstation of the weavers is the need of the hour, to improve work performance, comfort and operational easiness.

Chapter 2:- Assessment of occupational health status of women weavers of Assam

Location selection and demographic study was carried out on the workers of selected clusters. General assessment of working environment and work process, being practiced was captured with the help of videography and interviews. Further detailed questionnaire survey was carried out among the workers and management or owners of the handloom industry to figure out ergonomic problems existing in the present loom condition.

Ergonomic evaluation of stress development among weavers was assessed while performing weaving activity on the loom, by direct observation and videography method following step by step work analysis to recognize where design development could be beneficial.

Chapter 3:- Design development of seat and pedal of the horizontal frame loom

Participatory approach was used for design intervention, taking the views of the workers and managements to understand the type of seat and pedal they feel to be functional in the existing loom condition. Thus a seat and pedal design was conceptualized, designed and developed following ergonomic principles, looking forward to reduce work related problems existing in the present workstation. Trial and testing was carried out by relevant techniques, to evaluate efficacy of the new design. Ergonomic designed seat and pedal reported to decrease low back pain, increased the comfort level and operational easiness among the users.

Chapter 4:- Discussion

The results of the research findings were explained and compared with other research findings, Objectives and hypothesis of the research findings were established and salient research findings were discussed.

Chapter 5:- Conclusions

The last chapter tie together various research findings of the study and highlights the contribution of the present findings to the body of knowledge and discussed about the limitations and questions were raised for future research work.

Chapter 2

Assessment of occupational health status of women weavers of Assam

Chapter 2

Abstract: - *A study was conducted in the handloom industry of Assam with the objectives to determine whether long hours of traditional designed loom usage for commercial production have any significant occupational health problems among weavers. Ergonomic assessment was carried out in order to identify major risk factors associated with development of occupation related health problems. It was found that symptoms of musculoskeletal systems occurred in high rate among the weavers. A major cause of MSD was due to ergonomics shortcomings originated from ill-designed weaving workstation. Based on these findings, scope of design intervention was formulated. In this chapter, ergonomic assessment of the existing weaving workstation was presented.*

2.1 Introduction: NE the "Only Weaver States"

North Eastern states have the reservoir of weaving skills and highest concentration of handlooms (Figure 2.1). The states of NE only qualify to get "**Only Weaver States**" tag, because 94.3% adult workers are weavers. Over 53% of looms in the country and more than 50% of the weavers belongs to NE (Annual report, 2007-08).These region is renowned for its rich heritage of handlooms.

As mentioned earlier, there are major difference in gender composition, between handloom weavers of NE and other states. NE has predominantly female weavers (99%) compare to other states where male weavers are present in significant numbers (Handloom Census of India, 2009-2010). Types of loom found in NE are mainly frame loom (78%) and loin loom (21%) (Handloom Census of India, 2009-2010). Advent of commercialization could not influence loin loom weavers, and they still retain traditional tribal practices whereas, there is rapid transformation towards commercialization among frame loom weavers.

Figure. 2.1 : Women Weavers of North East India

2.2 Handloom industry of Assam- a state of NE India

In North Eastern states of India, Assam enjoys a place of pride for its rich heritage of artistic handloom products and it consist the highest number of handlooms (Handloom Census of India, 2009-2010). Almost every household in the rural areas of Assam are connected with weaving, which is the oldest and largest industry of the state and major contributor to the state revenue (Goswami, 2005).

Many small units of handloom sector of Assam, have taken weaving at commercial level under different co-operative organizations, as a result more women weavers are associating with weaving as a part time or full time profession. The activities that women performed for their domestic needs during leisure time, has now been transformed into professional work. Duration of loom usage for commercial weaving is quite longer, even extending beyond 8 hours of work schedule (India: The Factories Act, 1948). Hence, workstation for commercial purpose are different from domestic requirements, but in-spite of the changing necessities workstation are not modified, traditional designed frame looms are used for commercial purpose.

Weaving involves number of stages, but for study purpose weaving activity has only been considered, as weaving occupies over 50% of the work cycle time. The rest, adjustment and preparation of loom for weaving are not repetitive in nature (Banerjee & Gangopadhyay, 2003).

2.3 Fly-Shuttle Frame loom – common loom of Assam

In Assam weaving is commonly practiced both in the organized and unorganized sectors on fly-shuttle frame loom which is a horizontal loom. A fly-shuttle frame-loom or four-poster fly-shuttle loom is made of heavy wooden framing having an overhung slay. The slay holds two shuttle boxes at two ends and is suspended from the top of the loom by means of two slays words.

A smart blow is given to the shuttle with the help of picking handle connected by cords with pickers on both sides of the slay frame, which causes the shuttle to pass across the shed over the race. The process of passing a pick with the help of shuttle from one shuttle-box to the other over the race is known as "**picking**". Forward and backward swing of the overhung slay to beat the weft to give rise to cloth is known as "**beating"**. The fly-shuttle frame loom is illustrated in the following Figure 2.2.

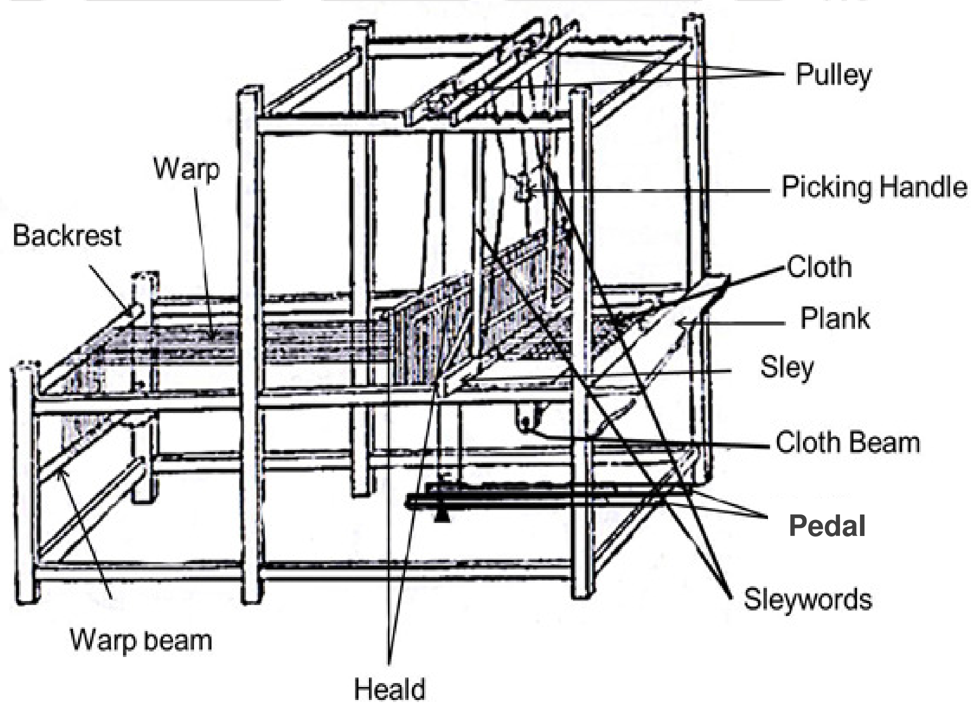


Figure. 2.2. A Fly-shuttle frame loom (Banerjee, 1982)

Two healds are connected with two pulleys on two ends of the heald frame. Cords from first heald are attached with second via overhead pulleys on both sides, which is (healds) again been connected below with pedals. Alternately pressing down the pedals upward and downward movements of the heald shaft takes place and plain weave is produced. Motion imparted to the healds by means of pedals, is called a "shedding motion" and the division of warp threads is "**shedding**".

2.4 Role of Ergonomics in Handloom

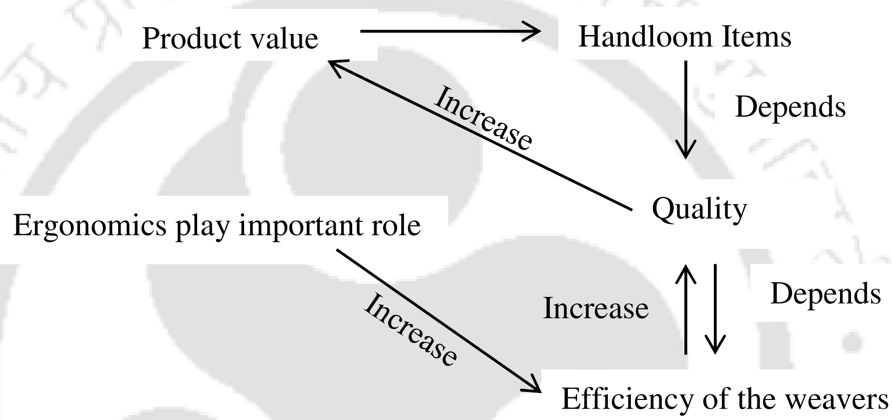


Figure 2.3. Role of ergonomics in the handloom industry

Product value of handloom items depend on quality, quality again depends upon the efficiency of the weavers. There are number of studies showing clear relationships on the influence of environmental factors on quality performance by humans (Sanders & McCormic, 1993; Smith & Jones, 1992). In a study it was found, worst body posture results 10 times higher quality deficiency than good posture (Axelsson, 2000). Working posture is highly dependent on workstation design, if it is not properly designed it leads to physical symptoms (Lu & Aghazadeh, 1996). Body pain, absenteeism and job turnover are indications of ergonomic deficiencies in a workstation. Error rates of work increases with body discomfort and pains on poor workstation (Grandjean, 1988; Corlett & Bishop, 1976; Eklund, 1995) which in turn decrease production and job loss. The situation gets even more exaggerated with long duration of poor workstation usage.

Price of craft item depends upon its aesthetic value which in case of handloom depends on artistic sense of the weavers, which gets transformed on fabrics in the form of motifs. Weaving on poor loom design will cause discomfort and muscular pain which in turn deteriorates quality performance due to loss of concentration. The ultimate goal of ergonomist is to design the workplace, so that it prevents from adverse effects of muscular pain, resulting poor quality performance. Well-functioning working environment makes the task better adapted to the abilities and limitations of the humans, less stressful, eliminates fatigue, discomfort and impose fewer risks performance.

2.5 Previous Ergonomic studies on horizontal frame loom of India

Solanki et al., (1993) in their research undergone physiological study on a group of male weavers at Ahmedabad found, by improving pedal operating loom from oscillatory to cyclic method decreases workload. Tiwari et al., (1999) in their study have reported higher prevalence of respiratory morbidity among handloom weavers. Bannerjee & Gangopadhyay, (2003) in their study on male weavers of West Bengal have found that weaving involves highly repetitive work leading to the development of repetitive strain injury in the upper limbs. Nag et al., (2010) in their study at Ahmedabad have reported that male and female workers involved in handloom sectors suffer from back and knee pain. They also opined poor workstation design aggravates the effect of musculoskeletal disorder among the weavers. Goel & Tyagi, (2012) in their study have reported that the weavers suffer from pain in the lower limb and back due to improper seat design and fixed posture.

Some initial studies have been conducted in the handloom industry of Assam addressing workstation and working posture related problems faced by the female weavers at workplace (Pandit et al., 2013; Pandit & Chakrabarti, 2014).

2.6 Necessities for ergonomic evaluation in the existing frame loom of Assam

To investigate and assess the prevalence of ergonomic issues, clusters of handloom units were visited (both in organized and unorganized sectors) and meetings were conducted with weavers, loom owners, and managers of both the sectors. From preliminary discussion and observation it was found, weaving involves prolonged seating with awkward posture to execute weaving task along with forceful repetitive activity for executing primary motion (discussed in Chapter 3) as well as eyestrain due to precision task.

From literature it was found, repetitive movement imposes cumulative workload which can cause pain and weakness and impaired function of the muscles and other soft tissues (Gangopadhyay et al., 2007; Gun & Jezukaitis, 1999). Valachi &Valachi, 2003 in their study have reported that physiological problems that arise from repetitive work or overuse of certain muscles, tendons and soft-tissue structures have been reported in terms of muscle fatigue. In another study Geronilla et al., 2003 have reported rate and degree of tissue damage depends on the amount of force, repetition and duration of exposure. Work is especially harmful when awkward movements are combined with force (Marras & Karwowski, 2006).

Understanding the importance, ergonomic study was carried out in details on different handloom clusters of Assam.

2.7 Methods and Materials

Ergonomic approach of assessing the present handloom working status might help in finding some effective solutions. Weaving has lots of components (Figure 2.4) but for the present study, weaving was only been considered. To understand the existing working condition of the handlooms, below were the detailed steps taken to obtain relevant information's.

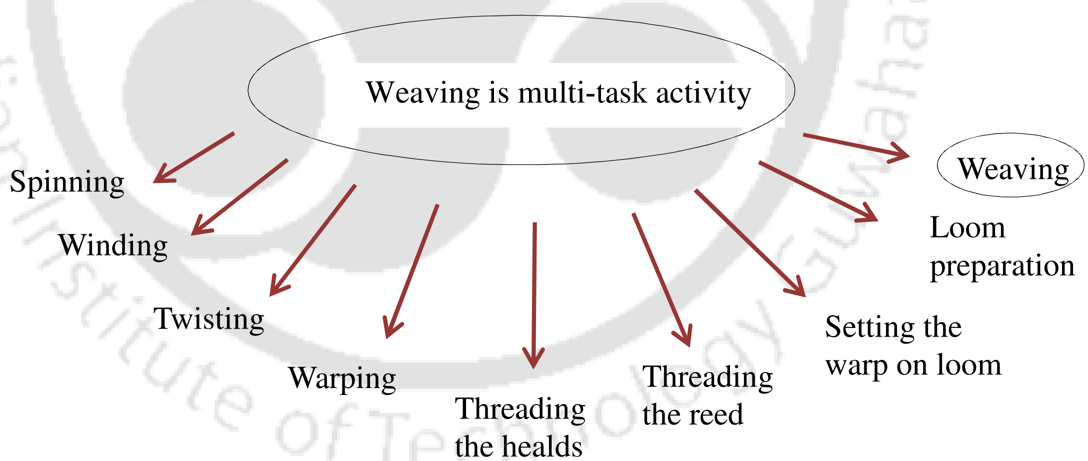


Figure: 2.4 Different Components of weaving process

2.7.1 Study Design

Survey was carried in different handloom units located in and around Guwahati under Kamrup district of Assam, to find out major work related problems prevailed among women weavers. 118 handloom clusters were visited (both organized and unorganized sectors) and meetings were conducted between loom owners, weavers and managers. Sampling was done by purposive and then random sampling method from both organized (government, semi-government and private agencies) and unorganized sectors (such as self-help group, small loom clusters). The workers were all females; within age group of 18-35 years because as per 'Handloom Census of India 2009-2010' maximum numbers of weavers belong to this age group and all the weavers chosen for the study were right limb dominant. Working hours of the selected handloom undergoes 4-12 hours of commercial production. From booklet published by State Institute of Rural Management (SIRD) it was found that for the last 10 years with initiatives of Government of India and Assam, home based handloom weaving is rapidly changing over to commercial industry (Eri and Muga thread cutting machine, 2007). Keeping this in view, weavers with weaving experience of 2-10 years involved with commercial productions were selected for the study group. Personal characteristics of the weavers were given below in Table 2.1.

Subjects were allowed to use work schedule and duration of work-pause of their own practice. Only one worker at a time was interviewed to avoid loss of productive time. Some of the questions were rephrased to find the consistency to the answers of the weavers.

Table 2.1
Personal characteristics of the weavers

Characteristics	**Female weavers (n=150)** $\overline{\mathbf{X}}$ **(range)**
Age (yrs)	27 (18-35) yrs
Yrs of involvement	6 (2-10) yrs
Working hours/day	8.55 hrs (4-12)
Literacy	100%

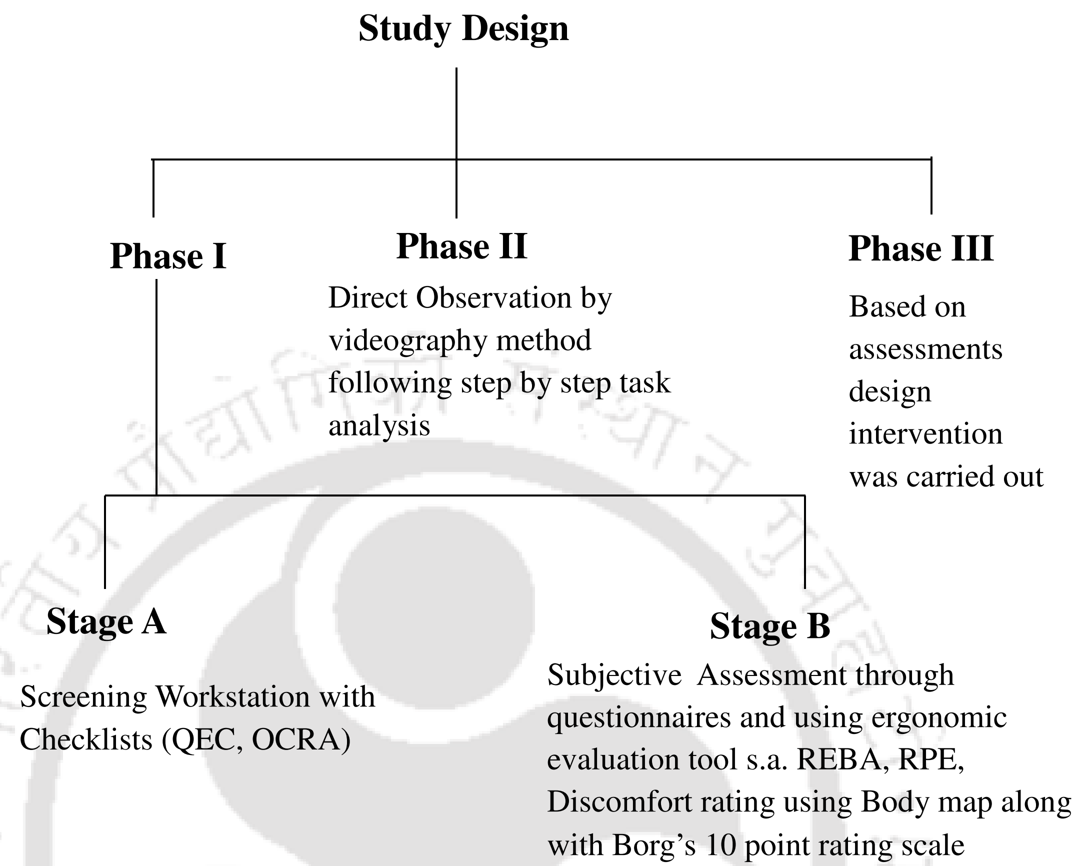


Figure 2.5 Schematic representation of study design

To identify potential problem areas in weaving, a holistic approach was carried out to understand work process. All the weavers selected for the study performed picking with right hand, beating with left hand and pedalling with right leg (Figure 2.13). The study was conducted in two phases (Figure. 2.5). Empirical assessments for ergonomic evaluation of the existing handloom workstation were first done with the help of checklists to understand level of occupational stress involved in the workstation. Quick Exposure Checklist (QEC) and Occupational Repetitive Assessment Checklist (OCRA) were used to screen the workstation followed by subjective assessment carried out by field study questionnaire (Appendix A) and ergonomic tools such as Rapid Entire Body Assessment (REBA), Discomfort rating using Body map along with Borg's 10 point rating scale to understand body parts affected to undergo a particular task. Direct observation by video-event analysis of the task was used to verify subjective reporting and to find out causative factors for such reporting. Based on workstation evaluation design intervention (Phase III) was executed, which is discussed in Chapter 3.

2.7.2 Sampling procedure

Three types of weaving practices are generally seen in Assam (Figure. 2.6), these are (a) Purely domestic weaving - whole upper Assam districts (b) Both Commercial and Domestic weaving - Kamrup and Goalpara district of lower Assam and some upper Assam districts (c) Commercial Weaving – Kamrup district and few pockets of Upper Assam (Chakravorty et al., 2010).

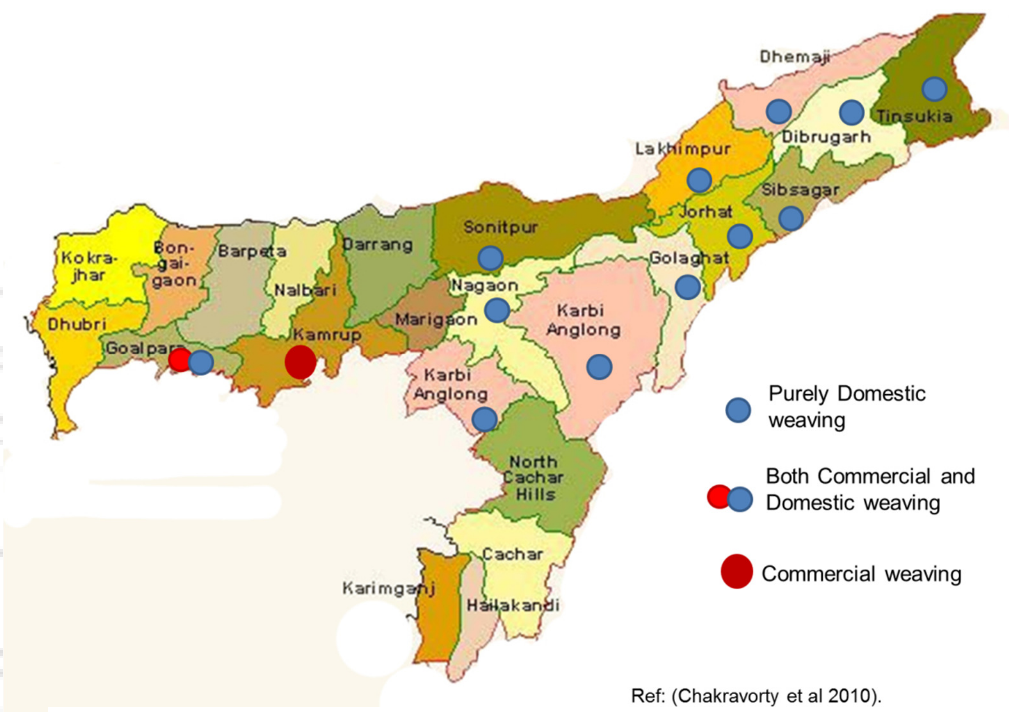


Figure 2.6. State map of Assam representing weaving practice

Sampling was done based on purposive and then random sampling method which was represented diagrammatically in Figure.2.7. Kamrup district was selected purposively for its contribution towards commercial production and from Kamrup a list of handlooms under both organized and unorganized sectors were selected for the study. State Institute of Rural Management (SIRD), Khadi and Village Industries Commission (KVIC), Institute of Rural Management (IRM), Artisans Cooperative Federation Limited (ARTFED), Fabric Plus (FP) under organized sector, Sualkuchi, Bijoynagar, Self-help group Dolgovindo (SHG) and Hajo under unorganized sector.

Discussing with administrative bodies of different organized sectors, number of weavers working under different Government aided projects were identified and from them random sampling was performed. Fabric Plus was a private organization and sampling was done based on the number of weavers working in that organization. Sualkuchi known as the Manchester of North East is famous for its commercial weaving worldwide. Bijaynagar and Hajo come after Sualkuchi for commercial productions also counted under Kamrup District. Each household of these villages consist 3-4 handlooms and practices weaving on commercial rate. Data base of number of weavers at Sualkuchi was available from an organization named as Shobhan which works for promoting handloom products of Sualkuchi not only to Indian market, put also across the sea. Number of weavers working for commercial weaving for Bijaynagar and Dolgovida village was available from SIRD Azara and Chansari unit and Hajo from Assam Government Marketing Corporation Limited (AGMC).

Finally a total of 150 women weavers were selected [7% of the total population from selected weaving pockets] as shown in Figure 2.7 from both organized and unorganized sectors for the study (Bhattacharyya, 2011). Weavers selected were all right limb dominant, apparently healthy without any specific physical problems. Pregnant and lactating women and those who had undergone any major operation within last one year were exempted from the study to avoid post-operative pain.

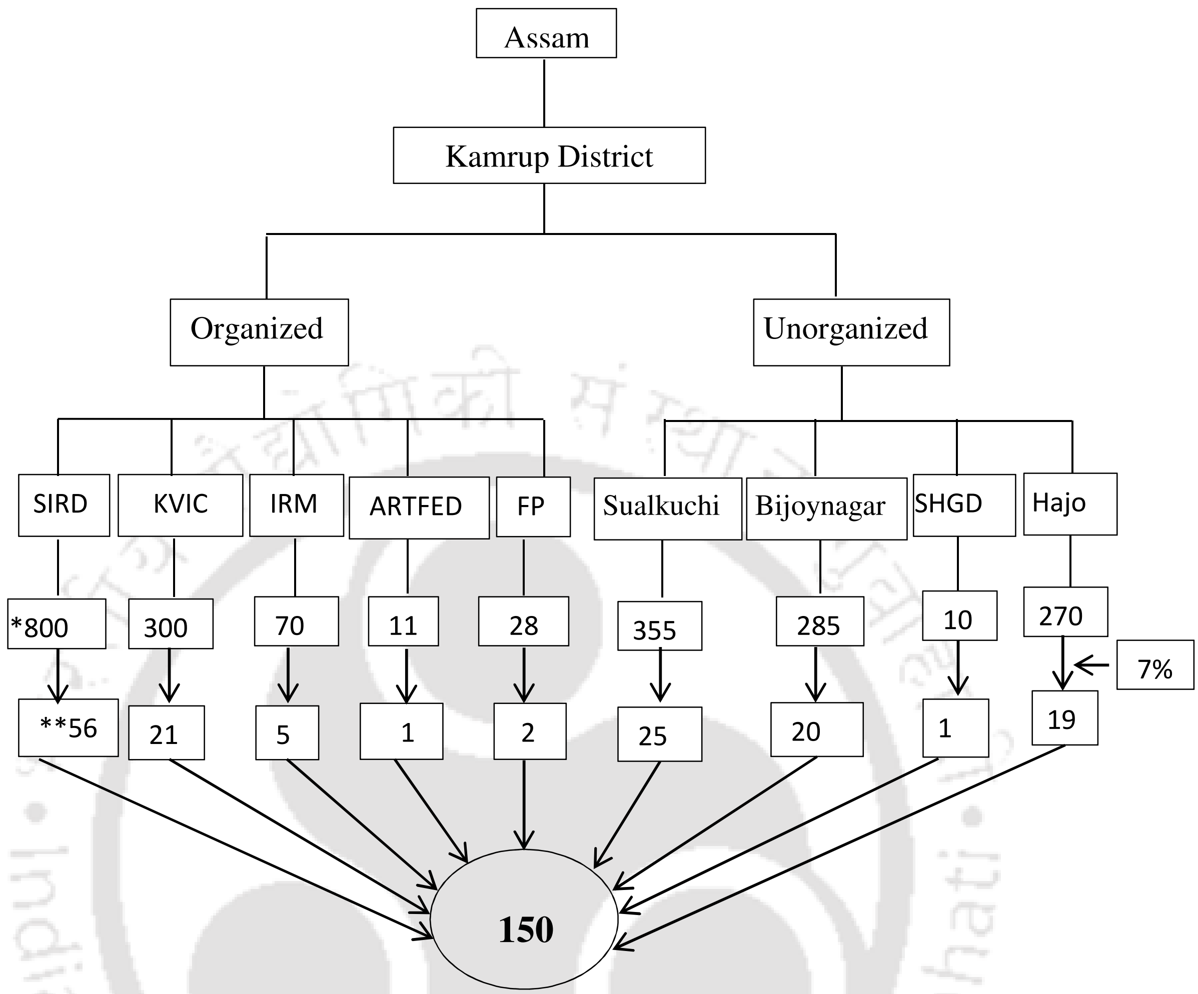


Figure 2.7. Sampling Procedure (* Total number of employees, ** sample size)

2.7.3 Methodologies used to assess ergonomic risk factors and occupational load in the existing handloom industry

a) **Quick Exposure Checklist (QEC):-** QEC is good tool (Appendix B) for initial screening and prioritizing the workstation (David et al., 2005). Easy to learn and can be used rapidly. It is a useful source of information for understanding root causes of most severe risk factors and workstation tasks that are most difficult for the workers. It involves the practitioner (i.e. the observer) who performs the evaluation and the workers who have direct experience of the task (Stanton et al., 2005). Activity levels from QEC% score is presented in Table 2.2.

Table 2.2

Recommended QEC% score

Action Level	Intervention Recommended	QEC% score
Acceptable risk	Acceptable posture	<40%
Moderate risk	Further investigation needed; changes may be required	40-90%
High risk	Investigation and changes needed soon	50-69%
Very High Risk	Investigation and changes needed immediately	>70%

b) **Occupational Repetitive Actions (OCRA) Checklist: -** OCRA checklist (Appendix C) describes a workplace and estimates intrinsic risk, as if the workplace is used for the whole of the shift by one worker. This procedure makes it possible to find out quickly, significant exposure level of the workplace (Stanton et al., 2005), Table 2.3.

Table 2.3

Scores and area of risk in OCRA checklist

OCRA checklist Value	Risk Level	Consequences
Up to 7.5	Acceptable	No consequences
7.6-11	Borderline or very low	Advisable to set up health surveillance
11.1-22.5	Presence of Risk	Re-design of tasks and workplaces according to priorities, health surveillance, training, information
More than 22.5	High Risk	

c) **Rapid Entire Body Assessment (REBA)** is an ergonomic assessment tool uses a systematic process to evaluate whole body postural MSD and risks associated with job tasks. REBA measures biomechanical and postural loading of the whole body. A single page worksheet is used to evaluate required or selected body posture, forceful exertions, type of movement or action, repetition, and coupling activity.

Using REBA worksheet (Appendix D), a score is assigned for each of the following body regions: neck, trunk, leg, Upper arm (UA) left (Lt), lower arm (LA) Lt, UA right (Rt), LA (Rt), wrist for both Rt and Lt arm. REBA score is calculated by three summary measurements. Score A which is derived by sum of the posture score of neck, trunk and leg and addition of force score. Score B is obtained by summing up posture scores for upper arm, lower arms and wrists and coupling scores for each hand. Final REBA score is derived by adding score A and B to activity score, measured based on duration of static posture, frequency of small range movements and frequency of large changes in dynamic posture. REBA score provides an Action Level (AL) on a five-point action category scale from 0 (no risk) to 4 (high risk) a guide to understand the level of musculoskeletal risk and an urgency with which action should be taken. REBA score sheet was developed by Hignett & McAtamney, 2000.

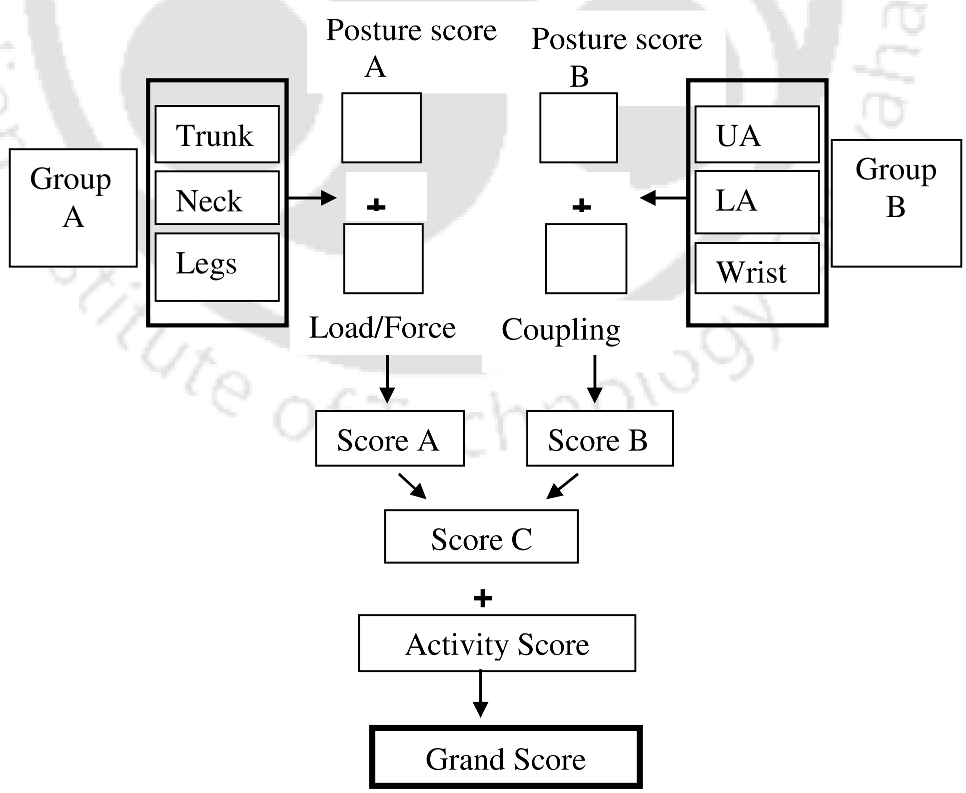


Figure 2.8 The REBA method scoring sheet

d) Discomfort Rating: - Discomfort or pain is the indicating parameter of occupational stress (Appendix E). Quantification of discomfort levels or pains in different body segments is one of the tools to assess occupational stress among the workers performing the tasks. To specify the site of discomfort a body map is used (Corlett & Bishop, 1976), divided into different segments (Figure 2.9). Depending on the region of discomfort pain is mapped in that segment. 10 point Borg's scale is used to rate the level of discomforts or pains. Grade 0, indicates no pain to Grade 10 representing severe pain (Borg, 1998).

<u>10 point scale</u>

0	No pain	6	Moderate Pain
1	Discomfortness	7	Severe Pain
2	Very mild pain	8	Very severe pain
3	Mild pain	9	Extreme severe pain
4	Numbness	10	Intolerable
5	Average Pain		

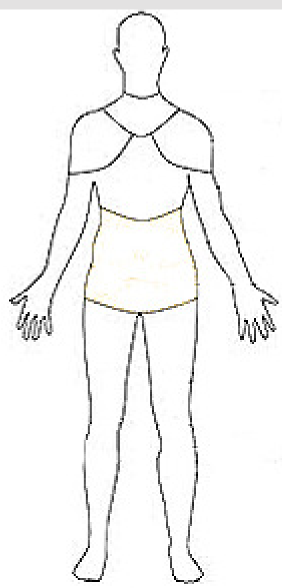


Figure. 2.9. Body Map

e) Direct Observation: - Direct observation method is a study carried out by video recording and replay event analysis in slow motion to analyse the job step-by-step. Analysis of the job is important to identify causative factors for development of work related occupational stress. It helped to have better insight of the situation for identifying possible areas where intervention could solve the problems.

2.7.4 Statistical Analysis

Data analysis was performed using Statistical Package for Social Sciences (SPSS) version 20. Frequencies, percentages, mean, standard deviations were calculated to answer various questions relevant to the objective of the study and different tests were performed for testing the hypothesis.

2.8 Results

2.8.1.1 Phase I:

Stage A: - Workstation Screening

Weaving activity in different handlooms were assessed with the help of checklists. Checklists were used for initial screening and prioritizing the workstations according to the action level. QEC and OCRA checklists were used to screen different frame looms based on workers perception and observers assessment.

2.8.1.1 a Quick Exposure Checklist (QEC)

Assessment of the workstation was started after completion of one cycle of weaving activity by direct observation at different handlooms. Evaluation of the workstation to measure risk factors for work related MSDs was conducted based on observation and feedbacks from the weavers. Based on evaluation, further workstation study was decided.

Analysis of weaving activity using QEC gives exposure scores to specific body parts including back, shoulder/arm, wrist/hand, and neck. The average of total QEC scores for weaving operation was found to be 145 out of 187 giving a percentage score of **77.86%** (Table 2.2) which falls under very high risk and gives indication that immediate ergonomic intervention was required.

To understand risk exposure of different body parts due to weaving task, obtained score of individual body parts from QEC checklist was compared with exposure categorical score (David et al., 2005). From comparative study it was observed except shoulder/arm region all body area score falls under very high priority risk levels (Table 2.4).

Table 2.4

Comparison of derived QEC score of weaving activity with recommended priority scores for different body parts (David et al., 2005)

Exposure Categories Scores					Obtain QEC score for weaving activity
Body area	**Low**	**Moderate**	**High**	**Very High**	**Score**
Back (Static)	8-15	16-22	23-29	29-40	31
Shoulder/Arm	10–20	21-30	31-40	41-56	37
Wrist/hand	10-20	21-30	31-40	41- 46	43
Neck	4-6	8-10	12-14	16-18	17

The reasons for such conditions might be due to:-

1. For weaving the back was continuously flexed forward either for motif formation or for performing beating.
2. The neck remains flexed during the whole working hours for inspecting breakage of warp and weft threads.
3. For wrist/hand it might be due to continuous extension and flexion of wrist and hand for picking and slay frame movement for beating.

QEC only gives an indication of the risk factors of the upper part of the body but risk of lower extremities remains unresolved from this checklist.

2.8.1.1 b Occupational Repetitive Actions (OCRA) Checklist:

In an article on Workplace Health and Safety Information it was stated that weaving involves repetitive motion of the whole body (McCann, n.d). Banerjee & Gangopadhyay, (2003) in their study have also opined that weaving is highly repetitive task. To estimate the level of risk involved due to repetitive nature of weaving, screening of weaving activity was performed with the help of OCRA checklist. The result of the study was presented in Table 2.5.

Table 2.5

Recommended and obtained OCRA checklist score for weaving operation.

OCRA Checklist value	Risk assessment	Checklist score of weaving activity
Up to 7.5	Acceptable	
7.6 - 11	Borderline or Very Low	
11.1 – 14.0	Low	
14.1- 22.5	Average	
$\geq$22.6	High	33.6

Comparing the result of Table 2.5 with Table 2.3 indicates high risk involvement in weaving where immediate attention was required to improve both work method and workstation.

For performing weaving both limbs were involved, in two different types of activities. Right hand is used for picking motion and left hand for beating. Activities of both arms were different but adding all the scores separately for two limbs (right and left) and multiplying with multiplier, gave same score for both the limbs.

Repetitiveness is one of the most important risk conditions for developing work related health problems (body pains). Task involving prolonged exposure to repeated activities were associated with body discomfort. In many workplaces, the time to complete a cycle of work is less than a few minutes. If the cycle is repeated continuously for 2 or more hours, the work is considered repetitive (Najarkola, 2005). Weaving involves highly repetitive activity where picking, beating and pedalling for shedding takes 74 cycles/min ± 13.59 (analysed in slow motion with videography method). One complete cycle was counted when the shuttle propelled from one shuttle-box to another and again returned back to the same. With onset of commercialization, the weavers used to spend around 4 hours continuously at a stretch on the loom for weaving. Repetitive use of same muscle groups cause quick muscle fatigue and the repeated movement around a joint induce micro-wear and tears causing inflammation and also soft tissue injury, leading to the development of muscular pain, contributing productive loss.

Analysis of different workstations with the help of QEC and OCRA checklist gave an indication that weaving activity falls under very high risk exposure level where immediate ergonomic intervention was the need of the hour. In a study it was observed that females were found to be more resilient to discomfort compared to males (Christopher et al., 2010) which was a condition of handloom weaving in Assam where all the weavers were found to be women. This gradually brings more serious health problems in later phase of life if not taken care at an early stage.

The results of the checklist generated a strong ardour to find out health condition of the handloom weavers performing weaving in such poor working conditions. In the next stage subjective assessment was performed with questionnaire and different assessment tools. Results obtained from such evaluation were discussed below.

2.8.1.2 Phase I

Stage B: - Subjective Assessment

Subjective assessment was done to quantify discomfort or pains in different body parts performing weaving with the help of field study questionnaire (Appendix A), body map (Appendix E) and Standard Nordic questionnaire (Kuorinka et al., 1987) to understand percentage of reported body pains among the weavers along with frequency and severity of pain among 150 women weavers of both organized and unorganized sectors.

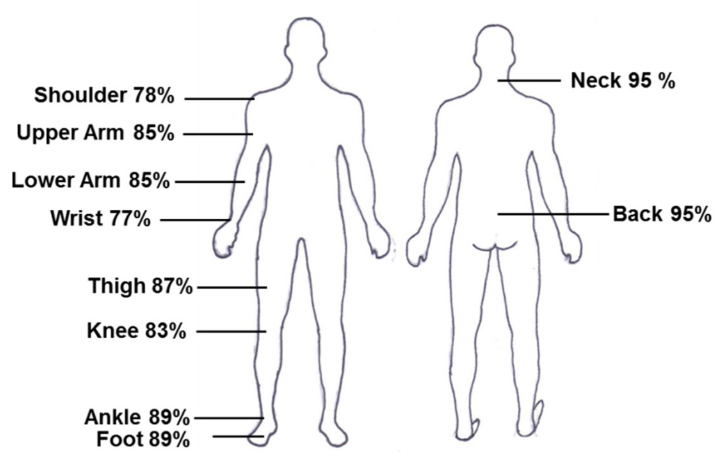


Figure. 2.10. Percentage of pain in different body parts

Region wise mapping of pain revealed that 95% of the weavers reported pain in the neck and back. Of the upper limbs, 78% of them reported of having pain in the shoulder, 85% in the upper and lower arms and 77% in the wrist area. Whereas in the lower limbs 89% of the weavers reported pain in the ankle and foot, 83% in the knees and 87% in the thighs shown in the following Figure. 2.10.

Neck, back, hand, ankle and foot were the most affected body areas where more than 80% weavers reported of having pain "always" followed by shoulder, wrist and knees where 70% and more weavers reported of having "always" pain shown in the following Figure.2.11. From reported pains in different body segments with body map it was found that neck, back, hand and lower leg were most affected body parts for performing weaving task which was further tested with the help of severity of pain sensation. To understand severity of pain, the body was categorized into four segments - neck, back, upper limb and lower limb which helped to understand which segment of the body was mostly affected. Reporting of the weavers revealed that maximum numbers of weavers were having acute pain at the back and lower limbs for handloom weaving (Figure. 2.12).

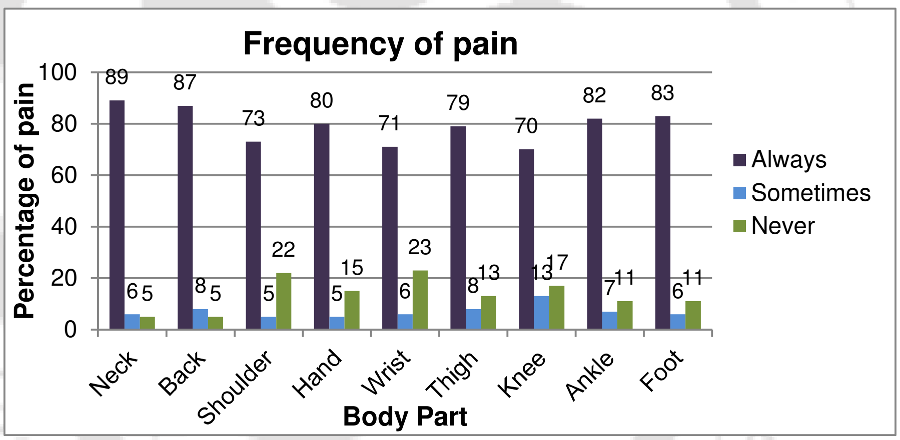


Figure. 2.11 Frequency of Muscular Pain

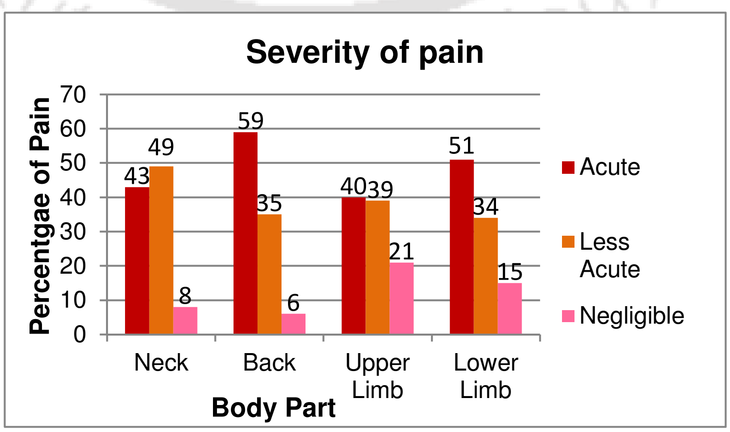


Figure 2.12 Severity of Muscular Pain

In order to understand which activity of weaving is associated with which part of the body movement, weaving activity was further divided into sub-tasks. Analysis of these subtasks helped in the identification of the tasks responsible for inducing pain in particular body regions and accordingly prioritization and ergonomic intervention could be development. A body map technique was used (Corlett & Bisop, 1976) where the subjects were asked to indicate body areas where they were experiencing pain while performing a particular sub-task (Figure. 2.13) and asked to rate the pain on Borg's CR-10 Pain scales (Borg, 1998) which is shown in Table 2.6.

Figure. 2.13. Body segments involved in weaving subtask: Right hand for picking, Left hand for beating, Right Leg for pedalling or shedding

Table 2.6

Analysis of pain rating with Borg CR-10 scale for performing different weaving sub-task

Sub-task	Body region	Rating(mean) (range)
	Rt shoulder	6 (4-8)
	Rt Hand	6 (4-8)
Picking	Wrist (Rt)	6 (3-7)
	Lt shoulder	4 (2-6)
	Lt Hand	5 (3-7)
	Wrist (Rt)	5 (3-6)
Beating	Back	**8(5-9)**
	Neck	7 (3-7)
Inspection task by seating	Back	**8 (5-9)**
Pedalling	Lower Limb	**7 (4-9)**

By analysing weaving subtask (Table 2.6), it was observed that, back muscle has the highest mean pain rating of 8 followed by lower limb and neck, having pain rating of 7. Second highest pain rating was observed for both neck and lower limb but noticeable reduction in the range was observed in case of neck pain. From observation it was clear that highest pain rating of the back muscle was due to constant flexion of the trunk for inspection of thread breakage and for performing beating. Incidence of neck pain was due to neck flexion for inspection of thread breakage. Pain in the lower limb was due to both pedalling and poor seat design. For right hand, shoulder and wrist, pain rating was found to be 6, which was due to repetitive forceful exertion to carry picking operation. Lateral flick (both right and left) of wrist pulled the cords attached with the shuttle box and the shuttle run over the race from one end to the other. Roughness of the slay race with age of the loom and improper maintenance increased frictional force resulting more force for its operation. Picking is highly repetitive resulting little time for muscle recovery. In almost all the cases the weavers performed picking with abducted shoulder. Pain rating for left hand and wrist was found to be 5; this was due to repetitive oscillatory movement of the slay frame. The movement was sudden, quick and with force for proper beating of the weft thread to give rise to the fell of the cloth.

Analysis of weaving sub-task revealed that back and lower limb was mostly affected body segments reported by the weavers undergoing weaving. Causative factors for pain in different body segments was further analysed with the help of video-event analysis of weaving activity.

2.8.2 Phase II Observation Method

Work system analysis of weaving task was performed with the help of video-event analysis to verify the findings of subjective assessment and helped to further investigate the problems in details. Video recording of weaving activity was conducted in different frame looms and analysed in slow motion in the laboratory. The purpose of weaving task analysis is to make a step-by-step investigation, to find out causative factors for the development of pains in those body regions, which the subjects reported while, subjective pain assessment. Duration and frequency of adopting different working postures and use of different body segments for loom operation was analysed carefully, it helped in better understanding the insight situation responsible for the development of work-related muscular pains and where modification could relief from the existing situation.

The identified ergonomic problems in the existing workstation are presented in Figure 2.14.

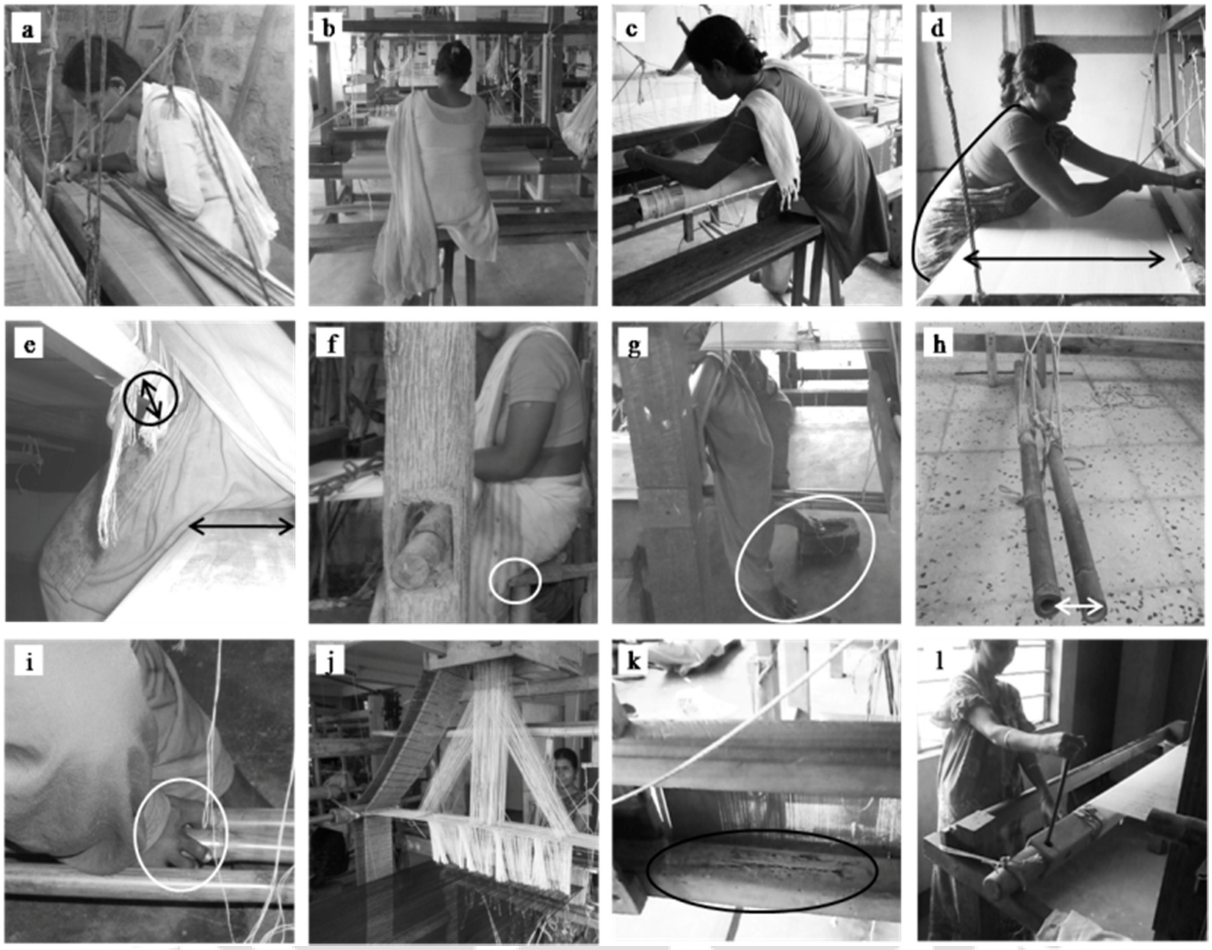


Figure. 2. 14. Observations of video analysis method – a) Forward bending posture and neck flexion for manual motif formation, b) Upright sitting posture for plain weaving, c) Side bending posture for maintaining side thread breakage, d) Forward stretching posture to avoid cloth rolling procedure, e) Lack of clearance space between thigh and cloth beam along with improper plank depth for sitting, f) Digging of posterior thigh muscle by the hard edge of the plank, g) High seat height leading to improper support for foot, h) Insufficient gap between two pedals, i) Small and slippery pedal surface made of bamboo sticks, j) Introduction of jacquard system enhancing pedalling force k) Dented surface of sley increases frictional force for picking and l) Adjustment of warp beam for let-off and take-up motion

2.8.2.1 Findings of an in-depth observational study

Seat related

i. Weaving involves highly inspection task, where weavers spend more than 8 hours job schedule in a narrow plank of about 13-15cm depth (Figure.2.14e). The weavers were found to adopt different types of postures continuously and repetitively for performing weaving (Figure. 2.14a-d). Above all these circumstances, no backrest was found for relaxing back muscle during intermittent rest (Figure 2.14b).

ii. No sufficient leg clearance space been observed between cloth beam and seat, which results hitting of the anterior thigh muscle during oscillatory pedal operation (Figure. 2.14e).

iii. Hard edge at the front of the plank was found to create pressure at the posterior thigh muscles resulting digging and redness with vertical downward leg movement for pedalling (Figure. 2.14f).

iv. Popliteal height of women weavers was found, not to be taken into consideration for seat height and in almost every handloom units, it was found that the foot of the weavers only partially reached the ground or dangled in air (Figure 2.14g). G force acting on the leg in this situation resulted development of more pressure underneath the thigh. This resulted in numbness, tingling and pins and needles effect in the lower leg.

Pedal Related

i. The gap between two pedals was found to be 6 to 8 cm which results single leg to operate both (Figure. 2.14h).

ii. Pedals made from thin bamboos was found to be smooth and slippery in due course of regular used, resulting minimum foot support, leading to pressure development in ankle and toe with operational force (Figure. 2.14i).

iii. Present way of pedal operation required high force and high repetition, leading to the development of muscular fatigue in the leg muscles. This also results repeated hitting of the anterior and posterior thigh muscles with hard seat edge below and cloth beam above (Figure. 2.14f and e).

iv. Introduction of Jacquard for commercial weaving required more pedalling force to push the pedals downward, against additional tension force of harness yarn (Figure. 2.14j) which is discussed in details later.

Picking and beating related

i. Picking involves high repetition leading to the development of fatigue in the right limb. With age of the loom and improper maintenance, roughness of the race increases which required more force for picking (Figure. 2.14k).

ii. Beating demands high force for oscillatory movement of the slay frame. Sudden high forward movement of the frame is required to give rise to the fell of the cloth.

Take-up and Let-off (clot rolling) related

Cloth rolling involved tedious job consisting of many steps and has to be done after every 20- 30 minutes interval. At first, the weaver has to get out of the seat and go to rear end of the loom. First the warp beam is required to be unlocked, followed by tightening and adjusting the cloth beam. After locking the cloth beam in front, the warp beam is relocked this is followed by returning and getting on to the seat. In order to avoid this whole process, they lean forward and maintain this posture as long as possible, leading to the development of severe back pain (Figure. 2.14 l).

Organizational factors related

With increased price of raw materials, there was a heavy challenge for the survival of the industry, as a result the weavers were paid per work basis. In order to finish task in single spell they spend long hours in the loom to earn more; this results in the development of multilevel occupational health problems.

Finally, from ergonomic evaluation of the existing workstation five operations were identified which were mainly responsible for pains in the mentioned body segments these were:

Plank or seat → Back and Lower limb pain

Pedal → Lower limb pain

Picking and Beating → Upper limb pain and

Cloth rolling operations (let-off and turn-up) → Back and Neck pain

2.9 Important findings of ergonomic assessments on commercial handloom

Introduction of Jacquard is the main difference in loom structure between domestic and commercial loom of Assam (Figure. 2.15). With changing trend towards commercialization, SIRD Assam have been working for betterment of production by providing Jacquard to the weavers through various loans at very low interest rate as well as training weavers with operational details under its training institutes.

*Figure 2.*15 Picture showing (A) Domestic loom without Jacquard (B) Commercial loom with Jacquard

Jacquard for producing design controls warp threads separately by means of harness cord. In order to form shed on warp threads of loom with jacquard, application of large force is required on the pedals against reverse action of harness cord of Jacquard and heald yarns of healds (Figure. 2.17). The operation is highly repetitive, forceful and carried throughout the working hours. This downward pushing force of the pedal increases consequently with:-

1) Width of the cloth: - Cloth width is directly related to the number of heald yarns. With increased cloth width, number of warp threads passing through the "eye" of the heald yarns rises (Figure. 2.16). This enhances tension on the warp threads against which more force is required on pedal for shedding.

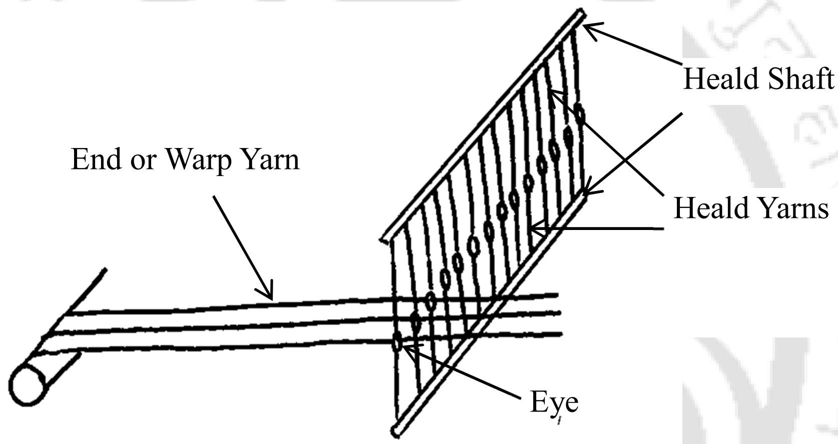


Figure. 2. 16 . Showing warp threads passing through "Eye" of the Heald Yarn/Thread

2) No of motifs: - With increased number and size of motifs amount of harness thread from Jacquard increases. Harness thread are connected with "ends" (a single thread of warp) based on the scheduled pattern of the design card. Harness yarn keeps the warp thread in tension from the direction of Jacquard. With shedding motion, Jacquard shedding pulls the warp threads or ends on the reverse direction of the pedal. This develops more force on the pedal for shedding.

Cumulative effect of both the factors increased tension against which the weavers operate the pedal for shedding.

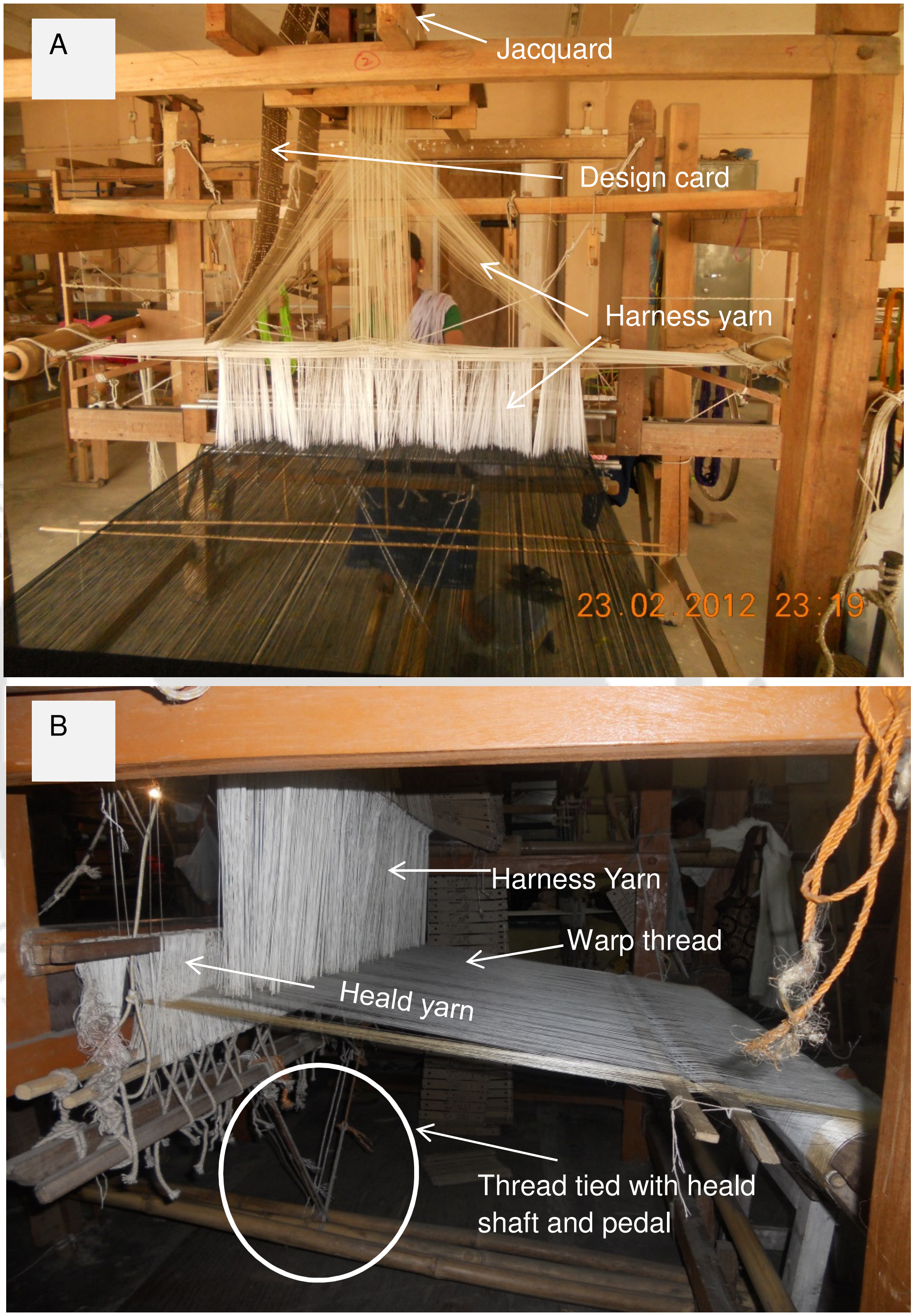


Figure. 2.17 Jacquard Frame loom: (A) Top view of the loom showing harness yarn from Jacquard (B) View of the pedal connected with Heald yarn and Harness yarn through heald shaft

Domestic looms are without any jacquard (Figure 2.15 A) and motifs are created manually by the weavers (Figure 2.18A). For domestic weaving, weavers generally used to weave “Gamocha” (towel) or “Meghla Chadar” (traditional dress attire of Assam), which are shorter by width and consist of smaller and lesser numbers of motifs. For commercial production in Jacquard loom, Assamese Sarees with heavy traditional motifs, bed-sheets with motifs were produced which were wider in width resulting increased number of heald yarns and harness yarns.

Figure.2.-18 Motif formation in (A) Domestic loom and (B) Jacquard loom

Importance of Jacquard for commercial production cannot be ignored. Previously weavers used to create motifs manually which resulted constant neck flexion (Figure. 2.18A) and eye strain. With Jacquard, incidence of neck pain was reducing which was reported by both weavers and loom owners but on the other hand lower limb pain was increasing. Same observation also surfaced out, during weaving sub-task analysis, though neck pain was found to be the second highest pain reporting but there was significant difference been observed in case of range of pain reporting (Table 2.6). Due to the use of larger leg muscle group, the weavers were unaware of the amount of force they were executing to operate the pedal. Other reason for lower limb pain was improper seat design. Downward vertical leg movement against hard edge at the front of the seat creates pressure resulting redness and digging of the posterior thigh muscle. Improper seat height resulted numbness, tingling and pins and needles effect at the lower extremities.

In order to find out whether ergonomic risk factors have any effect for the development of muscular pain, following hypothesis were tested

2.10 Testing of Hypotheses

The hypotheses were:

H: 1 Workstation related adaptation of awkward posture during weaving process increases risk of muscle pain.

H: 2 Force required and duration of pedaling is directly proportional to lower limb pain.

2.10.1 Testing of H: 1

From 118 handloom clusters, 150 women weavers were selected. The workers were all right limb dominant and all the handlooms undergo commercial production.

Weaving types

1. Continuous weaving and
2. Weaving with motifs

Nature of weaving is same in both the cases except presence and absence of harness yarn from Jacquard. In the former case there is no harness yarn from Jacquard while in the second case motif is created from harness yarn of Jacquard.

REBA method

Weavers in different weaving postures were photographed while weaving from sagittal (left and right side) and coronal (front and back) planes and REBA assessment was performed in the laboratory (Figure. 2.19). Using REBA worksheet (Appendix D), a score was assigned for each of the following body regions: neck, trunk, leg, Upper arm (UA) left (Lt), lower arm (LA) Lt, UA right (Rt), LA (Rt), wrist for both Rt and Lt arm and compared with muscular pains of respective body segments with the help of body map (Figure. 2.9) of the same individual undergoing REBA analysis. Individual REBA scores for above mentioned body parts were used to understand whether task defined posture has any influence on muscular pain. A χ^2 test was performed to find out whether or not any association exist between individual body-part posture score and muscular pain (Table 2.7).

REBA validation

To establish whether individual REBA body part scores obtained by weaving posture provided good indication of musculoskeletal loading by weaving task, $\chi 2$ test was performed to establish the level of association between body part scores with reported pains, aches or discomfort in the corresponding body regions of the individual. The presence of pain or discomfort was recorded as "yes pain", their absence as "no pain". Self- reported Body Discomfort Chart or body map (Corlett and Bishop, 1976) was used to establish body discomfort while at work. Individual REBA posture score of more than one categorizes underscore >1 and score 1 as 1 (Massaccsi et al., 2003; Pandit & Chakrabarti, 2014).

Figure. 2.19 Stick diagram of REBA posture analysis of individual body parts

Table 2. 7

Chi- square to find association between two categorical variable REBA score with Muscular pain

Body part	Pain	Posture score		χ^2	p
		1	>1		
Neck	No	12	23	12.63	0.001
	Yes	11	104		
Trunk	No	10	10	12.98	0.001
	Yes	20	110		
UA (RT)	No	8	33	3.76	0.05
	Yes	9	100		
LA (RT)	No	9	21	13.00	0.001
	Yes	8	112		
Wrist (Rt)	No	8	10	18.67	0.001
	Yes	11	121		
UA (LT)	No	7	13	16.03	0.001
	Yes	8	122		
LA (Lt)	No	23	8	1.61	0.2
	Yes	100	19		
Wrist (Lt)	No	17	26	15.77	0.001
	Yes	12	95		
Leg	No	7	38	1.14	0.29
	Yes	10	95		

The analysis of χ^2 test was given in Table 2.7. From the above analysis, it was found, neck score was found to be >1 in 84.67% of the weavers while pain was reported by 76.67%, yielding significant association between individual scores and self-reported pain (χ^2=12.63; p=0.001). For trunk, score of >1was found amongst 80% of the weavers while incidence of pain was found among 86.67%, showing significant association between individual trunk scores and reported pain (χ^2=12.98; p=0.001).

REBA posture score >1 for Upper Arm Right (UA) Rt was found among 88.67% weavers out of them occurrence of pain was reported by 72.67% showing a significant association between individual posture score and reported pain (χ^2= 3.76; p=0.05). For LA (Rt) score of >1 was observed among 89.33% of them pain was reported by 80% weavers showing significant association between incidence of pain and posture score (χ^2=13.00; p=0.001). Causative factor for muscular pain in the Rt wrist is similar to that of Rt LA. 87.33% weavers found to have score >1 while 88% weavers reported Rt wrist pain showing significant association between incidence of pain and posture score (χ^2=18.67; p=0.001). REBA assessment for Lt UA was found to be >1 in 90% weavers of them 86.67% has incidence of UA pain (χ^2=16.03; p=0.001). For Lt wrist, posture score of >1 was found for 80.67% weavers of them 71.33% have pain which shows significant association between posture score and muscular pain (χ^2=15.77; p=0.001).

There is significant association been observed between individual posture score of >1 for neck, trunk, Rt UA, Rt LA, Rt wrist, Lt UA, Lt wrist with muscular pain but no association was found between posture score >1for Lt LA and leg with muscle pain. For Lt LA posture score of >1 was observed among 18% weavers while pain was reported by 79.33% (χ^2=1.61; p=0.2). REBA assessment for leg was found to be >1 for 88.67% weavers while pain was reported by 70% of them (χ^2=1.14; p=0.29). So in this case, no association been observed between observed posture and pain.

The results of statistical analyses by χ2, evidenced that compensating or awkward posture adopted by the weavers while weaving was one of the major risk for development of muscular pain, except for LT LA and leg. According to REBA, these two postures were categorized as normal posture but muscle pain in these two body regions, was due to force and highly repetitive nature of the task, which is discussed in details in Chapter 4.

2.10.2 Testing of H: 2

Two way ANOVA was run to determine, whether increased pedalling force due to Jacquard and longer duration of work shift for commercial production has any effect on lower limb pain of 150 commercial weavers undergoing 2 types of weaving practice: a) continuous weaving for plain cloth rim and b) weaving with motifs. In the former case there is no harness yarn but weaving is done against heald yarns (of 48inches to 72 inches width), while in the latter situation weaving is done against both heald and harness yarn. Effects of two independent variables (weight for pedal depression and work shift) were tested on a single dependent variable (lower limb pain).

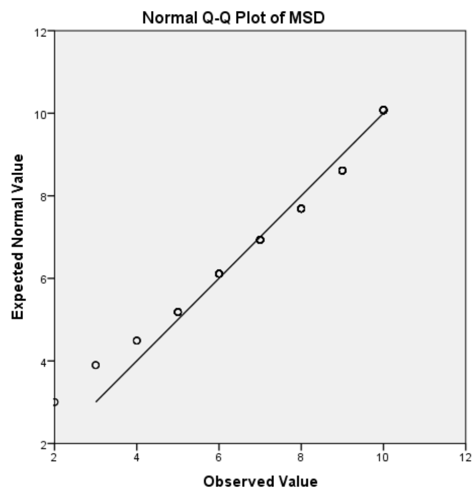


Figure 2.20 Graphical representation of normality test with Q-Q plot

Normality test was performed graphically with Q-Q plot (Figure. 2.20). The data points were observed to be normally distributed from close situation of data points from diagonal line.

Table 2.8

Levene's test of equality of error variances

F	df1	df2	Sig.
1.557	92	57	0.036

Homogeneity of variance was tested with Levene's Test (Table 2.8). The resulting p=0.036 thus, null hypothesis of equal variances was rejected and it was concluded that there was a difference between the variance in the population.

Table 2.9

Tests of between-subjects effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	512.423[a]	92	5.570	5.726	.000
Intercept	4278.443	1	4278.443	4398.039	.000
Wt	256.626	22	11.665	11.991	.000
Work_shift	76.008	8	9.501	9.767	.000
Wt * Work_shift	54.280	62	.875	.900	.658
Error	55.450	57	.973		
Total	9585.000	150			
Corrected Total	567.873	149			

From ANOVA analysis (Table 2.9), it was found with increased force of pedalling (measured by weight added on the surface of the pedal to depress for shedding) there was significant increase in lower limb pain $F_{(22,57)}$ =11.99, $p < 0.001$. Similar observation was also been noticed in case of duration of work shift with lower limb pain. As the duration of work shift increases in case of commercial weaving so does the lower limb pain as observed by $F_{(8,57)}$ =9.77, $p < 0.001$. But within group there was no significant relationship been observed with increased pedalling force and work shift with lower limb pain, $F_{(62,57)}$ =0.90, p=0.66.

From above findings it was clear that increased pedalling force and longer duration of loom usage for commercial production significantly increased incidence of lower limb pain. This is further discussed in Chapter 4.

2.11 Work load assessment leading to investigation for Assistive Design Development

There were several ergonomic risk factors in handloom workstation related to the development of muscle pain some of them were posture, repetitiveness, long duration of loom usage and force. Significant association of muscular pain with poor posture was observed (Table 2.7) but posture in handloom couldnot be altered as it is "task defined". Alteration of posture involved full modification of workstation which was both time consuming and required massive economic investments. This would not be a feasible solution for rural economy. Control over work practice to minimize repetitiveness (Table 2.5) and reducing working hours and increasing rest period was found not be a practical solution because it would slow down rate of production. Force was found to be the only risk factor whose effective reduction with assistive design could be effective in reducing overall health hazards. Exertion of force takes place in primary motions of weaving (Discussed in Chapter 3) Technological modification in picking and beating has already started penetrating in different weaving pockets (Figure. 3.4) but modification on pedalling has not been documented so far.

Engineering controls in a workstation modification includes - full modification of the workstation, assistive design modification and altering production process. Work practice include, controls of working posture, while administrative controls include job rotation, work-rest time determination etc. The final rule goes on to say that " Engineering Controls" are the preferred method of controlling work hazards in cases where these controls are feasible, in contrast to administrative and work practice controls. Engineering controls fix the problems once and for all (OSHA Technical Manual, n.d.).

Use of Jacquard was very much essential with present work context but its effect can be narrowed down with pedal redesign which could be operated with lesser force. With this objective in mind, present study was conducted to prevent from early muscle fatigue, discomfort and to make the task better adapted to the abilities and limitations of the weavers for long hours of commercial weaving.

Next phase (Phase III) of the study was on assistive pedal modification, to eliminate the risk of high force retaining same mode of operation, eliminating further training cost, keeping in view of low manufacturing price for rural masses as well as low maintenance cost. With this objective modification of pedal was tried out along with plank. This is presented in the following chapter.

Chapter 3

Design development of seat and pedal of the horizontal frame loom

Chapter 3

Abstract: *Understanding the importance of Jacquard for commercial production, pedal was redesigned so that it could be operated with lesser force. It was found that pedal operation was highly dependent with seat. Redesigned pedal would not be effective unless simultaneous seat modification was considered. Participatory approach was used for both seat and pedal modification. The results of laboratory based testing showed that new pedal and seat was found to be highly effective by the weavers involved in the modification process. Laboratory based testing like surface electromyography (sEMG), semi-quantitative assessment by weights and leverage calculation of the modified pedals found the new design to be highly effective in reducing pedalling force.*

3.1 Introduction: Uniqueness of handloom

The strength of handloom rests on innovative designs, which cannot be imitated by the power looms. It is because of such inimitable designs and weaving techniques that this sector has succeeded to withstand the onslaught of the powerloom and the mill sector in the country. In handloom weaving some of the excellent arts of work gets transformed on fabrics by expert weavers which gives a refreshing change of today's world, which is more inclined towards mechanization. This sector represents country's traditional art form that has been patronised and encouraged since time immemorial.

Handloom industry thrives on manual workforce and it is highly labour intensive sector. Technological intervention can be effective in saving human efforts, time and energy. Several Research & Development in the handloom industry resulted in reducing drudgery of the handloom weavers and improving their productivity.

3.2 An Outline of the weaving process

Weaving is the process of fabric production in which two distinct sets of threads are interlaced at right angles to give rise to cloth or fabric (Figure. 3.1). The longitudinal thread is known as "warp" and horizontal thread as "weft". The way in which these two threads are interwoven affects the characteristics of a cloth. A weaving machine is technically termed as a "loom" in which interlacement of these two threads takes place. A single thread of warp is known as an ‘end’ and a single thread of ‘weft’ is called ‘pick’.

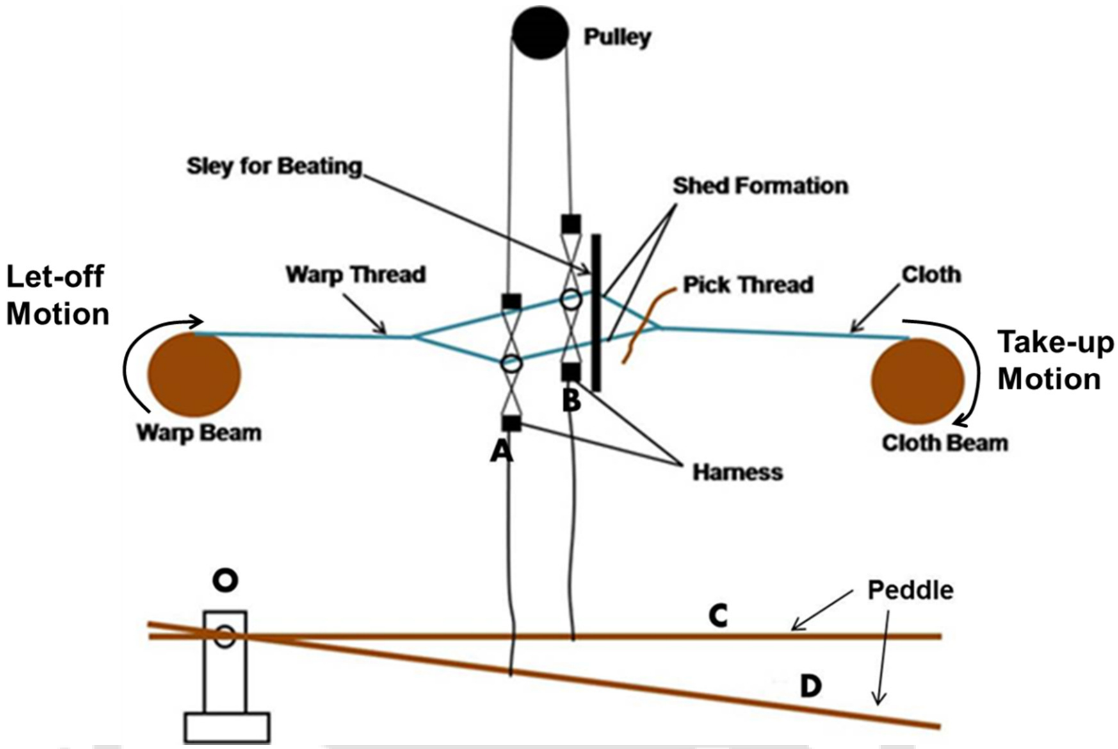


Figure.3.1 Schematic diagram of weaving process

Weaving is a repetitive action of three activities also called the **primary or fundamental motions** of the loom these are:

Shedding: Shedding or dividing the warp threads is the first primary motion of weaving (Banerjee, 1982) shown in the schematic diagram (Figure. 3.1). Pedals C and D, fulcrum at O, govern healds or harness to form shed. When D is pressed down, heald A connected by cords forms the lower line and causes heald B to form the upper line of the shed with the help of top pulley. Motion, imparted to the healds by means of pedals, is called “shedding motion” and division of warp threads is “shedding” which is shown in Figure 3.2 A.

Picking: The process of passing a pick with the help of shuttle from one shelvdge (or shuttle-box) to the other over the race is the second primary motion of weaving (Banerjee, 1982). This happens during shedding when two layers of warp threads upper and lower lines are formed (Figure. 3.2 B).

Beating: Beating-up is the third primary motion in weaving (Banerjee, 1982). It consists in beating-up the last pick of weft to the feel the formation of cloth with the help of a reed in the slay frame. A slay swings forward to beat up the last pick of weft and swings backward to allow the shuttle to pass through the shed (Figure. 3.2 C)

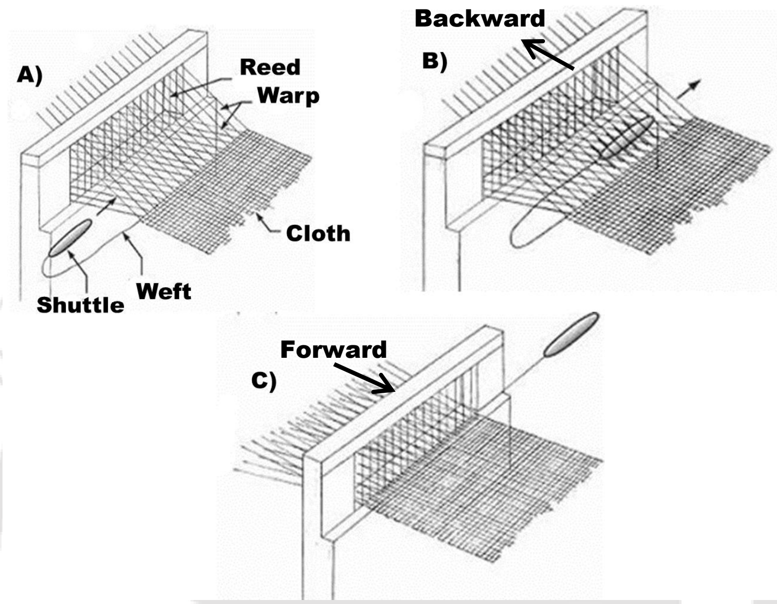


Figure.3.2. Primary motions of weaving: (A) Shedding, (B) Picking, (C) Beating ref: http://www.tikp.co.uk/knowledge/technology/warping-and-weaving/weaving-process/

These primary motions of weaving are actuated in succession with one another. In absence of shedding, picking cannot be affected and without picking beating-up is of no use.

The **secondary motions** of the loom are:

Take-up-motion:- This operation consists in taking up the cloth when being woven and then winding it onto the cloth roller. The taking-up motion may be either negative or positive in case of handloom it is negative as it is operated manually. In fly-shuttle loom, the cloth beam is held in position by a ratchet and a pawl and winding the cloth beam is done manually intermittently (Figure. 3.1).

Let-off Motion:- This operation consists of letting-off the warp threads from warp beam when the cloth is taking up onto the cloth roller. Both taking-up of the cloth and letting off of the warp are done simultaneously (Figure. 3.1).

The **Tertiary motions** of the loom are the stop motions: to stop the loom in the event of a Thread break. The two main stop motions are the

- warp stop motion
- weft stop motion

The principal parts of a loom are the frame, the warp-beam or weavers beam, cloth-roller or cloth beam, heddles and reed.

3.3 Steps towards technological up-gradation in the handloom industry of Assam and its dissemination through various programmes

In order to sustain the handloom sector up-gradation is required to improve productivity by reducing fatigue among the weavers.

First Step: Flying Shuttle

Introduction of Flying Shuttle by John Kay in 1973 for picking operation was one of the major developments in the handloom industry (Figure. 3.3). Initially if wider cloth was required to be weaved then two people were involved in picking operation. With introduction of flying shuttle with a flick of the wrist, one cord is pulled and the shuttle is propelled through the shed to the other end with considerable force, speed and efficiency. A flick in the opposite direction and the shuttle is propelled back. Single weavers have control over a wider fabric with a much greater speed than hand thrown shuttle.

With age of the loom, race turns rough which increases picking force. Understanding the importance of the problem from reporting of the weavers, initiatives of polishing and maintaining the race after every 2 years have already been initiated by different organizations, which was reported by loom owners and managers during research survey.

Figure. 3.3. Picking operation with flying shuttle

Further Innovations

Several assistive technological interventions have already been introduced in different handloom pockets of the country. Positive outcomes of these innovations still need to be spread and implemented. The innovations that have taken place in the handloom sectors are as follows

- Introduction of **Jacquard** by Joseph M. Jacquard in 1801- have reduced constant neck flexion and eye strain for creating motifs (Figure. 3.4A).
- **Crank mechanism** - reduced pulling force of the slay frame involved in beating operation (Das, 1990) (Figure. 3.4B).
- **Gear mechanism in Take-up & let off motions** – have reduced upper arms stretching and forward flexion of the trunk due to automatic winding of the cloth to cloth beam from warp beam (Figure. 3.4C).
- "**Extra Weft Insertion in Handloom for Frugal Handloom Design**". Conventionally designs were made by insertion of weft threads manually by tying knots. This is tedious and cumbersome process. Introduction of the device reduces the insertion time to one third the time required in a traditional loom (Bharali, 2010).

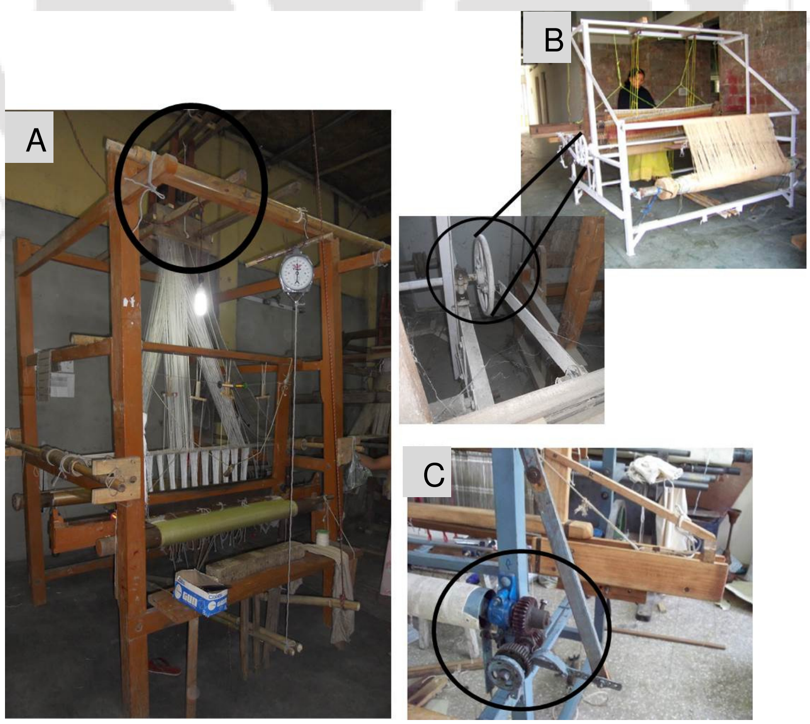


Figure. 3.4. Technological Up-gradation in the handloom industry, (A) Jacquard for motif (B) Crank for beating motion (C) Gear for Take-up & let off motions.

Office of the Development Commissioner for Handloom, Ministry of Textiles, Government of India is disseminating various technological innovations through different on-going programmes. As a result, a number of these innovations are being used in some handloom pockets, benefitting handloom weavers in terms of increased productivity and reduced drudgery. The fruitful outcomes of assistive design intervention such as flying shuttle for picking, crank mechanism for beating, gear for take-up and let-off motions and jacquard for motif formations has already started penetrating in different weaving pockets of Assam by the help of different organizations. However, there is still a need for further dissemination and deeper penetration of these innovations.

Government organizations like State Institute of Rural Development (SIRD), KHADI, Institute of Rural management (IORM), Assam Textile Institute (ATI) and many NGO's train the weavers with technological outcomes of research (Figure. 3.5). Design interventions in two areas of primary motions: picking and beating has already taken place but such intervention study on shedding has not been documented so far.

Figure 3.5. Training institutes educating women weavers with modern research interventions

3.4. Challenge of design intervention in handloom industry

Handloom is famous for innovative and eco-friendly design process. The challenge in this sector is introducing technology retaining manually driven operation, which is efficient in reducing strain on the weavers as well as employment is maintained. Huge rural mass of India especially Assam, directly or indirectly depends upon handloom for their livelihood, which cannot be replaced with automation, otherwise it will rise unemployment issues.

There are different types of shedding operations found in powerloom such as crank, camp, dobby, tappet shedding etc. but no documented study on modification of shedding procedure in handloom has been initiated so far. The need of the hour is to focus on ergonomic interventions on shedding motion with assistive design to reduce force, retaining manual mode of operation. Pedal for shedding is highly related to seat design. Seat plays vital role in supporting the body for performing pedalling. Improvement of one would not be effective, as both compensates with each other's function.

3.5 Need justification of design modification of seat and pedal in the existing handloom

3.5.1 Importance of Seat modification

Important reasons for development of musculoskeletal problems is when the sitter is forced into constrained and awkward posture during work activities, and when there is no possibilities to get relief or change of posture (van Wely, 1970). Many studies have shown strong association between prolonged sitting and increased risk of low back pain (Hartvigsen et al., 2000; Fogleman & Lewis, 2002; Nakazawa et al., 2002; Lis et al, 2007; Mork & Westgaard, 2009). Risk of low back pain increases manifold times with improper seat design. Seating in case of handloom weaving is task dependent. Presently price hike and unavailability of raw materials has increased financial challenge for the survival of the handloom industry as a result, workers are paid per work basis. This situation causes weavers to spend long hours on the plank of the loom in order to finish the task in single spell.

Prolonged seated work is a potential risk to spinal and paraspinal discomfort and disorders (Corlett, 1999). Kroemer et al., 1985 stated that prolong static sitting leads to isometric contraction of back muscles leading to endomuscular pressure restricting blood flow resulting ischemia, which reduces energy requirements of the muscles causing muscle fatigue. This is commonly observed posture among the weavers during continuous weaving when the trunk maintains a straight upright sitting for long hours. The intra-discal pressure at the lumbar region is high both in sitting and trunk-bent-forward posture (Wilder et al., 1988; Chaffin & Andersson, 1990; Bernard,

1997) which is commonly observed posture among weavers during motif formation and beating operation.

With long hours of sitting, adequate body support is required; otherwise sitting posture is maintained through muscles effort, by overstretching of the spinal ligaments and strain the disc and surrounding spine structure. Several studies have shown that proper lumber support resulted in the increase of lumber lordosis, decrease intradiscal pressure by reducing some of the trunk loads and helps in preventing vertebral strain (Andersson & Ortengren, 1974; Andersson et al., 1979; Corlett & Eklund, 1984; Bendix et al., 1996). On the contrary it was found that the plank, on which the weavers spend the whole day, was found only to be 13cm ± 2.59 without backrest. This results minimum hip support and body maintains upright posture by muscle efforts, above this, both the hands of the weavers are involved in loom operation. Study carried out by Andersson, (1974) and Pheasant, (1991) have found that forward directed forces of the hands should, on the contrary have a backrest. Corlett, (1999) in his study have found that backrest should be provided with seat so that its support can be taken as and when required.

3.5.2. Importance of pedal modification

Force directly represents biomechanical effort necessary to carry out a given action, or sequence of actions, it is of two types static and dynamic. In pedal operation in case of handloom, it is dynamic in nature. A multiplying interaction was found to exist between force and action frequency (Silverstein et al., 1986 and 1987), especially for tendon pathologies and nerve entrapment syndromes. Researchers of this study found that workers in high force, high-repetition jobs were 15 times more likely to have developed musculoskeletal disorders than workers in low-force, low-repetition jobs. In existing condition, both high force and high repetition are involved in pedalling, which is a strong indication of development of musculoskeletal disorders of lower extremity.

High force leads to inflammation strains and tear of muscles and tendons (Nwaigwe, 2005). For greater exertion of force, muscles have to contract strongly. If this force generation takes place in lesser time, muscles, tendons, ligaments and joints are driven into stress which can lead to muscular fatigue. Repetition cannot be altered, but decreasing the amount of force required for pedalling can be effective in lowering the risk of MSD (Openshaw & Taylor, 2006).

3.5.3 Previous ergonomic studies on leg operated pedal and significance of the present research study

Most of the ergonomic literature dealing with prevention and control of musculoskeletal disorders in the workplace focused on upper extremity and back. Comparatively, little attention has been given to lower extremity musculoskeletal disorders that occur in the workplace. Studies have begun to report the relationships between occupational factors and knee, hip, and foot trauma.

Vingard et al., (1991) in their study on blue-collar occupation, as to both static and dynamic forces acting on lower extremity found to have an increased risk of osteoarthritis. Compared to hand controls, foot controls often restrict the posture of the users, and an inappropriate pedal design may contribute to muscle fatigue and cause discomfort (Sanders & McCormick, 1993). Kroemer, (1970 and1971) in his studies observed influence of leg posture and body support on foot motion. Rees & Graham, (1952) has rightly pointed out, the role of backrest on force application for pedalling. Endorff, (1964) and Ayoub & Trobbley (1967) in their studies have measured reaction time, travel time of pedal with pivot locations at different foot length. Konz et al., (1971) undergone a detailed ergonomic studies of pedal design features for its application on automobiles such as pivot location, pedal angle, angular travel, force on brake and horizontal and vertical distance between pedal and seat. Rohmert & Jenik, (1971) found that mean ratio of female/male pedal force was the "classical" two-thirds.

Remarkably, very few studies on comfort of pedal operation have been reported in present literature (Haslegrave, 1995; Wang & Bullock, 2004). Moreover, studies on comfort/discomfort was only been conducted using subjective assessment method (Shackel et al., 1969; Giacomin & Quattrocolo, 1997; Buckle & Fernandes, 1998) but one cannot get a thorough understanding of discomfort using only subjective evaluation.

The objective of the present study was to investigate not only on subjective comfort perception based on rating scale and questionnaire, but also tried to compare and quantify force by objective measurements to find efficacy of the new design. Keeping this in view, goal of the present study was to modify existing pedal so that, exerting minimum force shedding can be performed along with seat modification. Following methodologies were applied to obtain the goal.

3.6 Methods and Material

Introduction of newer technologies often adversely increases frustration level among the users for developing skills to acquaint with its mode of operation and in most of the cases it affects unskilled women workers who are the first to suffer loss of job. Keeping this in mind the existing pedal was modified with assistive design intervention method retaining same operational principle, so that no further training is required to adopt with the modified design and can be manufactured locally.

In order to perform ergonomic design modification in the existing loom, a loom is simulated in the control laboratory environment (Figure. 3.6) and participatory approach was followed for the design development process. Comparative ergonomic evaluation study was carried in-between the existing and modified design through subjective and objective method to find the efficacy of the design.

Figure.3.6. Simulated loom in control laboratory environment to undergo ergonomic design modification by participatory approach

3.6.1 Methodology used

In the whole design development process participatory approach (PA) was adopted which is one of the realistic approach to solve workstation related problems. Skilled weavers and loom experts participated in the study for design development. PA helped in the development of local knowledge at the most fundamental level from formulation of the concept of the design till design development phase. This method was used, viewing to increase comfort and efficiency among the weavers by reducing workstation related hazards to enhance greater user satisfaction by reducing early fatigue. Following strategy was applied for design development.

3.6.2 Design Development Strategies followed

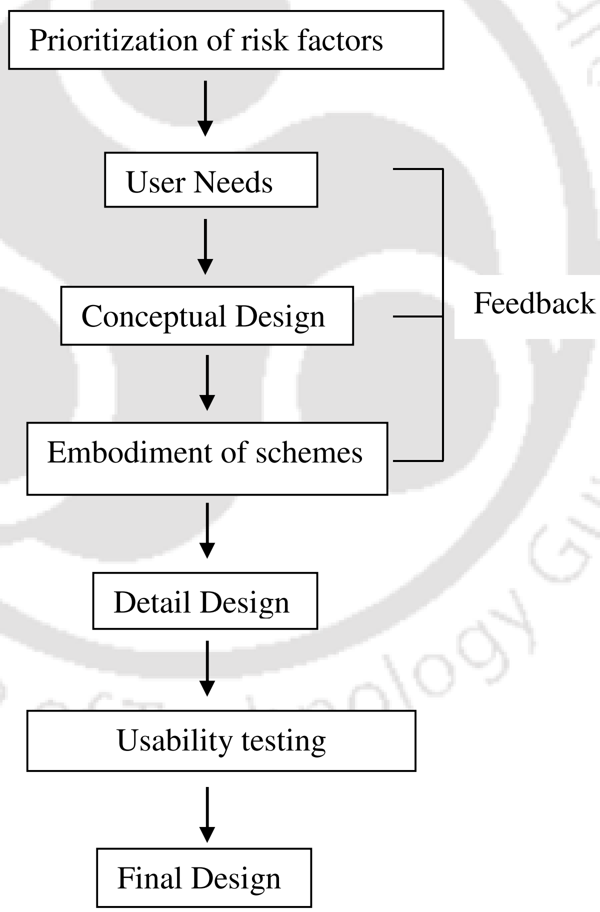


Figure.3.7. Process of Design Development

Following methodology (Figure 3.7) was used for workstation (plank and pedal) modification considering PA which is discussed in details below.

3.6.2. A. Prioritizing of the risk factors: - Identification of risk for work related health hazards (body pain) and quantifying level of pain is helpful to set priorities for ergonomic issues. Ergonomic problem solving can only be possible through identification of ergonomic risk factors affecting body parts which can be resolved, only by analysing the root causes. Accordingly strategies to reduce the risk are generated and short term and long term solutions are developed. Preferred solutions usually are the one that reduces the risk for injury substantially at a relatively low price.

Based on the assessments of occupational health status of handloom weavers discussed in details in Chapter 2, body segments were identified, which were under occupational stress. It was found back and lower limbs were the most affected body segments (Table 2.6, Figures 2.10 and 2.12).

Observation study from different looms revealed that the weavers spend whole working hours on a fixed narrow wooden plank which restrains their body movement. Due to minimal hip and body support from seating surface and improper seat, higher incidence of low-back and lower limb pain is observed among the weavers. Advent of Jacquard for commercial weaving has increased tension load on warp thread against which pedalling is performed. This resulted higher incidence of lower limb pain among the weavers.

3.6.2. B. User needs: - With commercialization of the industry, discussion with weavers, loom owners and managers of different handlooms, two areas were identified where design intervention is the need of the hour, these are pedal and seat. The weavers expressed that more leg force is required for pedalling in Jacquard operating loom compared to their traditional loom. They also stated of having severe leg, ankle and foot pain at the end of the day, weaving a heavy traditional motif Assamese saree. They showed digging and redness of the posterior thigh muscle due to the hard edge at the front of the plank over which they sit for the whole day and applied downward vertical force for pedalling (Photography was not allowed to be taken by the women weavers).

The weavers expressed if modification is brought in pedal and seat, it would be highly effective in near future. Conclusions drawn from loom users uncovers the fact, that the pedal modification alone would not be effective unless both seat and pedal designs are worked out together.

3.6.2. C Conceptual design: - Brainstorming was done to conceptualize seat and pedal designs (Figure. 3.8 and 3.9). From concepts, mock up models were developed in the laboratory (Figure. 3.10).

Brainstorming of Pedal and Seat design

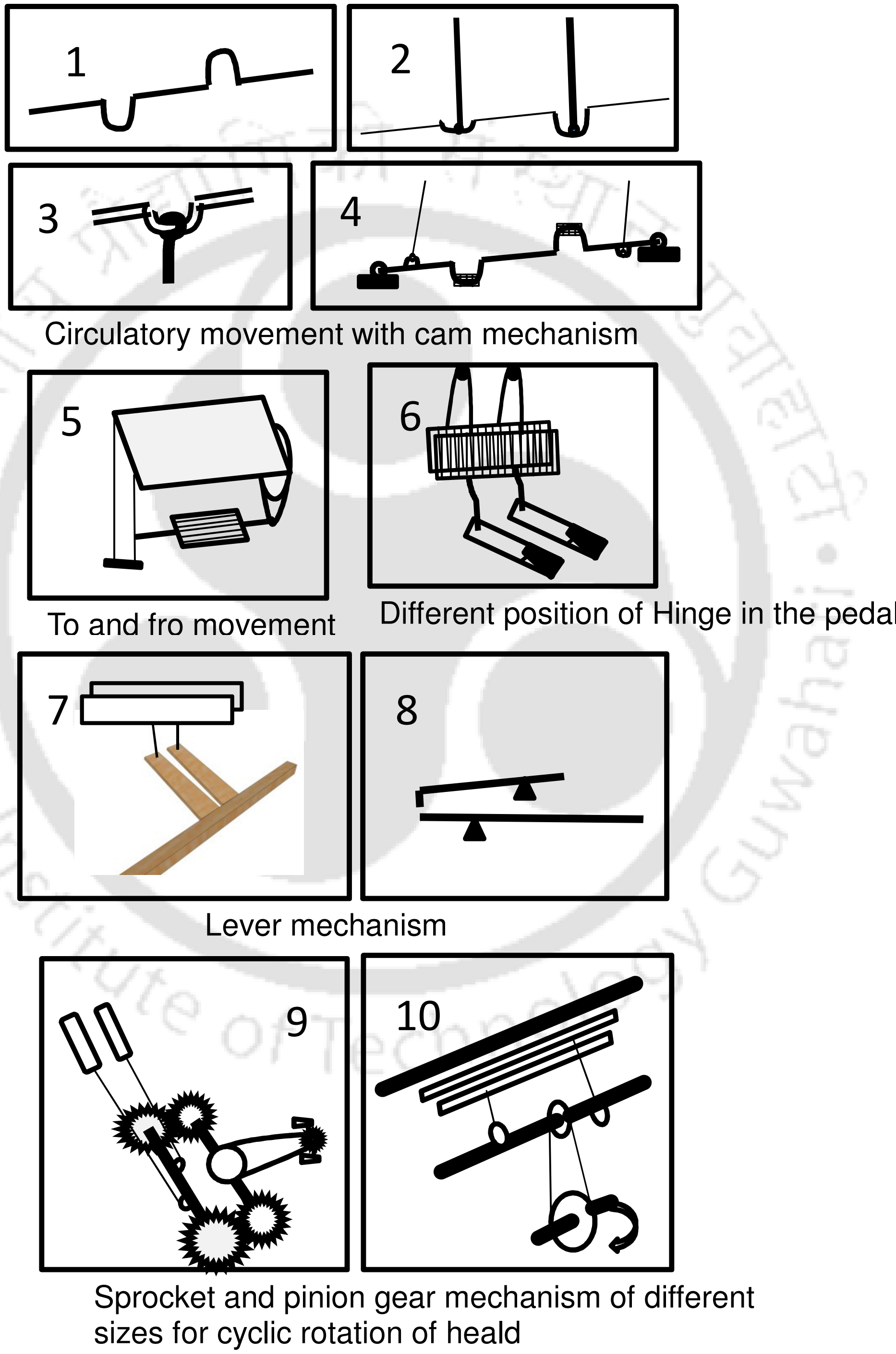


Figure. 3.8. Conceptual pedal design

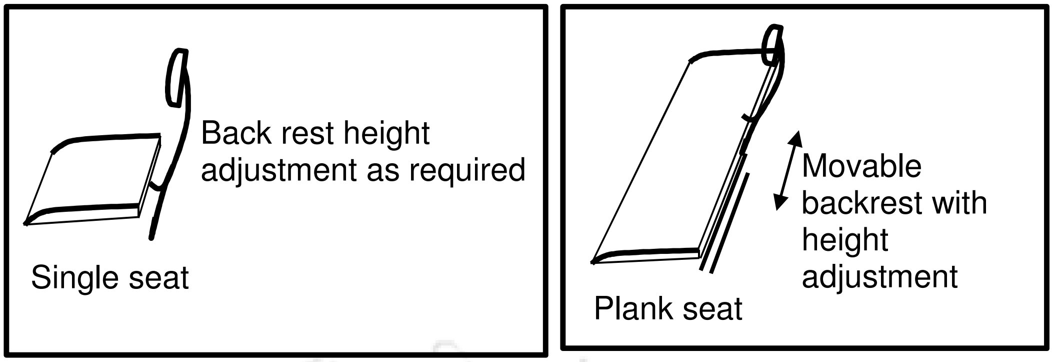


Figure. 3.9. Conceptual Seat design

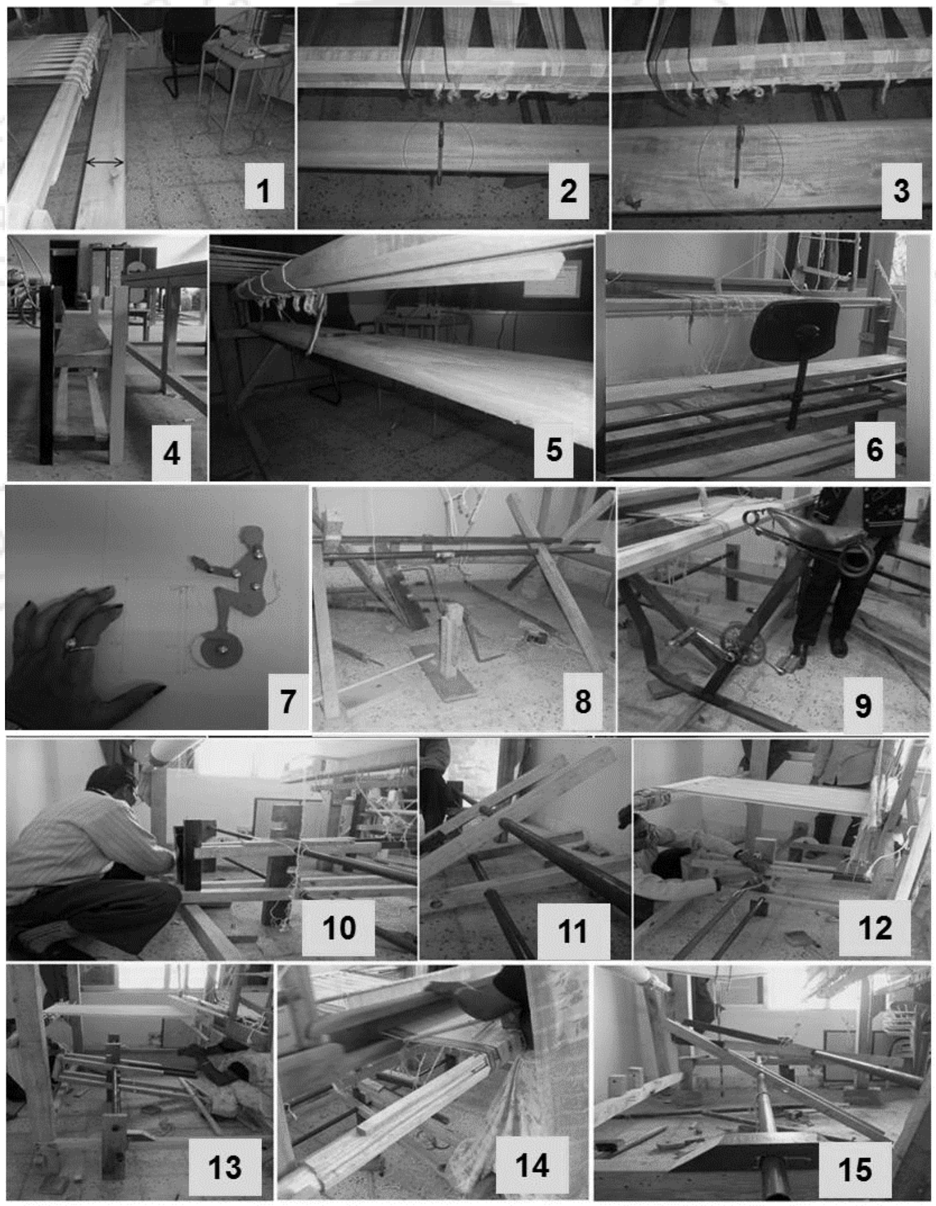


Figure. 3.10. Development of mock-up models in simulated loom, showing different stages of development

Pedal Mock-up(s)

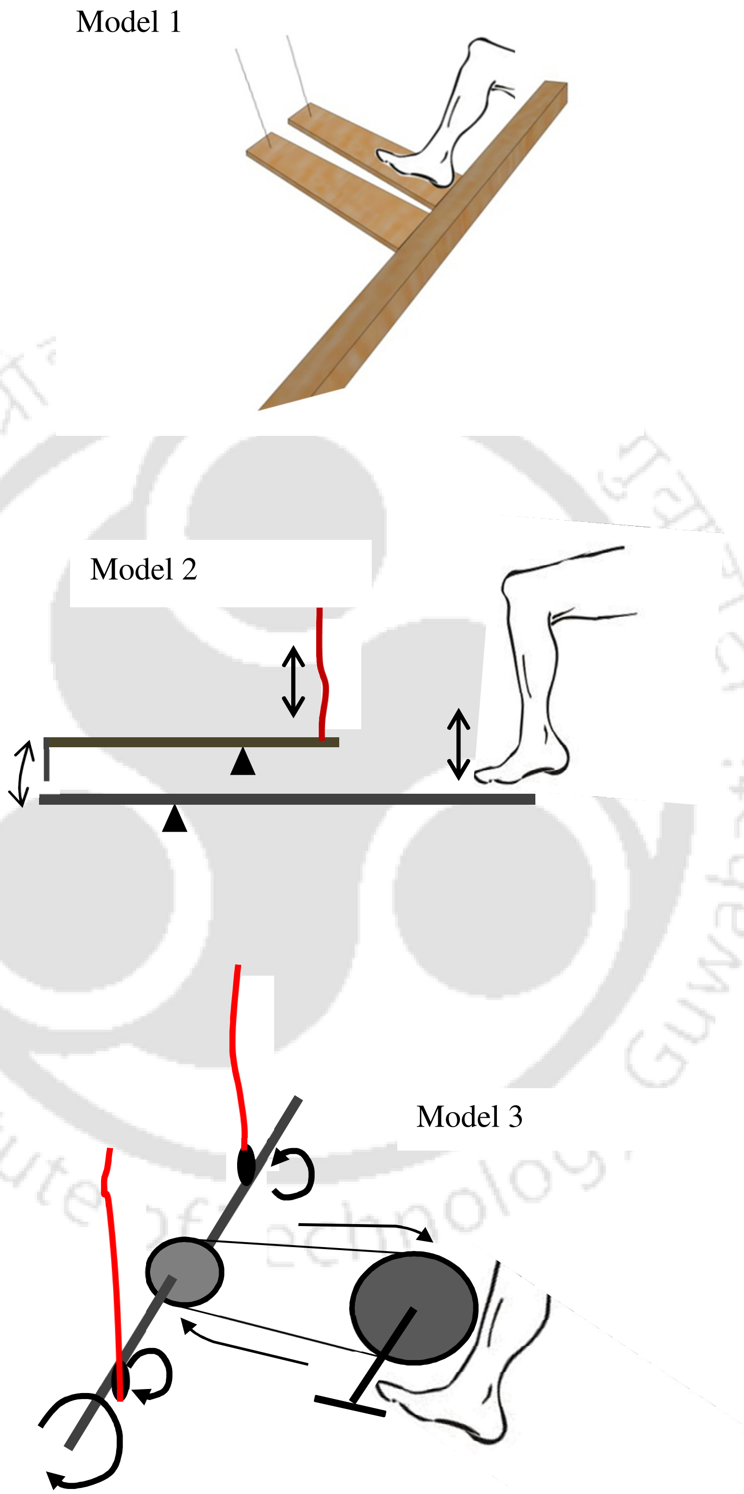


Figure. 3.11. Three Schematic diagram of Mock-up models

3.6.2. D. Embodiment of schemes: - From conceptualization phase three mock-up models of pedal was developed (Figure 3.11). Based on the feedback of experts and skilled weavers model 2 was selected for working prototype (Figure 3.12). According to loom experts' feedback, though model 3 which was a cyclic method of pedalling seems requirement of very less force, but problems would be encountered during warp stop motion, which would require more force to stop the loom during motif formation and re-joining of thread breakage. Model 1 follows 3rd class lever principle where pedalling force was greater than tension load. Hinged in the front will triggered development of shin splints (Figure 3.13) with repetitive ankle joint movement.

Figure. 3.12. Development of model 2 for working prototype

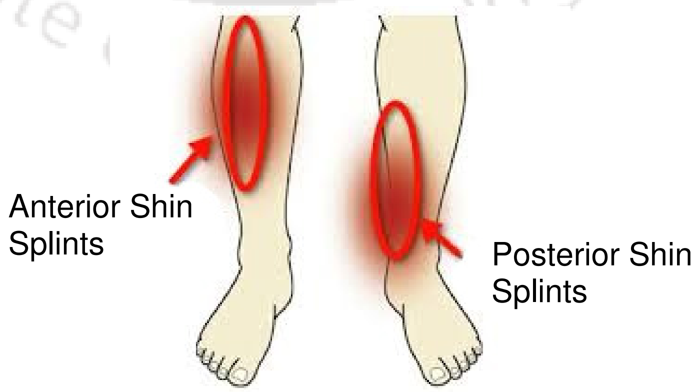


Figure.3.13. Showing shin splint of lower leg

3.6.2.E Detail Design:-

Detail design to finalize seat and pedal is discussed below:

3.6.2.E i Seat/Plank :- Four criteria's were studied for the plank redesign, adjustable height, seat depth, forward tilt at four different inclinations and plank with and without back support.

Seat Height

To arrive at a comfortable seat height, static anthropometric dimensions followed by dynamic dimensions (Figure. 3.14, 1) were considered to execute weaving task (Chakrabarti, 1997). Three different adjustable seat heights (Figure 3.15) were considered based on women popliteal height taking pedal surface from the floor height as reference point.

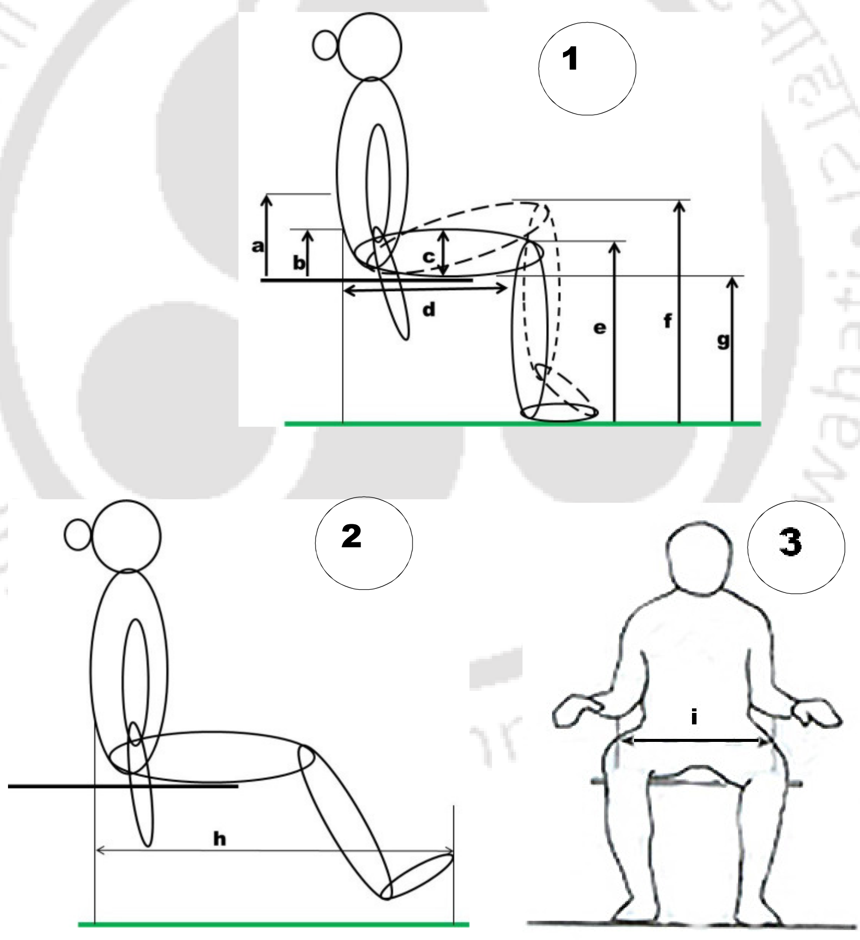


Figure. 3.14. Anthropometric dimensions considered for Seat and Pedal design**1,2** and **3**: a Upper lumbar, b Lower lumbar, c Midthigh, d Buttock to popliteal length normal sitting, e Knee height, f Thigh clearance height with raised knee, g Popliteal height, h Buttock to extended leg comfortable length i mid-thigh to thigh breadth relaxed

Three different seat heights were determined based on popliteal height:

95th percentile
[popliteal height = 44.1]
then (44.1 + 25) cm = 69.1 cm ≈ 69 cm

50th percentile
[popliteal height = 40]
then (40 + 25) cm = 65 cm

5th percentile
[popliteal height = 36.5]
then (36.5 + 25) cm = 61.5 cm ≈ 62 cm

Where 25cm was the height of the pedal surface from floor where the foot rest at resting phase.

Based on the above results three slots were fixed. The lowest slot was at 60 cm, middle one at 65 cm and top one at 70 cm which is shown in Figure 3.15.

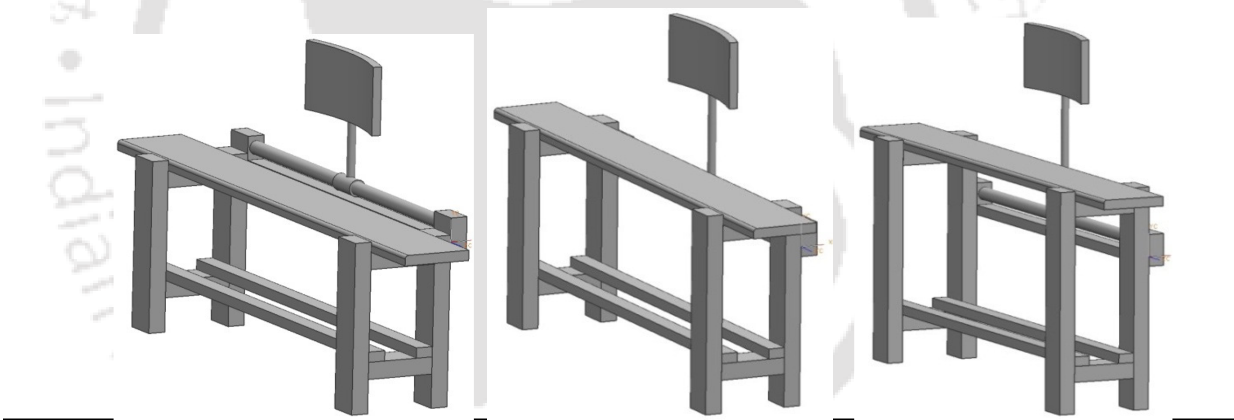


Figure.3.15. CAD drawing showing seat heights based on 5th, 50th and 95th percentile

Seat Inclination

Seat inclination was measured at 50th percentile seat height, at four different inclination levels (0^0, 5^0, 10^0, 15^0) to understand acceptance level on maximum number of weavers. Base of the rear portion of the plank, was raised by placing wooden angles (Figure 3.16) of 3 different inclinations, at two ends and middle of the loom seat frame. Level of comfortness while pedalling with different seat inclinations were noted to derive at the final seat proclivity. Different seat inclination in CAD and real time frame is shown in Figure 3.17 and 3.18.

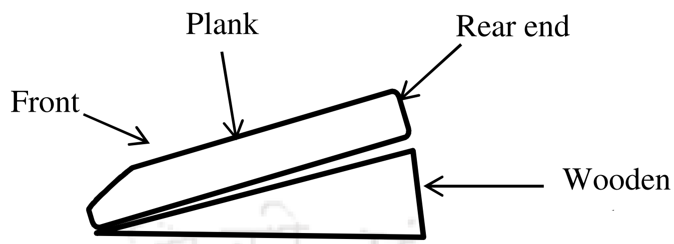


Figure. 3.16. Schematic diagram showing wooden slant to form different plank angles

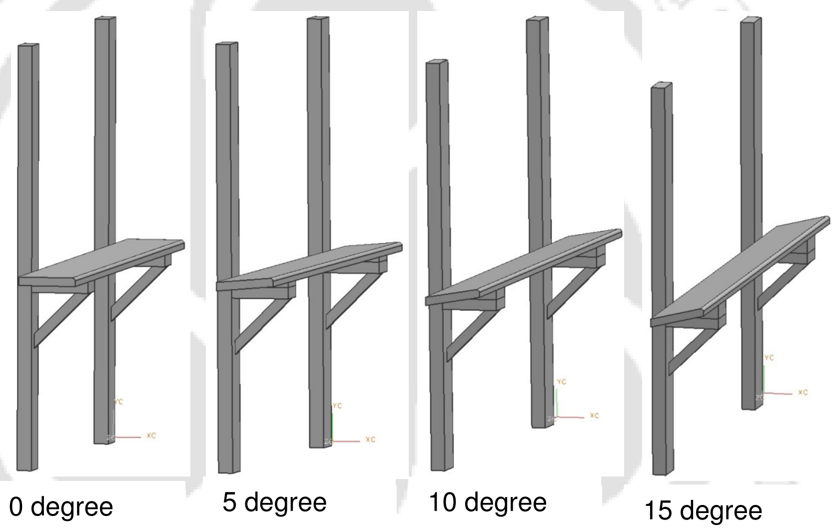


Figure.3.17. CAD drawing showing seat inclinations at four different angles

Figure. 3.18. Inclination of plank showing 5^o angle

Seat Depth

For normal office chair, seat depth was found to be 40 cm (Chakrabarti, 1997). Considering this as reference, plank depth was set at 40 cm for trial. It was observed that 40 cm seat depth creates hindrance in downward leg movement for pedal operation. Hence, observation with video analysis revealed that 30 cm would be preferred seat depth for easy downward leg movement. 6 cm from the front of the plank was given 0-3 degrees front slope which was again curved to reduce pressure underneath thigh muscle while pedalling. 2 cm from rear end of the plank was also given a slight backward slope of 2 degrees. The actual horizontal sitting surface consists of 24 cm this configuration was made for experimentation (Figure 3.19). Figure 3.20 A-A1 and B-B1 represents front edge and seat depth of the plank respectively for experimentation and usability testing.

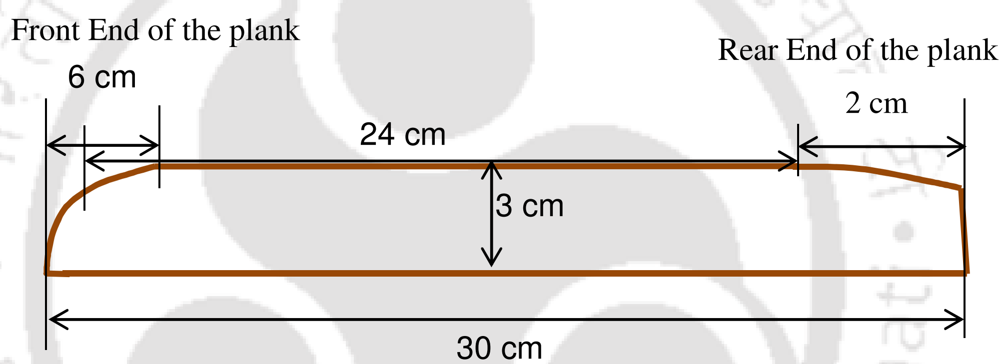


Figure 3.19 Schematic diagram showing seat depth with dimensions

Backrest

Backrest was not been observed in any of the handloom clusters but when the weavers were enquired about the need most of them opined about the need but they expressed their doubt that fixed backrest might restrict their sideways movement during loom operation. With this observation a movable single backrest unit was incorporated with the plank so that the weavers can fixed it according to their requirements (Figure 3.20 C1).

Experimental setup of the four criteria's of the plank was evaluated based on subjective assessment. The results of these experiments were discussed in details in Figures 3.32,3.34,3.35,3.36,3.37 along with preference of seat whether single or plank type (Figure 3.33).

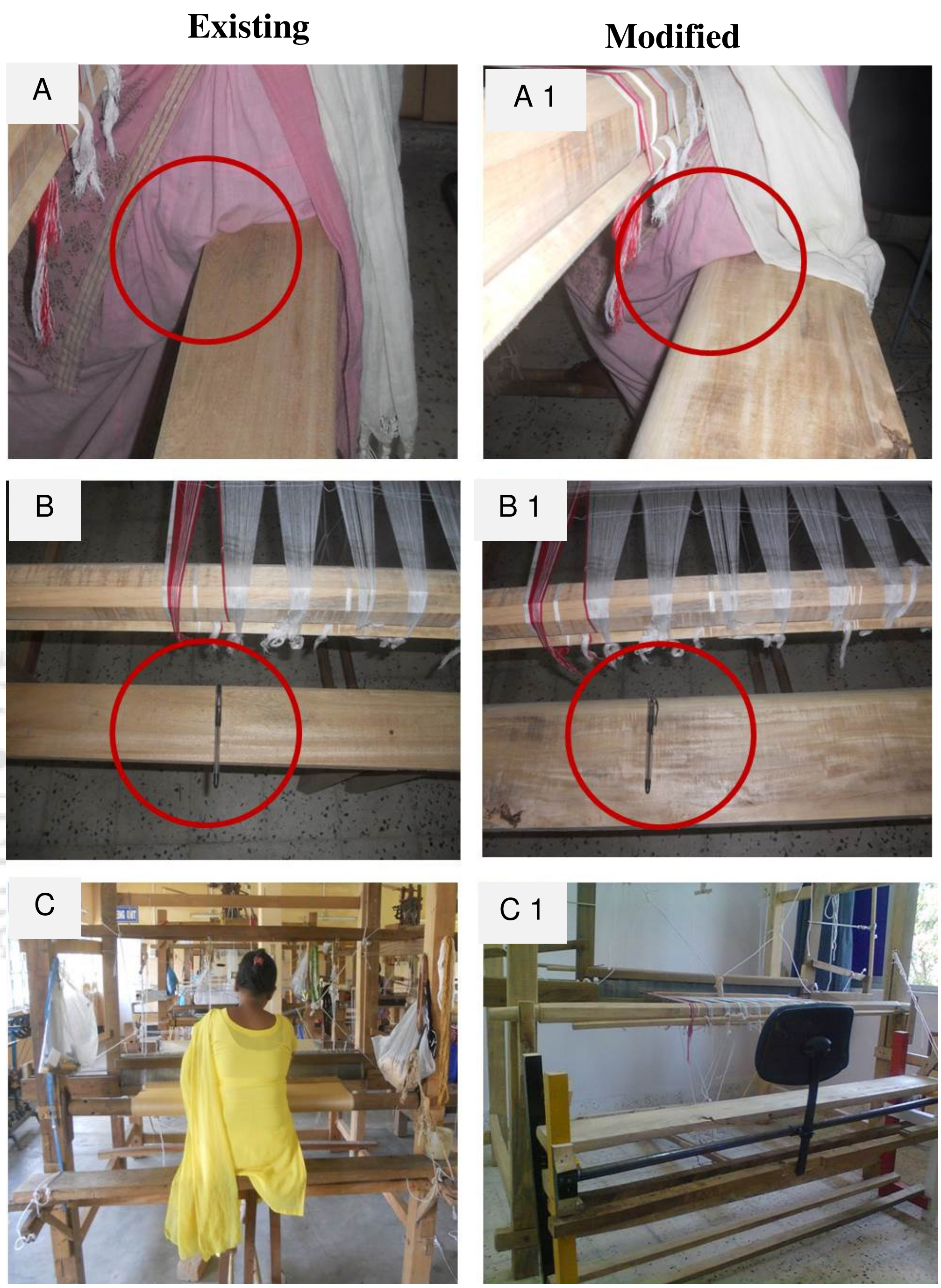


Figure.3.20. Showing existing and modified plank in the simulated laboratory condition. A, A1 represent front edge of the seat at two different conditions, B, B1 is the seat depth at two different phases and C, C1 represents existing and modified plank with and without backrest

3.6.2.E. ii **<u>Pedal</u>:-**

Existing condition

In the existing condition two bamboos were used for pedals. These pedals were hinged at rear end of the loom frame acting as 2nd class lever. Heald shafts were tied up with bamboo pedals which act as tension load shown schematically in (Figure 3.21). Hence, both load and force acts on the same direction of the lever arm. In the existing condition both the pedals are operated by right leg of the weavers. Vertical downward depression of these pedals by foot force forms lower line of the shaft and shedding of two layers on warp threads take place.

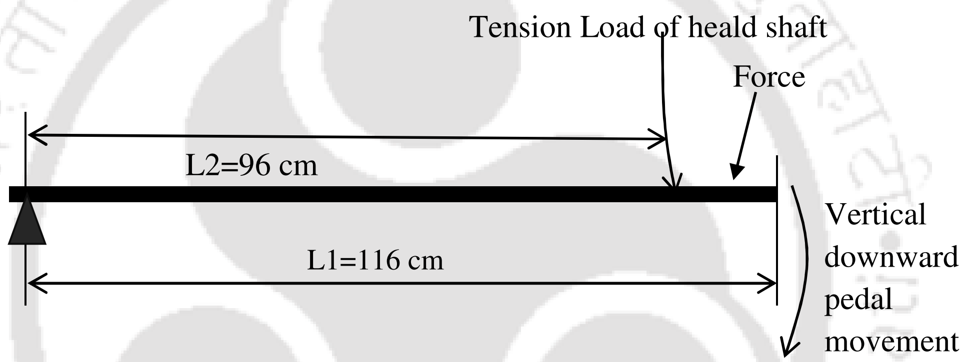


Figure.3.21. Schematic representation of existing pedal

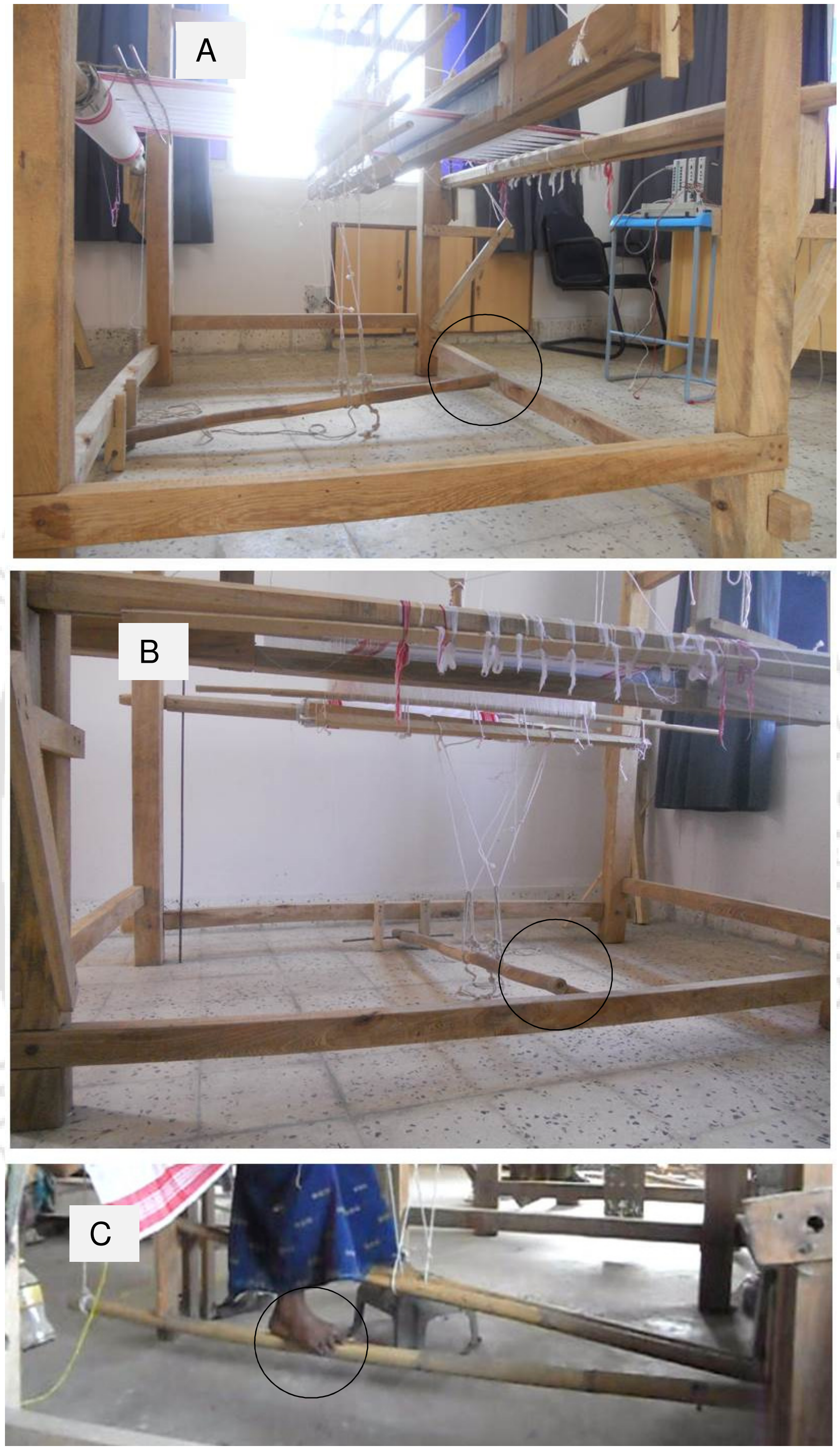


Figure.3.22. Existing pedal of the present handloom (A) Side view (B) Front View and (C) Mode of operation with Right Leg

Modified trial prototype

An experimental standalone pedal unit was developed (Figure 3.23). Two plywood boards were used as supports which were connected by two hollow round rods. One rod is situated 30 cm from the floor height, the other 3 cm above the first one. Two hollow cubical iron rods placed vertically were wielded in the middle with two connecting round rods situated horizontally acting as fulcrums respectively. Hollow cubical iron rods weighing 2 kgs were used to develop pedal to make it light weight. Women anthropometric dimensions (Figure. 3.14, 2 and 3) were considered for developing pedal prototype (Chakrabarti, 1997).

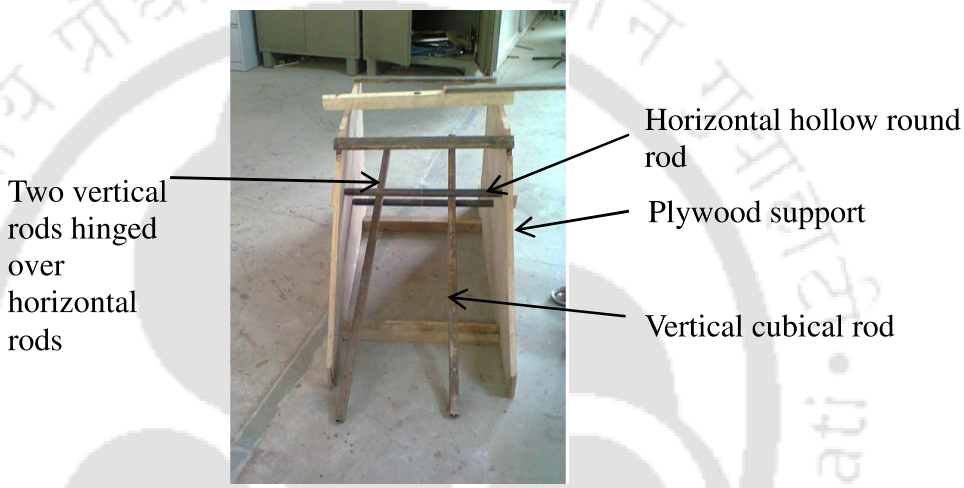


Figure. 3.23 Trial pedal prototype unit

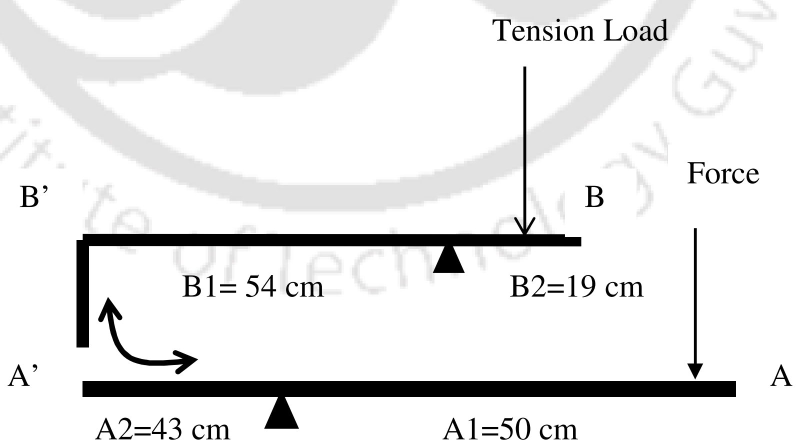


Figure. 3.24. Schematic representation of modified trial pedal prototype

The trial prototype was modified based on two compound lever mechanisms where both the arms were class 1 lever. This types of leverage helps to operate against much greater resistance with application of small force. Compound lever mechanism was found to be efficient in reducing human stress and fatigue and increasing performance, observed in a study on injection moldings machine (Ali &Ansari, 2009). In this design (Figure 3.24), tension was borne on one arm and force was applied on the other. Application of force on AA' arm transfers force to BB' arm which pulls the heald shafts downward to form shed.

This mechanism leads to drastic reduction of force, but observation and feedback from the weavers revealed that it increases the height of the pedal (AA' arm) from floor. As a result the weavers had to raise their legs to reach the surface of the pedal to push it down (Figure 3.25 and 3.26), which was not possible due to cloth beam resulting hitting of the anterior thigh muscle. This also leads to higher flexion and extension at the hip joint leading to more muscular fatigue (Figure. 3.25).

Drawbacks of the modified trial prototype

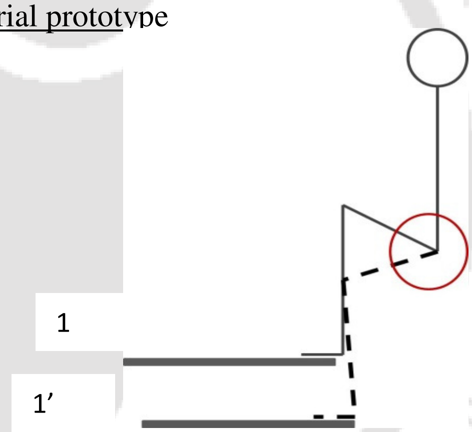


Figure. 3.25. Larger flexion and extension movement at the hip joint to reach the surface of the pedal to push it down

Figure. 3.26. Trial pedal prototype showing increased height of the pedal from floor

Further Modification

Based on the requirements, observations and suggestions from the weavers and experts, the pedal prototype was further modified. Wooden support was given to the rear end of the pedal (Figure 3.27) so that, front end gets downward slope which resulted in the lowering at the front end to 25 cm from floor which was 30 cm in the above situation. A 10^0 downward inclination was given which prevents hitting of the anterior thigh with cloth beam, easing out pedaling process. The point of application of foot pressure was further modified adding a broader foot base. 50th percentile foot length (22.7 cm) and breadth (8.4 cm) of women was considered with allowances for the development of foot base resulting 30 cm length and 10 cm breadth of the foot base with intra pedal distance of 10 cm considering 5th percentile thigh (middle) external breadth single (Chakrabarti, 1997) (Figure 3.27).

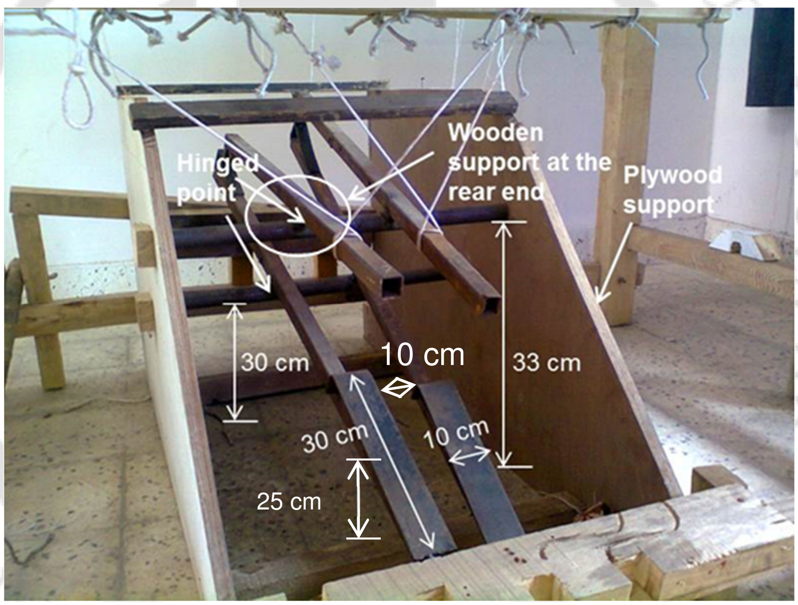


Figure. 3.27. Support in the rear end to form downward slope of the front end of the modified pedal prototype

Further, to increase Mechanical Advantage (MA) of the compound lever, cam profile was incorporated in the new design. Ball bearing was attached with the 2nd lever arm of the pedal which rolled over the cam profile of the 1st lever arm (Figure 3.28). Addition of the cam further decreases pedalling force. CAD drawing of the modified prototype was shown in Figure 3.29 and working CAD model of the pedal unit with loom structure along with working manikin showing foot control is shown in Figure 3.30.

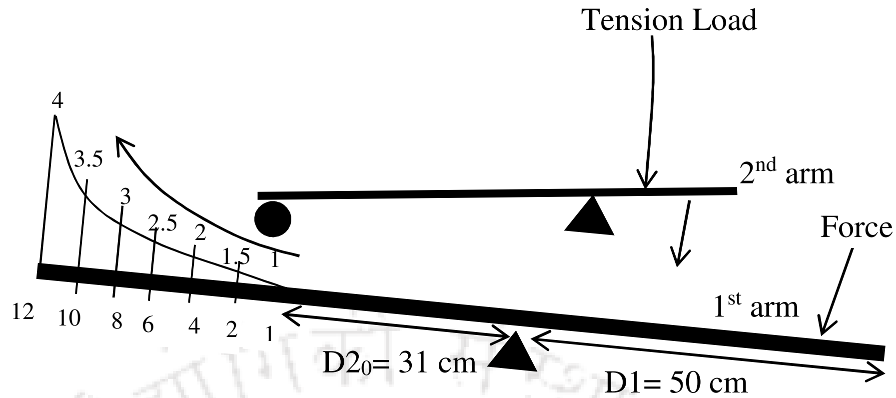


Figure. 3.28. Modification of the pedal with cam mechanism

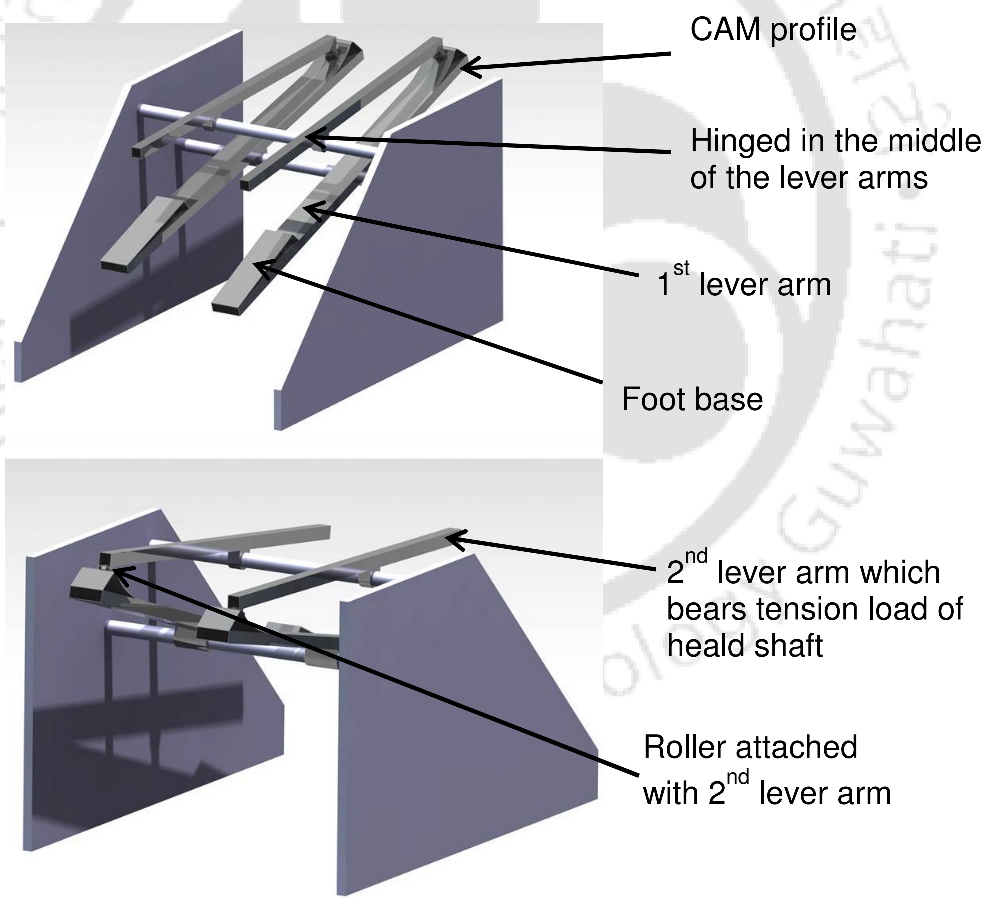


Figure. 3.29. CAD drawing of the modified pedal with cam profile

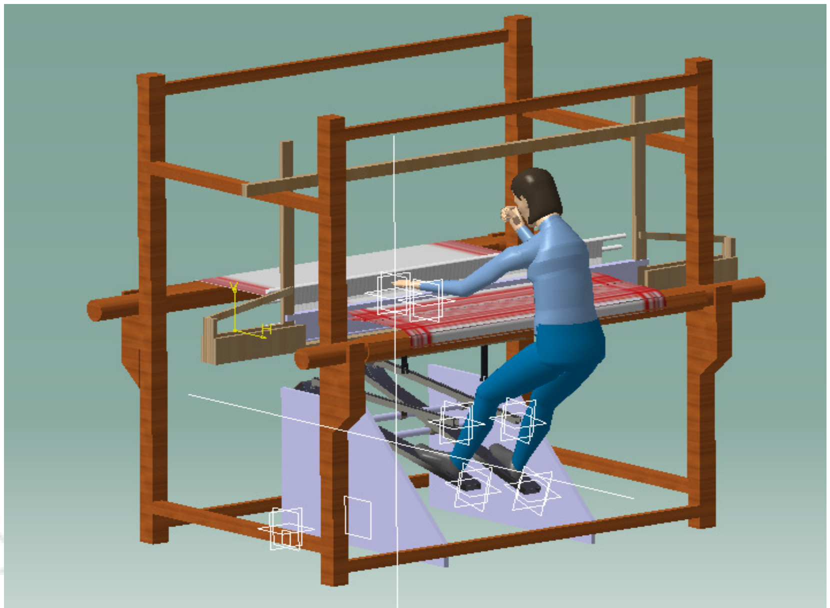


Figure. 3.30. CAD drawing of modified pedal operation where only foot control is shown

3.6.2. F Usability testing

3.6.2. F.1. **Subjective Evaluation**

For subjective evaluation 35 women weavers from 3 villages near IIT Guwahati were selected randomly and asked to evaluate existing and modified plank and pedal. All of them have weaving experience of more than 2 years and who were all attached with commercial weaving either on full time or part time basis. Selected chair features checklists and subjective assessments were carried out to evaluate existing and modified plank after one hour of seating to find effectiveness of the modified plank. Statistical analyses of the data were decided according to the requirements. Percentage, mean and standard deviations were calculated to answer various questions relevant to the objectives of the study.

Borg CR 100 scale (Figure 3.31) was used for comparative evaluation of force between existing and modified pedal design.

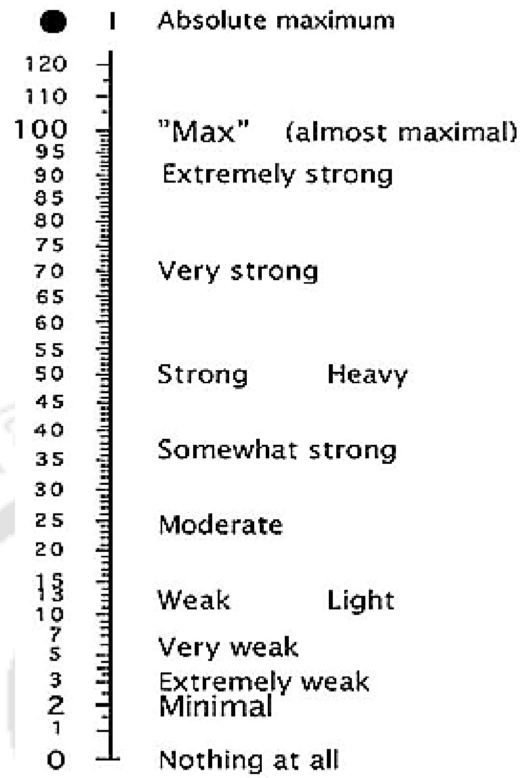


Figure. 3.31. Borg CR 100 scale for force evaluation

Borg CR-100 scale has 10 categories of verbal anchors for describing intensity variations. The verbal descriptors are summaries of the experiences individual weavers have about subjective force. 0 is described as “nothing at all” (i.e., no subjective force), and 100 as maximum perceived exertion. In between these points the descriptors minimal, extremely weak, very weak, weak, moderate, somewhat strong, strong, very strong and extremely strong are interspersed. 100 is considered as a referential point on the scale. The scale works as a percentage scale, and there is a good arrangement between what the verbal expression means and what the number stands for (Molander, 2013).

Results:

The results of the experimental findings of the plank evaluations were discussed as follows.

a. <u>Plank</u>

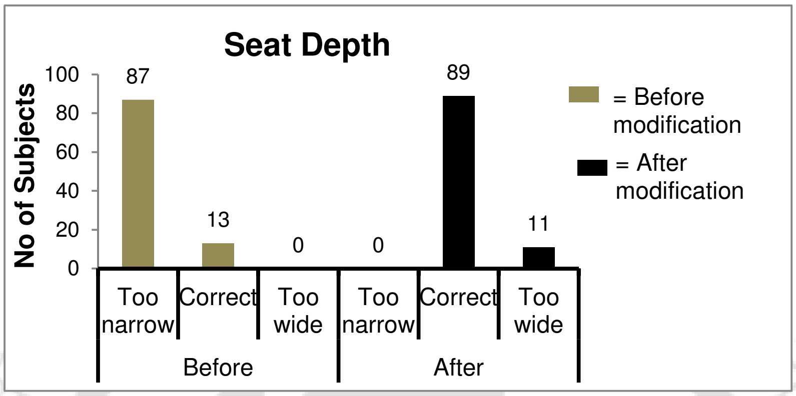


Figure. 3.32. Design evaluation of seat depth before and after plank modification

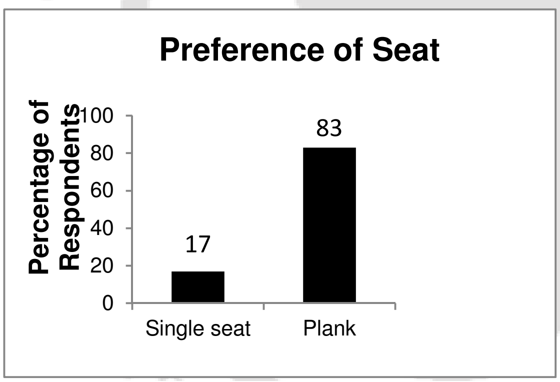


Figure. 3.33. Seat Preference by the weavers

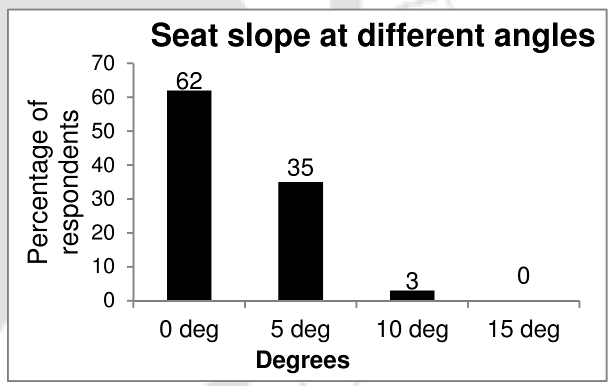


Figure. 3.34. Preference of seat slope by the weavers

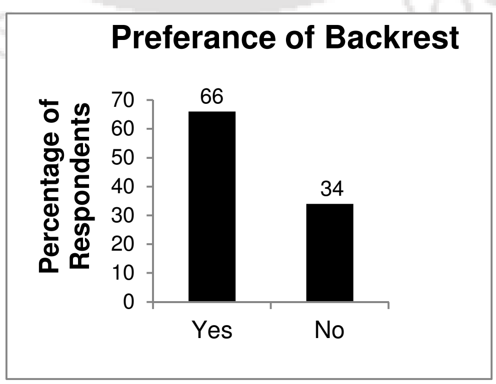


Figure. 3.35 Preference of Backrest with plank

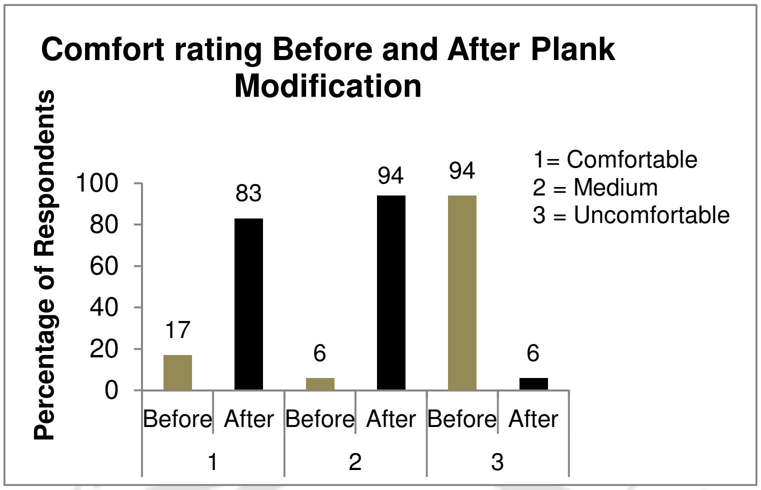


Figure. 3.36. General Comfort rating of seat before and after Modification by Mc Leod et al., 1980

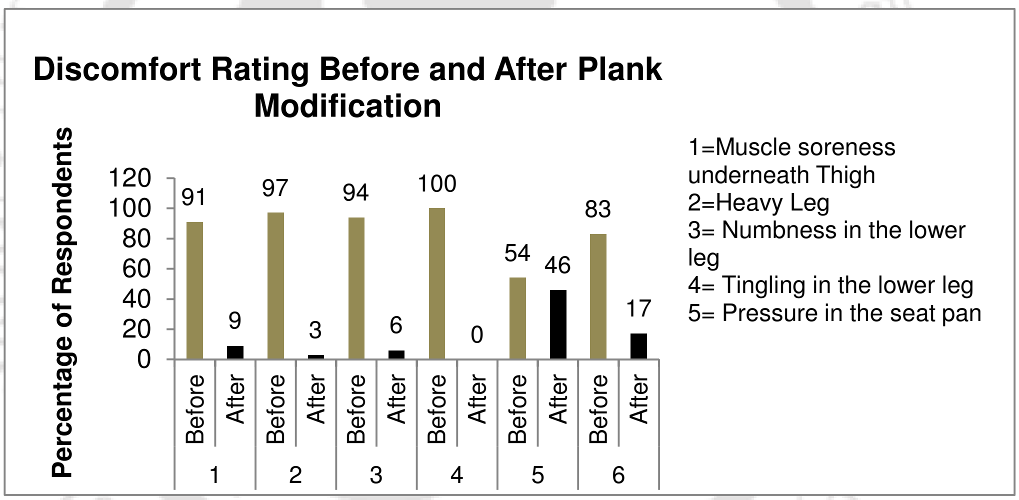


Figure. 3.37. General Discomfort evaluation before and after seat modification by (Helander & Zhang, 1997) checklist

The results of the seat depth of the plank (Figure 3.32) measured by Chair Feature Checklist of Shackel et al., 1969, observed that 87% weavers felt existing seat (before design) to be too narrow while 13% felt it to be correct. On the other hand for the modified plank (after design) 89% weavers felt the width to be correct and rest 11% felt it to be too wide.

In order to understand some other important features of seat for the existing working condition, specific seat feature questionnaires related to the work context was carried out like, seat slope, preference of backrest, type of seat preferred (single seat or plank).

From type of seat preference (Figure 3.33), 83% weavers expressed that they preferred for plank rather than single seat as it was easier for them to keep different weaving materials like bobbin box etc. to the unused plank part, as well as both the sides of the plank was helpful during re-joining of side warp thread breakage. Longer horizontal seating surface helped them to have more grip on the loom to work on side borders. Whereas only 17% preferred single seat as they felt it was easy for them, getting in and out of the loom.

In case of seat slope preference (Figure 3.34), 62% weavers expressed of not incorporating seat slope with the modified plank due to the following reasons, as most of the cases the weavers wearing silk Meghla chadar (traditional dress attire of Assam) have a tendency of slopping down. Weaving materials kept at the side of the plank 'slips and falls' with vibratory motion of the loom. On the other hand, 35% weavers favoured for an inclination of 5 degrees whereas only 3% opted for 10 degrees.

For backrest (Figure 3.35), 66% weavers expressed their interest of having intermittent back support after long period of weaving while 34% did not felt the requirement.

For evaluation of general comfort, chair feature checklist of McLeod et al., 1980 was used to compare between existing (before) and modified (after) plank which is shown in (Figure 3.36). From checklist, it reveals that before modification, 17% weavers felt the plank to be comfortable while 83% have the same feeling after the modification. Similarly, 94% of the weavers expressed that the modified plank to be medium than 6% weavers, who have the same feeling for the old (before) design. In respect to uncomfortableness, 94% weavers felt the old design to be uncomfortable compared to 6% who expressed similar feeling for the modified design.

To evaluate existing (before) and modified (after) plank (Figure 3.37), according to the requirements of the present work context, some selected chair features checklist of Helander & Zhang, 1997 was used. It was observed that 91% of the weavers expressed of having muscle soreness underneath the thigh with the existing plank whereas 9% experienced the same with the modified design. With modification of adjustable seat height, 3% weavers felt to have heavy legs compared to 97% with the old design. Similar observation was also been seen for numbness and tingling sensation where with seat height adjustability only 6% weavers felt numbness whereas 94% have the same feelings with old design and 0% weavers reported of having no tingling sensation with modified design for which 100% reported in case of the existing condition. There was not much difference been observed for pressure in seat pan as in both the cases the seat pan was not been padded. 83% of the weavers reported of restlessness with existing plank design due to the hard edge of the plank whereas 17% experienced same feeling with the modified design.

From the above findings it can be said that the modified plank was found to be effective in reducing stress and increasing comfort level among the weavers.

b. Pedal

Subjective evaluation of the pedal was done by simply operating the two pedals (existing and modified). Based on this, the two pedals were judged and force required for depressing the pedal was evaluated with Borg CR 100 scale. Comparative subjective evaluation of the two pedals was discussed below.

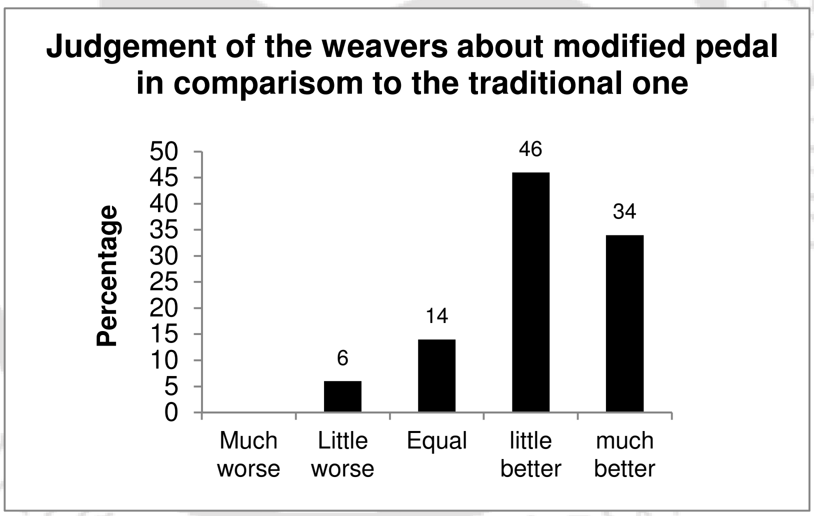


Figure. 3.38. Judgement of the modified pedal design

Judgement regarding existing and modified pedal was performed with the help of general questionnaire to find the significance and acceptance of the modified pedal among 35 women weavers in the laboratory condition.

According to the general judgement of the weavers regarding both the pedals (modified and existing) represented in Figure 3.38, around 46% weavers felt the modified design to be little better, 34% of them felt much better while

14% stated both the design to be equal and 6% expressed the modified design to be little worse compared to the existing one.

In the study Borg CR100 scale was used to evaluate and rate “force” to compare and find the relevance of the modified design (Appendix F). Muscular effort for pedalling was used in the sense of “subjective force” or “perceived force”. Before participants started rating force the weavers rating skill was studied individually. Rating skill of the weavers participated for the test was judged with the help of shades of black on A4-sized sheets of paper with varying in degrees of blackness. The purpose of this test was to ensure that the weavers understand and gets familiarized with CR-100 scale. All the weavers participated for the questionnaire study passed the test without problem. The use of verbal descriptors makes the scale easier and more natural for weavers to determine the intensity of force required for both the pedal.

Same subjects were asked to rate the amount of force required for pedalling on existing and modified design.

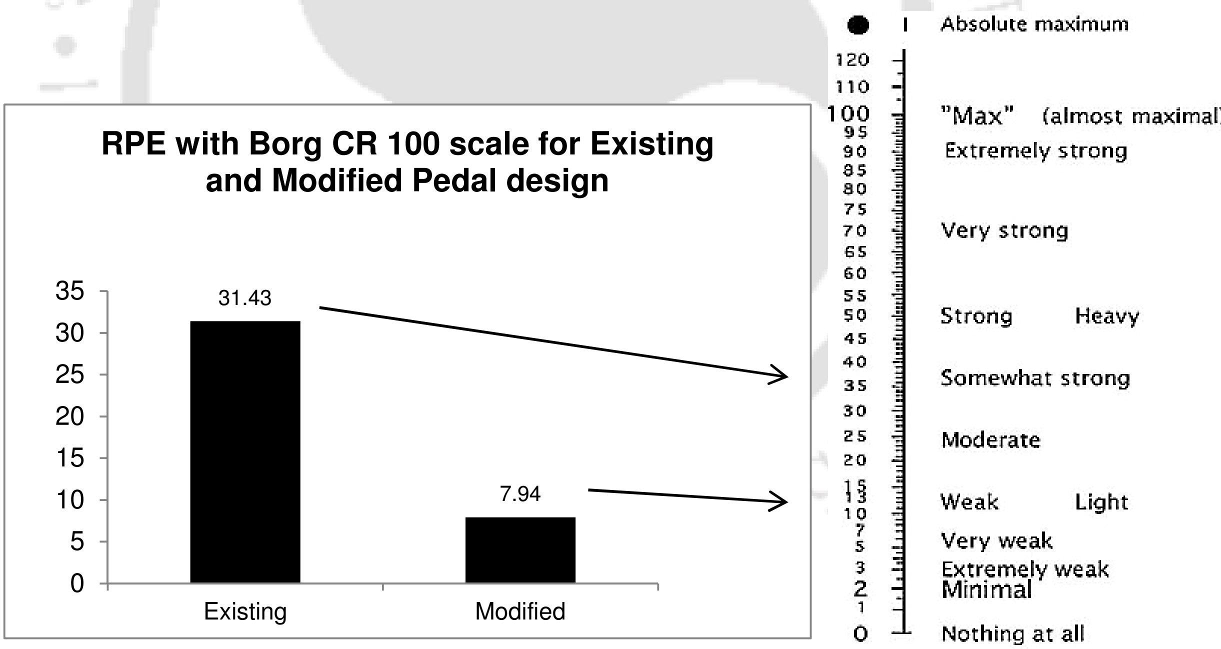


Figure 3.39 Subjective assessment of force exertion with existing and modified pedal with Borg CR 100 scale

It was found by force assessment with the help of Borg CR 100 scale, that the weavers perceived somewhat strong to moderate mucle force to execute pedalling with existing pedal, whereas very weak to light force was perceived to operate the modified pedal (Figure. 3.39).

Comparative testing of the pedals was further carried out with semiquantitative estimation of external force through weights and by means of Mechanical Advantage (M.A) calculation and further confirmtory test was performed to quantify internal force by sEMG.

3.6.2. F.2. **Semi-quantitative estimation by weights:-**

Force more directly represents the biomechanical involvement necessary to carry out a given action or sequence of actions. Force may be intended as being externally applied force or internal tension developed in the muscles, tendons and joint tissues. Some authors' use a semi-quantitative estimation of external force via weights of the objects being handled (Kumar, 1998).

In the present study, weights were added over the pedals to check rate of displacement from initial to final position with existing and modified pedal design in simulated loom without Jacquard. It was observed, that around 24 kgs of weight was required to displace the bamboo made pedal (existing) from initial to final position to form shed of 4 cm between two layers of warp threads so that shuttle can pass through. With the modified pedal only 3.6kgs ≈ 4kgs of weight was required for the same displacement of warp threads (Figure. 3.40).

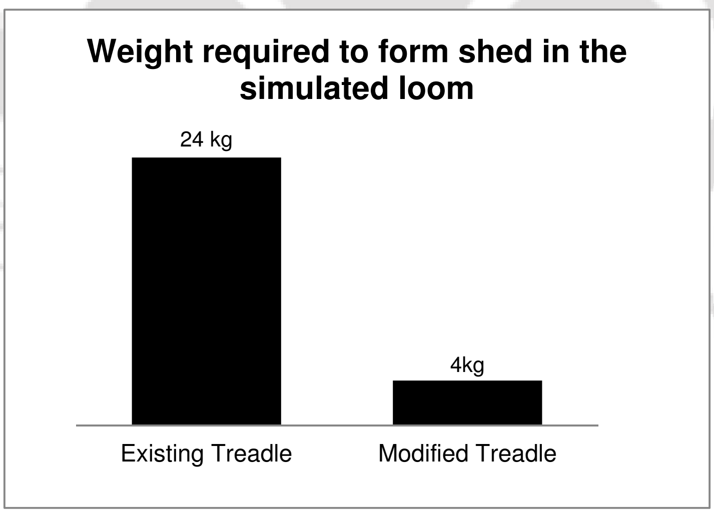
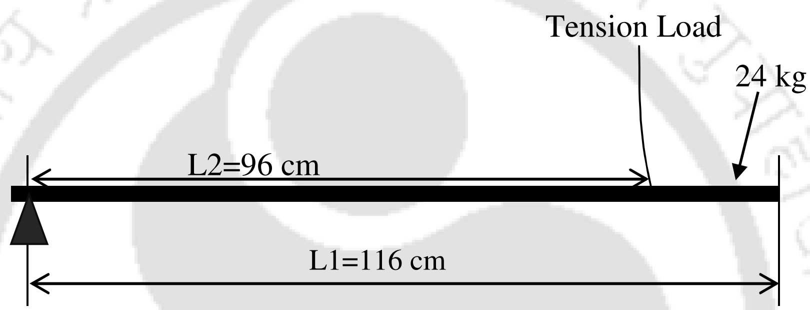


Figure. 3.40. External weights for the displacement of existing and modified pedal

3.6.2. F.3. **M.A. calculation of Lever Mechanism**

The operation of both the pedals (existing and modified) work on lever mechanism. In the existing condition it is made of 2nd class lever, which is hinged at the rear end and tension and force acts on the same side of the lever arm. For the modified condition, the pedal is developed based on compound leverage mechanism, where both lever arms follow 1st class lever principle with addition of cam profile. In modified condition, force is applied on one arm and tension load is carried by the other. M.A. is calculated between the pedals (existing and modified) to find efficiency of force reduction.

Existing Pedal



Lever Ratio

F2/F1=L1/L2=S1/S2

Mechanical Advantage (MA) =F2/F1

Given F2=?

F1=24 kg

L1=116 cm

L2=96 cm

F2/F1=L1/L2

Or F2/24=116/96

Or F2=29 kg

Now,

MA= F2/F1

= 29/24

= 1.21

Where

F1= Input force

F2= Output force

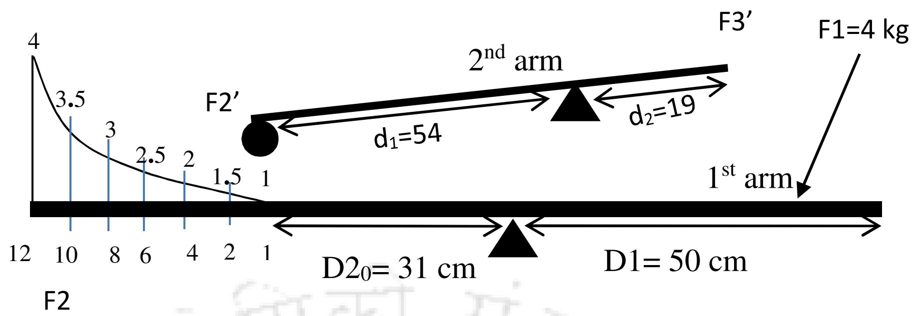
L1= Input length

L2= Output length

S1= Input displacement

S2= Output displacement

Modified Pedal



Length of D_2 arm

$D2_0$ = 31 cm

(1) $D2_1$= 31+1=32 cm

(2) $D2_2$= 31 + 2 =33 cm

(4) $D2_3$ = 31 +4 = 35 cm

(6) $D2_4$ = 31 + 6 =37 cm

(8) $D2_5$ = 31 + 8 = 39 cm

(10) $D2_6$ = 31 + 10 = 41 cm

(12) $D2_7$ = 31 + 12 = 43 cm

MA of inclined plane due to cam profile

1/1=1 ($D2_1$)

2/1.5=1.33 ($D2_2$)

4/2= 2 ($D2_3$)

6/2.5= 2.4 ($D2_4$)

8/3= 2.67 ($D2_5$)

10/3.5= 2.86 ($D2_6$)

12/4= 3 ($D2_7$)

MA of 1st lever arm

$D1/D2_0$= 50/31 = 1.61

$D1/D2_1$= 50/32 =1.56

$D1/D2_2$ = 50/33 = 1.52

$D1/D2_3$ = 50/35 =1.43

$D1/D2_4$= 50/37 = 1.35

$D1/D2_5$ = 50/39 = 1.28

$D1/D2_6$ = 50/41 = 1.22

$D1/D2_7$ = 50/43 = 1.16

MA at each point on the inclined plane

$D2_0$= 1.61* 1 =1.61

$D2_1$= 1.56* 1 =1.56

$D2_2$ = 1.52 *1.33 =2.02

$D2_3$ = 1.43 * 2 = 2.86

$D2_4$= 1.35 * 2.4 = 3.24

$D2_5$ = 1.28* 2.67 = 3.42

$D2_6$ = 1.22 * 2.86 = 3.49

$D2_7$ = 1.16 *3 = 3.48

Table 3.1

Mechanical advantage of compound lever with cam profile

1st Lever arm					Final force F_3 at 2nd lever arm
Measurement for D_2 arm	Input force on 1st lever F_1 (kg)	$F_2=F_1*D_1/D_2$	MA at each point on the inclined plane	F2* MA at each point on inclined plane = Total output of 1st lever	C * output of 1st arm Where C=54/19=2.84
$D2_0$	4	6.45	1.61	10.38	29.48
$D2_1$	4	6.25	1.56	9.75	27.69
$D2_2$	4	6.06	2.02	12.24	34.76
$D2_3$	4	5.71	2.86	16.33	46.38
$D2_4$	4	5.41	3.24	17.53	49.79
$D2_5$	4	5.13	3.42	17.54	**49.81**
$D2_6$	4	4.88	3.49	17.03	48.37
$D2_7$	4	4.65	3.48	16.18	45.95

C = constant where $C=d_1/d_2$

From Experimental result, 4kgs is taken as an input force.

In this pedal design modification, MA of the compound lever mechanism depends on the 1st arm of the lever which gradually changes with inclination due to cam profile. As there was no change in the 2nd arm, this lever arm was kept constant.

Cam profile increased the contact point between 1st and 2nd lever arm otherwise with force application in the 1st arm, contact area moved out. MA of 1st lever arm was due to dual effect of 1st class lever principal and cam profile. Final force available at the heald shaft was output force of 1st lever arm multiplied with a constant value. With initial force of 4kg on 1st lever, output force gradually increased from 29.48kg to 49.81 kg up to $D2_5$ position of cam after which it decreased (Table 3.1).

MA in the existing condition of pedal was found to be 1.21 which increased almost 12.5 times with modified compound lever system but the obtained result was without considering frictional loss. From the above results, it can be concluded that the modified pedal design with cam was highly effective in reducing force from the existing condition.

3.6.2. F.4. **sEMG as confirmatory test for pedal evaluation**

It has been observed that skilled labours always resist to new changes in system and they preferred to use their own techniques and skills. They need time to adapt to new system, for this reason a trial group was selected for EMG study from non-weavers group who were not influenced by skills, to see whether the change in design affects muscle efforts. If the modified design was found to be effective in reducing efforts on the muscles then its outcome on regular weavers was accepted to be operative.

EMG study was performed in simulated loom under laboratory condition among 13 female students of IIT Guwahati belonging to the same age group range (18-35) years. If the study was conducted in real time situation, other factors might also influence the condition. To avoid this and to find out whether there were any changes of internal muscle force on pedalling, with existing and modified pedal on muscle of interest, sEMG was conducted on simulated loom in the Ergonomics laboratory.

Electromyography has been a major quantitative tool, used in this study to determine muscular effort for pedalling. EMG in percent of maximal voluntary contraction (%MVC) was used for comparing muscular effort required in the two pedal designs. Before performing EMG, subjects were demonstrated how to perform pedalling with existing and modified pedal by a skilled weaver. Modes of operation of both pedals were same so no extensive training was required and the subjects with few trials very quickly got acquainted with its operation (as described by the subjects themselves). They were specifically asked to perform shedding movement (that is depressing the pedal) and not to perform picking in order to understand the effectiveness of the new design.

From minute observation of pedalling task, muscles of interest were chosen to execute following joint movements for pedalling. Finally two muscles Gastrocnemius and Rectus Femoris (RF) were confirmed by palpatory method for executing the experiments (Figure 3.41). Both RF and

Gastrocnemius are agonist muscles and generate most of the force for leg movements. The subjects were asked to perform the experiment with their dominant leg.

Muscles for Testing's

Gastrocnemius

Origin and Insertion:-

The two heads of the gastrocnemius originate at the long, thick bone of the upper leg known as the femur. The lateral head of the gastrocnemius originates from the inner, back surface of the lateral (outer) condyle, and the medial head originates from the inner, back surface of the medial (inner) condyle. The gastrocnemius inserts at the calcaneous bone of the heel of the foot by way of the Achilles tendon (Kendall & Mc Creary, 1983).

Fixation:-

The subjects were asked to stand on the tip of the toe (Kendall & Mc Creary, 1983).

Action:-

Helps in the movement of the ankle joint.

Rectus Femoris (RF)

Origin and Insertion:-

There are two heads of the RF, straight head originates from anterior inferior iliac spine, and reflected head from the groove above rim of acetabulum. RF inserts at Quadriceps tendon to base of patella and into tibial tuberosity via the patellar ligament (Kendall & Mc Creary, 1983).

Fixation:-

The subjects were asked to sit on a raised chair with only hip support. They were asked to extend their knee joint without rotation of the thigh. Pressure was applied against the leg above the ankle, in the direction of flexion (Kendall & Mc Creary, 1983).

Action:-

Helps in hip flexion and knee extension.

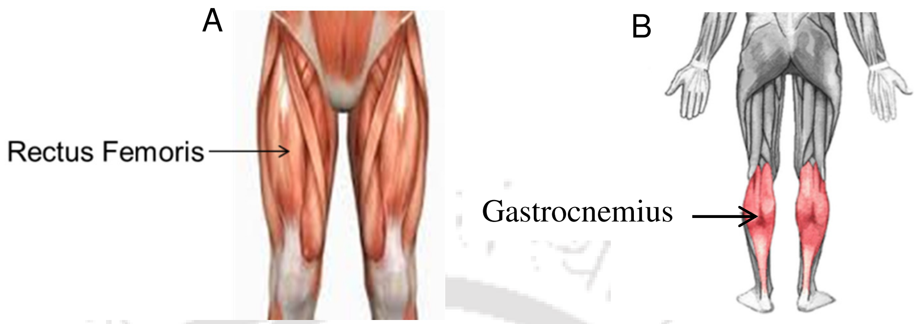


Figure. 3.41. Location of (A): Rectus Femoris (B): Gastrocnemius

Ref A. www.osteoarthritisblog.com
B http://footankleinstitute.com/uploads/images/current-site/ACHILLES/calf-muscles.jpeg

<u>Procedure</u>

Surface EMG (sEMG) of the two leg muscles that is Gastrocnemius and RF was obtained using bipolar disposable Silver-Silver Chloride (Ag-AgCl) surface electrodes with a gel-skin contact area of 1 cm^2 for each electrode and a centre to centre inter-electrode distance of 10 mm (Deluca, 1997) was maintained. Before identification of the muscles, dominant leg of the subjects was recognized and then procedure for placement of electrodes was followed. Muscle belly of Gastrocnemius was identified by asking the subjects to stand on tip-toe and RF by applying pressure above ankle in the direction of knee flexion and the subjects were asked to extend their leg against the given pressure. After locating the belly of the muscles skin surface was rubbed with cotton rinsed in rectified spirit and electrodes were placed. Ground electrode was placed on inactive site over forehead after cleaning the skin. Electrodes (positive and negative) were secured on the skin with medical adhesive tape and lead wires were connected with EMG amplifier - Biopac MP 100 (Figure 3.42) where the recorded signals were amplified 5 times with gain setting of 500 at sampling rate of 1000 samples per second. The signals were band pass filtered at 20-400 Hz and finally recorded and processed in Acqknowledge 3.7.2 software. 5 minutes elapse time was given after electrode placement and before starting of the recording. All jewellery and metal objects were asked to be removed from body and mobile phones were kept at switch off mode.

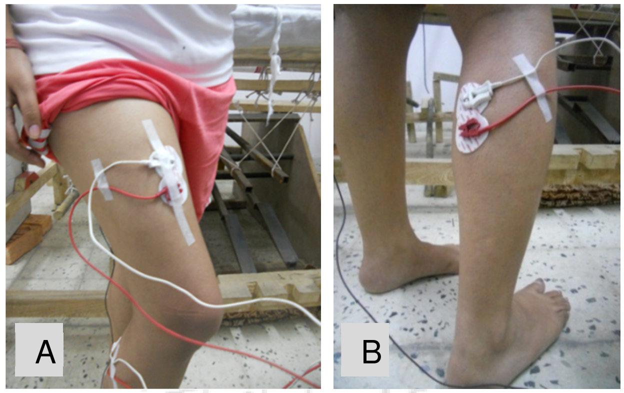


Figure. 3.42 . Placement of Electrodes over (A) Rectus Femoris and (B) Gastrocnemius

With some trials, it was found there was some difficulty in EMG recording with plank. Incidence of loose connection of electrodes took place when the subject started pedalling on seating on the plank due to space constrain and obstruction of electrode wires with plank structure. This resulted in the replacement of the plank with single seat for smooth EMG recording as the objective of the experiment was to determine whether modified pedal was effective in reducing muscular effort on lower limb. The height of the single seat chosen for the experiment was 66 cm.

Normalization of EMG signal

In order to compare the muscle activity between the experimental trials, a normalization procedure was performed (Mirka & Marras, 1991). The procedure followed for normalization was, the subjects were asked to be seated and resting their legs in the neutral posture with muscles relaxed. In this condition data was collected and formed the baseline resting EMG which was recorded for 60 seconds. Maximum Voluntary Contraction (MVC) of Gastrocnemius and RF was measured by the following methods; for gastrocnemius the subjects were instructed to stand on tip-toe for 30 seconds and the signals were recorded. Similarly for MVC of RF the subjects were asked to sit on a raised tool with only hip support and instructed to extend their knees against a constant weight of 5 kg hang just above ankle joint and asked to hold it for 30 second and EMG signals were recorded. Normalization of EMG recordings was done by expressing them as percentages of the maximal voluntary contraction (%MVC) (EMG: Normalizing to maximal voluntary contraction, n.d).

Processing of EMG signal

Before starting the experiments, subjects were explained the protocol of the tests. The two experiments were carried out for 15 minutes with 20 minutes of rest in between the experiments. Experiment 1 consists of pedalling with the existing pedal and experiment 2 with modified pedal in simulated laboratory condition (Figure 3.43). The raw %MVC was converted and processed as root mean square (RMS) value (Figure 3.44). Basmajian & Deluca, (1985) recommended RMS as the most desirable processing method for analysis of EMG signal.

Figure 3.43 EMG recording with (A) Existing and (B) Modified Pedal on single seat

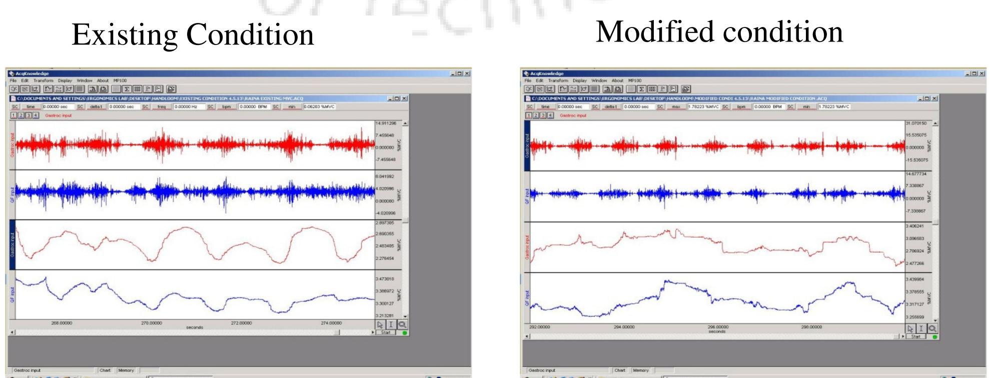


Figure. 3.44 . Raw and RMS %MVC graph plot of Gastrocnemius(red) and RF(blue) with existing and modified pedalling activity in Acqknowledge 3.7.2 software

Results of EMG

In this study, mean values of RMS %MVC of Gastrocnemius and RF was compared between exiting and modified pedalling activity by paired-t-test in SPSS version 20.

Testing of Hypothesis

3.6.2. F.4.i Testing of Hypothesis

H: 3 → Design interventions in workstation modifications is effective in increasing operational easiness and thus comfort and increases work efficiency.

Gastrocnemius Muscle:-

Table 3.2

Paired Samples Correlation by SPSS for Gastrocnemius muscle for existing and modified design

	N	Correlation	Sig
Pair 1 Existing and Modified	13	0.968	0.001

Table 3.3

Paired Sample t-Test by SPSS for Gastrocnemius muscle for existing and modified design

	Paired Differences					t	df	Sig(2 tailed)
				95% Confidence Interval of the difference				
	Mean	Std Deviation	Std Error Mean	Lower	Upper			
Pair 1 Existing-Modified	2.35	1.74	0.48	1.30	3.41	4.87	12	0.001

RF Muscle:-

Table 3.4

Paired Samples Correlation by SPSS for RF muscle for existing and modified design

	N	Correlation	Sig
Pair 1 Existing and Modified	13	0.974	0.001

Table 3.5

Paired Sample t-Test by SPSS for RF muscle for existing and modified design

	Paired Differences					t	df	Sig(2 tailed)
				95% Confidence Interval of the difference				
	Mean	Std Deviation	Std Error Mean	Lower	Upper			
Pair 1 Existing-Modified	0.75	0.83	0.23	0.25	1.26	3.24	12	0.01

Interpretation of Paired Samples correlation

Paired samples data always have equal N, so the homogeneity of variance assumption is not an issue. In this test, Pearson correlation was found to be statistically significant (gastrocnemius muscle where r = 0.968 and RF muscle where r = 0.978) (Table 3.2 and 3.4) thus, the variances are considered to be significantly different from each other. Statistically significant correlation means the variance at time one or paired one is statistically different from variance at time two or paired two thus, null hypothesis of equal variances was rejected and it was concluded that there was a difference between the variance in the population.

Contraction of muscle depends on muscle fibers. The samples participated in the study was heterogeneous, consisting of both ectomorphic and endomorphic. Muscle fibers varies from individual to individual which was been taken care by repeated measure paired t-test where same subject was measured twice. A subject who had fairly low RMS %MVC value in the first experiment should still have a fairly low RMS %MVC value relative to the other in experiment 2, even if everyone improved.

Interpretation of Paired t-test

Repeated measure paired t-test was performed on two muscles of same individual with existing and modified pedal to compare means at two time frames as per experimental protocol. RMS %MVC of RF and Gastrocnemius were compared using paired "t-test" The "computed t" was found to be higher than "critical t" at 0.001 level for Gastrocnemius muscle and 0.01 level for RF muscle (Table 3.3 and 3.5). The probability p of correctness of H_0 was less than 0.01 and 0.001 and was considered low. So, it was inferred that there was significant mean difference of muscle stress between existing and modified design. There was reduction of mean RMS %MVC for RF and Gastrocnemius in case of the new pedal design. As %MVC is directly related with muscular effort or muscle force, it can be said from the results that less muscular effort is required in case of modified pedal than existing pedal. The new design was found to be effective in reducing muscle force therefore; it would be effective in increasing operational easiness during weaving. Hence it could be concluded that design intervention have positive impact on weavers comfort and operational easiness during weaving process.

3.6.2. G Final Design

Usability evaluation of the newly developed pedal was found to be more effective and its operation was less stressful as evident by low RMS %MVC for the two selected lower limb muscles. From semi-quantitative estimation, it was also observed that less weight was required for depressing the modified pedal to form shed between the two layers of warp thread. Mechanical advantage of the modified pedal consisting of compound lever was also found to be higher than traditional pedal following second class lever principle. If new design could reduce muscle stress it would definitely have positive influence of increasing operational easiness. Based on these findings the final pedal and plank design was finalized which required field trials to implement in mass, so that the fruitful outcomes of the research proved by laboratory test in reducing muscular effort of the lower limb, could be reaped by the vast weaving population. Due to constrain of laboratory space, it was difficult to take a proper view of the modified pedal. Final plank and pedal design was shown in the following Figures 3.45 and 3.46.

Figure. 3.45. Final plank design with adjustable height and movable backrest

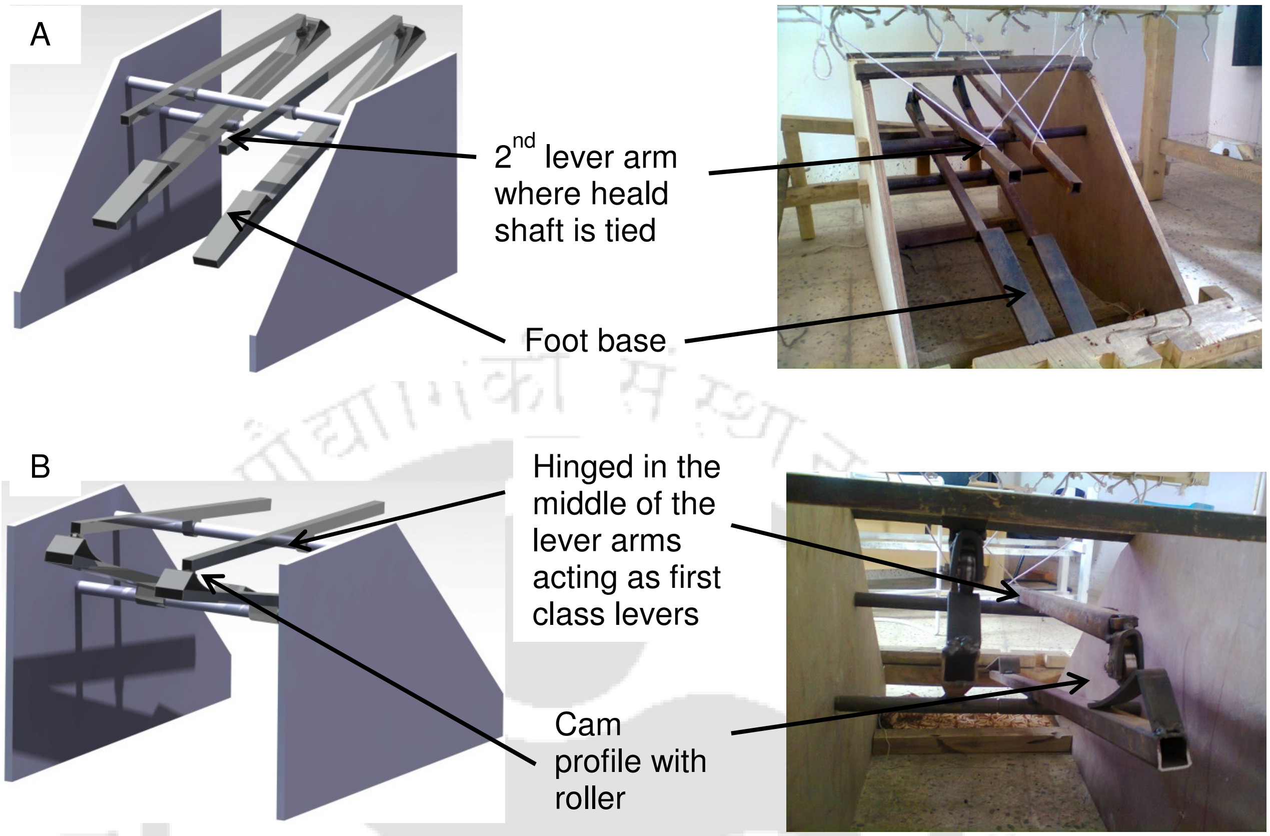


Figure. 3.46. Final pedal design shown in real time and in CAD model defining its different components (A) Front view, (B) Rear view

3.7 Significance of the modified pedal

Good design practice recommends fewer numbers of repetitions but repetition in the present context is unavoidable. To compensate repetitive effects of pedalling, care was taken to redesign the pedals so that it could minimize muscle force delaying muscle fatigue time. In order to prevent hitting of the anterior thigh from cloth beam and for preventing hip joint fatigue due to raised pedal arm, rear end of the pedal was raised in order to give a forward slope which forms a knee angle of around 100-110 degrees (Figure 3.47) measured by goniometer from a knee angle of 80-90 degrees in the existing condition, but hip angle remains same in both the situation. Knee angle of 105-110 degrees produce best leg performance and is the most natural and neutral position (Kroemer et al., 2001).

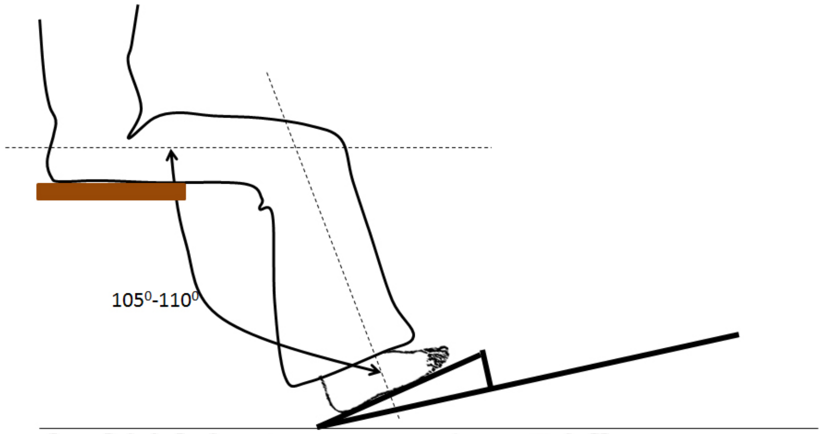


Figure. 3.47. Knee angle of women weavers shown schematically with modified pedal design

Effectiveness and acceptance of the final design comes from the end users. PA of the experts, skilled weavers played important role in the evolution of the modified pedal starting from conceptualization to finalize stage. The participants of the study found the new pedal very effective in reducing thrusting leg force. The volunteered weavers participated in the study were highly motivated to have this pedal and expressed that it would be effective for commercial production in the long run.

3.8 Salient findings of the modified designs (plank and pedal)

After laboratory test following conclusions were drawn

Plank

<u>Findings</u>

- Plank is preferred over single seat.
- Inclination of plank is not preferred.
- Adjustable seat height from 60- 70 cm with mid position of 65 cm was fixed according to women anthropometric dimensions.
- Seat depth of 30 cm with usable area of 24 cm, having round curvature of 6 cm in the front was preferred by the weavers.

Benefits

- Backrest of the chair reduces spinal and paraspinal load on the back muscles, after long hours of sitting and trunk-bend-forward posture for beating operation. The benefit of backrest can be used during rest or, as and whenever required.
- Adjustable seat height and smooth curvature at the front of the seat, prevents pressure development at the posterior thigh muscle while seating as well as during pedalling activity.
- Increasing the depth of the plank gives sufficient support to the body from sitting surface.

Pedal

Findings

- Modified pedal prototype is made of compound lever where both lever arms consist of first class lever with addition of cam profile.
- Foot base of 30 cm length, 10 cm breadth is provided where foot pressure is applied considering women foot anthropometry. An intra-pedal distance of 10 cm is given considering 5^{th} percentile thigh (middle) external breadth single of women for operating the pedals with both feet.
- The height of the first lever arm of the pedal is situated 25 cm from the floor and 10^0 downward inclination was given to the pedal from rear end.

Benefits

- New pedal reduced the force for pedalling
- Materials used were easily available from local market and could be manufactured locally
- Low cost and could be replaced easily with the existing pedal without changing the loom structure
- The new design do not required further training to get acquainted with its mode of operation rather; it follows the same pedalling process so additional training cost was not required for its implementation.
- It reduces pressure on single leg for pedalling as the design is made such, that both legs were required for its operation.

Chapter 4

Discussion

Chapter 4

4.1 Occupational health and safety: key to sustainable productivity in small scale industry

As discussed before, most successful economies have demonstrated that workplace design following ergonomic principles and taking care of occupational health and safety are most sustainable and productive. In addition, productivity for long-terms as well as quality products and services are difficult to achieve in poor working conditions where workers are exposed to health and safety hazards.

In Indian context, social and economic importance of work receives much more attention and far less importance is paid to individual's health. The workers' are unaware of occupational health and safety issues and pay less attention on their wellbeing and earn their livelihood on the cost of their health. The situation is even worst in small scale cottage industries, where contribution of the workers to economy is ignored and they are deprived of workers' right and other occupational safety and health regulations. Lack of strict adherence to work environments standards and legislations, these bulk workforces in small scale and cottage industries are subjected to various work hazards. It is observed that occupational health programmes focuses on large scale industries in urban areas, neglecting health issues of the vast majority of workforce which depends on small scale and cottage industries for their livelihood (Kromhout, 1999; Christiani et al., 1990). Characteristics of work practices and workstation denote likelihood of musculoskeletal injuries and accidents are greater, in small scale industries (Glass, 1998).

4.2 Handloom a sustainable model of rural economy

Handloom industry provides low capital costs and it is the mainstay of rural economy of India, as still India remains a country predominantly of villages. Handloom is extensive skill base, contributing nearly 22% of the total cloth production of the country (Chapter 3. Handloom of planning commission, n.d). This industry accounts 6% of GDP and 34% of total exports (Vidya & Shashidhar, 2007). In the present condition when technical know-how is increasing, handloom industry presents a sustainable model of rural economic background that is not energy-intensive, especially for Assam (Assam Powerloom Development

Corporation Limited, n.d), as power has not yet reached in many rural areas as a result power looms are in dormant condition. In the context of various limitations to the development of organized industries in Assam (106 Industry, trade and mining – planning, n.d) and because of inadequate potentialities of agricultural development and migration to urban areas, where opportunities are already limited, handloom plays a very important role in the economy of the state after Tea.

Three basis requirements of human are food, cloth and shelter. The providers of cloth, "the weavers" have always been an ignored population and occupational health problems among this group always been overlooked. Traditional approach of working for commercial production, lead to the development of Work related Musculoskeletal Disorders (WMSD) among women weavers of Assam. Similar studies have shown that, traditional approach should be changed, as there is immense importance of small scale industries in diverse socio-economic aspects and sustainable development (Chen et al., 1999; Frijns & Vliet, 1999). The findings of the present study are discussed below.

4.3 Validation of the hypotheses

Three experimental hypotheses H1,H2 and H3 as assumed in the very beginning thus fulfilled with the research findings.

H:1 Workstation related adaptation of awkward posture during weaving process increases risk of muscle pain.

In order to derive first hypothesis, individual body part posture scores obtained by REBA was compared with reported bodily pain obtained by body map. $\chi 2$ was used to determine whether compensating posture for weaving was the reason for frequent complains of pains, aches or discomfort. Results of the present study showed significant association between neck, trunk, Rt UA, Rt LA, Rt wrist, Lt UA, Lt wrist with reported body pain, but no association was found between posture score for Lt LA and leg with muscle pain (Table 2.7).

For neck, weaving demands constant flexion and twisted posture due to inspection of thread breakage these causes loading on neck muscle resulting pain. For to and fro movement of the slay frame for beating, as well as for joining thread breakage the trunk maintains a constant forward bend and twisted side bending posture resulting back pain.

Rt UA was involved in picking operation and the posture depends on the height of the picking handle or picker. A considerable raised height of the picking handle was required in order to generate pulling force so that the shuttle runs from one selvedge to the other. In order to hold the picker for picking operation, constant raised shoulder and abducted upper arm was maintained, this results in static contraction resulting pain in the upper arm. In order to hold the picking handle, constant flexion angle ($<60^0$) was maintained by the Rt LA. Pain in the Rt LA was not only due to posture, but also due to sudden lateral forceful flick of the wrist to propel the shuttle over the slay from one selvedge to the other. This movement causes contraction of flexor digitorum muscles of LA. The task was highly repetitive and forceful in nature causing less time for the muscles to recover leading to muscular fatigue and subsequent pain. Causative factor for muscular pain in the Rt wrist was similar to that of Rt LA. Due to lateral pulling of the picking handle, the wrist repetitively undergoes flexion and twisting. The action was highly repetitive and involves sudden lateral forceful flick of the wrist. Combination of force, awkward posture and repetitive nature of task leads to susceptible pain in wrist area.

Lt UA was involved in beating where the upper arm remains constantly abducted for to and fro movements of slay frame. Depending on the length of the cloth from cloth beam to reed the arm was stretched to hold the slay frame for beating. In order to maintain this posture static loading develops on Trapezius muscle resulting Lt LA pain. Flexion, extension of Lt wrist results to and fro movements of slay frame which helps in beating. Deviation of wrist from midline was also been observed while performing this operation resulting wrist pain. Beating was highly repetitive and less time was achieved for muscle recovery causing muscle fatigue.

As already stated from the results of $\chi 2$, that no association was found between posture score and Lt LA and leg pain, Lt LA was responsible for pulling the slay frame for beating. For beating LA forms 100^0 angle with upper arm. As per REBA posture score this was categorized as good posture but pain develops due to repetitive flexion and extension of the lower arm along with, forceful pulling of the heavy slay frame. The task was highly repetitive and forceful in nature resulting little time for muscle recovery.

As per REBA score sheet, leg posture analysis was done at the knee articular angle to determine bilateral weight bearing and angle of flexion.

For leg no separate REBA analysis was done for upper leg, lower leg, ankle and foot separately. For weaving, weavers have a firm support on the plank and the knee angle due to sitting posture was more than 30^0 flexion. From body map, assessment tool for pain indicates that mostly weavers reported pain in the upper leg (thigh) and Gastrocnemius of lower leg (cup) muscle and ankle joint and foot of Right leg. Leg pain was mostly due to internal force required for pedalling and due to repetitive nature of work but not due to bad posture.

The results of statistical analyses by $\chi 2$, evidenced that compensating or awkward posture adopted by the weavers while weaving was one of the major risk for development of muscular pain, except for LT LA and leg. According to REBA, these two postures were categorized as normal posture but muscle pain in these two body regions, was due to force and highly repetitive nature of the task.

Hence it could be concluded that workstation related awkward posture during weaving increases risk of muscle pain.

H:2 Force required and duration of pedaling is directly proportional to lower limb pain.

With commercialization in the handloom industry of Assam, weavers used to weave on Jacquard operated loom for commercial production with fixed work schedule. Previously for domestic weaving, there was no fixed time and women of the household used to weave whenever they were free from domestic work out of pleasure. For commercial production time plays an important role.

It was observed that there was difference in pedalling force between Jacquard loom and domestic loom. These raises inquisitiveness for studying the effect, whether increased pedalling force due to Jacquard and longer duration of work shift for commercial production has any effect on lower limb pain. To find out this, two way ANOVA was performed to see the effect of two independent variables (pedal force and work shift) on a single dependent variable (lower limb pain).

From ANOVA analysis it was found, there was significant relation with pedal force and duration of work shift with lower limb pain (Table 2.9). As pedalling force increases there was significant increase of lower limb pain. Similar observation was also been reported with work shift duration, as duration increases so does the lower limb pain. But no relation was observed within group for increased pedalling force and work shift on lower limb pain. This might be due to two types of weaving practice, continuous weaving and weaving for motif making. Harness Yarns from Jacquard form motifs. Depending on the number of motifs harness yarn increases, which increases tension force on warp threads against which pedal depression was carried out to form two layers of shed for picking. Weaving heavy motifs increases pedalling force but at the same time micro pauses were there during warp stop motion to move extra weft. During these micro pauses, leg muscle recovery takes place.

For continuous weaving for plain weave, pedalling force was less, but constant pedalling takes place relatively for longer duration. ANOVA indicated that an increase in pedalling force and work shift duration increases incidence of lower limb pain among handloom weavers for commercial production but due to two types of pedalling, there was no significant relation found within group for pedalling force and work shift duration on lower limb pain.

Hence, it could be concluded, that pedaling force with longer duration of work shift is directly related to lower limb pain.

H:3 Design interventions in workstation modification is effective in increasing operational easiness and thus comfort and increases work efficiency.

Usability test was performed with repeated measure paired t-test on mean RMS %MVC value of two leg muscles (Gastrocnemius and RF) involved in pedalling on same individual, with existing and modified pedal to find effectiveness of the modified pedal design. It was observed that there was reduction of mean RMS %MVC for RF and Gastrocnemius in case of the new pedal design compared to the existing one. Reduction of force on the lower limb muscle was due to M.A. of compound leverage and cam profile on the modified pedal design. Gastrocnemius was responsible for the movement of ankle joint. As less foot pressure was required for pedal depression due to M.A. this resulted decrease of RMS % MVC value. RF was responsible for hip flexion and knee extension. With modified design, a knee angle of 100-110 degree was formed by giving downward slope in front, resulting change of pedal operation from vertical downward movement to angular movement. Previously during vertical downward leg movement there was constant flexion and extension at hip joint. With angular pedal movement with modified design there was slight hip joint movement for pedal depression due to less force. Thus the modified design reduced muscular activity of both gastrocnemius and RF muscle.

Usability test by EMG recording reveals that design intervention in pedal modification was highly effective in reducing internal muscle force for pedalling resulting comfort and operational easiness and work efficiency among the weavers.

4.4 Fulfilment of the Objectives of the study

There were two objectives for the research findings, these were

i. To find out occupational stressors prevailed in the existing workstation that influence work performance among women weavers.
ii. To understand scopes, where design intervention could be effective in improving work efficiency retaining traditional method of loom practice.

In order to achieve the objectives of the study, work carried out in the present workstation is discussed in the following three phases. First different workstations were screened followed by subjective assessments among the weavers. Further, step by step video-event analysis was carried out to find out the reasons for development of muscular stress. Based on the findings of workstation assessments, ergonomic design intervention was undertaken and usability test was performed in the laboratory to find the effectiveness of the new designs. In the following, findings of the present studies are discussed in order to present how they fulfil the requirements of the two objectives. Present data represents the sample population of predominant handloom clusters of Kamrup districts of Assam, which is well-known for commercial production.

Phase I

Ergonomic risk factors are synergistic elements that enforce biomechanical stress on the workers and results work related hazards. Large body of evidences supporting the findings that exposure to ergonomic risk factors in the workplace contributes to the risk of development of MSDs. Screening of the weaving workstation revealed that, handloom weaving comes under very high risk zone (Table 2.2, 2.3, 2.4 and 2.5). Weaving involves, highly repetitive work (Table 2.5) which develops stress on the musculoskeletal system increasing the likelihood of fatigue and decreasing the opportunity for tissue to recover causing pain and discomfort. This is similar to the observations made by Banerjee & Gangopadhyay, 2003.

Study carried out by Choobineh et al., 2004 have stated that majority of ergonomic shortcomings and important ergonomic risk factors for musculoskeletal symptoms in weaving operation originated from ill-designed workstation resulting different work related hazards. Existing workstation also revealed musculoskeletal problems among weavers due to poor posture, repetition, force execution, contact stress, daily working time and seat type. It is noted that posture was not mutually exclusive and could be considered as task-defined. Intensified workload and repetitive nature of work with limited job control were some causes for muscle pain among the weavers. The observations were similar to the research findings of Putz-Anderson et al., 1997. Observations from present study revealed, as the duration of loom usage increases for commercial production, it has positive impact on the occurrence of MSDs (Table 2.9) which is similar to the observation reported by Costa et al., 2006.

Reported studies on weavers of horizontal frame loom of India revealed that muscular pain were common among weavers. Findings of the present study revealed that reported percentage of weavers having back pain (95%) and knee pain (83%) [Figure 2.10] was much higher than reported by the studies carried out by Nag et al., 2010 and Tiwari et al., 2003. The population of weavers in the present study were all women, so one of the possibilities of higher incidence of MSDs, might be due to the physiological demands to perform household activities. This reduces their physical recovery throughout the day which gets adverse with commercial weaving practice. Consideration of non-work related social factors for MSDs was not carried out in the present research study but similar observations revealed that women weavers were more affected with MSDs in the handloom sectors due to household and workplace activities (Nag et al., 2010 and Motamedzade & Moghimbeigi, 2012).

In the second phase of the study, detailed comparison of multiple dimensions of work aspects in weaving and its relationship with MSDs was analysed step by step with video-event analysis, which provided an indication and direction of design intervention strategies.

Phase II

Observation from work system analysis of weaving task (Table 2.6) showed that forced forward and twisted bend sitting posture for beating and inspection of thread breakage, as well as upright sitting for continuous weaving at a stretch for 4 hours for commercial production lead to the development of back pain which was similar to the research findings on back pain by van Weky, 1970; Hartvigsen et al., 2001; Fogleman & Lewis, 2002; Nakazawa et al., 2002; Lis et al., 2007; Mork & Westgaard, 2009. Above this, non-adjustability with minimum hip and body support by the seat, added up muscle load on the weavers resulting back pain which was also been reported by Nag et al., 2010 and Goel & Tyagi, 2012. Repetitive motion, of upper and lower limbs for loom operation develops upper and lower limb pain. Upper limb pain, for loom operation was also been reported by Goel & Tyagi 2012; Banerjee & Gangopadhyay, 2003.

Nag et al., 2010 in their study have reported that leg pain among handloom weavers was due to maximum stretching of legs for pedalling. Goel & Tyagi, 2012 in their study have reported leg pain due to fixed leg posture but the present research findings revealed some other causative factors for leg pain. Leg pain in the existing condition, was due to commercial production on Jacquard operated handloom and for improper seat design. Pedalling was found to be highly repetitive task involving along with high force against Jacquard. With commercialization, introduction of Jacquard has increased pedalling force which increases with cloth width and number of harness yarn. Vertical downward leg movement for oscillatory pedal operation deteriorates with hard edge at the front of the seating surface. This along with fixed seat height resulted dangling of leg in the air. It causes uncomfortable swelling, numbness and tingling on lower limbs.

The results indicated that the determinant factors for the weavers' perception of back and leg pain was seat and pedal. From phase I and II it was confirmed that there was occupational stressors prevailed in different weaving pockets that influence work performance among weavers due to bodily discomfort and pain. Sen, 1984 in his study have reported, small improvement in the workstation in small scale cottage industry can bring into significant changes and is highly beneficial. In order to optimize the effect of commercial weaving, pedal and seat modification was worked out to reduce changing effects of work practice.

Phase III

The study focussed on ergonomic design intervention on seat and pedal modification with the help of participatory approach. Modification has been undertaken keeping in view of the following:-

- Low cost
- Easily manufacture
- Low maintenance cost and
- Long durability

Previous ergonomic studies, carried out in the handloom industry in India were evaluation based but design solution was not been reported in any of the research findings. Design intervention studies in the carpet industry of Iran, witnessed improvement of occupational problems among carpet weavers (Choobineh et al., 2004; Motamedzade et al., 2007; Choobineh et al., 2007).

From usability testing of the present workstation modification revealed that, the weavers of the present study were not in favour of having seat slope (Figure. 3.33) which was similar to the observations made by Goel & Tyagi, 2012, where the weavers reported of having stress in the lower limb, calf muscles and back due to slanting seat. The modified design (both seat and pedal) was found to reduce biomechanical stress, reported by the weavers which would be effective in reducing muscle fatigue and increasing efficiency among the weavers. Thus, both the objectives of the study were fulfilled, where occupational stressors were identified in the existing workstation and necessary design solutions to overcome this were set.

4.6 Salient findings of the thesis

- Change of work practice from domestic (no time bound) to commercial (time bound), has resulted in the development of occupation related problems among weavers of Assam.
- Ergonomic study in existing handloom workstation confirms work practice in inappropriate workstation not designed as per women anthropometric and physiological consideration resulted development

of work related musculoskeletal disorder (WMSDs) among women weavers.

- Specific women anthropometric dimensions must be considered for loom development.
- Present study revealed that modification of workstation by development of seat and pedal was found to be effective in increasing efficiency of the weavers by increasing comfort.
- Modification of pedal from existing second class lever to compound lever with cam profile and considering women anthropometric dimension for seat development was found to be highly effective by the users.
- Modification of workstation, retaining traditional method of work practice, reduces training cost and prevents job loss from frustration to familiarize with new technology.
- The new design was highly effective in increasing efficiency; by decreasing muscle load resulting increased time for muscle fatigue as a result production time could be increased.

Chapter 5

Conclusion

Chapter 5

5.1 Weaving: culture of Assam

Assam is a proud owner of more than 13.00 lakh handlooms out of a total 28.00 lakhs in the country. Inspite of cultural connection of weaving with the state, handloom industry has not flourished in commercial domain to the required extent. At present, understanding rich artistic skill of the weavers of Assam, Government has taken different initiatives for commercializing the industry through financial assistance and implementation of various developmental and welfare schemes. Apart from this, upper hand position of handloom industry in this state is due to lack of organized industries and power crisis (106 Industry, trade and mining – planning, n.d). Powerlooms are in dormant state (Assam Powerloom Development Corporation Limited, n.d) which gives additional benefits to handloom sector of Assam unlike other states like Gujarat, Mumbai, Andhra Pradesh and many more. This result, rapid transformation of the handloom industry towards commercialization. Transformation of work practice has taken place, but workstation remains same. Commercial production on age-old loom added workstation related health problems among weavers of Assam.

5.2 Poor production of raw materials and its effect on commercial weavers

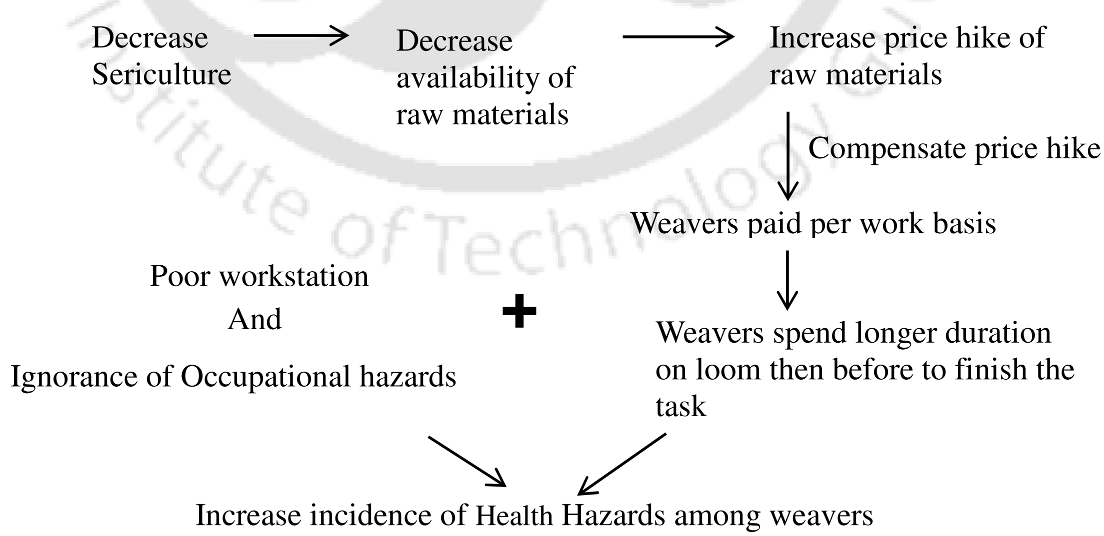


Figure. 5.1. Influence of price hike of raw materials on health hazards

Sericulture is steadily declining in Assam, owing to climatic changes and air pollutions from pesticides of surrounding tea gardens resulting decline in mulberry leaf production. This allows only two cocoon crops per annum, which increases the cost of raw silk. Price hike of raw material due to poor availability, directly influence production on handloom industry. To compensate with economic rise, weavers are paid per work basis, this results them to spend longer hours in loom in order to finish the task in single spell.

5.3 Present research findings

The present research findings showed high rate of musculoskeletal pain among women weavers. Root causes of ergonomic risk factors for muscular pain and discomfort among weavers was, work demand and poor workstations design. Harmful effect of awkward posture, repetitiveness and long duration of weaving cannot be altered as posture was found to be task defined, administrative control over repetition and duration of work would slow down production rate. Force was found to be the only risk factor, whose reduction was found to be optimum solution to reduce harmful effect of commercial weaving.

Force was found to be involved in 3 primary motions of weaving; these were picking, beating and shedding. Technological interventions have already been carried out on two primary motions these are, fly-shuttle for picking, and crank mechanism for beating. Fruitful outcomes of these two interventions has started disseminating in different weaving pockets of Assam involved with commercial production, but technological support on 1st primary motion of weaving that is shedding has not been documented so far.

Structure of domestic and commercial four pillar frame loom was found to be identical except Jacquard, which converts domestic loom to commercial loom. To form motifs, previously weavers maintained constant neck flexion in order to pass weft yarn in between the warp threads based on the pattern. Now, design is formed by Jacquard with the help of design cards through which harness yarn pass and control over warp threads giving rise to computer aided design (CAD). Jacquard has lowered incidence of neck pain, on the other hand, increased tension on warp yarn against which pedal operation is executed. During domestic weaving, weavers only work against tension force of lesser numbers of heald yarns, while for commercial production on Jacquard loom weavers had to work against tension of both heald and harness yarn along with design cards. This increased incidence of leg pain which aggravates with high repetition and longer duration of loom usage. Highly repetitive forceful task leads to soft tissue injury and micro wear and tear of joints resulting leg pain. Introduction of Jacquard along with improper seat was another cause of leg pain and back pain. Poor seat causes development of pressure on lower leg and static loading on back muscle.

Importance of Jacquard for increasing commercial production cannot be ignored. Understanding the importance, pedal was redesigned so that it could be operated with lesser force. It was also noted that pedal operation was highly dependent with seat. Redesigned pedal would not be effective unless simultaneous seat modification was considered. Participatory method was used for both seat and pedal modification.

From usability test, it could be concluded that, the modified plank was found to be comfortable in reducing pressure at the posterior thigh muscle, decreasing numbness and tingling of the lower leg. Adjustable seat height and backrest was appreciated by the weavers and they reported it to be comfortable for easy pedal operation and useful during intermittent rest. For evaluating the modified pedal both subjective and objective evaluation was carried out to find the efficiency of the modified design. The modified pedal, following compound leverage principle, was found to be highly effective in reducing force determined by both semi quantitative evaluations by weights and by sEMG method. Mechanical Advantage (MA) of the modified pedal was found to be increased by 12 times but the obtained result was without considering frictional loss. It was found that both subjective and objective measurement of seat and pedal redesign, indicated that the modified designs was effective in reducing muscular loading and thus would be effective in reducing muscle pain.

5.4 Limitations of the study

- Comparative study of force was carried out on simulated loom (in the laboratory) which is a four pillar frame loom without jacquard, on existing bamboo pedal and with modified pedal. Effective force reduction was found against heald yarn. As a result, it is assumed that if the modified pedal is effective in reducing force, against heald yarn responsible for width of the cloth, it will also be effective in reducing force against cumulative effect of heald yarn and harness yarn of Jacquard.

- ❖ New ergonomically designed seat and pedal was found to be applicable and acceptable by the handloom weavers. However, further field trials are needed to test efficiency under real conditions for mass production.

- ❖ Rate of production in real time situation with the modified design need to be tested.

- ❖ Non work related social factors for MSDs was not been carried out in the present study.

5.5 Scope for future research works

1. With introduction of flying shuttle, weaving time has reduced. Previously if wider cloth was required to be weaved then two people were involved in picking operation. Now, with a flick of the wrist, one cord is pulled and the shuttle is propelled through the shed to the other end with considerable force, speed and efficiency. Gradual aging of the loom increases roughness of the race which requires more force for shuttle movement. Ergonomic design intervention on picking operation needs to be studied.

2. A detailed ergonomic study was required on horizontal frame loom by incorporating all the technological intervention of loom research to find out an idle loom for commercial production.

3. Environmental factors and workplace issues for commercial production needs to be studied.

5.6 Contribution of the research findings to the handloom industry

Handloom clothes are not products of technical excellence, but are an integral part of the culture and heritage of the country and the state. However, saving handloom industry will be helpful in saving the culture of the state and of the country as a whole. Though various attempts have been taken for design development of the handloom products and its marketing; occupational wellbeing of the weavers always remains unnoticed and unattended.

There are two types of frame looms in India, Fly-shuttle frame loom and Fly-shuttle pit loom. In some places, the pedals are made of wooden rectangular blocks and in some parts it is made of bamboos. In both the cases pedalling operation are almost identical, where pedals are hinged at the rear end of the loom frame and operated by seating on the plank in the front of the frame. In both the situations, mode of pedalling follows second class lever principle.

The modified pedal in the present study is made of compound lever, where both lever arms follow first class lever principle with an additional cam profile which increases the mechanical advantage resulting drastic reduction of pedalling force. Achievement over reduction of pedalling force by the new pedal design will be beneficial enormously not only for the handloom weavers of Assam but weavers all over the country as well.

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Appendices

Appendix- A

Questionnaire used for field study

Part I

Personal details

1. Name: 2. Age:
3. Height: 4. Weight:
5. Marital status (M/S): 6. Income of the family:
7. Type of family (Joint/nuclear/extended):
8. Number of family members:
9. Medical history of any major operation within last six months:

Organizational information

10. Unorganized/Organized: 11. Salary:
12. Shift duration: 13. Duration of break:
14. Years of joining in the present job?:
15. Did you discontinue your job in between these years? Yes/No:
16. Reasons for job discontinuation:
17. How many days in a week do you work?
18. Do you undertake commercial production or restrain only towards domestic weaving?
19. Are you a part-time or full time commercial weaver?
20. What type of product do you weave?
    Meghla chadar, Gamocha, Assamese silk, Bedcover etc
21. Which component of weaving task do you perform the most? Spinning, winding, twisting, warping, threading the healds,, threading the reed, setting the warp on the loom.
22. Hours of performing the activity specified above?:
23. Do you feel tired while performing the most performed activity?:
24. Involvement of the participants in the various activities

	Extent of involvement		
Activities	**Daily**	**Sometimes**	**Rarely**
Spinning			
Winding			
Twisting			
Warping			
Threading the healds			
Threading the reed			
Setting the warp			
Preparing the loom for weaving			
Weaving			

Part II

25. While performing weaving activity do you have trouble with pains in different parts of the body? (Yes/No)
26. If you have pain, mention the regions from body map.
27. How often do you feel pain?

Pain in Body part	Always	Sometimes	Never
Neck Back Shoulder Hand Wrist Thigh Knee Ankle Foot			

28. How severe is the pain?

Pain in Body part	Acute	Less acute	Negligible
Neck Back Upper Limb Lower Limb			

29. Rating of discomfort of different body regions while performing weaving task.

Weaving sub-task	Body region	Rating
Picking Beating Inspection of thread breakage Pedalling		

30. Questionnaire to analyse pain for specific body parts

a. <u>Low back trouble</u>

Do you have low back pain? (Yes/No):

Does that pain extend to one or both the legs?:

Have you ever visited doctor for low back pain?:

What is the total length of time that you had low back trouble during the last 12 months?

- 0 days
- 1-7 days
- 8-30 days
- More than 30 days but not every day
- Every day

Have that low back trouble caused you to reduce your activity during the last 12 months?

What is the total length of time that low back trouble has prevented you from doing your normal work during the last 12 months?

- 0 days
- 1-7 days
- 8-30 days
- More than 30 days

Have you had low back trouble at any time during the last 7 days? (Yes/No):

b. Neck Trouble

Have you ever had neck pain (ache, pains, numbness, discomfort)? (Yes/No)

How bad was the pain during the worst episode? (Mild/Severe/very severe)

Have you ever been absent from work because of neck pain?

What is the total length of time that you have had neck trouble during the last 12 months?

- 0 days
- 1-7 days
- 8-30 days
- More than 30 days but not every day
- Every day

Has neck trouble caused you to reduce your activity during the last 12 months?

What is the total length of time that neck trouble has prevented you from doing your normal work during last 12 months?

- 0 days
- 1-7 days
- 8-30 days
- More than 30 days

Have you ever visited doctor for neck pain?

Shoulder pain

Have you ever had shoulder pain (ache, pains, numbness, discomfort)? (Yes/No)

How bad was the pain during the worst episode? (Mild/Severe/very severe)

Have you ever been absent from work because of shoulder pain?

What is the total length of time that you have had shoulder trouble during the last 12 months?

- 0 days
- 1-7 days
- 8-30 days
- More than 30 days but not every day
- Every day

Has shoulder trouble caused you to reduce your activity during the last 12 months?

What is the total length of time that shoulder trouble has prevented you from doing your normal work during last 12 months?

- 0 days

- 1-7 days
- 8-30 days
- More than 30 days

Have you ever visited doctor for shoulder pain?

<u>Leg Pain</u>

Have you ever had leg pain (ache, pains, numbness, discomfort)? (Yes/No)
How bad was the pain during the worst episode? (Mild/Severe/very severe)
Have you ever been absent from work because of leg pain?
What is the total length of time that you have had leg trouble during the last 12 months?

- 0 days
- 1-7 days
- 8-30 days
- More than 30 days but not every day
- Every day

Has leg trouble caused you to reduce your activity during the last 12 months?
What is the total length of time that leg trouble has prevented you from doing your normal work during last 12 months?

- 0 days
- 1-7 days
- 8-30 days
- More than 30 days

Have you ever visited doctor for leg pain?:
Do you feel pain in your feet after pedalling?:
31. Do you feel exhausted after each hour of weaving activity?

Appendix- B

Checklist used for workstation screening

Quick Exposure Check (QEC)

QEC has been designed to:

- assess the changes in exposure to musculoskeletal risk factors of the back, shoulders and arms, hands and wrists, and neck before and after an ergonomic intervention
- involve the practitioner (i.e. the observer) who conducts the assessment, and the worker who has direct experience of the task
- indicate change in exposure scores following an intervention

The QEC Guide gives more detailed information about each question and the background to QEC.

Worker's name: ____________________

Worker's job title: ____________________

Task: ____________________

Assessment conducted by: ____________________

Date: __________ Time: __________

Action(s) required: ____________________

____

____

For more information on the Quick Exposure Check contact:
The Robens Centre for Health Ergonomics
European Institute of Health and Medical Sciences
University of Surrey, Guildford GU2 7TE
Telephone 01483 689 213
www.surrey.ac.uk/robens/erg

Robens UniS

Worker's name ______________________ Date ______________

Observer's Assessment

Back

A When performing the task, is the back
(select worse case situation)

- A1 Almost neutral?
- A2 Moderately flexed or twisted or side bent?
- A3 Excessively flexed or twisted or side bent?

B Select <u>ONLY ONE</u> of the two following task options:

EITHER

For seated or standing stationary tasks. Does the back remain in a <u>static</u> position most of the time?

- B1 No
- B2 Yes

OR

For lifting, pushing/pulling and carrying tasks (i.e. moving a load). Is the <u>movement</u> of the back

- B3 Infrequent (around 3 times per minute or less)?
- B4 Frequent (around 8 times per minute)?
- B5 Very frequent (around 12 times per minute or more)?

Shoulder/Arm

C When the task is performed, are the hands
(select worse case situation)

- C1 At or below waist height?
- C2 At about chest height?
- C3 At or above shoulder height?

D Is the shoulder/arm movement

- D1 Infrequent (some intermittent movement)?
- D2 Frequent (regular movement with some pauses)?
- D3 Very frequent (almost continuous movement)?

Wrist/Hand

E Is the task performed with
(select worse case situation)

- E1 An almost straight wrist?
- E2 A deviated or bent wrist?

F Are similar motion patterns repeated

- F1 10 times per minute or less?
- F2 11 to 20 times per minute?
- F3 More than 20 times per minute?

Neck

G When performing the task, is the head/neck bent or twisted?

- G1 No
- G2 Yes, occasionally
- G3 Yes, continuously

Worker's Assessment

Workers

H Is the maximum weight handled MANUALLY BY YOU in this task?

- H1 Light (5 kg or less)
- H2 Moderate (6 to 10 kg)
- H3 Heavy (11 to 20kg)
- H4 Very heavy (more than 20 kg)

J On average, how much time do you spend per day on this task?

- J1 Less than 2 hours
- J2 2 to 4 hours
- J3 More than 4 hours

K When performing this task, is the maximum force level exerted by one hand?

- K1 Low (e.g. less than 1 kg)
- K2 Medium (e.g. 1 to 4 kg)
- K3 High (e.g. more than 4 kg)

L Is the visual demand of this task

- L1 Low (almost no need to view fine details)?
- •L2 High (need to view some fine details)?

• *<u>If High, please give details in the box below</u>*

M At work do you drive a vehicle for

- M1 Less than one hour per day or Never?
- M2 Between 1 and 4 hours per day?
- M3 More than 4 hours per day?

N At work do you use vibrating tools for

- N1 Less than one hour per day or Never?
- N2 Between 1 and 4 hours per day?
- N3 More than 4 hours per day?

P Do you have difficulty keeping up with this work?

- P1 Never
- P2 Sometimes
- •P3 Often

• *<u>If Often, please give details in the box below</u>*

Q In general, how do you find this job

- Q1 Not at all stressful?
- Q2 Mildly stressful?
- •Q3 Moderately stressful?
- •Q4 Very stressful?

• *<u>If Moderately or Very, please give details in the box below</u>*

• *Additional details for L, P and Q if appropriate*

• L

• P

• Q

Exposure Scores

Worker's name ______________________ Date ____________

Back

Back Posture (A) & Weight (H)

	A1	A2	A3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 1 ☐

Back Posture (A) & Duration (J)

	A1	A2	A3
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 2 ☐

Duration (J) & Weight (H)

	J1	J2	J3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 3 ☐

Now do **ONLY** 4 if static
OR 5 and 6 if manual handling

Static Posture (B) & Duration (J)

	B1	B2
J1	2	4
J2	4	6
J3	6	8

Score 4 ☐

Frequency (B) & Weight (H)

	B3	B4	B5
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 5 ☐

Frequency (B) & Duration (J)

	B3	B4	B5
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 6 ☐

Total score for Back
Sum of scores 1 to 4 **OR**
Scores 1 to 3 plus 5 and 6 ______

Shoulder/Arm

Height (C) & Weight (H)

	C1	C2	C3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 1 ☐

Height (C) & Duration (J)

	C1	C2	C3
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 2 ☐

Duration (J) & Weight (H)

	J1	J2	J3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 3 ☐

Frequency (D) & Weight (H)

	D1	D2	D3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 4 ☐

Frequency (D) & Duration (J)

	D1	D2	D3
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 5 ☐

Total score for Shoulder/Arm
Sum of Scores 1 to 5 ______

Wrist/Hand

Repeated Motion (F) & Force (K)

	F1	F2	F3
K1	2	4	6
K2	4	6	8
K3	6	8	10

Score 1 ☐

Repeated Motion (F) & Duration (J)

	F1	F2	F3
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 2 ☐

Duration (J) & Force (K)

	J1	J2	J3
K1	2	4	6
K2	4	6	8
K3	6	8	10

Score 3 ☐

Wrist Posture (E) & Force (K)

	E1	E2
K1	2	4
K2	4	6
K3	6	8

Score 4 ☐

Wrist Posture (E) & Duration (J)

	E1	E2
J1	2	4
J2	4	6
J3	6	8

Score 5 ☐

Total score for Wrist/Hand
Sum of Scores 1 to 5 ______

Neck

Neck Posture (G) & Duration (J)

	G1	G2	G3
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 1 ☐

Visual Demand (L) & Duration (J)

	L1	L2
J1	2	4
J2	4	6
J3	6	8

Score 2 ☐

Total score for Neck
Sum of Scores 1 to 2 ______

Driving

M1	M2	M3
1	4	9

Total for Driving ______

Vibration

N1	N2	N3
1	4	9

Total for Vibration ______

Work pace

P1	P2	P3
1	4	9

Total for Work pace ______

Stress

Q1	Q2	Q3	Q4
1	4	9	16

Total for Stress ______

Appendix- C

OCRA checklist used for workstation screening

OCRA CHECKLIST

A shortened procedure for the identification of upper limb overload in repetitive tasks

COMPILED BY/I
DAY
DENOMINATION OF THE WORKPLACE

BRIEF DESCRIPTION OF THE TASK

how many work places are identical or very similar
how many shifts are present in a day
how many workers work in these workplaces during a day and considering all the identical workplaces

DESCRIPTION of SHIFT CONTENTS		MINUTES
SHIFT DURATION	official	
	real	
OFFICIAL PAUSES	contractual	
REAL BREAKS	real	
LUNCH BREAK	official	
	real	
NON REPETITIVE TASKS (eg: cleaning, supplies, etc)	official	
	real	
NET DURATION OF REPETITIVE TASK/S		
NO OF UNIT (OR CYCLE)	planned	
	real	
NET CYCLE TIME (secs.)		
OBSERVED CYCLE TIME		

MULTIPLIERS FOR THE TOTAL NET DURATION OF REPETITIVE TASK/TASKS IN THE SHIFT					
minutes	duration multiplier	minutes	duration multiplier	minutes	duration multiplier
60-120	0,5	241-300	0,85	**421-480**	**1**
121-180	0,65	301-360	0,925	sup 480	1,5
181-240	0,75	361-420	0,95		

DURATION MULTIPLIER

Type of work interruptions *(distribution of breaks or other visual control tasks).*

Choose one answer. It is possible to choose intermediate values.

0	There is an interruption of at least 8 minutes every hour in the repetitive work (also count the lunch break)
1	There are 2 interruptions in the morning and 2 in the afternoon (plus the lunch break), lasting at least 8 – 10 minutes on the 7 – 8 hour shift, or at least 4 interruptions per shift (plus the lunch break), or four 8 – 10 minute interruptions in the 6 hour shift
3	There are 2 breaks, lasting at least 8 – 10 minutes each in the 6-hour shift (without lunch break), or 3 breaks, plus the lunch break in a 7 – 8 hour shift
4	There are 2 breaks, plus the lunch break, lasting at least 8 – 10 minutes each over a 7 – 8 hour shift (or 3 breaks without the lunch break, or 1 break of at least 8 – 10 minutes over a 6-hour shift
6	There is a single break, lasting at least 10 minutes, in a 7-hour shift without lunch break, or, in a 8-hour shift, there is only a lunch break (the lunch break is not counted in the working hours)
10	There are no real breaks except for a few minutes (less than 5) in a 7 to 8-hour shift

RECOVERY SCORE

Arm activity and frequency of actions

☐ RIGHT ☐ LEFT ☐ BOTH

	DINAMIC ACTIONS
0	Arm movements are slow and frequent short interruptions are possible (20 actions per minute)
1	Arm movements are not too fast, theyare constant and regular. Short interruptions are possible (30 actions per minute)
3	Arm movements are quite fast and regular, only occasional and irregular short pauses are possible (about 40 actions per minute
4	Arm movements are fast. Only occasional and irregular short pauses are possible (about 40 actions per minute)
6	Arm movements are fast. Only occasional and irregular short pauses are possible (about 50 actions per minute)
8	Arm movements are very fast. The lack of interruptions makes it difficult to hold the pace, which is about 60 actions per minute
10	Very high frequencies (70 actions per minute or more). Absolutely no interruptions are possible
	STATIC ACTIONS
2,5	an object is held for at least 5 consecutive seconds secs., incurring one or more static actions for 2/3 of the cycle (or observation) time
4,5	an object is held for at least 5 consecutive seconds secs., incurring one or more static actions for 3/3 of the cycle (or observation) time .

FREQUENCY SCORE

RIGHT	LEFT

Choose one answer for each upper limbs. It is possible to use intermediate scores. If both static and dynamic actions are present: CONSIDER both static and dynamic actions •As most representative of the task CHOOSE the one with the highest risk value.

Presence of working activities involving the repeated use of force in the hands/arms

More than one answer can be ticked: add up the partial scores obtained. If necessary, choose intermediate scores, and then add them together.

☐ RIGHT ☐ LEFT ☐ BOTH

The working activity requires the use of almost maximal force (score 8 or more on the Borg scale) for: When:	6	2 seconds every 10 min
	12	1 % of the time
	24	5 %of the time
	32	over 10% of the time
The working activity requires the use of intense force (score 5-6-7 on the Borg scale) force for When:	4	2 seconds every 10 min
	8	1 % of the time
	16	5 %of the time
	24	over 10% of the time
The working activity requires the use of moderate force (score 3-4 on the Borg scale) force for: When:	2	1/3 of the time
	4	About half the time
	6	Over half the time
	8	Nearly all the time

FORCE SCORE

RIGHT	LEFT

Presence of additional factors occupying over half the time

(choose only one answer per group of questions)

☐ RIGHT ☐ LEFT ☐ BOTH

	PHYSICAL
2	Gloves inadequate to the task are used for over half the time
2	Vibrating tools are used for over half the time
2	The employed tools cause skin compressions
2	The task implies repeated impacts by the hand (the hand is used as a tool)
2	Cold temperature
2	Other additional factors are present :specify
3	More then 1 additional factors are present, and they occupy the whole of the time
	ORGANISATIONAL
1	Working pace is set by the machine, but there are "buffers" by which the working pace may either be slowed down or accelerated.
2	Working pace is completely determined by the machine.

ADDITIONAL SCORE

RIGHT	LEFT

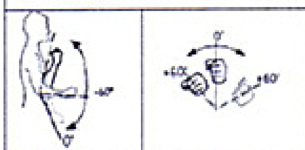
Presence of awkward posture and movement and/or stereotypy ☐ RIGHT ☐ LEFT ☐ BOTH

A. ARMS

1	The arm are not leaning on the workbench but are a little uplifted for half (or more) of the time

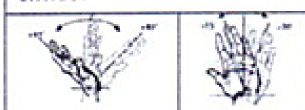
The arms are kept nearly at shoulder height, without support	**2**	for about 10% of the time
	6	for about 1/3 of the time
	12	for about 1/2 of the time
	24	nearly all the time

B. ELBOW



The elbow executes wide movements (wide flexion-extension or prono-supination) or sudden movements (jerking movements, striking movements)	**2**	for about 1/3 of the time
	4	for over half the time
	8	nearly all the time

C. WRIST



The wrist must bend in an extreme position, or must keep awkward postures (such as wide flexions or extensions, or wide lateral deviations)	**2**	for about 1/3 of the time
	4	for over half the time
	8	nearly all the time

D. HAND

Grip objects, parts or tools with fingertips with constricted fingers (pinch) or with a nearly open hand (palmar grip) or keeping fingers hooked	**2**	for about 1/3 of the time
	4	for over half the time
	8	nearly all the time

E. lack of variation or stereotypy

1,5	Perfoms working gestures of the same type involving shoulders and/or elbow and/or wrist and/or fingers for 51-80% of time (or cycle time between 8 and 15 seconds, full of manual actions
3	Perfoms working gestures of the same type involving shoulders and/or elbow and/or wrist and/or fingers for 81-100% of time (or cycle time less than 8 seconds, full of manual actions

Final awkward postures and movements score

Use the highest value obtained among the four groups of questions (A, B, C, D) only once, and eventually add to that of the last question E.

POSTURE SCORE

RIGHT LEFT

OCRA CHECKLIST FINAL SCORE

RIGHT LEFT

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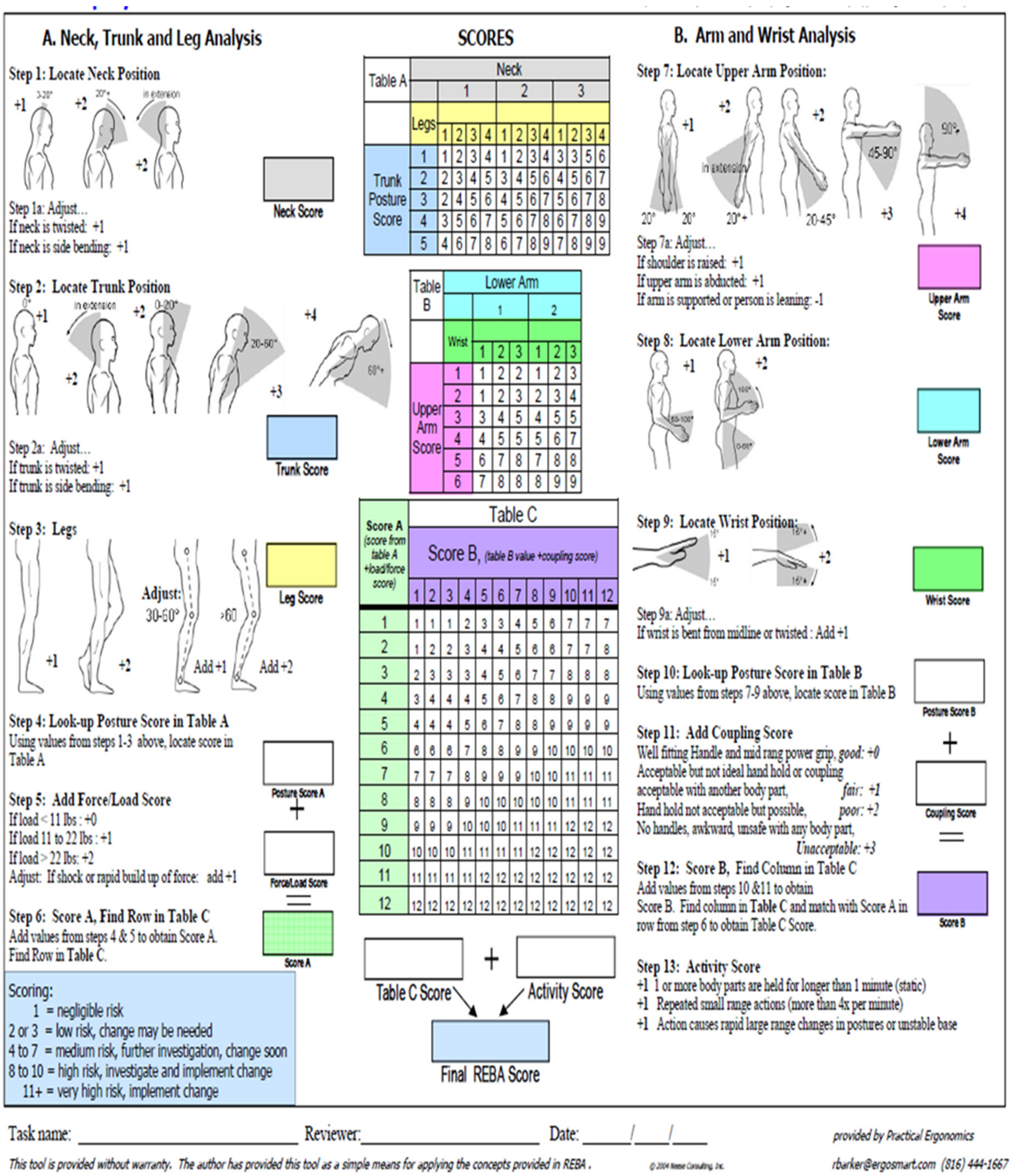
Appendix- D

REBA Employee Assessment Worksheet used for posture evaluation



A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position

+1 (0-20°) +2 (20°+) +2 (in extension)

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

Neck Score

Step 2: Locate Trunk Position

+1 (0°) +2 (in extension) +2 (0-20°) +3 (20-60°) +4 (60°+)

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

Trunk Score

Step 3: Legs

+1 +2 Adjust: 30-60° Add +1; >60 Add +2

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				Neck 2				Neck 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			Lower Arm 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

Table C

Score A (score from table A +load/force score)	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:

+1 (20° 20°) +2 (in extension, 20°+) +2 (20-45°) +3 (45-90°) +4 (90°+)

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:

+1 (60-100°) +2 (100°+, 0-60°)

Lower Arm Score

Step 9: Locate Wrist Position:

+1 (15°) +2 (15°+)

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

Wrist Score

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: ____/____/____

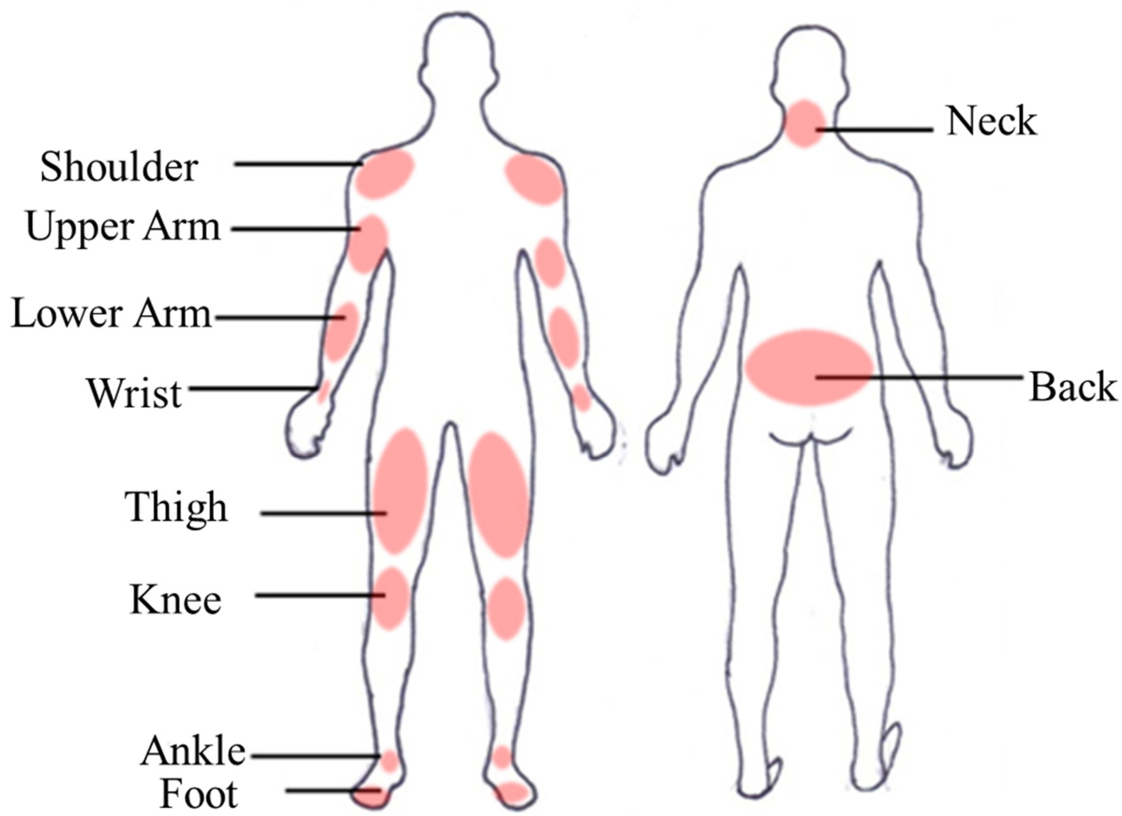
provided by Practical Ergonomics

This tool is provided without warranty. The author has provided this tool as a simple means for applying the concepts provided in REBA.

rbarker@ergosmart.com (816) 444-1667

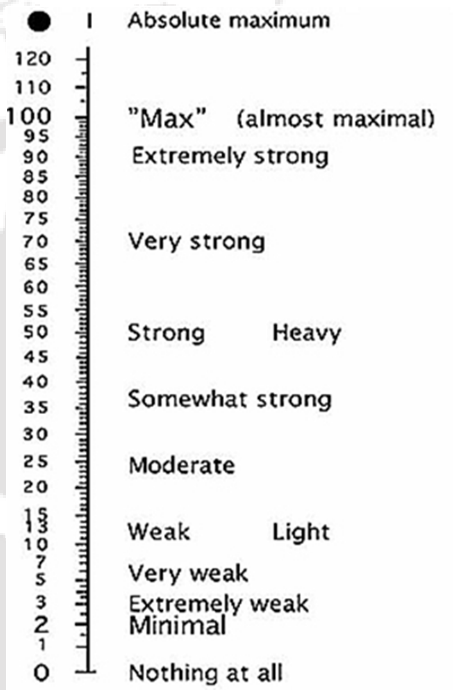
Appendix-E

Body map used to find out areas having MSDs



Appendix-F

Borg's CR 100 Perceived Exertion Rating scale was followed for subjective evaluation of pedal design



Appendix-G

List of Publications from the present thesis work

National publications

Conference proceeding Abstracts published, full papers communicated)

Sangeeta Pandit, Nandita Bhattacharyya and Debkumar Chakrabarti. An ergonomic study on women weavers performance: Design and Occupational assessment in the handloom industries in Assam; Indian Science Congress, Chennai, January 2011. Pg no.211.

Nandita Bhattacharyya, **Sangeeta Pand**it and Debkumar Chakrabarti. Work related upper limb disorders among the women workers engaged in fruit processing industries of Assam and design development scope, Indian Science Congress, Chennai, January 2011. Pg no.140.

Sangeeta Pandit and Debkumar Chakrabarti; Ergonomic Design intervention reducing physiological problems among women weavers of NE India, Indian Science Congress, Bhubanesware, January 2012. Pg176

Sangeeta Pandit, Debkumar Chakrabarti; Assessment of Occupational Workload among Women Weavers in Handloom Industries of Assam, 100th session of Indian Science Congress, Kolkata, January 2013 pg 181

International publications

Conference proceeding full papers (peer reviewed)

Sangeeta Pandit, Debkumar Chakrabarti: An ergonomic study of working posture among women weavers involved in handloom industries of Assam. Proc. HWWE 2011, International Conference on Ergonomics and Human Factors, Chennai, India, December 2011

Sangeeta Pandit, Debkumar Chakrabarti: Effect of Sitting postures on Lung capacity among women weavers involved in traditional handloom industries of Assam. Proc. ICMSP 100, International conference on Molecules to Systems Physiology: 100 Years Journey, Kolkata, India, September 2011

T. Ravi, **Sangeeta Pandit**, Debkumar Chakrabarti: User's Experience and Functional issues for Indian Railway Coach Interior: Proc. HWWE 2011, International Conference on Ergonomics and Human Factors, Chennai, December 2011

Sangeeta Pandit and Debkumar Chakrabarti. Occupational Load Assessment of Sitting Posture of Women Handloom Weavers of Assam Through Lung Capacity and Expiratory Flow: Proc. International Conference on Humanizing Work and Work Environment, Uttarakhand, India, December 2012

Sangeeta Pandit and Debkumar Chakrabarti. Ergonomic approach of seat design in the handloom industry of Assam. Proceeding HWWE, International conference on ergonomics and Human Factors, pp 133-145, Midnapur, India, December 2013.

Sangeeta Pandit,. and Debkumar Chakrabarti. Investigation of work-related muscular pain among women handloom weavers of Assam a state of North-East India using REBA method. In Proceedings of 1st Asian Conference of Ergonomics in Design. Jeju, South Korea, May 2014.

Accepted paper (peer reviewed)

Sangeeta Pandit and Debkumar Chakrabarti (2015). Ergonomic risk of Handloom weavers of Assam with introduction of Jacquard on four pillar frame loom. ICORD 2015. Indian Institute of Science Bangalore, India

Journal

Pandit S., Kumar P, Chakrabarti D: Ergonomic problems prevalent in handloom units of North East India: International Journal of Scientific and Research Publications, Volume 3, Issue 1, January 2013