4. Methodology

4.1. Selection of Site and Participants:

The study of the present research was conducted on carpenters which were selected from different districts of West Bengal state in India. All selected subjects were male because the carpentry tasks were carried out by male workers only. The study was carried out on different carpenter's workshop and furniture shop having amenities for furniture making and repairing. In this research study, 330 male carpenters primarily selected. Some of the carpenters (41) were excluded (10.54%) because they were not suitable by the inclusion criteria. Among the remaining 289 relevant candidates about 6.95% of them didn't turnup for the ongoing study. Further, seven of them were excluded because some of the data of those subjects were incomplete. Hence, 91.54% , i.e. 256, of the participating carpenters were found to be eligible.

Prior to the collection of data, the procedure and purpose were explained to carpenters in their mother tongue, i.e., Bengali for their better understanding and cooperation. A signed written note were obtained from the willing carpenters for this investigation. Ethical approval (No, IEC/6-2/C-2/16, dated 19.04.2016) was given by Institutional Ethics Committee for carrying out the investigation. Different parameters relevant to this investigation were evaluated. In some of the studies like, designing the handtool (chisel) and work station, the variables were measured on subsamples among the total selected subjects.

4.1.1. Inclusion Criteria: The eligibility criterion were- i) atleast one year experience carpentry task ii) the age range of eighteen to sixty years iii) carpenters supposed to be free from any acute illness, physical deformity and having heathy physique.

4.1.2. Exclusion Criteria: The exclusion criterion for the investigation includes i) participants having medical history of chronic hypertension, cardiac problems, diabetic, damage in musculoskeletal system due to accidents or having severe orthopaedics issues ii) the age range of carpenter below or above 18 and 60 years respectively.

4.2. Study of Socioeconomic Status:

The modified Kuppuswami scale, as recommended by Raj *et.al.* (2015), the socioeconomic feautures of the workmen was evaluated. Questionaire technique was an important tool to judge the educational level of the participating workmen. The participating carpenters were classified as illiterate, educated till primary, upper primary , secondary level etc. For grouping of the subjects of the annual family income of the workmen was also taken into account. The socioeconomic status of the workers was represented by the scoring system following the modified Kuppuswami scale , as pointed out above. The cumulative scores obtained from education level , occupation and per capita annual income was used for final score and on the basis of this value the participants were further categorically divided into five classes starting from upper to lower socioeconomic groups. Appendix-I gives the clear picture of socioeconomic features of the workmen based on modified Kuppuswami scale

4.3. Nutritional Assessment by Anthropometric Index:

One of the useful tool for assessment of nutritional status is the anthropometric study. As per WHO, 1986 guidelines the height and weight of the body are the two criterion for accessing nutritional status.

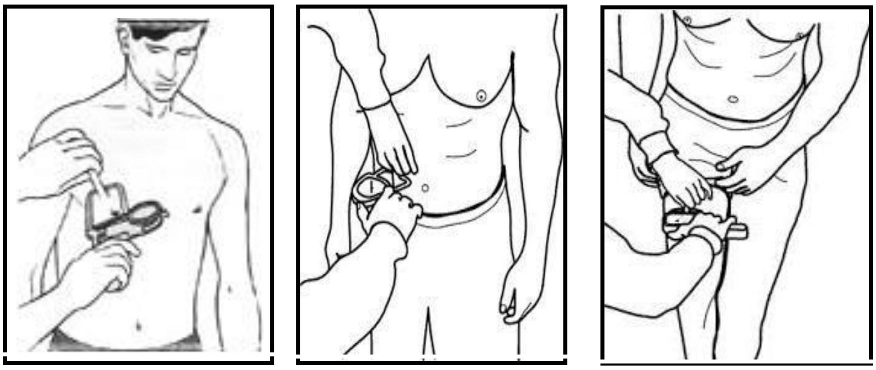
In the present research study the weight of the carpenters were measured by a highly précised weighing machine with a precision of 0.1 kg (Libra Weighing Machine Limited, Thailand) and the stature was measured nearest to 0.1 cm using an anthropometer (The Hindustan Mineral Products Co. Ltd., Kolkata, India). The body height and body weight of the subjects were used to determine the body mass index (BMI) from the following mathematical formula (Park, 2005) :

$$BMI = Weight\ (kg) / Height^2\ (mt.^2)$$

4.4. Evaluation of Body Composition:

By measuring the of skinfold thickness of the carpenters the body compositional parameters were evaluated. Three skinfolds of the body ,viz., chest, abdomen and thigh of male worker were measured. For this measurement a highly calibrated skinfold caliper (Holtain, England) was used. A standardized condition was followed to take the measures of skinfold thickness (Jhonson and Nelson, 1986). The standard anatomic positions for measuring skinfolds of the participants have been mentioned bellow (Fig 4.1):

1. **Chest:** Middle portion between the nipple and the frontal fold of the axilla.
2. **Abdomen:** A perpendicular folding around 1cm to the right side of the umbilicus.
3. **Thigh:** A perpendicular fold on the anterior of the right thigh middle amid the knee and hip and during the measurement was taken the subjects' standing on left foot.



Chest Skindfold Abdomen Skindfold Thigh Skindfold

Fig 4.1: Position for determining the thickness of skinfolds.

After finding out the body skinfold data, by the computing the body density and body fat percentage the entire mass of body fat and lean body mass were computed (Jackson and Pollok, 1978; Siri, 1956). The following steps were employed:

(a) Body density (gm/cc) = 1.10938 – 0.0008276 (sum of chest, abdomen and thigh skin folds in mm) + 0.0000016 (sum of the same three skin folds in mm)^2 – 0.0002574 (age in years)

(b) Percentage of fat = {(4.95 ÷ Body density) – 4.50} * 100

(c) Total weight of fat = (Weight in kg * Percentage of fat) ÷ 100

(d) Lean body weight = Total weight (kg) – Total weight of fat (kg)

4.5. Determination of blood pressure (BP):

The auscultatory method was applied for determination of blood pressure of the carpenters. Mercury type sphygmomanometer and a stethoscope were used for this method (Tesfaye et al., 2007). Prior to measuring of the resting systolic and diastolic BP ,the carpenters was given a 15 minute rest in a sedentary position and for a second time rest of at least 10 minutes was taken by the workers again after the first reading. For analysis, mean value of three measurements was used. According to the guidelines of the US Seventh Joint National Committee on Detection, Evaluation, and Treatment of Hypertension (JNC VII) (Chobanian et al., 2003) the carpenters were classified as normotensive, hypotensive and hypertensive, as presented in Table 4.1.

Table 4.1: Cutoff values of systolic (SBP) and Diastolic (DBP) blood pressure for classifying the subjects (Chobanian et al., 2003)

Status according to BP	Cutoff values of SBP and DBP
Normotensive	SBP <120 mm Hg and DBP <80 mm Hg
Hypertensive	SBP ≥140 mmHg and DBP ≥90 mmHg
Hypotensive	SBP ≤ 90 mmHg and DBP ≤ 60 mmHg

4.6. Occupational Health Hazards:

4.6.1. Musculoskeletal Disorder:

Modified Nordic Questionnaire technique (Kuorinka et al., 1987) was apied for determining the musculoskeletal disorders (MSD) of the carpenters while executing different carpentry tasks, viz., chiseling, planning, and sawing. Details of modified Nordic Questionnaire table has been presented in Appendix-II.

4.6.2. Body part discomfort (BPD) Rating:

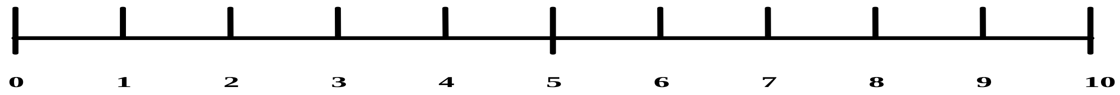
The extent of segmental discomfort or pain was assessed in this research study. To execute this method a 10-point subjective scale was used. This scale contained some points from 0 to 10 representing noticeable discomfort to intolerable discomfort / pain. For no segmental pain '0' point was given in this scale. With successive increasing the segmental pain, the point of this scale was also increased successively. That means '10' point of this scale indicated maximum level of discomfort / pain. The mean value of scores of all segments was taken as the overall discomfort rating of the workers (all scores details regarding all segmental pain scores has been shown in Appendix-III). In Fig 4.2 a modified pain mapping scale of Corlett and Bishop, (1976) has been presented. According to method, human body was divided into 12 segments (Fig.4.3).

The subject was requested put a score of subjective feeling of discomfort/ pain in any segment of the body in the given scale. The grade of discomfort / pain , according to the assigned scores of the participants , was classified into three subcategories (Dutta and Dhara, 2012), as stated below:

i) Grade : Mild pain : scores: 1 to 4

ii) Grade : Moderate pain : scores: >4 to 7

iii) Grade : Severe pain : scores: > 7



The 10 point scale:

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

Fig 4.2: Modified ten point scales to rate the discomfort experienced by the workers

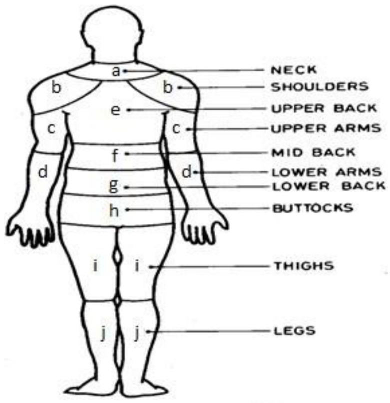


Fig 4.3: Different segments of the body.

4.7. Evaluation of Work-Rest Cycle:

The work-rest pattern of carpenters were evaluated through nonstop noticing their work in addition to interviewing the workers (Wilson and Corlett, 1985). The cyclical process of work and rest of different carpentry tasks was determined by capturing the actual rest and work time. The entire working hours was alienated into work and rest periods. The total rest period was the summation of two types of break - one is prearranged break (mainly food break) and another one is task-associated break. The actual working time was computed by deducting the actual rest time from entire working period.

Video-photographic technique was applied for direct observation method from the beginning to end of the work period. With the help of this method entire task performed in a day was captured in DVD mode and the recorded video was run by a media player (Xing MPEG DVD player, version 3.30) in the computer with a proper time setting. After a thorough and recurrent surveillance, the entire day work period was calculated and the extent of work period along with all rest periods of carpentry tasks were noted.

4.8. Study of Postural Stress:

Throughout the working period the carpenters had to adopt different postural patterns with change of time. Some of the carpenters had to work by stationary muscular contraction and some other carpenters had recurrent vigorous activities during the work. Therefore, the workers had to alter their postural pattern in different stages of their task that may be related to some category of postural strain. Researcher projected some methods for ergonomic evaluation of working posture to quantify the ergonomic risk aspects of those working postures. In this research study, to assess the working posture and to identify the stresses of the workers engaged in different carpentry tasks, some varied methods have been applied. For each method image analysis of carpentry tasks was employed. From the recorded image from the camera (Sony Handycam and Nikon SLR), the particular posture for a given task was captured for the duration of the total work cycle. The dominant postures of the tasks were selected and used analysis.

4.8.1. Study of Postural Pattern:

The postures acquired in different carpentry tasks, viz. chiseling, planning and sawing were assessed by direct observation method with the help of video photographic technique, as stated earlier. The images of performing the tasks, from the commencement to termination, were documented including all prime postures acquired by the carpenters. Suitable precaution had been taken throughout the recurrent observation to diminish errors. The postural pattern was assessed via the Xing MPEG player (Version 3.30) software. The time for adopting each kind of working posture was determined with the help of a timer set in the computer. From this record the total time of adopting a posture for executing a particular carpentry task as well as for the whole working period was computed.

4.8.2. Postural analysis:

Researchers had taken varied approaches for ergonomic evaluation of work posture and enumerated ergonomic threat issues. Different technical procedure have been applied for working posture investigation to distinguish the strain of diverse stages of the study. OVAKO Working Postural Analysis System (OWAS) method was applied for assessing work posture of the carpenters. (Heinsalmi, 1986). Although, the results obtained from OWAS method has a wide assortment of application and poor in details (Hignett and McAtamney, 2000). Thus, the Rapid Entire Body Assessment (REBA) method (Hignett and McAtamney, 2000) and Rapid Upper Limb Assessment (RULA) method (Mc-Atamney and Corlett, 1993) were correspondingly applied for analysis the work posture of the carpenters. Some of the scientist (Pal et al., 2015; Sahu and Sett, 2010; and Mukhopadhyay and Srivastava, 2010) also used several work posture assessment techniques. However, there are some lacunae in each of the methods. Thus to overcome such limitations four methods , viz., OWAS, RULA, REBA and QUC were applied for postural analysis in this study.

4.8.2.1. OWAS:

The OVAKO working postures analysis system (OWAS) was first established in the Finnish steel industry (OVAKO) throughout 1974-1978 (Heinsalmi, 1986). OWAS method diagnose four work postures for the spinal, seven for the inferior extremities, three for the arms and three classes for the load handling or the quantity of power used. Depending on the level of their stimulus on the musculoskeletal system for all type of work postures, this technique categorizes the mixtures of these four groupings. Different body segmental score of this method has been given in Appendix-IV. The grades of the measured perniciousness of postural load amalgamations are convened into four diverse action categories:

- Action category 1: No corrective measures are needed.
- Action category 2: Corrective measures are needed in the near future.
- Action category 3: Corrective measures are needed as soon as possible.
- Action category 4: Corrective measures are needed immediately.

4.8.2.2. RULA:

The methods of RULA (Rapid Upper Limb Assessment) technique was established to deliver a rapid assessment of the load applied on the musculoskeletal system of the trunk, neck and upper limbs due to different working postures, heavy muscular work and the exterior loads exerted (McAtamney and Coriett, 1993). Reliant upon the magnificent score of its coding technique (shown in Appendix-V), four diverse action categories, which indicates the grade of interference essentiality to diminish the threats of injury due to physical load applied on the worker, were diverse action levels recommended:

- Action level 1: Working posture is acceptable.
- Action level 2: Further analysis is needed and changes may be required.
- Action level 3: Investigation and changes are needed quickly.
- Action level 4: Investigation and changes are required as soon as possible.

4.8.2.3. REBA:

Another postural analysis system is REBA (Rapid Entire Body Assessment) which is reactive to musculoskeletal threats in an assortment of tasks, mainly for evaluation of work postures (Hignett and McAtamney, 2000). This postural cataloguing method, which incorporated with upper arms, lower arms, wrist, trunk, neck and legs, was established on body segment drawings. Detailing of scores for different body parts according to this method has been mentioned in Appendix-VI. The result of this method imitates the gradation of outer load or forces applied, activeness of muscle produced by static, dynamic, rapid changing or unsteady postures and the coupling outcome. Apart from OWAS and RULA technique, this method offers five action levels for assessing the corrective actions level:

- Action level 1: Corrective action including further assessment is not needed.
- Action level 2: Corrective action including further assessment may be needed.
- Action level 3: Corrective action including further assessment is required.
- Action level 4: Corrective action with further assessment is as early as possible.
- Action level 5: Corrective action as well as further assessment is needed now.

4.8.2.4. QEC:

One of the most important observational method of postural analysis is Quick Exposure Checklist (QEC) established by Li and Buckle (1998) and enhanced by David et al. (2008). QEC is introduced to find out the grade of experience to ergonomic threats. Evaluation of the back, shoulder/upper arm, wrist/hand and neck, with reverence to posture adoption and frequency of movement were incorporate in this method. Statistics about time duration on job, hand strength level, graphic mandate of the task and complications to withstand with the task along with the stressfulness of the task are also acquired from the worker. The ratings are slanted into scores and added up to immediate scores for individual body segments and additional substances like pace of work, and strain. The worksheet/assessment sheet QEC method comprises of queries that necessity to be responded by the workers. These queries are intended to enumerate the acquaintance of threat for the four central part of the body (back, shoulder /arm, wrist, and neck).

The QEC method questionnaire sheet has been given in Appendix-VII.

4.8.3. Analysis of Center of Gravity:

The segmental method (Page, 1978) was applied for determining of whole body center of gravity (CG) of the carpenters during adopting different work postures. It was evaluated during resting condition (normal erect posture) and also during different working condition. The whole body CG in addition to segmental CG of the workers was estimated and the location of the CG was expressed as the proportion of entire body length. Comparison of the site of the CG in the body was made between the normal erect posture and working postures of the carpenters. For this method the still photographs of resting and working posture of the workers were captured by high precision camera (Nikon) and these photographs were used to determine the CG with the help of a CG analysis software. The software indicated the location of whole body CG. The vertical location of CG was expressed in terms of proportion of body height of the subject (percentage.)

4.8.4. Recording of EMG (Electromyography):

Electromyography (EMG) is a technique which represents the activity of a particular muscle or group of muscles during executing a task. This method is related to the expansion, footage and analysis of myoelectric signals. Myoelectric signals are created through the physiological difference in the circumstances of muscle fiber membranes related to work (Basmajian et al., 1985). Recording of EMG of the muscle of the workers was recorded through BioGraph Infiniti system (Pate-1). EMG recording was made during the activity of the muscle at the time of execution of task in different working postures (Maity et al.,2014). Recording of EMG was also made during normal erect posture which was taken as reference posture.

During execution of the task of carpenters, with frequent using hand tool (chisel), the upper limb muscle which is primarily made up of the fore arm, biceps, triceps and trapezious of the users generated forces or power for executing the job (Rockwood,2007). The surface EMG of the muscle of the upper limb of carpenters was recorded. For recording electromyogram, a commercial device BioGraph Infiniti system (Pate-1), which was used for in this study. A couple of Ag/ AgCl exterior electrodes was placed on the skin along with a 3cm inter-electrode distance. Impedance in skin was a significant issue that could be the reason for error during gaining of data. In view to diminish the impedance the skin was rubbed and cleaned with alcohol prior to the experiment or placement of the electrodes on the skin. Cable and electrodes was protected with adhesive tape to both make contact between the skin layer of muscle and the electrodes and to decrease the movement at the time of work. The arm and shoulder muscles which were selected for the recording of EMG are as follows - fore arm: extensor carpi radialis, and Flexor Carpi Ulnaris; upper arm: biceps and triceps muscle; shoulder: trapezius muscle and back: latissimus dorsi.

The carpenters were requested to operate a hand tool (chisel) without giving any additional load. The EMG was taken in different postures of workers adopted during the operation of hand tool.

4.9. Study of Physiological Stress:

During executing different carpentry tasks some physiological parameters of the carpenters were evaluated. All the parameters which were taken in this study were dicussed below.

4.9.1. Heart Rate:

One of the most important parameters in this study was heart rate of the workers. The method of 30 and 10 beats time recording was applied for resting and working heart rate of the carpenters respectively. Measurement of the resting heart rate of the carpenters were taken with a rest for not less than 20 minutes under sitting position preceding to measurement. During the execution of task the working heart rate of the carpenters was measured for four times and the mean value of the heart rate of the workers taken. During every hour of the work period the working heart rate was measured and a mean working heart rate was determined. The maximum value of heart rate throughout work time was taken as peak heart rate.

4.9.2. Cardiovascular Stress Index (CSI):

In this present study cardiovascular stress of the carpenters were evaluated by means of an index named as Cardiovascular Stress Index (CSI). The CSI was determined by a formula, in this formula both taken measurements of resting and working heart rate of the workers were used. The formula was given below(Chatterjee et al., 2014; Trites et al., 1993).

$$CSI = \frac{100\ (\text{Heart rate during work} - \text{Heart rate during rest})}{\text{Heart rate maximum} - \text{Heart rate at rest}}$$

Where, Heart rate max. = 220 – Age (years).

4.10. Assessment of Pulmonary Functional parameters:

4.10.1. Pulmonary Function tests (PFT):

A portable PC based MICRO-DATO Spirometer (Micro Medical Ltd., England) was used for determining different variables of pulmonary function parameters, viz., FVC, FEV_1, FEF, FEF_{25-75}%, MVV-index and FEV_1/ FVC of the carpenters and also of a group of control subjects (age matched and sedentary men). The measurement was taken in sitting posture. The carpenters were instructed to take breath (inspiration) as much as possible and to breath out (expiration) as quickly as possible. The maximum value of three trials was taken. As drawn in the instruction manual book of the spirometer, spirometer calibration and all analysis procedures were followed.

Plate 4.1: Measurement of pulmonary functional variables by PC based MICRO-DATO Spirometer in carpenter's workshop during work.

The participants were divided those two groups - smokers and non-smokers. This grouping procedure ware performed by interviewing the subjects (Appendix-VIII). During data collection the practice of smoking was noted.

4.10.2. Determination of COPD:

Chronic Obstructive Pulmonary Disease (COPD) of the carpenters was determined from the pulmonary function parameters. The definition of COPD was based on Global Initiative for Chronic Obstructive Lung Disease (GOLD) working group criteria (Bodas and Vij, 2017) of forced expiratory volume in 1 second (FEV1) / forced vital capacity (FVC) less than 70 percent and FEV1 less than 80 percent predicted. The criteria followed for categorization of the severity of COPD were based upon the GOLD spirometric criteria for COPD severity (Table.-2)

To assess the severity of COPD, lung function test value was predicted from the standard prediction equation of normal male subjects. The following equation was used for predicted FEV_1 :

Predicted FEV_1= -0.028 * A+0.047 * H-3.737,

Where, A =Age in years, and H = Height in Centimeter

COPD% = Predicted FEV_1 / FEV_1 *100

The criteria followed for categorization of the severity of COPD were based upon the GOLD spirometric criteria for COPD severity as given in Table 4.2.

Table 4. 2.: **GOLD Spirometric Criteria for COPD Severity**

Stage	Severity	FEV1/FVC	FEV1	Symptoms
I.	Mild COPD	FEV1/FVC < 0.7	FEV1 >/= 80% predicted	At this stage, the patient is probably unaware that lung function is starting to decline
II.	Moderate COPD	FEV1/FVC < 0.7	50% </= FEV1 < 80% predicted	Symptoms during this stage progress, with shortness of breathe developing upon exertion.
III.	Severe COPD	FEV1/FVC < 0.7	30% </= FEV1 < 50% predicted	Shortness of breath becomes worse at this stage and COPD exacerbations are common.
IV.	Very Severe COPD	FEV1/FVC < 0.7	FEV1 < 30% predicted or FEV1 < 50% predicted with chronic respiratory failure	Quality of life at this stage is gravely impaired. COPD exacerbations can be life threatening.

4.11. Ergonomic intervention

Two ergonomic interventions in carpentry tasks were made:

1. Ergonomic assessment and designing of chisel, a frequently used hand tool of the carpenters
2. Optimization of work surface height for the operation of plane in the carpenter's workshop.

Bearing in mind the human factors and ergonomics principles the carpentry tasks were modified. The chisel , which is the most commonly used in carpentry task was assessed and redesigned from ergonomics viewpoints. Secondly, some of the tasks were performed on a working table. Here the work surface for the operation carpenters plane was taken into consideration. The height of work surface was optimized.

4.11.1. Assessment of existing hand tool (chisel) and workstation:

At first different types of existing chisels were gathered and the drawbacks of the design criteria were assessed from the ergonomics point of view. Similarly. The problems of workstation for plane operation was evaluated. Studies were made on different types of existing workstations.

The following parameters were considered during the evaluation of the existing chisel and workstation.

4.11.2. Subjective Evaluation:

Questionnaire method was accounted for determining the subjective evaluation of the existing chisel and workstation. The personal feeling related to comfort/discomfort of the carpenters and the posture related to the work were listed by taking interview of the workers during using chisel. In the same way the existing workstation (work surface height) was evaluated (appendix – IX).

4.11.3. Evaluation of mode of operation:

The mode of operation of the existing chisel was analyzed by video photographic method. From the studies on the existing chisel, the drawbacks of the design of existing chisel were recognized. Similarly, limitations and difficulties of mode of operation in existing height of workstation the same method was followed. The complications was noted after recurrent observations of the operations of the chisel and using workstation and the relative locations of different body parts of workers were also recorded during these studies with the chisel and workstation

4.11.4. Capturing of Anthropometric data:

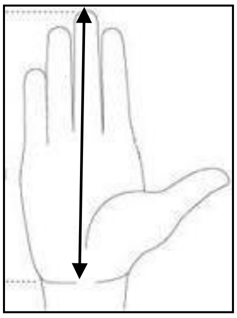
A set of body dimensions, which were associated with the design of the tool and optimizing the height of the workstation, was measured following proper land marks (Ermakova *et al.*, 1985).

The following anthropometric measures were taken:

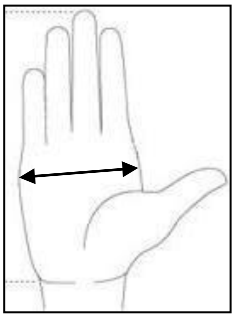
- Hand length: from the tip of the middle finger to starting point of the forearm was measured as hand length.
- Hand breadth: it was measured at the maximum bulge portion of the palm excluding the thumb.
- Maximum hand breadth: it was measured at the maximum bulge portion of the palm including the thumb.
- Hand grip circumference (inner): measured by using the wooden cone.
- Fist girth: it was measured by wrapping the steel tape around the hand during the hand was clogged with the thumb.

  The measurement of the hand dimensions have been explained in Fig 4.4.

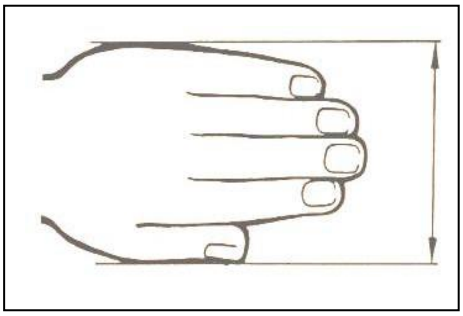
The percentile values (either 5^{th} or 95^{th}) of anthropometric measurements were computed for the application in the design process.



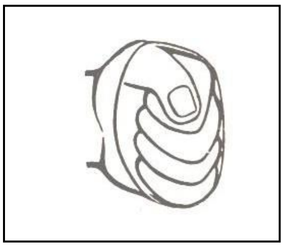
HandLength



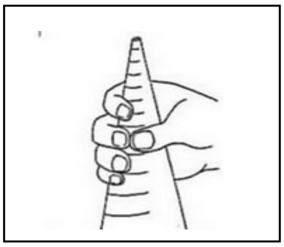
Handbreadth



Max. hand



Fistgirth



Hand Grip circumference

Fig 4.4.: Different hand measurement

4.11.5. Development of Design Concept:

Keeping in mind the limitations and shortcomings of the existing tool and workstation some design concepts were evolved. Concepts were based on the mismatch of between the physical dimensions of the tool / workstation and body dimensions of the users , operation difficulties, biomechanical factors and body posture. The design ideation also included the safety criteria of the workers. Some novel criteria was also assimilated in the new design concepts.

4.11.6. Preparation of prototypes considering the developed concept:

Depending on the design ideas some prototypes models of chisel have been made. On the other hand some protypes of working tables with varied heights were prepared. The advantages and drawbacks of the protypes was assessed by psycho-physical test.

4.11.7. Psychophysical Analysis:

Different design parameters of the chisel and working table were tested to find out the preference level of the users. Psychophysical analysis was a suitable tool for this purpose. There are many tests for psychophysical analysis. For the present study the paired comparison tests , a powerful test , was conducted ((Dhara et al., 2015; Hunns, 1982).

This test was carried out for some of the selected design criteria of prototypes. In this testing procedure, all the prototype models of the proposed product were taken. The testing was made by taking a single pair of prototype model at a time. Throughout the testing procedure one of those prototype models was denoted as fixed or control model and other one was considered as variable prototype model. Every variable prototype models was compared with that fixed or control prototype model after doing a given task with both of them. and the carpenters were requested to work with those two models. The subjects were asked to define their impression on relative easiness or intricacy of using the prototypes and put a score on the basis of an 11-point scale, as presented below. Similarly , other prototypes were compared with the control model. The experiment was continued by taking the second prototype as fixed model and others as variable models and scores were recorded for all the cases. The process was repeated by taking another item as fixed model.

An 11 point subjective scale ranging from -5 (at left hand) to +5 (at the right hand) with zero mark in the middle was used for paired comparison test (Ebe and Griffin, 2001) (Fig 4.5).

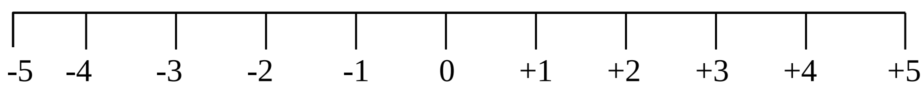


Fig 4.5.: Subjective scale asked for paired comparison test.

The subjective impression of each of the points on the scale was expressed as follows:

+5 : 1^{st} very very much more comfort than the2^{nd}

+4 : 1^{st} very much more comfort than the2^{nd}

+3 : 1^{st} definitely more comfort than the2^{nd}

+2 : 1^{st} moderately more comfort than the2^{nd}

+1 : 1^{st} slightly more comfort than the2^{nd}

0 : 1^{st} same comfort as the2^{nd}

-1 : 1^{st} slightly less comfort than the2^{nd}

-2 : 1^{st} moderately less comfort than the2^{nd}

-3 : 1^{st} definitely less comfort than the2^{nd}

-4 : 1^{st} very much less comfort than the2^{nd}

-5 : 1^{st} very very much less comfort than the2^{nd}

Calculation: The normal worth given by the subjects for each pair of boost was processed. From every one of the mean scores, singular scores for each model/stimulus (say, handle length) was isolated with its individual sign and those were independently added. This total with its separate sign was partitioned by the complete number of times it was thought about. This got esteem was scaled along the emotional 11-point scale, as appeared previously. The overall situation of the figured score (improvements) demonstrated the best and most exceedingly terrible attributes of models picked by the participants. For every attribute of the instruments tests were proceeded as portrayed previously.

4.11.8. Design and fabrication:

As per resultant score of the paired comparison test and anthropometric dimensions of the users, a new chisel was made and the workstation for planning work was modified.

4.11.9. Assessment Of Redesigned Carpenters Chisel And Workstation:

The effectiveness of the modified chisel and workstation was evaluated by the following parameters.

A. **Subjective evaluation:**

The feeling of comfort / discomfort of the carpenters while using redesigned chisel and the workstation was conducted by questionnaire technique. The workers were asked to use both the existing and modified tools and express their views on the modified tool as 'bad' or 'fair', or 'good', or 'very good', in comparison to existing one.

B. **Physiological Response**

- **Heart Rate Study:**

  The working heart rate was measured during working with different modified models of chisel, and the results were compared with that of existing one.

- **Electromyographic study:** The electromyographic study, as discussed earlier (section 4.84.), of the workers was carried out while executing tasks with the modified as well as conventional workstation.

- **Joint angle study:** During the execution of task with different existing and modified models of chisel and workstations, some body joint angles, viz. shoulder, elbow, wrist, hip, knee and ankle was measured. The angles of joints were measured in usual standing posture and in different work postures. The deviations of measured joint angles in working conditions from that of the normal standing posture was computed in all the cases. A Goniometer (Lafette. USA) was used for measuring the body joint angles. Proper placement goniometer at body joints and reading was taken. For some situation, mostly in working condition, photographic technique was used.

  - **Angle of elbow joint:** Angle between upper arm and lower arm.

- **Angle of wrist joint: A**ngle between lower arm and hand.
- **Angle of hip joint: A**ngle between trunk and thigh.
- **Angle of knee joint:** Angle between thigh and lower leg.

- **Productivity Study:**

  The productivity study was made during executing the work with redesigned tool an workstation and the scores were compared to that of conventional one.

  The productivity was determined by measuring the product made in a unit time or time taken to finish a specified work.

4.11.10. Final design:

Depending on the subjective evaluation and other evaluating studies on the redesigned chisel and workstation some corrections and modifications was made, wherever necessary and the design was then be finalized.