TOOL HANDLE DESIGN FOR POWER GRIP

A THESIS SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY
In
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Submitted by

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CERTITIFICATE

This is to certify that the thesis titled, "**TOOL HANDLE DESIGN FOR POWER GRIP**" submitted by Mr. G ROHIT SAI KIRAN and Mr. PRAKASH KUMAR in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Industrial Design at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other university/ institute for award of any Degree or Diploma.

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ABSTRACT

The use of tools is still widely appreciated in industries at various levels. The range of their application varies from a simple task like hammering to a complicated, complex and precision-demanding tasks such as that of surgical scalpels. Hence, it becomes highly essential to design the tool for 'comfort' from the perspective of user. The aim of this study is to design a tool handle for a task involving a simple power grip such as hammer. The focus of this study is mainly confined to identify the right cross-section and profile of the tool handle, based on subjective experimentation of a group of subjects and find the approximate dimension and shape(of both cross-section and profile) which outstands in subject's perception of comfort. In this study, a new criteria for decision making has been employed during a brief subjective analysis to find out the better cross- section shape among the various possible shapes for the handle. The shape of the profile has been reverse engineered from an existing tool handle using a CAD software which was been rated high in market. At various turns during this study, new simplified approaches were used to accomplish certain tasks which can be considered as reasonable approximation to standard methods. The final step is to evaluate the design which has been perceived most comfortable by the subjects, using a subjective analysis through hand-mapping of discomfort.

Keywords: hand tool, power grip, cross-section shape, hand mapping.

NOMENCLATURE

D_{opt}	Optimal diameter for tool handle
D_{grip}	Grip Diameter of the subject
$L_{F,2}$	Length of Middle finger of the subject
L_t	Length of thumb finger of subject
c	Constant for optimal handle diameter (usually 10mm)
$\prod$	Constant of Value 22/7
H.L	Hand Length
H.B	Hand Breadth

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1 INTRODUCTION

Tools have been playing a critical role in simplifying and aiding certain complex and complicated tasks which may lie out of the human domain of capability. The uses of 'tools' range from non-professional use at domestic level to high profile professional use at industrial level. Though the types of tool are many on the horizon of applications, they may be briefly classified on the type of grip they impart. There are 11 standard grips (), out of which the most encountered grip is the 'Power Grip'. The typical examples of power grip in 'hand tool' are hammers, saw, hand wrenches, chisels and that in power tools include neck grinder, angle grinder and battery drills. Design of a tool from the perspective of ergonomics opens various options such as tool handle design, intervention in existing tools or proposing an entirely new design for the whole tool. The aim of this study is to design a tool handle for a power grip which increases the comfort of user.

Table 1.1: Types of Grip [1]

Types of grip			
Contact	**Type of grip**	**Description**	**Application**
Finger	Finger	Single finger placed on surface. Finger either rested or pushed in	Push buttons or touchscreens
Palm	Palmar	Palm placed on surface	Using sandpaper
Finger palm	Hook	Palm against surface and fingers hooked around object	Pulling a lever
Thumb fingertip	Tip	Object held between thumb and (any) finger	Using a sewing needle
Thumb finger palm	Pinch	Object resting against palm and grasped between thumb and fingers	Positioning screwdriver head onto a screw
Thumb forefinger	Lateral	Object held between thumb and forefinger	Using tweezers
Thumb two fingers (outside)	Pen	Object rested on thumb and pressed by two fingers	Writing with a pen
Thumb two fingers (inside)	Scissor	Fingers and thumb placed inside handles	Cutting paper with scissors
Thumb fingertip	Disk	Thumb and fingers curled around outside of object	Holding sanding block
Finger palm	Collet	Object rested on palm and enclosed by fingers	Holding a ball
Hand	Power	Object rested across palm and enclosed by fingers	Holding a hammer or a saw

1.1 Objective of work

The primary objective of this research study is to design the tool handle for power grip through subjective analysis on a focus group. The 'design of tool handle' is to find out the appropriate values of the design parameters related to the elements of tool design. The tool handle has to improve the comfort level for the user and thereby improving the performance of the user. It is to be noted clearly that the aim is not to judge whether the type of grip is suitable for the selected tool. The target here is to assume a particular type of grip for a selected tool and evaluate it with respect to functionalities of the tool, rather being worried about an alternatively better grip which can improve the user's comfort and performance that changes the whole design of the tool. The secondary objective is to use alternative and simplified methods which are a reasonable approximation of standard methods while 'decision-making' regarding which factor of an element of tool handle is suitable.

1.2 Literature review

A tool can be defined as a 'handheld artefact which acts as an extension of the user that can be used to perform a task' [1]. As defined by Samuel Butler, "*Strictly speaking, nothing is a tool except during use. "The essence of a tool, therefore, lies in something outside the tool itself. It is not in the head of the hammer, nor in the handle, nor in the combination of the two that the essence of the mechanical characteristics exists, but in the recognition of its unity and in the force directed through it in virtue of this recognition*"[1]. A tool may also be defined as any form of assistance that allows us to expand upon the limited repertoire of manual and cognitive skills that we possess [1].

The design of a hand tool requires prior knowledge of comfort or discomfort level. Webster's dictionary defines comfort as 'a state or feeling of having relief, encouragement and enjoyment'. Comfort can be understood as a state in which a human is in pleasant state of physiological, psychological and physical harmony with his/her environment [3]. It is the state of a person being in subjective well-being with situation existing in the environment [2]. **L.F.M Kuijt-Evers, L Groenesteijna, M.P de Loozea, P Vinka** in 2004 investigated the factors of comfort/discomfort in hand tools according to user and collected the descriptors of comfort/discomfort level from various literature [2]. They investigated, the relatedness of a selection of the descriptors to comfort in using hand tools. They found that six factors can be distinguished and classified these six factors into three groups: functionality, physical interaction and appearance. They concluded that the same descriptors were related to comfort and discomfort in using hand tools, descriptors of functionality are most related to comfort in using hand tools followed by descriptors of physical interaction while descriptors of appearance become secondary in comfort in using hand tools. **L.F.M Kuijt-Evers, L Groenesteijna, M.P de Loozea, P Vinka** in 2005 developed a Comfort Questionnaire Hand tools (CQH) . The CQH contained various descriptors of comfort/discomfort in using hand tools and an overall comfort rating [3]. They found that to design hand tools that provide much comfort, designers have to focus on functionality and physical interaction and avoiding discomfort. It was also concluded that aesthetics is important to expected comfort and can play a major role in product sales.

Kuijt Evers, L.F.M., Vink, P., Looze, M.P. de in 2005 studied the differences and similarities between comfort factors of three tool: screw drivers. Handsaws and paint brush. Functionality and physical interaction with the hand tool were clubbed into the same factor (called functionality and physical interaction) for screwdrivers and paintbrushes [4]. However, in the case of hand saws these two factors were considered as two distinct factors (namely, 'functionality' and 'physical interaction and adverse effects on skin') [3]. This meant that the ratings on comfort descriptors of functionality are not related to the ratings on comfort descriptors of physical interaction in the hand saws. **Gregor Harih and Bojan Dolšak** developed digital human hand models using Magnetic Resonance Imaging and 3D reconstruction on tool handles with optimal diameters obtained from anthropometric data [5]. This gave the tool handle an anatomical shape which increased the contact area and subject's perceived level of comfort. **M. Aptel, L. Claudon and J. Marsot** suggested the following criteria for tool design: Tool mass, Center of gravity Handle form and dimensions, Handle

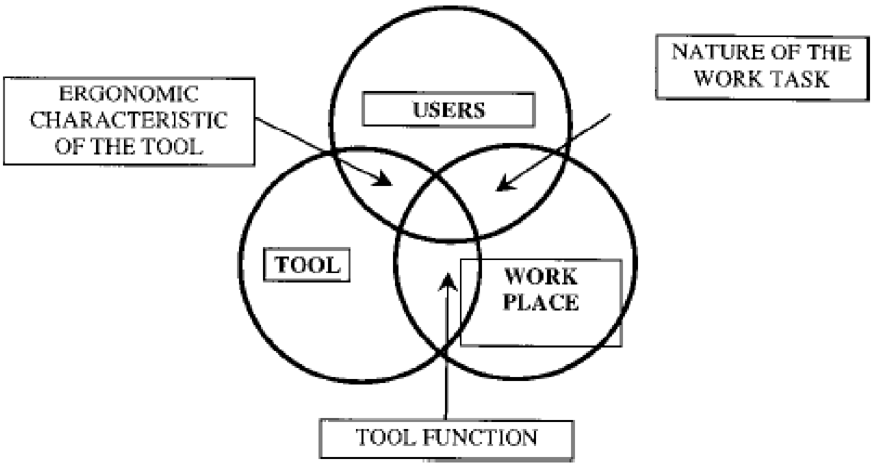


Figure 1.2.1: Elements involved in the ergonomic approach to tool design [2]

length Handle material and texture Trigger Inclination of the tool handle in relation to the functional part of the tool [6]. An ergonomic approach to the design of whole tool was suggested, as shown in Figure 1.2.1.

L.F.M. Kuijt-Evers, T. Bosch, M.A. Huysmans, M.P. de Looze, P. Vink studied the relationship between objective measurements and subjective ratings of comfort and discomfort in using handsaws [7]. It was concluded that EMG measurements cannot be used as an objective measurement to subscribe to comfort or discomfort experience measured subjectively while using hand tools for dynamic tasks. Contact pressure cannot be used as a predictive measurement of comfort experience too. However, contact pressure (i.e., pressure area) is an appropriate objective measurement to support subjective findings on discomfort in using hand tools.

Chris Baber in his study 'Cognitive aspects of tool use**'** points out that there exists very literature when it comes to cognitive aspects of tool use [1]. He highlights the actuality of tool-use as the ability of the humans to internalize the tool. He proposed a new approach to considering tool use in terms of Forms of Engagement (Figure 1.2.2). It is also proposed that the management and control of a motor response is covered by an appropriate task specific device which is selected from possible alternatives on the basis of an appropriate schema.

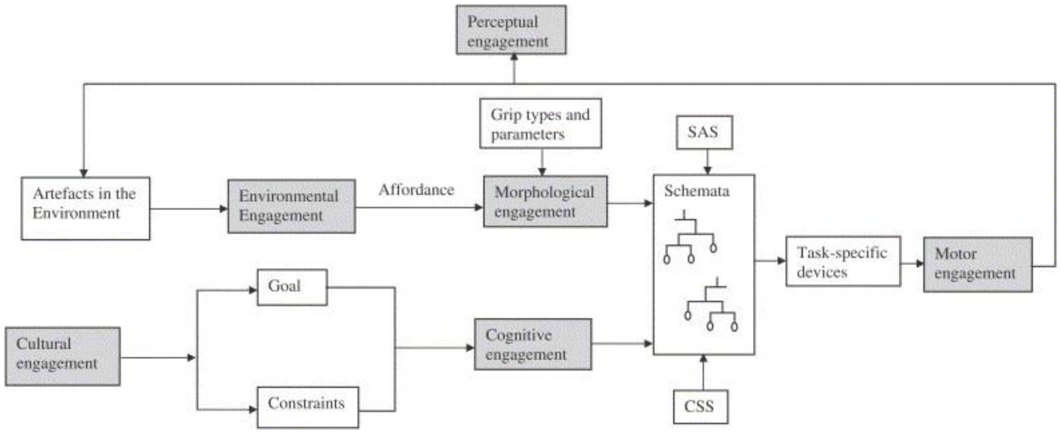


Figure 1.2.2: Forms of Engagement [1]

Danilo Corrêa Silva, Élen Sayuri Inokuti,e Luis Carlos Paschoarelli used hand maps(Figure 1.2.4) to assess discomfort during the use of tool by the people of different age groups[10]. These hand maps can be used with certain questionnaires which concentrate on various symptoms encountered during occupational tasks. Standard Nordic Questionnaire (SNQ) uses descriptors for identifying discomfort such as, “pain,” “bother,” “problems,” and “discomfort” and rate these with severity indicators [14,15]. Similarly the UMUEQ about the presence and severity of a “problem” in a specific location, but also asks the respondent to qualify the problem in terms of the types of symptoms experienced. The NIOSH and SNQ surveys used body maps along with rating scales to assess the attributes of discomfort. **Orawan Kaewboonchoo, Hiroichi Yamamoto, Nobuyuki Miyai, Seyed Mohamad Mirbod, Ikuharu Moriokai and Kazuhisa Miyashita** applied SNQ to study the discomfort caused by hand-arm vibration[9]. The subjects involved were chain saw operators and bush cleaners. Through SNQ they could identify the severity and duration of the discomfort, which was high in the case of chain saw operators.. **Grant, K.A., Habes, D.J., Steward, L.L.,** performed a study on the effect that cylindrical handle diameter can have on manual effort [11]. A user’s grip strength is co-related to grip strength for a particular hand size and grip diameter. It was found that, grip strength was maximized with the smaller diameter handle in which the fingers overlap. Equation 1 specifies the relation between D_{opt} and D_{grip}.

$$D_{opt} = ((D_{grip} \times \pi) - c)) \div \pi \qquad \text{Equation (1)}$$

Seo and Armstrong examined the relationship between various parameters of tool handle, such as grip forces, contact area, handle diameter, and hand size [12]. They proposed a physics-based solution for the constant ‘c’. The assumption behind this solution is that an optimal tool handle diameter is one which can align the ‘middle of the thumb tip and middle of middle finger tip’ parallel to the axis of the tool handle. The following equation was postulated.

$$D_{opt} = ((D_{grip} \times \pi) - (L_{F,2} + L_T)/2)) \div \pi \qquad \text{Equation (2)}$$

M. Braun and R. Schopp suggest a step-by-step process (Figure 1.2.3) that could be followed while designing a hand tool from ergonomics perspective [8].

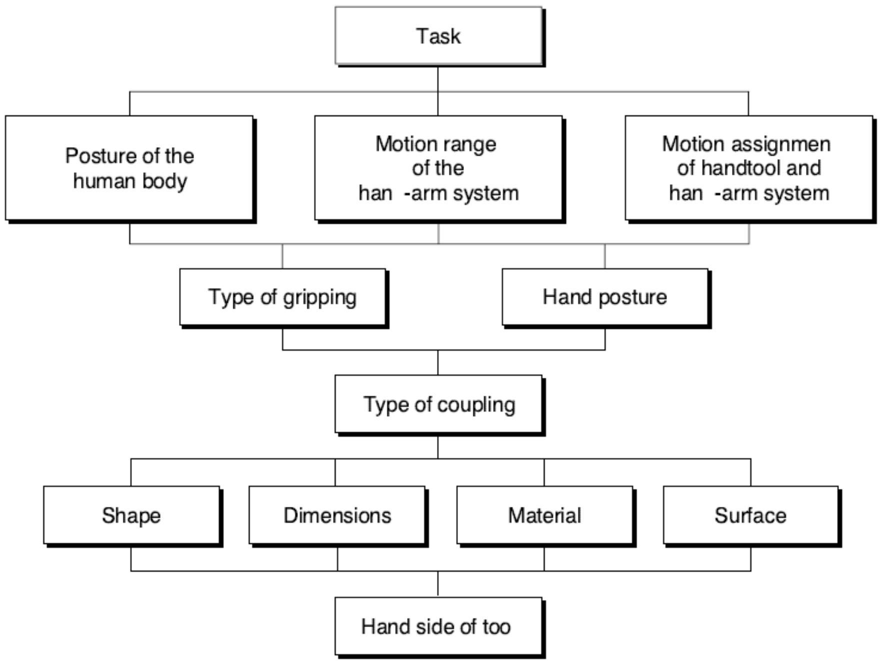


Figure 1.2.3: Process for ergonomic design of hand tool [8]

Figure 1.2.4: Hand Mapping for identification of discomfort zones and rating them [10]

1.3 Structure of thesis

The thesis has been structured into nine parts to report the happenings of this research study in detail. The structure of the thesis is a close replica of the methodology that has been followed to accomplish the objective that is Introduction, Methodology, Theoretical analysis, Data collection, Data analysis of anthropometric data, Experimentation, Results and Discussion, Conclusion and Future scope of this study. Chapter 1 introduces the basic definitions of tool handle design, types of grips and other terminology related to the process of tool handle design. This chapter documents the existing background literature on hand ergonomics, tool designs and occupational ergonomics related to use of tools. Chapter 2 outlines the procedure to be followed throughout the research study. The details of steps that have been followed have been described here. Chapter 3 provides with the results of theoretical analysis that has to be done prior to start of the study. For instance, the list of cross-section shapes which are of interest or the anthropometric variables for which data has to be collected. Chapter 4 describes the procedure that is to be followed while collecting the anthropometric data of the subjects and experiment conducted on the subjects to obtain data pertaining to comfort ratings. Chapter 5 provides the results of data analysis performed on the collected anthropometric data and data collected from experimentation. Chapter 6 discusses the results observed in chapter 5 and proposed new design is presented. Chapter 7 concludes the research study with discussion of future scope this research study in Chapter 8.

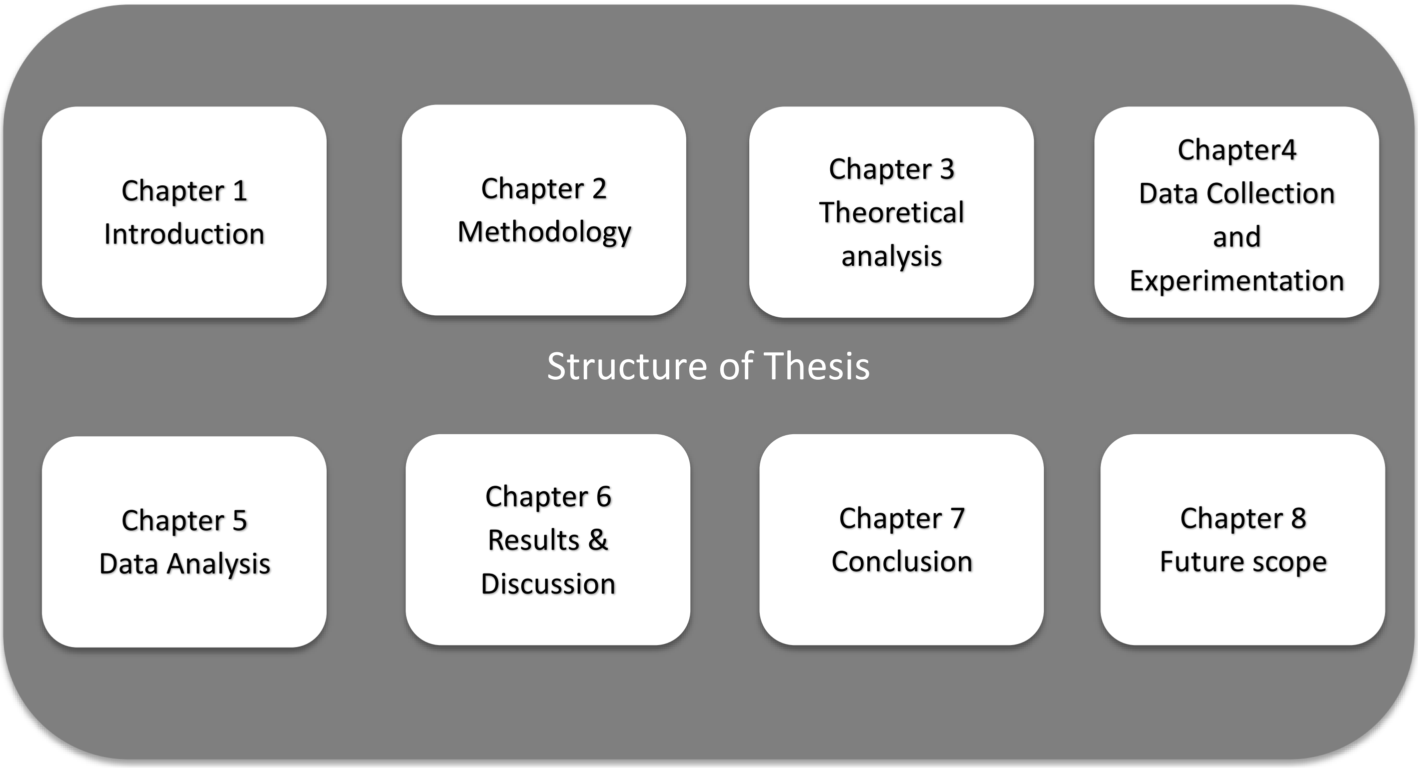


Figure 1.3.1: A schematic representation showing the Structure of Thesis

2 METHODOLOGY

The objective as stated in section 1.1 will be achieved through the methodology shown in Figure 5. The proceedings of the project are divided into four phases:

Phase I

i. **Literature Survey:** The study of existing research literature which can educate regarding new approaches and research studies being done or already done on design of tool handle for better ergonomics during tooling. The main aim here is to acquaint with the existing designs, mathematical equations derived between user comfort and anthropometric data, various existing questionnaires, comfort/discomfort factors and basic steps or process tools involved in the ergonomics design process of tool handle.

ii. **Identify the Comfort/discomfort factors:** Based on the literature survey, identify the factors/discomfort factors which predict comfort of a tool handle. Brainstorm for any other factor apart from those existing in literature which might affect the comfort of the tool handle.

iii. **Prepare Questionnaires:** Prepare questionnaires for evaluating the design of the tool handle. Three questionnaires were prepared, the first one to evaluate the optimized diameter, the second one for cross-section shape and the third one for evaluating the final design. The third questionnaire is accompanied with a hand map and a pain scale

Phase-II

i. **Identify the different shapes of cross-section and profile:** Cross-section shape and profile are the basic elements of design of a tool handle. Different possible shapes which might be of interest are to be identified.

ii. **Identify the anthropometric data variables and data collection and analysis:** At this stage the anthropometric data variables which might be necessary in determination of dimensions of the tool handle for various shapes identified in the previous step are noted. The anthropometric data of a random population is collected and necessary data analysis is performed to divide the subjects for further experimentation.

iii. **Prototype:** When the focus group of interest is selected use the anthropometric data collected and mathematical equations that have been established for calculating the D_{opt} and prepare CAD model of various cross-section shapes. Prototype the experimental prototypes for further experimentation.

Phase-III

i. **Experiment:** Two subjective experiments were conducted. The first one was to find the optimized diameter and the other one is gather the hand imprints which resemble that of contact area between hand and the tool handle surface. The third experiment to be conducted is aimed at evaluating the final design which is accompanied with questionnaire.
ii. **Analyze the data:** The data obtained from the two surveys and hand imprints was analyzed. A scoring scheme was adopted to include both the subjective perception of comfort of the user and the contact area.
iii. **Final Design:** Results obtained from the data analysis of two surveys and hand imprints data were used to finalize the design of the cross-section. The profile of the tool handle is reverse engineered from the best-selling model existing in the market.

Phase-IV

i. **Prototype:** The finalized design is modelled in CAD software and prototyped.
ii. **Evaluation of the final design:** The prototyped design is evaluated against the comfort factors through subject's perception of comfort after using for certain time in a simplified task assigned to them.

The flow chart of the methodology followed during the course of this research study is shown in Figure 2.1.

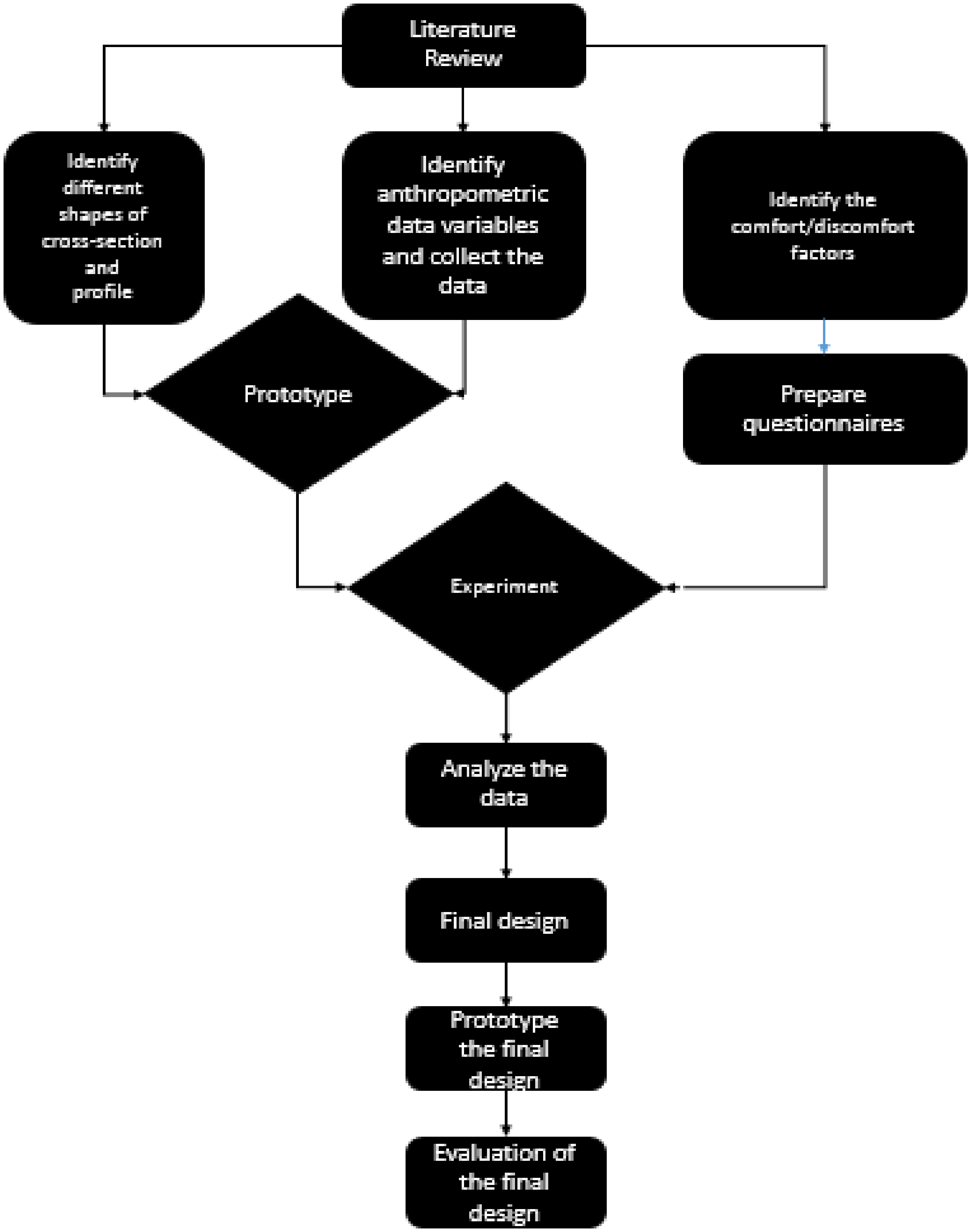


Figure 21.3.1: The methodology employed in the course of this research study

3 THEORETICAL ANALYSIS

A theoretical analysis was performed to recognize the various elements of design for a tool handle. These elements with the exception of cross-section shape and dimension and profile shape and dimension are to be kept constant while experimentation. That way, when a subject provides his/her comfort ratings for different designs of the handle, the difference in ratings of different handles can be traced to change in handle cross-section and profile while keeping all the other elements same. Different cross section shapes of interest were then finalized and questionnaires were prepared for subjective analysis.

3.1 Elements of tool design

The elements of tool handle refer to the components or features of a handle. The typical features of a tool handle are its shape, size, surface properties and color. The shape of the handle refers to the shape of the cross-section, Finger grooves and the form of the tool. Diameter of the cross section and length of the tool constitute the size of the tool. Surface properties contain the reflectivity of the surface, texture of the surface and surface roughness i.e., the friction between the hand and tool handle.

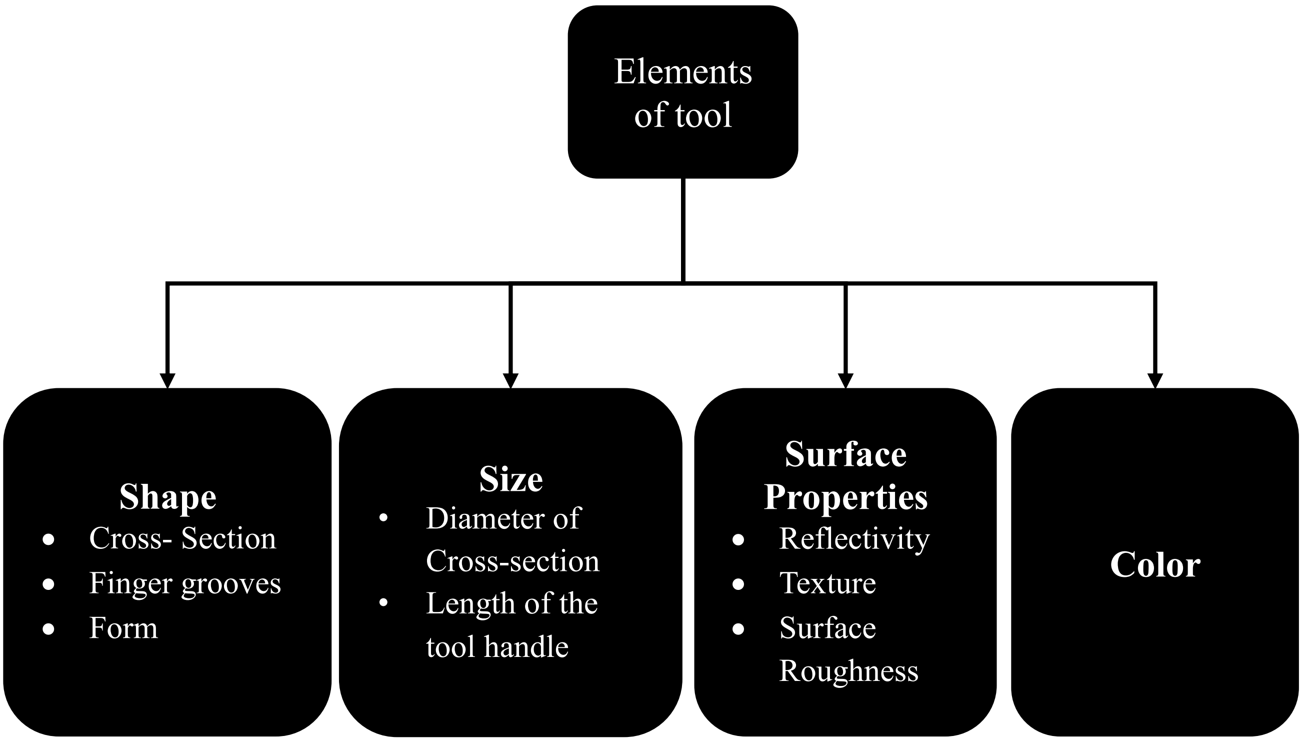


Figure 3.1.1: Elements of tool handle design

3.2 Cross-section shapes of tool handle

The domain of shapes is of infinite elements. Shape of tool handle can be any arbitrary closed curve. It becomes a direction-less search if an attempt is made in experimenting arbitrary shapes. One approach to find the optimum shape is to follow the procedure described by **Gregor Harih and Bojan Dolšak** [5] who used MRI and 3D reconstruction techniques to find out the anatomical shape of the hand which ensured higher contact area. Another approach is to experiment with primitive shapes or combinations of primitive shapes to find out which has the highest contact area. Though this would be comparatively less comfortable than that of the anatomical shape, the best possible primitive shape which is suitable for power grip may be identified. Since primitive shapes are easy to manufacture, the identification of the best shape for cross-section among these shapes can enhance comfort to some extent even in less costlier tools. The shapes shown in Figure 3.2.1 were considered for further study.

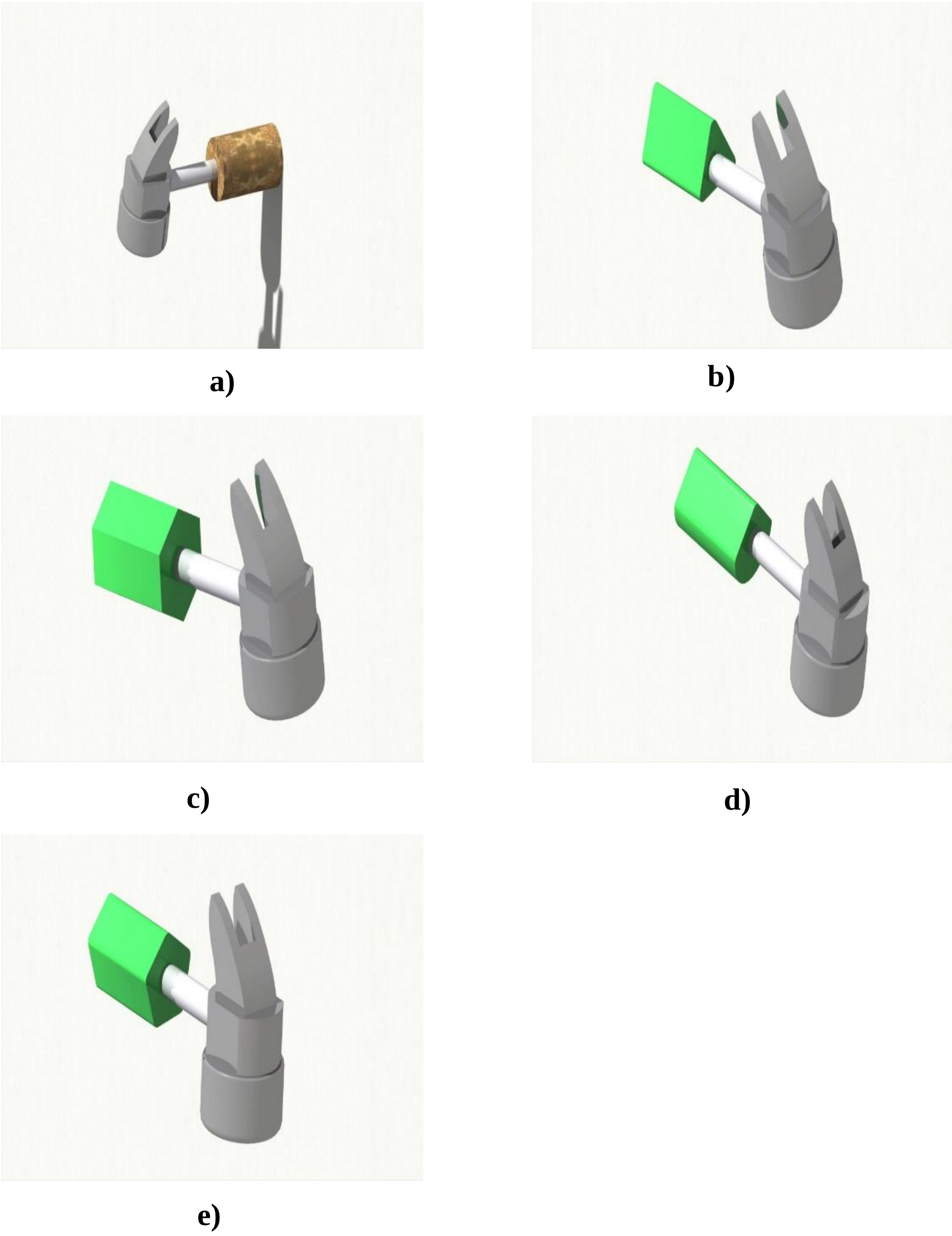


Figure 3.2.1: Different shapes of cross-sections: a) Circle b) Triangle c) Hexagon d) Combination of Circle and Triangle e) Pentagon

The dimensions of the cross-section were calculated as discussed below:

i. Cylinder: The diameter was taken equal to that of D_{opt}, which is obtained from either Equation 1 or Equation 2, which is preferred as the most comfortable by the subjects.
ii. Triangle, Hexagon and Pentagon: The D_{opt} calculated for the cylinder is used in determining the dimensions of these cross-sections. The dimensions of these shapes are chosen such that the ex-circle for each of these shapes has diameter equal to D_{opt}.
iii. Combination of triangle and circle: In this case, the circle region of the cross-section is a semi-circle with diameter equal to $D_{opt,}$ while the vertex of the triangular part of the cross-section is at distance equal to $D_{opt}/2$ from the center of the semi-circle as shown in the Figure 3.2.2.

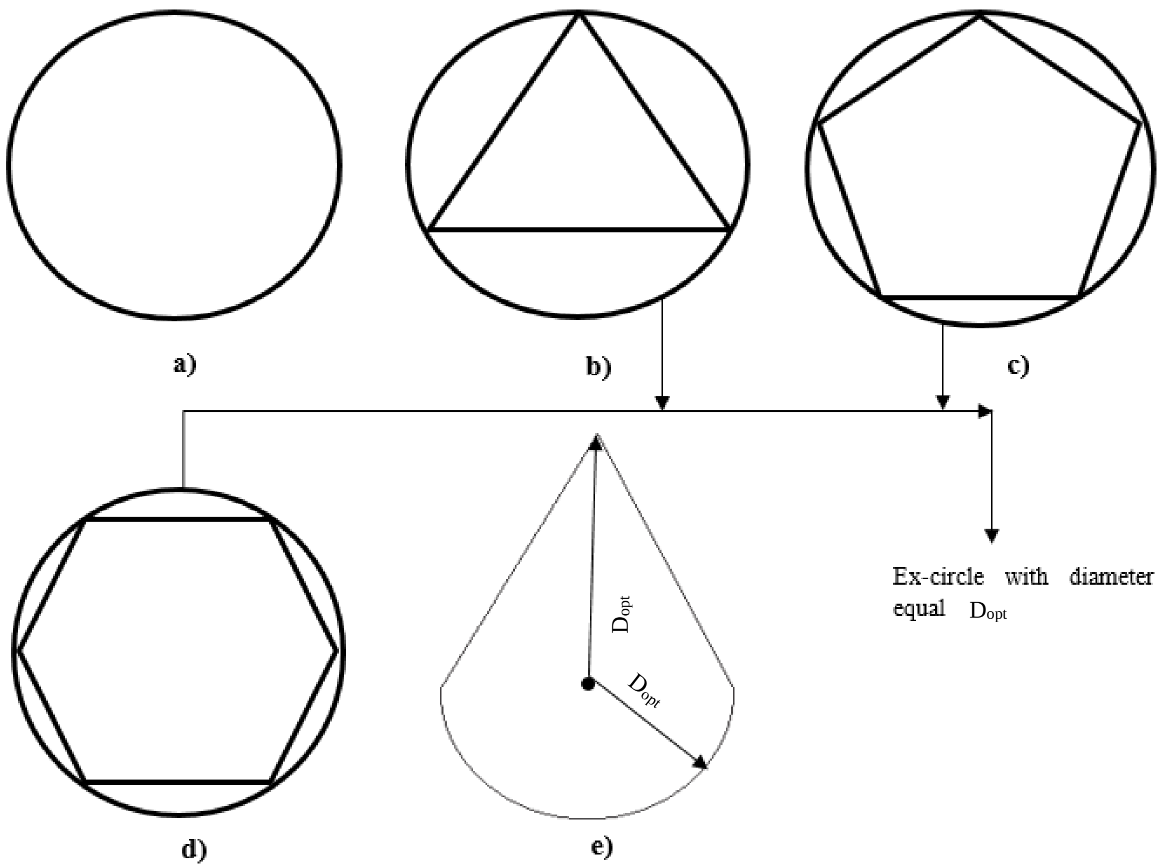


Figure 3.2.2: Different cross-section shapes of interest: a) Cylinder b) Triangle c) Hexagon d) Pentagon e) Combination of Triangle and circle

3.3 Profile shape of the tool handle

The profile shape or the form of the tool handle is reverse engineered from an existing design in the market which has been well-rated by the customers. The profile curve was obtained by tracing the image of tool handle of the existing hand tool in CAD software. The traced profile curve was then scaled appropriately so as to fit to the anthropometric data of the hand collected, i.e. the length of the tool handle must be greater than the breadth of the hand. The scaled profile curve was then used to create a CAD model of the tool handle. The finger grooves were also traced using the same process and scaled appropriately and added to the CAD model of the tool handle.

3.4 Questionnaires

In this research study, questionnaires which required the subjects to evaluate the design were used. Three questionnaires were prepared; the first one for recording user evaluation on the optimal grip diameter, the second one was to find out the subject's perception of comfort and the third one for the evaluation of the final design after performing a standard task with the tool for particular time.

3.4.1 Questionnaire for Optimal Diameter

Equations 1) and 2) as discussed in section 1.2 give us an option to choose between two possible optimal diameter one of which is obtained after assuming the constant value 'c' as 10 mm (which is considered optimum to obtain maximum grip strength) and the other one is obtained by averaging the lengths of middle and thumb fingers. The questionnaire is aimed at finding out answers to two questions, firstly whether the tool fits the hand properly and secondly how comfortable the tool is to hold. The subjects are required to rate them on a scale of 1-5, whose descriptors are shown in Table 3.4.1.1.

Table 3.4.1.1: Questionnaire for Optimal diameter

Questionnaire for optimal diameter					
Whether the tool fits in to your hand comfortably?	Fits Excellent	Fits Good	Fits Just Okay	Fits worse	Fits Worst
	5	4	3	2	1
How do you rate the overall comfort of the tool?	Extremely uncomfortable	Moderately uncomfortable	Cannot say	Moderately Comfortable	Highly Comfortable
	1	2	3	4	5

3.4.2 Questionnaire for cross-section shape

The questionnaire for cross-section is a supplementary added to the contact area between the hand and the tool handle surface calculated through hand imprints to note the subject's level of overall comfort. The questionnaire contains a simple question asking the subject to rate the overall comfort of each cross section shape on a scale 1-5. The descriptors of which are shown in Table 3.4.2.1.

Table 3.4.2.1: Questionnaire for Cross-section shape

Questionnaire for Cross-section shape					
How do you rate the overall comfort of the tool?	Extremely uncomfortable	Moderately uncomfortable	Cannot say	Moderately Comfortable	Highly Comfortable
	1	2	3	4	5

3.4.3 Questionnaire for evaluation of final design

The identified predictors of comfort/discomfort level of customer from the works are supplemented by **L.F.M. Kuijt-Evers, T. Bosch, M.A. Huysmans, M.P. de Looze, P. Vink [2,3,4,7]** were supplemented with few factors identified by us were used to prepare a questionnaire for subjective analysis. The factors along with descriptors/predictors are tabulated below. The final questionnaire to be used in the interview can be found in Appendix-I. The inputs of the users are converted into values on a scale of 1 to 5 where 1 is used to denote highest level of discomfort and 5 is the highest level of comfort. The questionnaire also includes questions related to location of perceived discomfort and assessment of the level of discomfort.

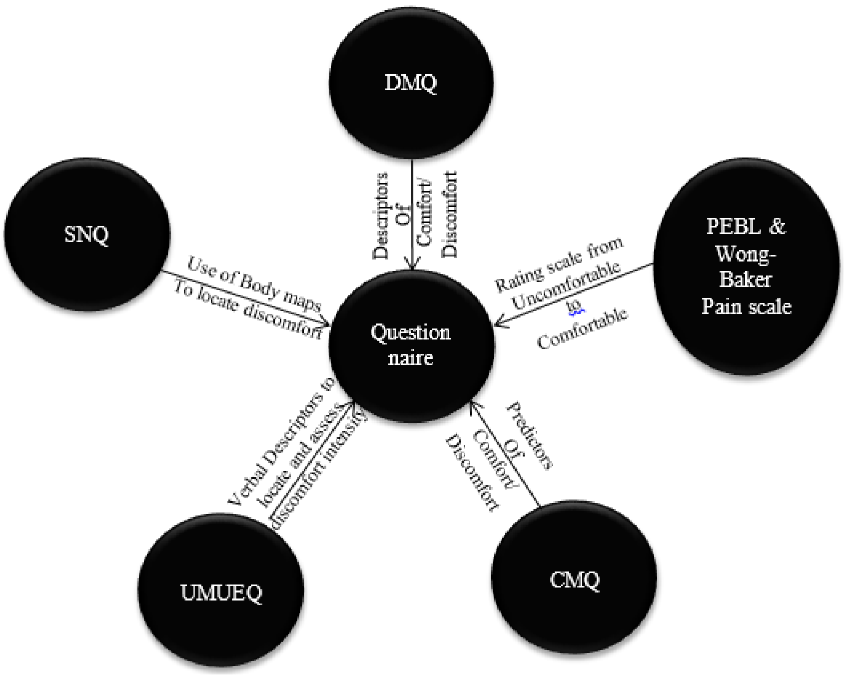


Figure 3.4.3.1: Data flow into preparation of questionnaire for evaluation

Table 3.4.3.1: Comfort factors to be included in Questionnaire

Comfort factors to be included in Questionnaire
Customer Perception of Product on first look
Quality of the tool handle
1. Surface Finish
2. Material
3. Texture
Reliability
Aesthetics
1. Has a solid Design
2. Has a functional Color
Compatibility for the type of grip
Overall Comfort at first look
Comfort/Discomfort Questionnaire
Based on human-tool interaction
1. can transmit acceptable amount of applied force
2. level of force or effort required during use
3. Fits the hand
4. Overall nice-feeling and confidence
5. dampens tool vibration/shock
Effect of tool use on hand/arm
1. Causes pain in regions of the palm
Task Performance
Performance to be evaluated on the basis of tool and the task selected

3.4.4 List of anthropometric variables

Anthropometric data is required to determine the appropriate product dimensions to ensure user comfort and usability. For the design of a tool handle, certain hand anthropometric data variables are required to optimize the handle diameter and handle length. These anthropometric data variables with their definitions are listed below in Table 3.4.4.1. These variables are defined using terminology of hand anatomy. A pictorial representation of hand anatomy, naming different regions on the hand is shown in Figures 3.4.1, 3.4.2, 3.4.3. The hand length, hand breadth, length of middle finger, length of thumb finger and grip diameter are necessary for calculation of optimal handle diameter, data of some supplementary variables were also collected. These data variables may be of use while designing the finger grooves of the handle.

Table 3.4.4.1: List of anthropometric variables

Anthropometric data variables	Definition
Hand Length	The length of the hand as measured between the wrist crease and the tip of the longest finger on the hand, usually thumb finger
Hand Breadth	The length of the palm of the hand, measured perpendicular to hand length
Length of Thumb Finger	The length of the thumb finger as measured between palmar digital and the tip of the thumb finger.
Length of Middle finger	The length of the thumb finger as measured between the palmar digital and the tip of the middle finger.
Grip diameter	Grip diameter is defined as the diameter of the largest cylinder that can be held in the hand such that the tip of the thumb finger and the tip of middle finger are in contact.
Diameter of Distal interphalangeal (All fingers)	The diameter of finger at the distal interphalangeal joint
Diameter of Proximal interphalangeal (All fingers)	The diameter of finger at the proximal interphalangeal joint.
Diameter of Palmar digital Phalanx (All fingers)	The diameter of finger at the palmar digital joint.

The landmarks for the anthropometric data are shown in Figure 3.4.4.2. Landmarks are points on the hand between which measurements were taken between on the right hand of all subjects.

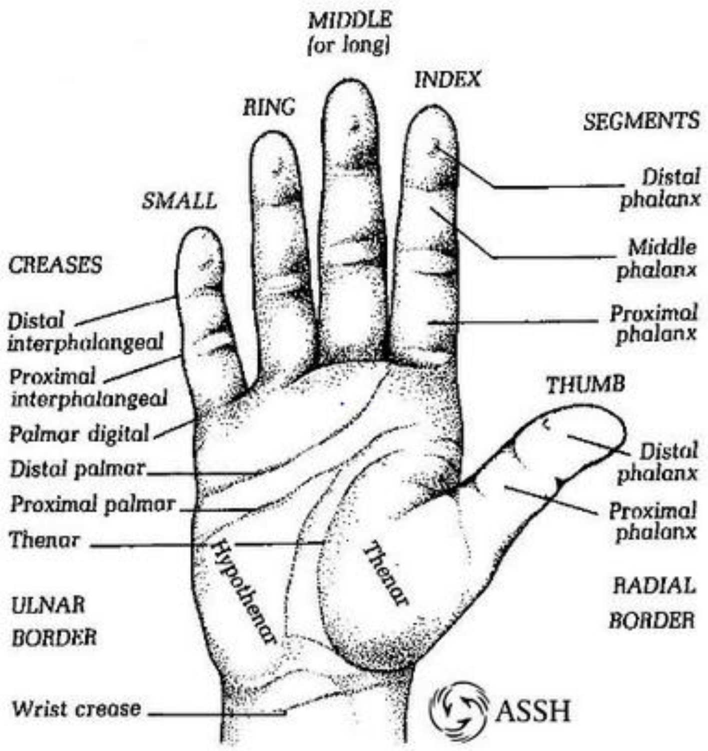


Figure 3.4.4.2: Anatomy of hand [13]

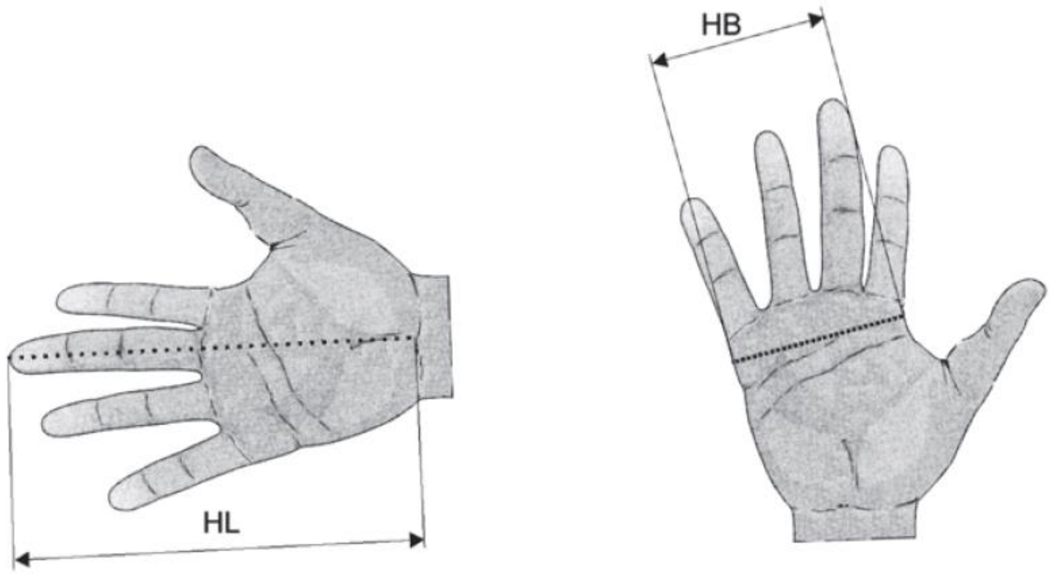


Figure 3.4.4.1: Landmarks for hand length and hand breadth

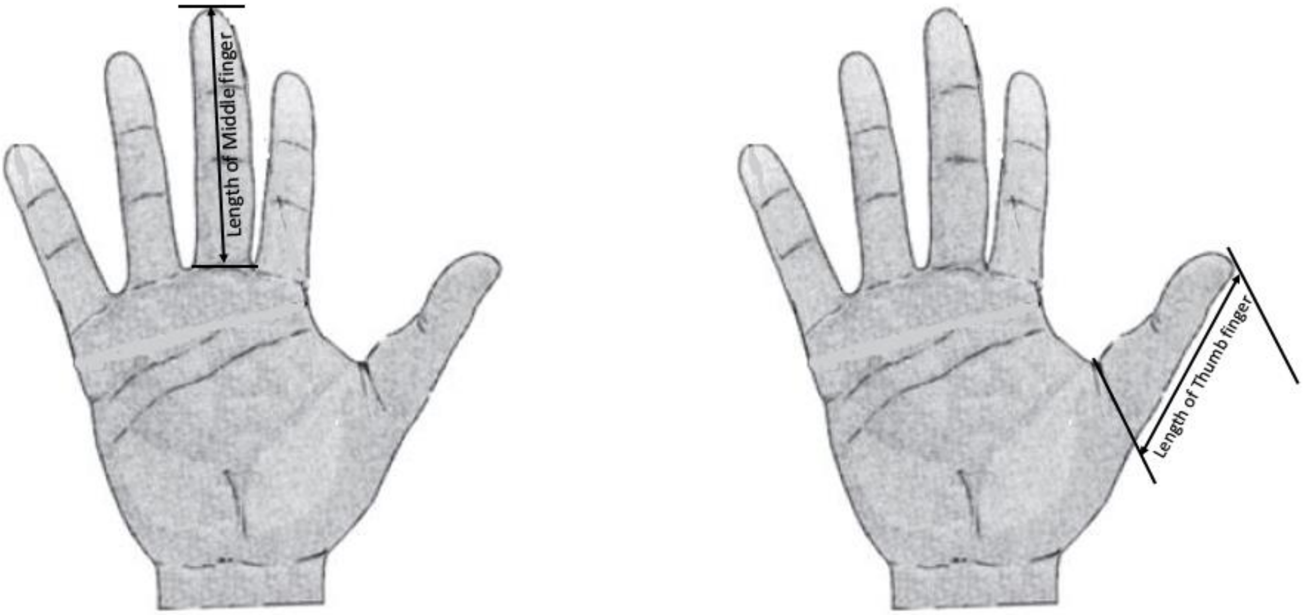


Figure 3.4.4.3: Landmarks for measurement of middle finger and thumb finger length

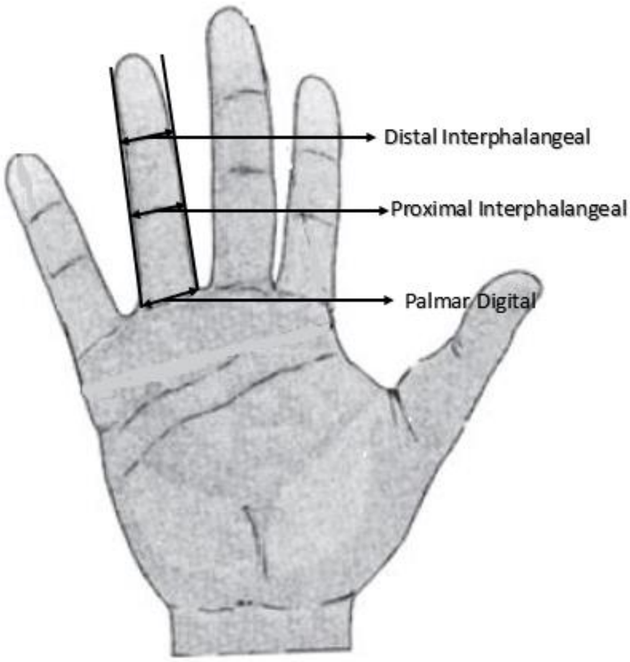


Figure 3.4.4.4: Landmarks for measurement of breadth of fingers

4 DATA COLLECTION AND EXPERIMENTATION

In this chapter, the procedure adopted during data collection and experimentation are described in detail. Data collection refers to anthropometric data collected and experimentation refers to collection of data pertaining to subjective comfort rating and contact area of hand through hand imprints

4.1 Data Collection

Anthropometric data of 67 subjects chosen at random were collected using a measuring tape and digital Vernier caliper. The data was collected for anthropometric variables mentioned in section 3.4.4. In this section, the procedure employed during measuring these variables has been detailed. During data collection, all the subjects were made to sit in a comfortable posture and were instructed not to move until further instructions were provided.

4.1.1 Hand Length

The subjects were instructed in sit in chair in a comfortable posture and were asked to put their hand on a table situated at a reachable distance such that, the wrist crease coincides with the sharp edge of the table. A right angle was placed and the length was measured using a measuring tape. It is shown in Figure.

4.1.2 Hand Breadth

The subjects were instructed to orient his hand such that the palm faces upwards towards the experimenter. A Vernier caliper was used to measure the length of the hand breadth between the landmarks of hand breadth as discussed in section 3.4.4. It is shown in Figure.

Figure 4.1.2.1: Measurement of Hand breadth

4.1.3 Length of middle finger

The subjects were instructed to orient his hand such that the palm faces upwards towards the experimenter and broadly opens his/her fingers. A Vernier caliper was used to measure the length of the middle finger between the landmarks of middle finger as discussed in section 3.4.4. It is shown in Figure.

Figure 4.1.3.1: Measurement of middle finger

4.1.4 Length of Thumb Finger

The subjects were instructed to orient his hand such that the palm faces upwards towards the experimenter and broadly opens his/her fingers. A Vernier caliper was used to measure the

Figure 4.1.4.1: Measurement of Thumb

length of the middle finger between the landmarks of thumb finger as discussed in section 3.4.4. It is shown in Figure 4.1.4.1

4.1.5 Breadth of Finger

The breadth of each finger was to be taken at three different locations for four fingers and two locations for the thumb fingers. The subject was asked to broadly open his fingers. The location of each finger which was to be measured was placed between the Vernier caliper and the reading was taken. It is shown in Figure 4.1.5.1.

Figure 4.1.5.1: Measurement of breadth of finger

4.1.6 Grip Diameter

The grip diameter was measured using a shaft whose diameter was changed by adding or removing padding material. The subject was asked to hold the shaft such that the tip of the thumb finger and the tip of the middle finger touch each other. If the diameter was insufficient, the padding material was changed until the subject was just able to touch his/her thumb and middle finger. When the right amount of padding material is added, the diameter of the shaft along with the padding material is measured using a Vernier calipers. It is shown in Figure 4.1.6.1.

Figure 4.1.6.1: Measurement of grip diameter using padding material

4.2 Experimentation

The experiments performed during the research study were of subjective nature to find out the optimal diameter and the better cross-sectional shape of the considered shapes. Prior to this experimentation, a cluster analysis of two dimensional nature with hand length and hand breadth as variates, was performed on the data collected from 67 subjects. A cluster was selected solely on the basis of the availability and willingness of the subjects to participate in the study for further experimentation. The two subjective experiments performed are discussed below.

4.2.1 Prototypes for experimentation

The optimal diameter has been calculated using two equations, Equation (1) and Equation (2) and the anthropometric data of selected cluster of subjects. Equation (1) gave a result of 35 mm and Equation (2) gave a diameter of 44 mm. Two experimental prototypes were prepared of each diameter using shafts of 30 mm and increasing their diameters to desired lengths by using soft tissue paper as padding material. These prototypes are shown in Figure 4.2.1.1. Once the optimal diameter has been established, virtual prototypes of different cross-section discussed in section 3.2 were modelled using a CAD software and exported to 'stl' format.

Figure 4.2.1.1: Experimental prototypes used for experimentation to obtain subjective ratings for optimal diameter

These file were given as an input to a rapid prototyping machine for manufacturing. The prototypes were made ABS material and the prototyped handle were padded with rubber.

4.2.2 Experimentation for optimal diameter

Two experimental prototypes shown in Figure 4.2.1.1 were given to each subject one by one and were instructed to hold them as a power grip. The subject was asked to rate fitness of the handle into hand and the overall comfort of the hand using the questionnaire prepared in section 3.4.1.

4.2.3 Experimentation for Cross-section shape

The different cross-section shapes of interest were already discussed in section 3.2. Prototype of each cross-section type were given to subjects to hold as a power grip and were asked to rate

Figure 4.2.3.1: Procedure of experimentation for cross-sectional shape

the tool handle in terms of overall perceived comfort in the questionnaire of 3.4.2. The next step was to find the hand contact area for each cross-section type. This was accomplished by applying paint to each prototype and letting the subject hold the prototype. The subject was then asked to put his hand on a white paper to create a hand imprint. This procedure is shown in Figure 4.2.3.1.

5 Data Analysis

This chapter briefs the results of data analysis performed on the anthropometric data, cluster analysis and subjective ratings during experimentations. The data analysis of anthropometric data includes the detailed descriptive statistics of the subjects, demographics of the population, region-specific normality tests and co-relation co-efficient between various data variables.

5.1 Descriptive statistics

The descriptive statistics shows the overview of the data. It shows the statistical characteristics of the data such as the mean, median, mode and so on. In this section the descriptive statistics of whole population and statistics of the region specific population are given.

5.1.1 Statistics of whole population

Table 5.1.1.1: Descriptive statistics for whole population

Statistic	Age (Years)	Hand length(mm)	Breadth(mm)	Length of Middle finger(mm)	Length of thumb(mm)
No. of observations	67	67	67	67	67
Minimum	19.000	18.600	60.000	67.200	53.500
Maximum	33.000	215.000	90.700	91.900	82.800
Median	22.000	190.000	81.700	79.000	66.200
Mean	22.761	187.367	81.073	79.370	65.955
Variance (n-1)	6.306	548.129	40.906	29.937	31.093
Standard deviation (n-1)	2.511	23.412	6.396	5.471	5.576
Skewness (Fisher)	2.055	-5.780	-0.916	0.017	0.042
Kurtosis (Fisher)	5.116	41.802	0.916	-0.425	0.650

In this section the descriptive statistics of the whole population set are described in Table 5.1.1.1. These statistics give an overview of the data collected and certain statistical characteristics of the data.

5.1.2 Statistics of region-specific population

The whole population set consists of 67 subjects, out of which 18 subjects were from Andhra Pradesh, 11 subjects from Bihar, 19 subjects from Odisha, 5 from Uttar Pradesh, 4 from Madhya Pradesh, 3 from Jharkhand, 2 from West Bengal, 2 from Delhi and 1 from Punjab. Descriptive statistics of these subjects divided on region basis is shown in Tables 5.1.2.1-5.1.2.3. Scatter-grams in Figures 5.1.2.1-5.1.2.3 show the distribution of data along the mean. In this section the descriptive statistics of Andhra Pradesh, Bihar and Odisha are shown, while the statistics of the other regions were ignored owing to the fact that the population data set is quite low compared to these three states.

I. Andhra Pradesh

The descriptive statistics of the subjects belonging to Andhra Pradesh are shown in Table 5.1.2.1. The scatter-grams of the anthropometric variables are shown in Figure 5.1.2.1

Table 5.1.2.1: Descriptive statistics for subjects of Andhra Pradesh

Statistic	Hand Length	Hand Breadth	Middle Finger	Thumb Finger
No. of observations	18	18	18	18
Minimum	173.000	73.600	67.700	53.900
Maximum	215.000	90.400	88.100	82.800
Median	194.000	81.400	81.200	67.600
Mean	194.667	82.150	80.161	67.928
Variance (n-1)	127.882	18.993	31.906	46.939
Standard deviation (n-1)	11.309	4.358	5.649	6.851
Skewness (Fisher)	-0.064	0.098	-0.561	0.005
Kurtosis (Fisher)	-0.586	-0.277	-0.147	1.012

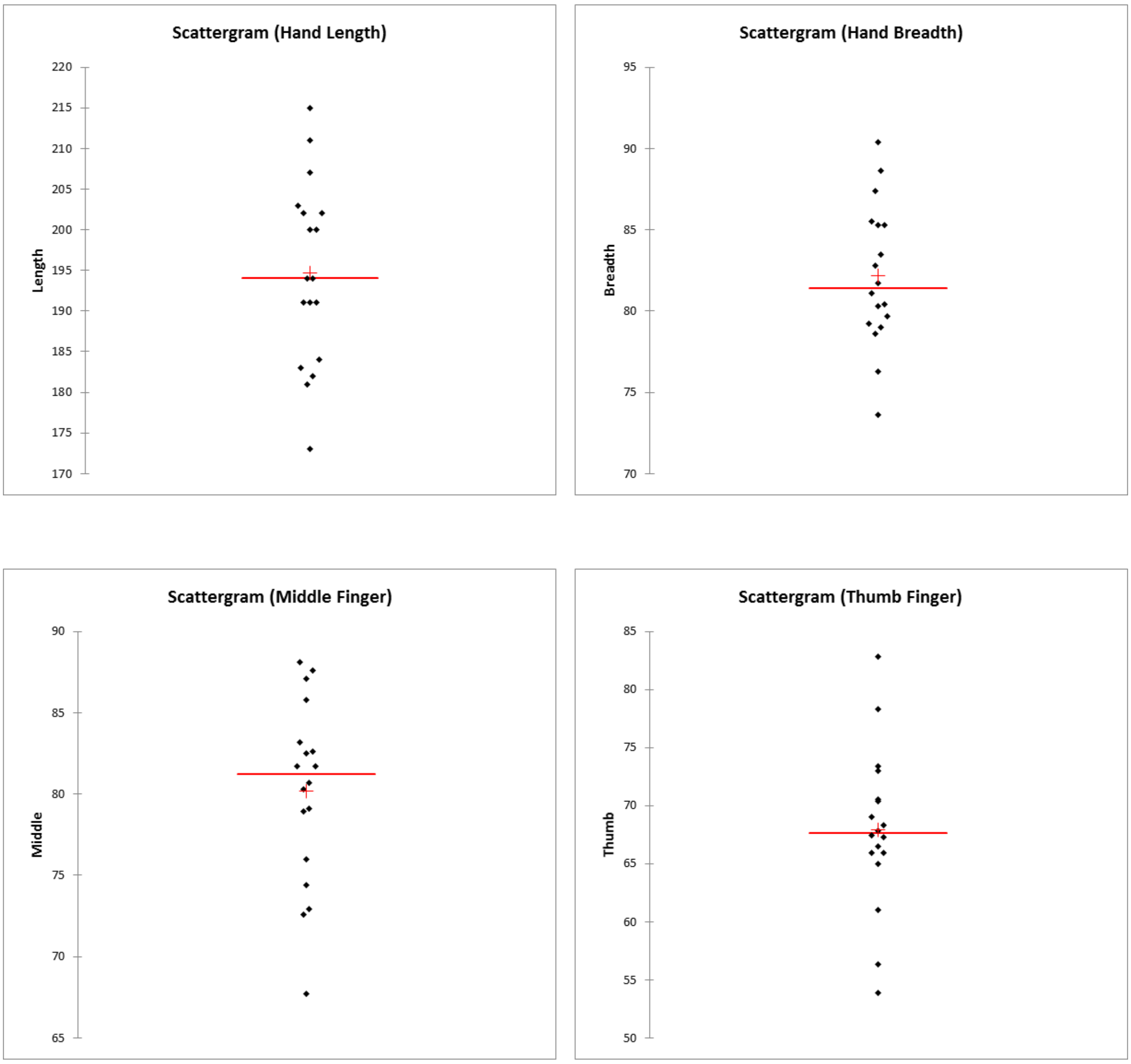


Figure 5.1.2.1: Scatter-grams of subjects of Andhra Pradesh; (from top left) Scatter-gram of Hand length, Hand breadth, Middle finger and Thumb finger

II. Bihar

The descriptive statistics of the subjects belonging to Bihar are shown in Table 5.1.2.2. The scatter-grams of the anthropometric variables are shown in Figure 5.1.2.2

Table 5.1.2.2: Descriptive statistics for subjects of Bihar

Statistic	Hand Length	Hand Breadth	Middle Finger	Thumb Finger
No. of observations	11	11	11	11
Minimum	165.000	72.000	70.400	53.500
Maximum	200.000	90.600	86.100	72.000
Median	188.000	81.700	78.600	66.100

Mean	186.545	81.118	78.400	64.927
Variance (n-1)	89.473	28.072	21.628	22.982
Standard deviation (n-1)	9.459	5.298	4.651	4.794
Skewness (Fisher)	-1.038	-0.051	-0.072	-1.280
Kurtosis (Fisher)	1.769	-0.010	0.310	2.805

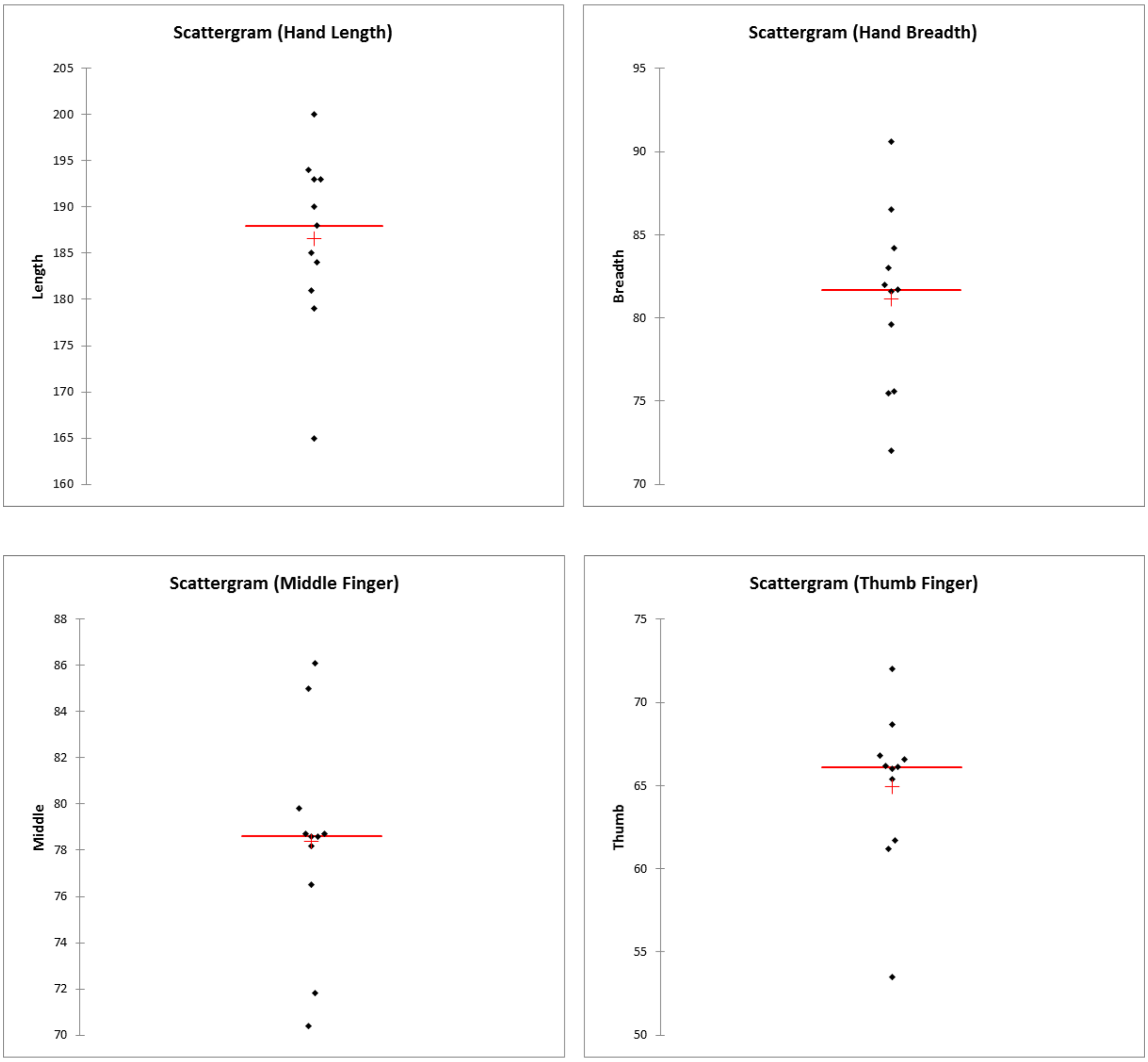


Figure 5.1.2.2: Scatter-grams of subjects of Bihar; (from top left) Scatter-gram of Hand length, Hand breadth, Middle finger and Thumb finger

III. Odisha

The descriptive statistics of the subjects belonging to Odisha are shown in Table 5.1.2.3. The scatter-grams of the anthropometric variables are shown in Figure 5.1.2.3

Table 5.1.2.3: Descriptive statistics for subjects of Odisha

Statistic	Length	Breadth	Middle	Thumb
No. of observations	19	19	19	19
Minimum	169.000	60.000	67.200	54.800
Maximum	210.000	90.400	91.900	71.500
Median	187.000	80.300	77.200	62.300
Mean	186.579	78.495	77.368	63.611
Variance (n-1)	140.813	75.582	33.769	26.488
Standard deviation (n-1)	11.866	8.694	5.811	5.147
Skewness (Fisher)	0.383	-0.632	0.732	0.028
Kurtosis (Fisher)	-0.433	-0.696	1.067	-0.956

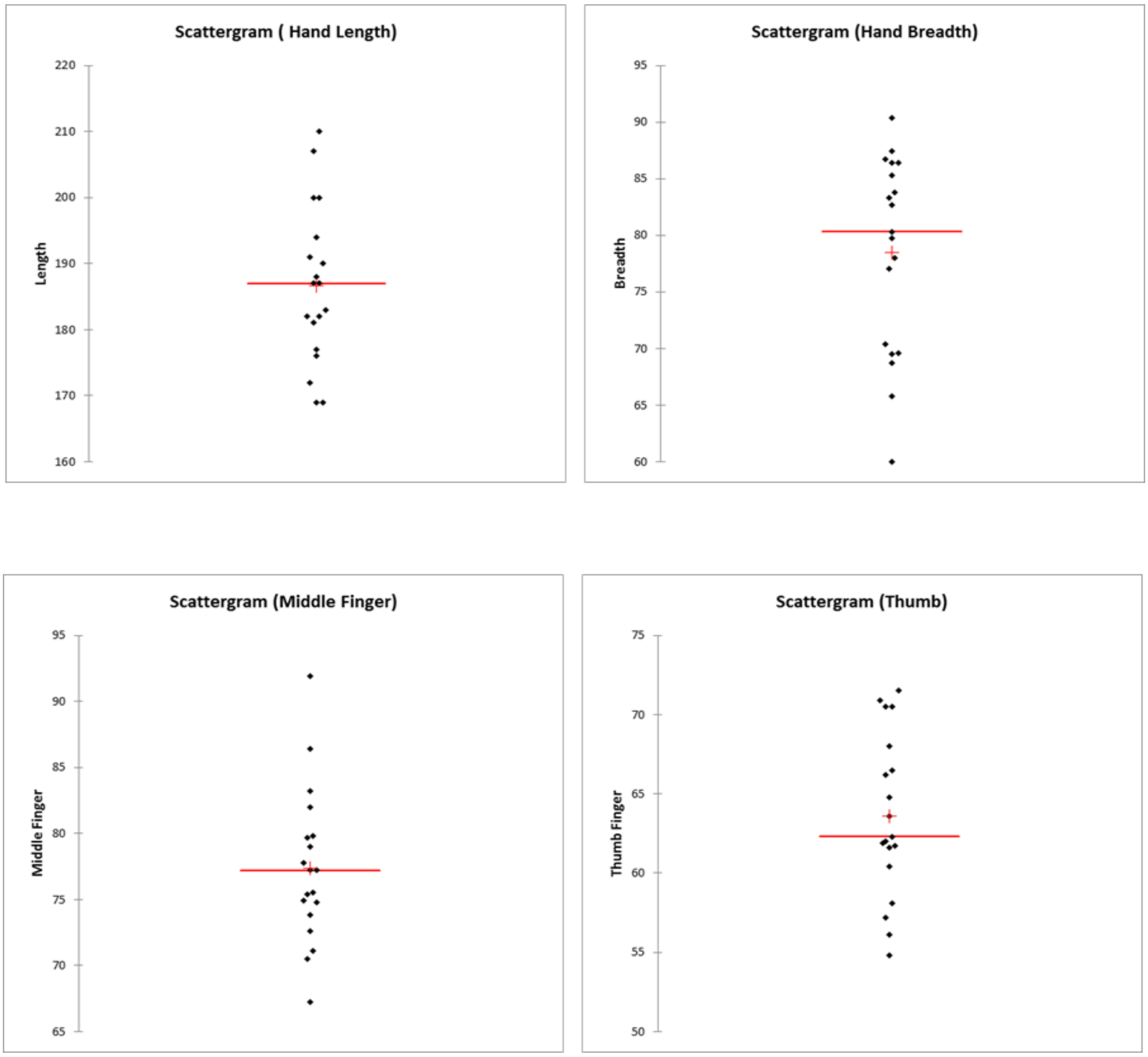


Figure 5.1.2.3: Scatter-grams of subjects of Odisha; (from top left) Scatter-gram of Hand length, Hand breadth, Middle finger and Thumb finger

5.2 Demographics

Demographics of a population set are the quantifiable statistics of the data set. Demographics are used to study the quantifiable statistics of population set at a particular time. In this section, the quantifiable statistics are identified on the verticals of regions from which subjects hail, the composition of the population and the gender composition of the population. Figure 5.2.1 and Figure 5.2.1 shows the age composition of the population, region based composition of the population is shown in Figure 5.2.3 and the gender based composition of the population is shown in Figure 5.2.4. It is noted that 71% of the population was in the age range of 21-23.

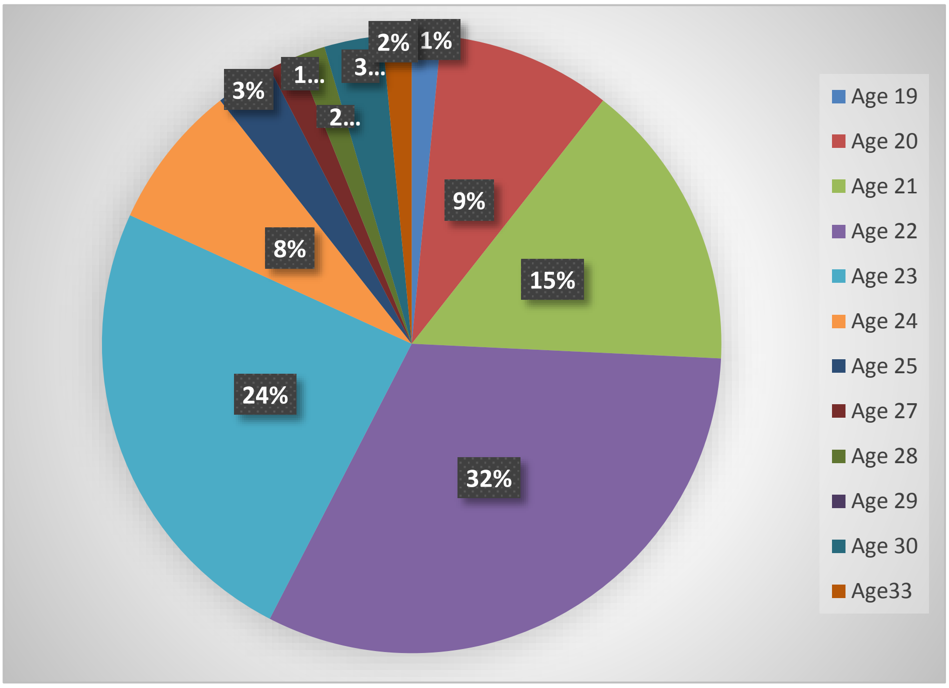


Figure 5.2.1: A pie chart showing age composition

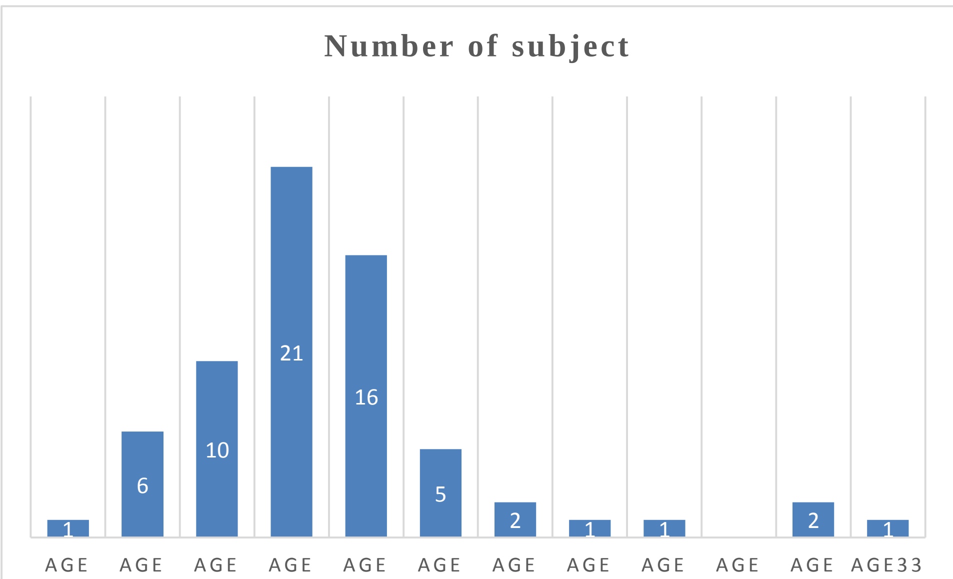


Figure 5.2.2: Age distribution of the subjects

The pie chart of composition of population according to their regions shows that maximum subjects belonged to Odisha, followed by Andhra Pradesh and Bihar. The gender composition shows that 87% of the population were men and 13% were women.

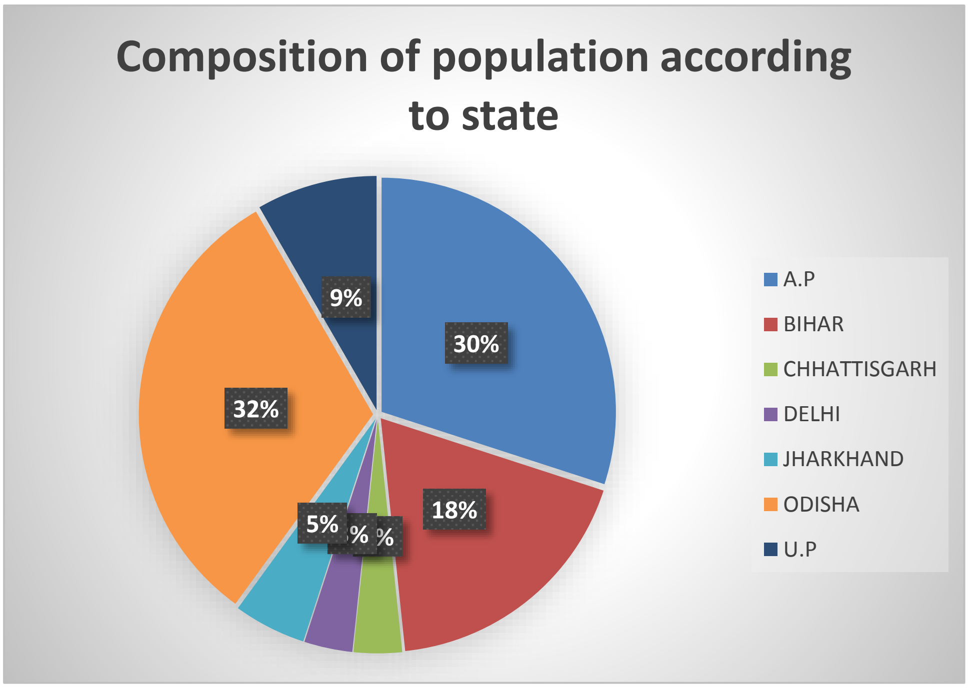


Figure 5.2.3: Composition of population of subjects according to state

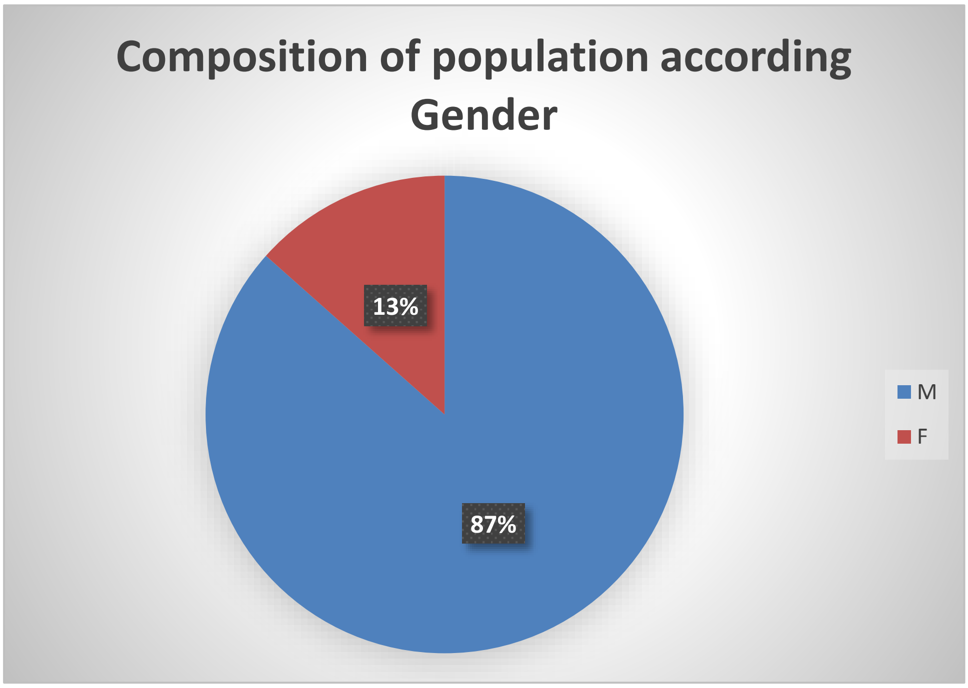


Figure 5.2.4: Composition of subjects according to gender

5.3 Co-relation tests

The co-relation tests between two variates shows the extent of linear relationship that can exist between them. The co-relation test shows whether there is a positive co-relation, negative co-relation or zero co-relation between the variates. The co-relation between important anthropometric variables is calculated in this section

5.3.1 Co-relation between Hand length- Hand breadth

Table 5.3.1.1 shows the correlation matrix of hand length and hand breadth. Figure 5.3.1.1 shows the bar charts showing the distribution of hand length and hand breadth and scatter plots between the same.

Table 5.3.1.1: Correlation Matrix of Hand length- Hand Breadth

Variables	Correlation matrix (Pearson)		p-values:		Coefficients of determination (R^2)	
	Length	Breadth	Length	Breadth	Length	Breadth
Length	1	0.216	0	0.079	1	0.047
Breadth	0.216	1	0.079	0	0.047	1

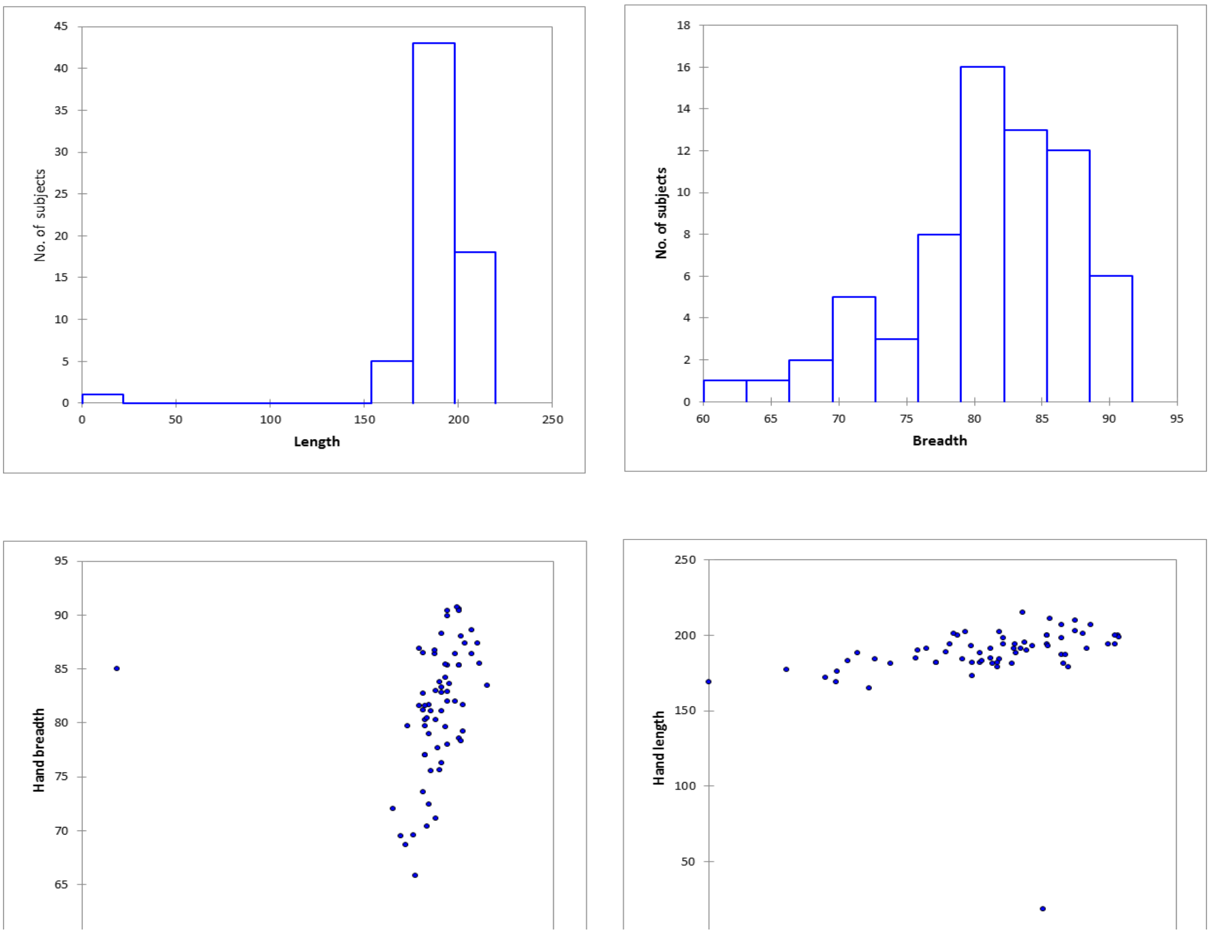


Figure 5.3.1.1: Bar charts showing the distribution of hand length and hand breadth (top) and scatter plots of hand breadth and hand length (bottom)

5.3.2 Co-relation between Hand length-Middle finger

Table 5.3.2.1 shows the correlation matrix of hand length and hand breadth. Figure 5.3.2.1 shows the bar charts showing the distribution of hand length and hand breadth and scatter plots between the same.

Table 5.3.2.1: Correlation Matrix of Hand length- Middle finger

Variables	Correlation matrix (Pearson)		p-values:		Coefficients of determination (R^2)	
	Length	Middle finger	Length	Middle finger	Length	Middle finger
Length	1	0.347	0	0.004	1	0.121
Middle finger	0.347	1	0.004	0	0.121	1

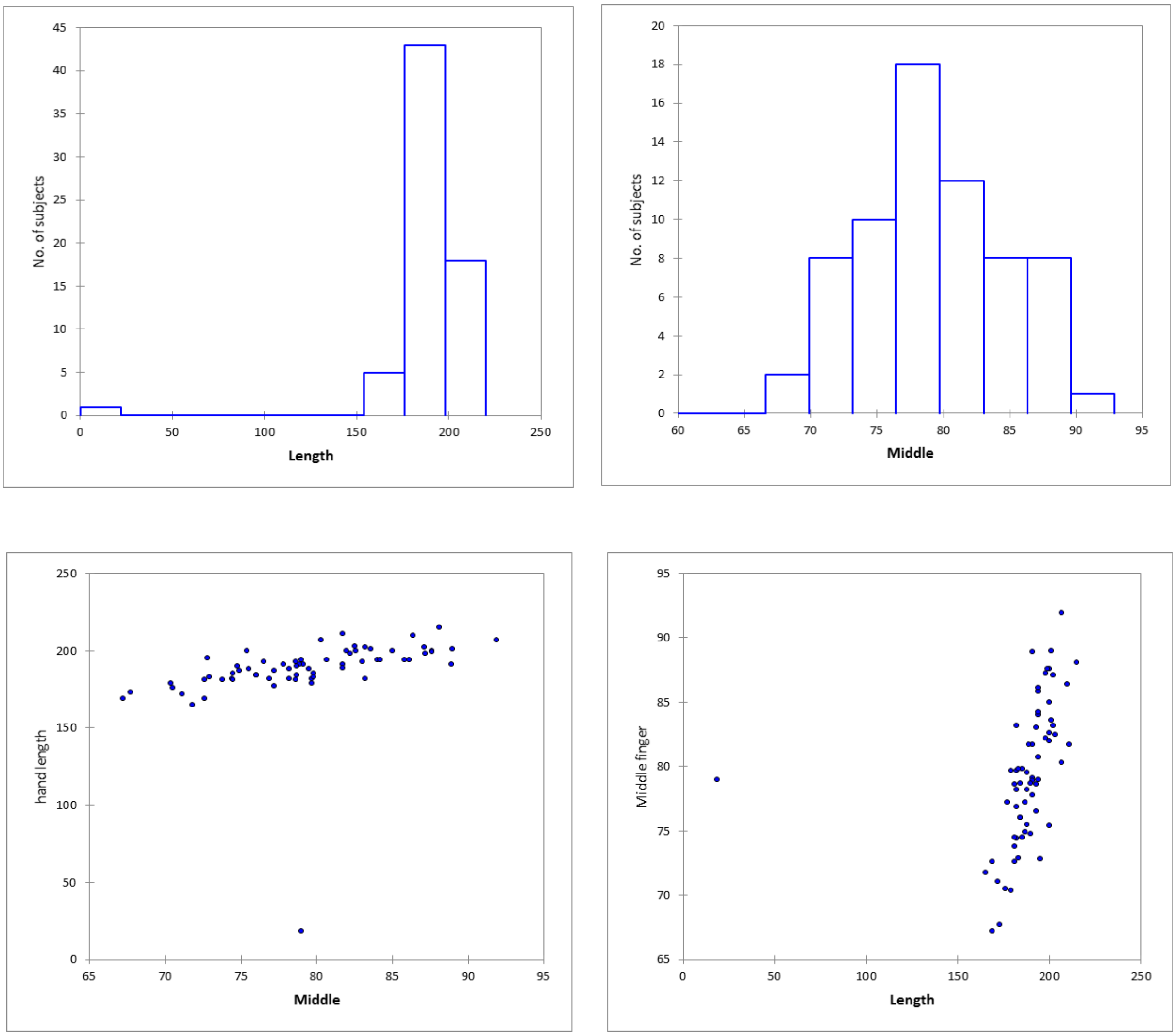


Figure 5.3.2.1: : Bar charts showing the distribution of hand length and hand breadth (top) and scatter plots of hand breadth and hand length (bottom)

5.3.3 Co-relation between Hand length-Thumb finger

Table 5.3.3.1 shows the correlation matrix of hand length and hand breadth. Figure 5.3.3.1 shows the bar charts showing the distribution of hand length and hand breadth and scatter plots between the same.

Table 5.3.3.1: Correlation Matrix of Hand length- Thumb finger

Variables	Correlation matrix (Pearson)		p-values:		Coefficients of determination (R^2)	
	Length	Thumb finger	Length	Thumb finger	Length	Thumb finger
Length	1	0.204	0	0.097	1	0.042
Thumb finger	0.204	1	0.097	0	0.042	1

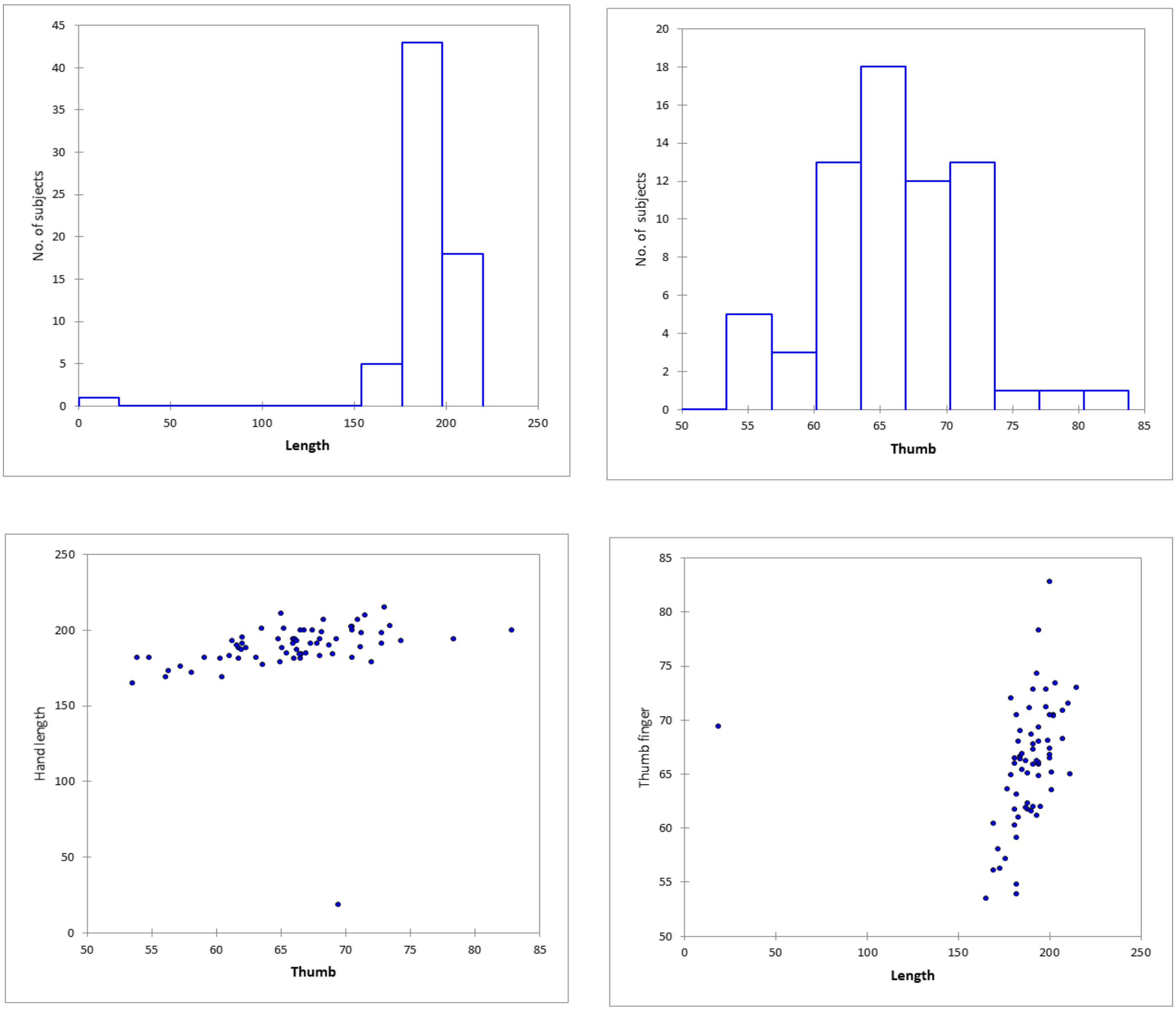


Figure 5.3.3.1: Bar charts showing the distribution of hand length and Thumb finger (top) and scatter plots of Thumb finger and hand length (bottom)

5.3.4 Co-relation between Hand breadth-Middle finger

Table 5.3.4.1 shows the correlation matrix of hand length and hand breadth. Figure 5.3.4.1 shows the bar charts showing the distribution of hand length and hand breadth and scatter plots between the same.

Table 5.3.4.1: Correlation Matrix of Middle finger- Hand Breadth

Variables	Correlation matrix (Pearson)		p-values:		Coefficients of determination (R^2)	
	Breadth	Middle finger	Breadth	Middle finger	Breadth	Middle finger
Breadth	1	0.514	0	0.000	1	0.264
Middle finger	0.514	1	< 0.0001	0	0.264	1

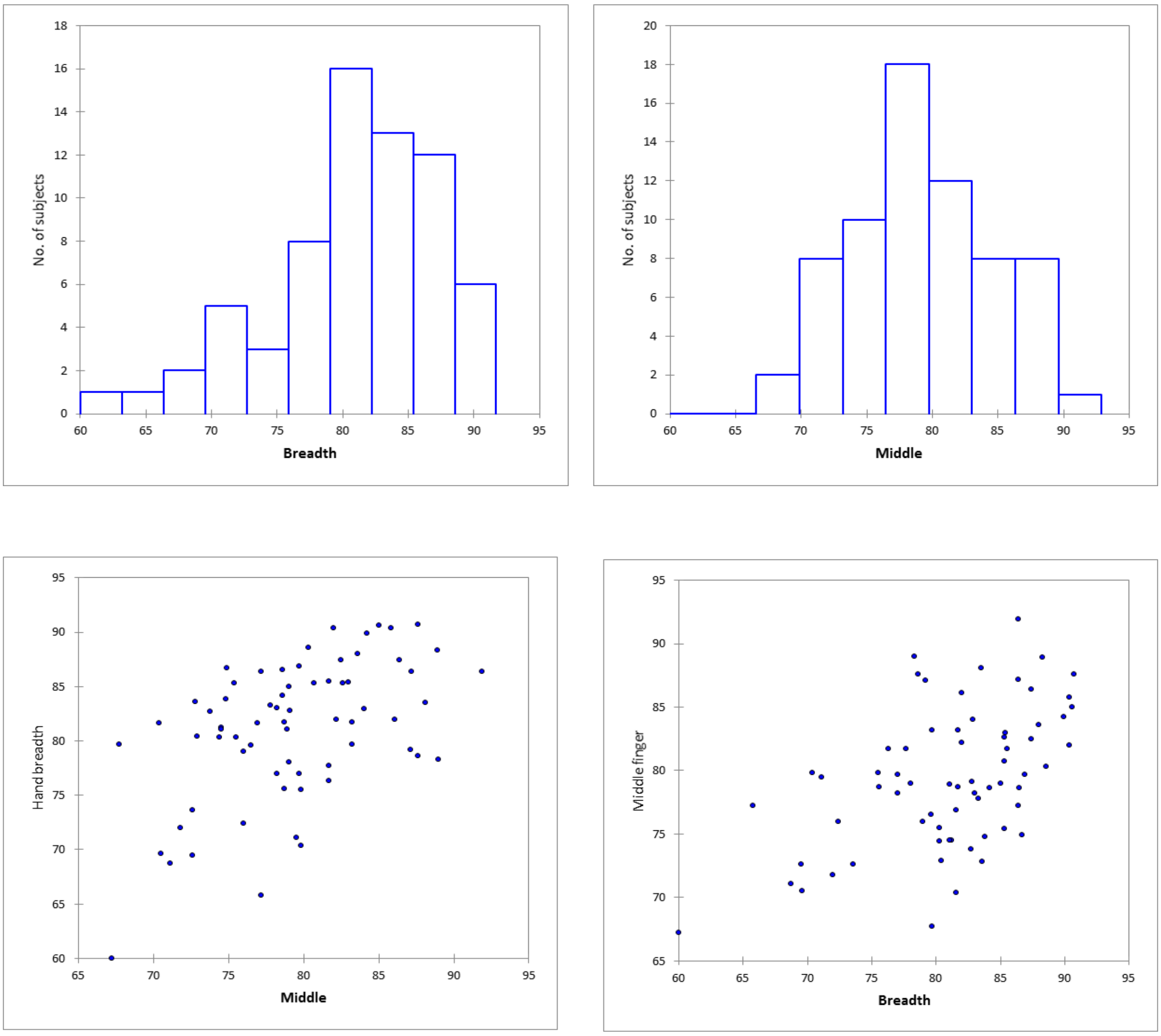


Figure 5.3.4.1: Bar charts showing the distribution of hand length and hand breadth (top) and scatter plots of hand breadth and Middle finger (bottom)

5.3.5 Co-relation between Hand breadth-Thumb finger

Table 5.3.5.1 shows the correlation matrix of hand length and hand breadth. Figure 5.3.5.1 shows the bar charts showing the distribution of hand length and hand breadth and scatter plots between the same.

Table 5.3.5.1: Correlation Matrix of Thumb finger- Hand Breadth

Variables	Correlation matrix (Pearson)		p-values:		Coefficients of determination (R^2)	
	Breadth	Thumb finger	Breadth	Thumb finger	Breadth	Thumb finger
Breadth	1	0.422	0	0.000	1	0.178
Thumb finger	0.422	1	0.000	0	0.178	1

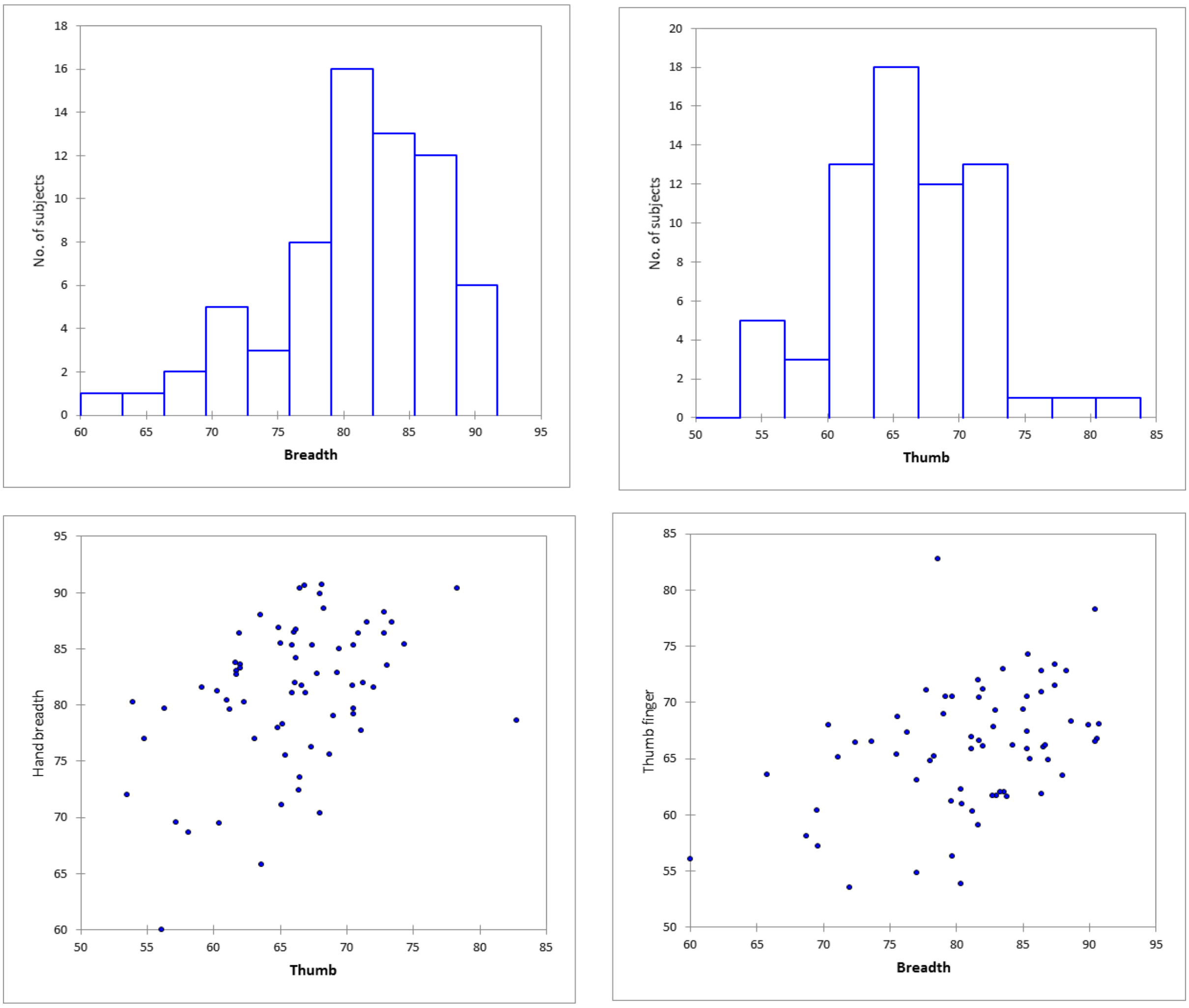


Figure 5.3.5.1: Bar charts showing the distribution of hand length and hand breadth (top) and scatter plots of hand breadth and Thumb finger (bottom)

5.3.6 Co-relation between Middle finger-Thumb finger

Table 5.3.1.1 shows the correlation matrix of hand length and hand breadth. Figure 5.3.1.1 shows the bar charts showing the distribution of hand length and hand breadth and scatter plots between the same.

Table 5.3.6.1: Correlation Matrix of Middle finger-Thumb finger

Variables	Correlation matrix (Pearson)		p-values:		Coefficients of determination (R^2)	
	Middle finger	Thumb finger	Middle finger	Thumb finger	Middle finger	Thumb finger
Middle finger	1	0.674	0	0.000	1	0.455
Thumb finger	0.674	1	< 0.0001	0	0.455	1

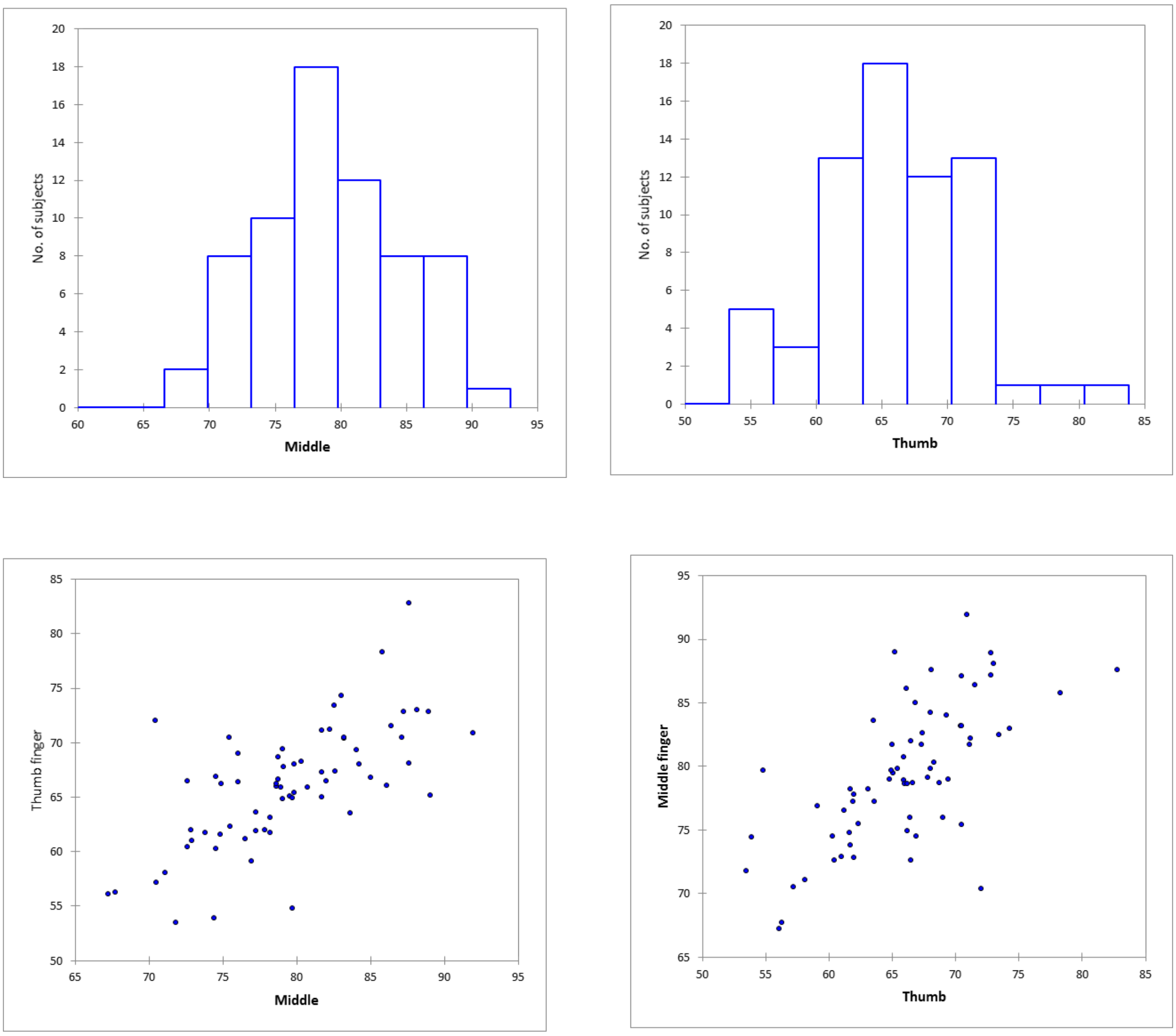


Figure 5.3.6.1: Bar charts showing the distribution of Middle finger-Thumb finger (top) and scatter plots of Middle finger-Thumb finger (bottom)

5.4 Normality tests

The normality tests were performed for hand length, hand breadth, length of middle finger and length of thumb finger. The normality test was conducted wing Shapiro-Wilk, Anderson-Darling, Lilliefors and Jarque-Bera test. The test interpretation was taken as H0: The variable from which the sample was extracted follows a Normal distribution. The risk to reject this hypothesis while it it true is calculated in percentage. The results are shown in Tables 5.4.1-5.4.3.

Table 5.4.1: Results of normality tests for anthropometric variables for Bihar

Variate	Test	Risk to reject the null hypothesis H0
Hand length	Shapiro-Wilk test	46.39%
	Anderson-Darling test	47.45%
	Lilliefors test	90.51%
	Jarque-Bera test	44.93%
Hand breadth	Shapiro-Wilk test	90.97%
	Anderson-Darling test	71.59%
	Lilliefors test	47.68%
	Jarque-Bera test	94.14%
Middle finger	Shapiro-Wilk test	21.42%
	Anderson-Darling test	8.94%
	Lilliefors test	19.09%
	Jarque-Bera test	97.42%
Thumb finger	Shapiro-Wilk test	9.13%
	Anderson-Darling test	4.94%
	Lilliefors test	2.80%
	Jarque-Bera test	24.01%

Table 5.4.2: Results of normality tests for anthropometric variables for Andhra Pradesh

Variate	Test	Risk to reject the null hypothesis H0
Hand length	Shapiro-Wilk test	91.37%
	Anderson-Darling test	79.92%
	Lilliefors test	63.40%
	Jarque-Bera test	80.52%
Hand breadth	Shapiro-Wilk test	97.03%
	Anderson-Darling test	86.51%
	Lilliefors test	90.18%
	Jarque-Bera test	89.22%
Middle finger	Shapiro-Wilk test	47.29%
	Anderson-Darling test	50.91%
	Lilliefors test	53.48%

Table continued……….

	Jarque-Bera test	62,95%
Thumb finger	Shapiro-Wilk test	50.12%
	Anderson-Darling test	21.69%
	Lilliefors test	19.76%
	Jarque-Bera test	93.11%

Table 5.4.3: Results of normality tests for anthropometric variables for Odisha

Variate	Test	Risk to reject the null hypothesis H0
Hand length	Shapiro-Wilk test	62.90%
	Anderson-Darling test	78.35%
	Lilliefors test	94.06%
	Jarque-Bera test	70.36%
Hand breadth	Shapiro-Wilk test	11.51%
	Anderson-Darling test	7.92%
	Lilliefors test	23.07%
	Jarque-Bera test	44.76%
Middle finger	Shapiro-Wilk test	70.12%
	Anderson-Darling test	61.96%
	Lilliefors test	57.68%
	Jarque-Bera test	44.14%
Thumb finger	Shapiro-Wilk test	39.86%
	Anderson-Darling test	50.95%
	Lilliefors test	58.28%
	Jarque-Bera test	66.06%

5.5 Subjective Ratings in Experimentation

The subjects were requested to rate the prototypes in two separate instances, once to determine the fitness and overall comfort of tool handle for the diameters calculated using Equations (1) and (2) and the other to determine the overall comfort of the tool handles of different cross-section shapes. In this section, an overview of the ratings provided by the subjects is detailed.

5.5.1 Subjective ratings for optimal diameter

The subjective ratings recorded for optimal diameter using experimental prototypes are shown in Tables 5.5.1.1 & 5.5.1.2.

Table 5.5.1.1: Overview of subjective ratings given by subjects for tool handle of 44 mm diameter

Subjective ratings for optimal diameter						
44 mm	Fitness into hand	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	No. of subjects	2	3	11	0	0
	Overall Comfort	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	No. of subjects	1	15	1	0	0

Table 5.5.1.1: Overview of subjective ratings given by subjects for tool handle of 44 mm diameter

Subjective ratings for optimal diameter						
35 mm	Fitness into hand	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	No. of subjects	9	7	1	0	0
	Overall Comfort	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	No. of subjects	10	6	1	0	0

5.5.2 Subjective ratings for Cross-section shapes

The subjective ratings recorded for cross-section shape using prototypes manufactured through rapid prototyping are shown in Tables 5.5.2.1.

Table 5.5.2.1: Overview of subjective ratings given by subjects for tool handles of various cross-section shapes

Comfort rating	Extremely uncomfortable	Moderately uncomfortable	Cannot say	Moderately comfortable	Extremely comfortable
	1	2	3	4	5
Triangle No. of Subjects	3	12	0	1	1
Pentagon **No. of Subjects**	0	2	10	5	0
Hexagon **No. of Subjects**	0	0	3	12	2
Cylinder **No. of Subjects**	0	0	1	15	1
Tri-Circle I **No. of Subjects**	0	0	0	7	10
Tri-Circle II **No. of Subjects**	0	0	2	9	6

5.6 Cluster Analysis

Cluster analysis was performed using agglomerative hierarchal clustering and K-means clustering. The hierarchal clustering provided with the value of K, the number of cluster to be divided using K-means. Using this K, the final clustering was done. The results are shown in Tables. The clustering was done using two-dimensional variables Hand length and Hand breadth. The second cluster in K-means analysis was chosen. This does not mean that this cluster is a representative sample for the whole population. This cluster was taken solely on the basis of availability of the subjects and their willingness to participate in this research study as subjects. The total number of subjects used in the clustering were 67. The second cluster in K-means contained 26 subjects. Out of whom 17 were willing to participate. These subjects were considered for further experimentation.

Table 5.6.1: Results of clustering using agglomerative hierarchal clustering

Class	1	2	3	4
Objects	42	18	6	1
Sum of weights	42	18	6	1
Within-class variance	52.325	40.053	38.903	0.000
Minimum distance to centroid	1.296	2.106	1.286	0.000
Average distance to centroid	6.598	5.701	5.163	0.000

Table continued……….

Maximum distance to centroid	14.046	12.133	7.950	0.000
Clustered Observations	Obs1	Obs8	Obs14	Obs36
	Obs2	Obs10	Obs19	
	Obs3	Obs12	Obs20	
	Obs4	Obs18	Obs26	
	Obs5	Obs22	Obs28	
	Obs6	Obs24	Obs29	
	Obs7	Obs34		
	Obs9	Obs39		
	Obs11	Obs43		
	Obs13	Obs44		
	Obs15	Obs45		
	Obs16	Obs46		
	Obs17	Obs49		
	Obs21	Obs50		
	Obs23	Obs52		
	Obs25	Obs53		
	Obs27	Obs59		
	Obs30	Obs62		
	Obs31			
	Obs32			
	Obs33			
	Obs35			
	Obs37			
	Obs38			
	Obs40			
	Obs41			
	Obs42			
	Obs47			
	Obs48			
	Obs51			
	Obs54			
	Obs55			
	Obs56			
	Obs57			
	Obs58			
	Obs60			
	Obs61			
	Obs63			
	Obs64			
	Obs65			
	Obs66			
	Obs67			

Table 5.6.2: Results of clustering using K-means clustering

Class	1	2	3	4
Objects	30	26	10	1
Sum of weights	30	26	10	1
Within-class variance	34.807	48.513	67.480	0.000
Minimum distance to centroid	1.058	0.198	1.239	0.000
Average distance to centroid	5.392	6.112	7.129	0.000
Maximum distance to centroid	9.969	14.922	11.758	0.000
Clustered Observations	Obs1	Obs7	Obs14	Obs36
	Obs2	Obs8	Obs15	
	Obs3	Obs10	Obs17	
	Obs4	Obs12	Obs19	
	Obs5	Obs16	Obs20	
	Obs6	Obs18	Obs26	
	Obs9	Obs22	Obs28	
	Obs11	Obs24	Obs29	
	Obs13	Obs30	Obs35	
	Obs21	Obs34	Obs57	
	Obs23	Obs39		
	Obs25	Obs40		
	Obs27	Obs43		
	Obs31	Obs44		
	Obs32	Obs45		
	Obs33	Obs46		
	Obs37	Obs49		
	Obs38	Obs50		
	Obs41	Obs52		
	Obs42	Obs53		
	Obs47	Obs54		
	Obs48	Obs56		
	Obs51	Obs59		
	Obs55	Obs62		
	Obs58	Obs65		
	Obs60	Obs67		
	Obs61			
	Obs63			
	Obs64			
	Obs66			

6 RESULTS AND DISCUSSION

6.1 Results

The procedure employed for the accomplishment of the objective is to first identify the right dimension of the cross-section through a brief subjective analysis followed by identification of right cross-section shape through subject's perception of overall comfort. This can be done only when a sample population upon which experimentation to be done is selected. This was done using agglomerative hierarchal clustering and K-means clustering. A cluster that was selected was experimented upon with procedures planned in the early stages of the project. The first result that has to be discussed is that of the selection of optimal diameter. As shown in tables 5.5.1.1 & 5.5.1.2, 9 out of 17 subjects rated the 35mm diameter handle to have better fitness and 10 out of 17 rated it have an overall good comfort. The results of 44mm diameter were comparatively less by a great margin. Hence, 35 mm diameter is considered as the optimal diameter.

The next step is to find out which of the identified cross-section shapes are better off. The subjective ratings are shown in table 5.5.2.1. The subjective ratings along with contact area of the subjects calculated for handle of each cross-section type were used to score the each handle. The scoring mechanism was kept simple. Equal weightages of 0.5 were given to normalized subjective ratings and the normalized ranking score of contact area of each handle, i.e. if cross section shape of triangle ranked 3 out of 6, the normalized score is 3/6 for a particular user. This score is multiplied with 0.5 and the score S_c score for contact area was calculated. Similarly, the score for subjective ratings S_s was calculated for each user. The final score of a cross-section type is obtained by summing the scores of all subjects. These values are shown in tables 6.1-6.3. The final score is denoted by S_T. The column with 'Sub No.' represents the identification of the subject who is under the selected cluster. The columns with 'Tri-Circle I' and 'Tri-Circle II' denote the orientations of the tool handle with thee cross section which is a combination triangle and circle. These two orientation are shown in Figure 6.1.

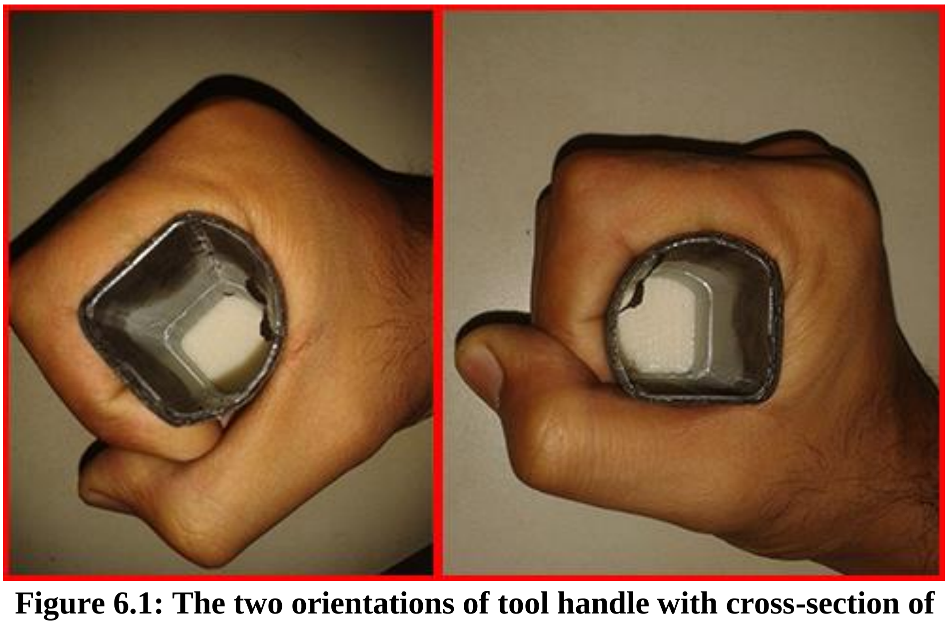


Figure 6.1: The two orientations of tool handle with cross-section of combination of triangle and circle

Table 6.2: Scoring of the tool hand on the basis of contact area

Sub No.	Rating						Score					
	Triangle	Pentagon	Hexagon	Cylinder	Tri-Circle I	Tri-Circle II	Triangle	Pentagon	Hexagon	Cylinder	Tri-Circle I	Tri_Circle II
10	2	3	3	4	4	5	0.2	0.3	0.3	0.4	0.4	0.5
34	1	3	3	4	5	3	0.1	0.3	0.3	0.4	0.5	0.3
8	2	3	4	4	5	4	0.2	0.3	0.4	0.4	0.5	0.4
24	4	3	4	5	5	4	0.4	0.3	0.4	0.5	0.5	0.4
12	2	4	4	4	4	5	0.2	0.4	0.4	0.4	0.4	0.5
18	2	3	4	4	4	5	0.2	0.3	0.4	0.4	0.4	0.5
39	2	2	4	4	5	4	0.2	0.2	0.4	0.4	0.5	0.4
22	1	4	5	4	4	4	0.1	0.4	0.5	0.4	0.4	0.4
45	5	4	4	4	4	5	0.5	0.4	0.4	0.4	0.4	0.5
44	2	4	4	4	5	4	0.2	0.4	0.4	0.4	0.5	0.4
16	1	3	4	3	5	4	0.1	0.3	0.4	0.3	0.5	0.4
62	2	4	5	4	5	5	0.2	0.4	0.5	0.4	0.5	0.5
56	2	2	3	4	5	4	0.2	0.2	0.3	0.4	0.5	0.4
59	2	3	4	4	5	4	0.2	0.3	0.4	0.4	0.5	0.4
43	2	3	4	4	4	3	0.2	0.3	0.4	0.4	0.4	0.3
49	2	3	4	4	5	4	0.2	0.3	0.4	0.4	0.5	0.4
47	2	3	4	4	4	5	0.2	0.3	0.4	0.4	0.4	0.5

Table 6.3: Total score calculated for each handle

Sub No.	Triangle	Pentagon	Hexagon	Cylinder	Tri-Circle I	Tri-Circle II
	S_C+S_S	S_C+S_S	S_C+S_S	S_C+S_S	S_C+S_S	S_C+S_S
10	0.28	0.47	0.72	0.90	0.73	0.75
34	0.35	0.38	0.47	0.73	1.00	0.72
8	0.28	0.72	0.73	0.57	1.00	0.65
24	0.48	0.55	0.57	1.00	0.83	0.82
12	0.28	0.65	0.57	0.40	0.73	1.00
18	0.28	0.72	0.90	0.73	0.65	0.67
39	0.28	0.53	0.82	0.65	0.67	0.90
22	0.18	0.73	0.67	0.65	0.82	0.90
45	0.67	0.73	0.48	0.65	0.82	1.00
44	0.28	0.82	0.65	0.57	0.83	0.90
16	0.18	0.63	0.90	0.72	0.75	0.57
62	0.28	0.65	0.67	0.82	0.83	1.00
56	0.28	0.45	0.47	0.73	0.92	0.90
59	0.28	0.55	0.57	0.82	1.00	0.73
43	0.28	0.47	0.90	0.65	0.82	0.63
49	0.28	0.47	0.65	0.90	0.83	0.82
47	0.37	0.72	0.73	0.65	0.48	1.00
S_T	5.35	10.23	11.45	12.13	13.72	13.95

6.2 Discussion

The final score of the tool handle in Table 6.3 showed that, the total score for the tool handle with cross-section of combination of triangle and circle was comparatively higher in orientation 2 than in orientation 1. However, most of the subjects opined that there was not much difference in the overall comfort of this tool handle. Despite this, orientation 2 fared better than orientation 1 because of the higher ranks obtained in surface contact area. This however, does not mean that the contact area of orientation 2 is far greater compared to orientation 1 or as a matter of fact to any other shape. There were instances where the contact area was differing in units of pixels. On the basis of technicality, a higher rank was assigned. Hence, decision was made to model both the orientations and prototype them for evaluation using questionnaire 3 and a simple standard task.

The scoring scheme assumed for the calculation of the total score applied equal weightages to both subjective ratings and contact area. This assumption was only made due to lack of any background work which could quantize the appropriate weightages. The fact that contact area is much closer to objective analysis, leads to a temptation to assume it has to be given a much higher weightage than the subjective ratings. Since the appropriate weightages are not yet determined the study was completed assuming equal weightages.

7 CONCLUSION

Grant, K.A., Habes, D.J., Steward, L.L. and **Seo and Armstrong** have come up with equations for optimal diameter for tool handle in separate research studies. These equations were the cue for the current research study [11, 12]. These equations simplified the task the determining the right dimension for power grip tool. It must be noted that both of these equations provide an optimal diameter for better grip strength. Thus, the dimension derived through these equations not only ensured greater subjective perceived comfort but also made sure that maximum grip strength can be obtained for a particular set. Here off, the task was streamlined to find an appropriate shape for cross-section and a profile that could enhance the user comfort. This was accomplished using the approach of subjective analysis as done in various research papers. Prior to this subjective analysis, data collection for anthropometric data of 67 subjects was carried out. These subjects were clustered and a cluster was selected for further experimentation. The overall comfort rating of various cross-section shapes is accompanied by the surface contact area of the subjects. A relatively new type of cross-section was appreciated by most of the subjects and this was supplemented by the high score in simple scoring scheme adopted. The two orientation are to be appreciated and hence it was decided that both of these orientations would proceed to the next step where the subjects evaluate on the basis of a simple task. The profile of the model was reverse engineered from an existing handle using a new approach through the application of a CAD software as discussed in section 3.3. The geometry of the profile with finger grooves is shown in Figure 6.2.1. The rendered model without finger grooves is shown in Figure and with Finger grooves is shown in Figure.

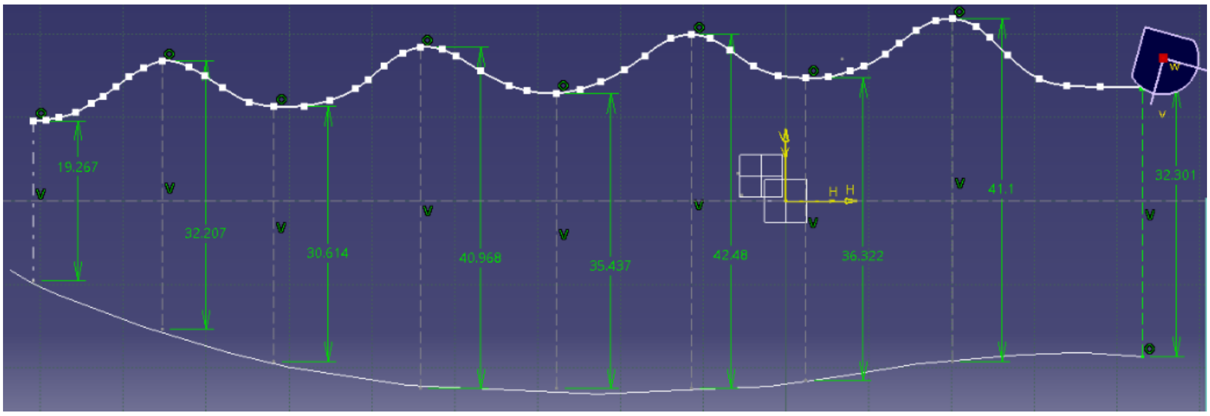


Figure 7.1: Profile of the tool handle showing the width of the cross section

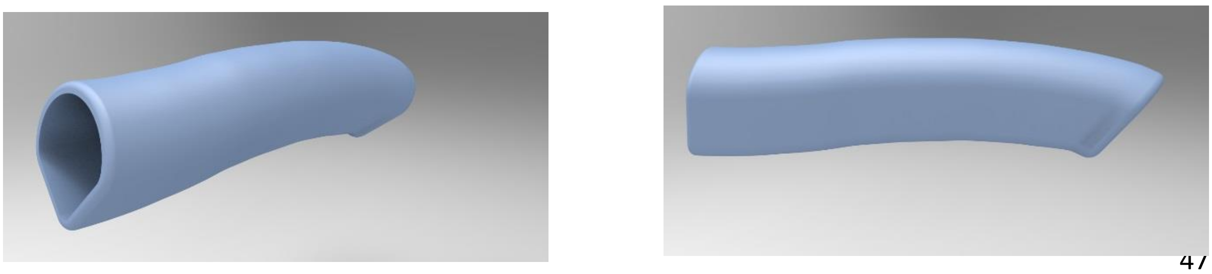


Figure 7.2: Rendered model of tool handle with groove

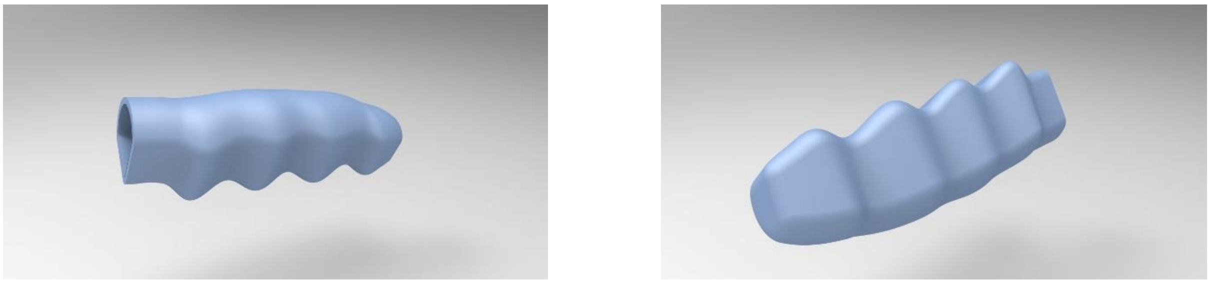


Figure 7.3: Rendered model of tool handle with finger grooves for orientation 1

Some of the shortcomings of this research study are worth noting. Firstly, the idea of using hand imprints relieves the need for costly equipment, it has to be verified for providing close by results using a pressure map. Secondly, an appropriate weightage set has to be determined for the contact surface area and the subjective ratings for better results. Thirdly, some of the factors for comfort in questionnaire for final evaluation were used directly from existing literature. It might happen that these factors are irrelevant to the Indian population or some other important factors were missed out. Apart from these three drawbacks in this research study, the comfort scale ratings were required to be more elaborate for the subjects.

7.1 Future Scope

The future scope of this research study can be discussed in two aspects, the first one being further work that has to be done and the second one being the varies paths that can be drawn to extend and supplement this study. Discussing the first aspect, CAD modelling of tool handle for orientation 2 is to be done and both of these models are to be prototyped. Following this, the prototypes are to be used for a subjective analysis through assignment of a simple and standard task to the subjects using questionnaire 3. The necessary changes according to the data obtained from this analysis must be used to change the design. This design is also to be verified using pressure mapping of the hand for regions of discomfort. The second aspect provides a broader view of what can be done further. The first thing that can be done is to replace the clustering method for sampling of the population with Gaussian plot sampling. Though the optimal diameters are 35 or 44 mm, a diameter between these two might exist which might be highly optimized. Design of experiments can be applied to find out this diameter. Regression analysis may be performed to find out a relation between the important anthropometric data variables and subject's overall perceived level of comfort. An objective analysis can be performed to define the shape of the tool handle anatomically rather than with primitives or combination of primitives.

REFERENCE

[1] Chris Baber, Cognitive aspect of tool use, Elsevier, Applied Ergonomics, Volume 37, Issue 1, January 2006, Pages 3-15

[2] L.F.M Kuijt-Evers, L Groenesteijna, M.P de Loozea, P Vinka, Identifying factors of comfort in using hand tools, Elsevier, Applied Ergonomics, Volume 35, Issue 5, Pages 453-458.

[3] L.F.M Kuijt-Evers, L Groenesteijna, M.P de Loozea, P Vinka, Identifying predictors of comfort and discomfort in using hand tools Applied Ergonomics, Volume 48, Issue 6, Pages 692-702

[4] Kuijt Evers, L.F.M., Vink, P., Looze, M.P. de, Comfort predictors for different kinds of hand tools: differences and similarities. International Journal of Industrial Ergonomics Volume 37, Issue 1, January 2007, Pages 73-84.

[5] Gregor Harih, Bojan Dolšak ,Tool-handle design based on a digital human hand model ,
International Journal of Industrial Ergonomics, Volume 43, Issue 4, July 2013, Pages 288-295

[6] Design M. Aptel, L. Claudon and J. Marsot, Principles of Hand tool, International Encyclopedia of Ergonomics and Human factors, Volume 1, 2001, Pages 947-950

[7] L.F.M. Kuijt-Evers, T. Bosch, M.A. Huysmans, M.P. de Looze, P. Vink, Association between objective and subjective measures of comfort and discomfort in hand tools, Elsevier, Applied Ergonomics, Volume 38, Issue 5, September 2007, Pages 643-654

[8] M. Braun and R. Schopp, Hand tools, International Encyclopedia of Ergonomics and Human factors, Volume 1, 2001, Pages 947-950

[9] Orawan Kaewboonchoo, Hiroichi Yamamoto, Nobuyuki Miyai, Seyed Mohamad Mirbod, Ikuharu Moriokai and Kazuhisa Miyashita,The Standardized Nordic Questionnaire Applied to Workers Exposed to Hand-Arm Vibration, Journal of Occupational Health 1998, Volume 40, Pages 218–222

[10] Danilo Corrêa Silva, Élen Sayuri Inokuti,e Luis Carlos Paschoarelli, Evaluation of discomfort in manual activities using hand mapping:the influence of age, Human factors in Design,2011.

[11] Christopher J. Garneau, Matthew B. Parkinson Optimization of product dimensions for discrete sizing applied to a tool handle, International Journal of Industrial Ergonomics 42 (2012) Pages 56-64

[12] Seo, N.J., Armstrong, T.J., 2008. Investigation of grip force, normal force, contact area, hand size, and handle size for cylindrical handles. Human Factors 50, Pages 734-744.

[13] https://www.assh.org/PUBLIC/HANDANATOMY/Pages/default.aspx

[14] I. Kuorinka, B. Jonsson , A. Kilbom, H. Vinterberg, F. Biering-Sorensen, G. Andersson and K. Jorgensen, Standardised Nordic questionnaires for the analysis of Musculoskeletal symptoms, Applied Ergonomics, Volume 18, Issue 3, Pages 233-237

[15] Steven L. Sauter, Naomi G. Swanson, Thomas R. Waters, Thomas R. Hales, and Robin Dunkin-Chadwick, Musculoskeletal Discomfort Surveys Used at NIOSH, Handbook of Ergonomics, Chapter 4, Pages 4-1-4-3

Appendix

I. Anthropometric data

Table A1: Anthropometric data for hand length, hand breadth, Middle finger length, thumb finger length

Subject No.	Age	Gender	Region	Hand length	Hand Breadth	Middle Finger Length	Thumb Finger Length
S1	20	M	WEST BENGAL	179	86.9	79.7	64.9
S2	22	M	ODISHA	188	80.3	75.5	62.3
S3	21	M	ODISHA	190	83.8	74.8	61.6
S4	23	M	ODISHA	182	77	79.7	54.8
S5	22	M	ODISHA	191	83.3	77.8	62
S6	20	M	ODISHA	194	78	79	64.8
S7	20	M	DELHI	195	83.6	72.8	62
S8	21	M	ODISHA	200	90.4	82	66.5
S9	22	M	A.P.	191	76.3	81.7	67.3
S10	21	M	BIHAR	200	90.6	85	66.8
S11	21	M	U.P.	185	81.1	74.5	66.9
S12	22	M	M.P	201	78.3	89	65.2
S13	22	M	ODISHA	182	79.7	83.2	70.5
S14	22	F	ODISHA	169	69.5	72.6	60.4
S15	22	F	U.P.	184	72.4	76	66.4
S16	22	M	JHARKHAND	194	82.9	84	69.3
S17	22	F	ODISHA	183	70.4	79.8	68
S18	22	M	ODISHA	210	87.4	86.4	71.5
S19	21	F	ODISHA	169	60	67.2	56.1
S20	22	F	BIHAR	165	72	71.8	53.5
S21	23	M	BIHAR	188	83	78.2	61.7
S22	23	M	ODISHA	207	86.4	91.9	70.9
S23	24	M	M.P	181	81.2	74.5	60.3
S24	23	M	ODISHA	200	85.3	75.4	70.5
S25	24	M	ODISHA	187	86.4	77.2	61.9
S26	22	F	ODISHA	176	69.6	70.5	57.2
S27	24	F	JHARKHAND	188	71.1	79.5	65.1
S28	23	F	ODISHA	172	68.7	71.1	58.1
S29	23	F	ODISHA	177	65.8	77.2	63.6
S30	22	m	M.P	194	89.9	84.2	68
S31	24	M	BIHAR	181	86.5	78.6	66
S32	22	M	WEST BENGAL	189	77.7	81.7	71.1
S33	25	M	BIHAR	193	79.6	76.5	61.2
S34	22	M	A.P.	207	88.6	80.3	68.3
S35	23	M	A.P.	173	79.7	67.7	56.3
S36	24	M	PUNJAB	18.6	85	79	69.4
S37	30	M	ODISHA	181	82.7	73.8	61.7
S38	27	M	ODISHA	187	86.7	74.9	66.2
S39	21	M	A.P.	200	78.6	87.6	82.8
S40	28	M	JHARKHAND	193	85.4	83	74.3
S41	23	M	CHHATTISGARH	191	88.3	88.9	72.8
S42	33	M	BIHAR	179	81.6	70.4	72
S43	23	M	M.P	198	82	82.2	71.2
S44	23	M	DELHI	199	90.7	87.6	68.1
S45	25	M	A.P.	200	85.3	82.6	67.4
S46	29	M	CHHATTISGARH	198	86.4	87.2	72.8
S47	30	M	A.P.	182		74.4	53.9
S48	22	M	A.P.	183	80.4	72.9	61
S49	22	M	A.P.	203	87.4	82.5	73.4
S50	21	M	A.P.	202	79.2	87.1	70.5
S51	22	M	A.P.	184	79	76	69
S52	19	M	A.P.	215	83.5	88.1	73
S53	20	M	A.P.	202	81.7	83.2	70.4

S54	20	M	A.P.	194	85.3	80.7	65.9
S55	20	M	A.P.	191	82.8	79.1	67.8
S56	22	M	A.P.	194	90.4	85.8	78.3
S57	21	M	A.P.	181	73.6	72.6	66.5
S58	21	M	A.P.	191	81.1	78.9	65.9
S59	21	M	A.P.	211	85.5	81.7	65
S60	23	M	U.P.	182	81.6	76.9	59.1
S61	23	M	U.P.	182	77	78.2	63.1
S62	23	M	U.P.	182	77	78.2	63.1
S63	22	M	BIHAR	184	81.7	78.7	66.6
S64	23	M	BIHAR	190	75.6	78.7	68.7
S65	23	M	BIHAR	194	82	86.1	66.1
S66	22	M	BIHAR	185	75.5	79.8	65.4
S67	23	M	BIHAR	193	84.2	78.6	66.2

Table A2: Anthropometric data for finger breadth

Subject No.	Thumb Finger		Fore-finger			Middle finger			Ring finger			Little finger		
S1	18.4	17	19.2	28.4	15.6	18.5	17.3	14.9	18.3	19	17.1	13.9	14.5	15
S2	16.7	26.3	13.5	16.6	17.9	14.1	17.1	15.5	13.9	15.6	13.4	11.3	13.5	14
S3	19.3	28.1	14.2	17.7	20.1	14.5	17.2	19.6	14.3	17.1	15.5	11.8	15.3	14
S4	18.6	23	14.2	17.5	17.7	14.8	19.1	17	14.2	16.8	14	12	14.6	13.4
S5	18.6	27.4	14.4	18.3	17.6	14.1	18.4	18.5	13.3	17.1	16.31	11.4	14.5	15
S6	18.3	25.6	14.1	17	19	15.2	17.7	15.9	14.2	16.2	14.1	12.7	14.4	14.4
S7	19.5	30	14.8	18.2	20.7	14.6	17.7	16.7	13.7	17.1	14.5	12	14.6	15.3
S8	20.7	26.4	16.6	20.5	19.5	16.8	20.7	17.8	15	19	17.1	13.9	17.1	15.1
S9	18.4	28	14	17	16	14.9	16.9	14.6	14.1	16.1	14	10.4	13	13.2
S10	21	29.4	16.5	19.5	17.8	16.8	19.4	16.6	15.2	18.3	16.3	13.5	15.9	14.3
S11	19.2	28.4	15.6	18.5	17.3	14.9	18.3	15.9	14.8	17.5	15.3	13.4	16.7	13.3
S12	18.6	24.8	14.5	17.7	15.2	15.1	18.1	15	13.9	16.6	14.8	12.7	14.6	14
S13	18.9	27.7	14.7	17.6	16.5	15.5	18.2	15.5	14.1	17	13.7	11.8	14.3	13.3
S14	16.8	16.2	11.5	14.6	14.5	13.1	15.2	14.4	12.3	14.6	13.8	10	12.9	12.2
S15	16	23.3	13.3	16.6	14.6	13.4	16	14.5	12.6	14.8	14.6	11.2	13.8	13.6
S16	19.4	27.2	13.8	16.5	15.7	14.8	16.4	15.9	14	16.1	14.8	12.6	13.6	14.1
S17	17.2	26.4	13.1	15.9	14.6	14	16	12.4	12	15	13.5	11.3	12.8	12.7
S18	19.6	27.6	14.7	17.3	14.8	15	17.9	14.7	14.6	17	15	12.5	14.8	14.1
S19	15.7	20.2	10.6	14.1	11.7	11.6	14.2	13.2	10.9	13.1	12	9.1	11	10
S20	16.2	22.5	12	14.8	14.5	12.9	15.3	14	12.5	15.3	14	11	13.5	13.3
S21	18.9	26.4	14.6	18.2	17.5	15.2	19.6	16.4	13.7	17.1	14.7	11.6	14.8	14.8
S22	20.1	27.7	16	19.3	17.5	17	20	18.6	16.2	19.4	16.9	15	16.9	15.5
S23	19.1	26.2	14	18.1	16.2	15.7	18.6	15.6	14.1	16.9	14.9	13.1	15.2	13.5
S24	18.1	28	16	19.1	17.3	16	18.3	16.1	15.1	17.2	15.4	14.1	15.1	16
S25	18.5	26	14.4	18	17	15.5	18.7	15.4	14.7	18.2	15.3	13.1	15.5	15.3
S26	15.2	20.4	12	14.6	13.8	12.6	14.6	12.8	11.9	13.8	13	9.7	12.5	12.1
S27	15.5	23.1	12.5	15.3	14	12.5	15.2	12.9	11.9	15.1	12.7	8.6	13.5	11.8
S28	16.8	21.5	12.2	15.3	13	12.7	15.6	12.9	11.8	14.2	12.1	10.5	12.5	10.9
S29	17.2	22.9	13.1	15.4	13.4	13.5	16.6	13.3	12.3	14.9	13.6	10	13.2	12
S30	19.9	26.8	15.1	19	17.8	15.7	19	15.6	14.4	18.3	15.2	13.3	15.2	14.7
S31	19.6	28.9	15.7	18.7	17.6	16.1	18.6	16.5	15.7	18.6	15.2	13.9	16.1	15.7
S32	18.3	25.2	14.6	17.5	16	15.4	16.6	14.1	14.4	16	13.6	12.3	14.6	13.5
S33	18.9	25	14.5	17.8	18.5	15.5	18.1	17.7	14.5	17.2	16.2	12.9	15.6	16.1
S34	21.2	29.3	16.2	20.2	16.1	19.3	17.3	15.1	17.8	15.5	13.7	14.8	15.8	16.1
S35	19.6	14.6	14.3	16.7	16.5	14.2	17.5	14.6	13.5	14.1	13.4	12.9	15.4	14.2
S36	20.7	26.8	15.8	18.9	20.4	15.6	18.7	17.9	14.1	17.6	15.2	17.7	15.4	16.2
S37	20.9	27.5	15.5	18	17.9	15.4	18.1	14.9	14.2	17.5	16.2	12.3	15.7	14.4
S38	19.5	28.3	14.7	18.6	19.7	15	18.4	14.8	14.4	18.4	15.9	18.4	15.4	13.6

S39	18.9	25.2	13.9	17.8	17.5	14.8	18.6	14.2	13.9	16.5	14.7	12	18.3	13.6
S40	21.5	27.8	16.3	19.9	19	16.3	19.2	15.8	14.9	18.4	15.3	13.9	15.9	15.2
S41	22.2	26.7	16.2	19.2	18	16.3	19.3	16	15.3	18.7	16.4	13.8	15.8	14.8
S42	19.2	26.6	15.6	17.9	18.7	15.3	18.7	15.4	14.4	18.3	14.7	13.7	15.9	14.8
S43	19.9	28.6	15.1	18.2	16.7	15.6	18.2	15.3	14.2	17.5	13.2	11.7	16.1	13.3
S44	21.1	28.8	15.2	17.7	18.4	16.3	18.2	17	14.1	18.8	15.1	13.2	15.6	14.5
S45	20.6	25.8	15.1	19.2	18.5	16.3	20.5	15.2	15.1	18.1	16.1	13.6	16.3	16.2
S46	18.2	29.1	16.3	19.2	18	16.2	19.8	15.9	15.7	17.7	14.4	13.2	18	14.7
S47	21.4	26.5	15	17.2	16.1	15.7	17.9	15.5	14.3	15.5	14.3	12.6	15.8	14.6
S48	18.4	25.4	13.7	16.8	15.4	13.7	17	14.2	13.6	16.1	14.4	12.5	13.3	13.8
S49	20.1	27.5	15.5	18.8	15.3	16.2	18.5	15.2	15.5	17.7	14.7	13.4	13.9	13.5
S50	20.1	26.9	14.6	17.6	15.4	14.3	18.9	13.6	14.1	17.1	12.5	12.8	15.2	13.3
S51	18	26	14.5	18.3	15.3	14.6	18.7	14.5	14.2	17	14	12.9	15	14.5
S52	20.5	25.8	14.9	18.1	16.3	15.3	19	15.1	14.8	18.6	14	13.2	15.8	13.5
S53	19	26.3	15	17.6	17.4	15.4	18.1	15.1	14.5	17.3	14.4	13.4	14.8	13.3
S54	19.8	26.7	14.8	17.4	16.3	15.1	18.1	15.3	14.8	17	14.7	13.2	13.8	13.3
S55	20.7	26.6	14.5	17.2	16.9	14.6	18.5	15.1	14.4	17.1	13	13	15.2	12.8
S56	20.8	29.6	15.6	18.6	19.6	16.1	19.8	17.6	15.9	18.6	16.3	14.4	16.9	17.3
S57	18.7	27.3	13.2	16.8	16.2	14.3	17.3	13.7	13.4	16.4	12.7	12.1	14.4	11.8
S59	21.2	26.6	15.8	18.8	19	15.4	19.1	15.1	14.3	17.5	14.9	13.5	14.9	13.9
S60	18.9	30	14.4	16.4	15.9	14.9	17.5	15.1	14.2	15.3	14.7	12.5	14.7	12.7
S61	19	24.6	14.9	17.8	15.1	14.8	18.1	14.5	14.2	17.2	13.5	12.9	14.6	12.3
S62	20.5	25.3	16.1	18.3	17.3	16.4	18.4	14.1	16.2	18.1	14.6	14	16.2	15.4
S63	18.5	25.2	15.1	17.9	15.2	15.8	17.7	13.9	14.8	16.5	18.7	13.6	16.1	13.4
S64	18.3	24.6	12.6	15.8	14.2	13	15.9	13.5	12.7	15.4	13	10.1	13.7	11.8
S65	18.9	27.2	14.9	17.1	16.7	15.2	18.1	15.5	14	17.3	14.7	12.3	15.6	11.2
S66	17.2	24.2	13.8	17.4	15.2	14.7	17.6	14.7	13.9	16.8	13.5	13.3	14.2	13.1
S67	19.1	26.2	14.8	17.7	16.5	14.7	17.3	13.8	14.3	16.4	13.7	12.7	14.3	12.2

II. Subject ratings during subjective analysis

i. Subject ratings for 44mm Diameter

S7

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	**3**	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	4	**3**	2	1

S8

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	**3**	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	**4**	3	2	1

S10

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	**3**	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	**4**	3	2	1

S12

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	**4**	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	**4**	3	2	1

S16

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	**3**	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	**4**	3	2	1

S18

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	**4**	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	**4**	3	2	1

S22

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	**3**	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	**4**	3	2	1

S24

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	**3**	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	**4**	3	2	1

S34

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	**4**	3	2	1

S44					
Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	**4**	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	4	3	2	1

S45					
Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	**4**	3	2	1

S39					
Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	**4**	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	**4**	3	2	1

S43					
Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	**3**	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	**4**	3	2	1

S49					
Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	**3**	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	**4**	3	2	1

S56					
Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	**3**	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	**4**	3	2	1

S59					
Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	**3**	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	**4**	3	2	1

S62					
Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	**3**	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	**4**	3	2	1

ii. Subjective ratings for 35 mm Diameter

S7					
Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	**4**	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	**4**	3	2	1

S8

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortabl e	Extremely Uncomfortable
	5	4	3	2	1

S10

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortabl e	Extremely Uncomfortable
	5	4	3	2	1

S12

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	**4**	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortabl e	Extremely Uncomfortable
	5	**4**	3	2	1

S16

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	**4**	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortabl e	Extremely Uncomfortable
	5	**4**	3	2	1

S18

Question					
Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortabl e	Extremely Uncomfortable
	5	4	3	2	1

S22

Question					
Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortabl e	Extremely Uncomfortable
	5	4	3	2	1

S24

Question					
Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortabl e	Extremely Uncomfortable
	5	4	3	2	1

S34

Question					
Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	**4**	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortabl e	Extremely Uncomfortable
	5	4	3	2	1

S44

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	4	3	2	1

S45

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	4	3	2	1

S39

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	4	3	2	1

S43

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	**4**	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	**4**	3	2	1

S49

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	**4**	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortable	Extremely Uncomfortable
	5	**4**	3	2	1

S56

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	**3**	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortabl e	Extremely Uncomfortable
	5	4	**3**	2	1

S59

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	**4**	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortabl e	Extremely Uncomfortable
	5	**4**	3	2	1

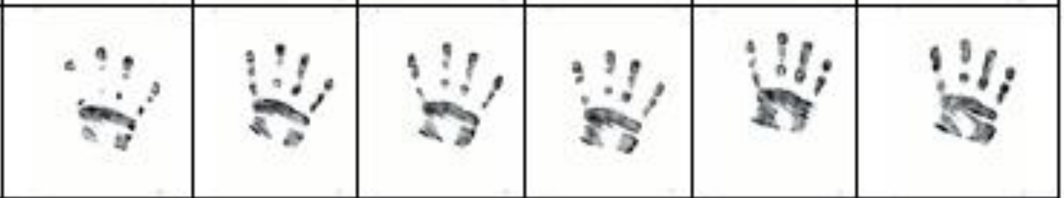
S62

Whether the tool fits into your hand comfortably (diameter-wise). Rate it on the scale provided	Fits Excellent	Fits Good	Fits just ok	Fits Worse	Fits Worst
	5	4	3	2	1
How do you rate the overall comfort of the handle?	Highly Comfortable	Moderately Comfortable	Cannot say	Moderately uncomfortabl e	Extremely Uncomfortable
	5	4	3	2	1

iii. Hand Imprints of subjects

Table A.3: Hand imprints of subjects

Subject No.	Triangle	Pentagon	Hexagon	Cylinder	Tri-Circle_I	Tri-Circle_II
10						
34						
8						
24						
12						
18						
39						
22						
45						

44	
16	
62	
56	
59	
43	
49	
47