A

Dissertation report

on

# "IDENTIFYING THE PREDICTORS OF COMFORT IN USING HAND TOOL (HAMMER)"

*Submitted in partial fulfillment of the requirements for the award of the degree of*

**MASTER OF TECHNOLOGY**

**IN**

**INDUSTRIAL ENGINEERING**


Submitted by

**DIPAYAN DAS**

**(2013PIE5151)**

Supervised by

**PROF. AWADHESH BHARDWAJ**

Department of Mechanical Engineering

MNIT


**DEPARTMENT OF MECHANICAL ENGINEERING**

**MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR**

**JUNE 2015**

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR
JAIPUR – 302017 (RAJASTHAN), INDIA

# CERTIFICATE

This is to certify that the dissertation entitled **"Identifying the predictors of comfort in using hand tool (Hammer)"** being submitted by **Dipayan Das (2013PIE5151)** is a bonafide work carried out by him under my supervision and guidance, and hence approved for submission to the **Department of Mechanical Engineering, Malaviya National Institute of Technology Jaipur** in partial fulfillment of the requirements for the award of the degree of **Master of Technology (M.Tech.) in Industrial Engineering**. The matter embodied in this dissertation report has not been submitted anywhere else for award of any other degree or diploma.

Place: Jaipur
Date:

**Prof. Awadhesh Bhardwaj**
Department of Mechanical Engineering
MNIT Jaipur

**MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR**
**JAIPUR – 302017 (RAJASTHAN), INDIA**

# CANDIDATE’S DECLARATION

I hereby declare that the work which is being presented in this dissertation entitled **“Identifying the predictors of comfort in using hand tool (Hammer)”** in partial fulfillment of the requirements for the award of the degree of **Master of Technology (M.Tech.)** in **Industrial Engineering**, and submitted to the **Department of Mechanical Engineering, Malaviya National Institute of Technology Jaipur** is an authentic record of my own work carried out by me during a period of one year from July 2014 to June 2015 under the guidance and supervision of **Prof. Awadhesh Bhardwaj** of the Department of Mechanical Engineering, Malaviya National Institute of Technology Jaipur.

The matter presented in this dissertation embodies the results of my own work and has not been submitted anywhere else for award of any other degree or diploma.

**Dipayan Das**
**(2013PIE5151)**

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

**Prof. Awadhesh Bhardwaj**
Supervisor

Place: Jaipur
Dated: June 2015

# PLAGIARISM DETECTION CHART

6/15/2015 originality report 15.6.2015 13-56-44 - dipyan das.pdf.html

## Plagiarism Detector - Originality Report:

Analyzed document:

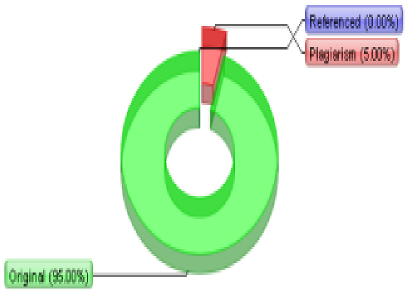
# "dipyan das.pdf"

Relation chart:

Warning: Demo Version - reports are incomplete!

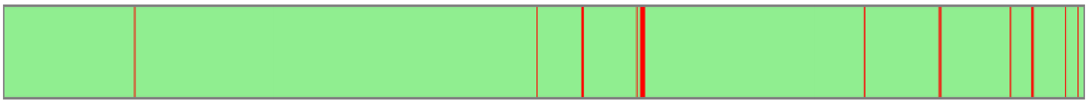
To get full version, please order the software:

Buy Now BlueSnap Take Charge




| | |
|---|---|
| Core version: | 874 |
| Size: | 91919 words |
| Registered to: | Originality report generated by unregistered Demo version! |
| Generated: | 2015-06-15 13:56:44 |
| License type: | Plagiarism Detector |

Distribution graph:



Top sources of plagiarism:

| | | |
|---|---|---|
| % 4 | Words# 686 | Demo mode! Please register! |
| % 3 | Words# 497 | Demo mode! Please register! |
| % 2 | Words# 507 | Demo mode! Please register! |

[Toggle other sources:]

Top referenced sources:

# ACKNOWLEDGEMENT

With great delight, I acknowledge my indebted thanks to my guide and mentor **Prof. Awadhesh Bhardwaj** who has always been a source of inspiration and encouragement for me. His stimulated guidance and unwavering support always motivated me to reach out for, and achieve higher levels of excellence. This dissertation could not have attained its present form, both in content and presentation without his active interest, direction and help. I am grateful to him for keeping trust in me in all circumstances. I thank him for being big-hearted with any amateurish mistakes of mine.

I express my sincere gratitude to **Prof. A.P.S. Rathore, Prof. G.S. Dangayach, Prof. Rakesh Jain, Dr. M.L. Mittal and Dr. Gunjan Soni** for their support and guidance throughout the course of study at MNIT Jaipur.

I highly acknowledge and duly appreciate the support extended by my seniors, colleagues-friends and juniors for their help & support in accomplishment of this work during my stay at MNIT Jaipur.

**- Dipayan Das**

# ABSTRACT

Comfort is a well-balanced state of physiological, psychological and physical factors of a human being and its environment. Before going to start the design of a comfortable hand tool, having the knowledge of comfort/discomfort is important. This research is aimed at identifying the factors that determine comfort in using hammer according to the users. Therefore, comfort/discomfort underlying descriptors are collected from literature. Then relatedness of a selection of the descriptors to comfort in using hammer is investigated. Principal component analysis is used to classify the descriptors into factors. Eight factors can be classified (functionality, body posture and muscles, tool characteristics, pain in hand or fingers, handle and hand interaction, quality, effects on palm, aesthetics). The factors that predict expected comfort at first sight and overall comfort after short time use are identified and their relationships with expected comfort and overall comfort are calculated. The main conclusions are (1) the same descriptors underlie comfort and discomfort in using hammer, (2) aesthetics is the most important factor of expected comfort with the beta value of 0.603 followed by handle and hand interaction with the beta value of 0.293, (3) functionality is the most imperative factor of overall comfort with the beta value of 0.685 followed by body posture and muscles, pain in hand or fingers, handle and hand interaction, aesthetics. Moreover, fits the hand and nice feeling handle are the expected comfort predicting descriptors whereas overall comfort predicting descriptors are easy in use, no inflamed skin, functional, easy to take along, relaxed working posture and low hand grip force supply.

***Keywords:*** comfort/discomfort, expected comfort predicting descriptors, overall comfort predicting descriptors, principal component analysis, expected and overall comfort predicting factors.

# CONTENTS

CERTIFICATE ........ i
CANDIDATE'S DECLARATION ........ ii
PLAGIARISM DETECTION CHART ........ iii
ACKNOWLEDGEMENT ........ iv
ABSTRACT ........ v
LIST OF FIGURES ........ vii
LIST OF TABLES ........ viii
CHAPTER 1: INTRODUCTION ........ 1
1.1 Comfort Measurement Techniques ........ 3
1.2 Design and Variations in Hammer ........ 4
1.3 Consideration for Selecting Subjective Measurement Technique ........ 4
1.4 Relevance to the Design Industry ........ 5
1.5 Objectives ........ 5
1.6 Structure of Dissertation ........ 6
CHAPTER 2: LITERATURE REVIEW ........ 8
2.1 Comfort in Scientific Literature ........ 8
2.2 Factors Affecting Comfort Experience of a Product ........ 8
2.3 Hand Tool Evaluation ........ 12
2.4 Different Comfort Models ........ 13
CHAPTER 3: RESEARCH METHODOLOGY ........ 15
3.1 Pre-Study ........ 15
3.2 Main Study ........ 16
3.2.1 Participants ........ 16
3.2.3 Limitations of the questionnaire ........ 17
3.2.4 Experimental setting ........ 17
CHAPTER 4: DATA COLLECTION ........ 19
4.1 Assumptions During Data Collection ........ 19
4.2 Data Collection ........ 19
CHAPTER 5: DATA ANALYSIS ........ 21
5.1 Descriptors as Predictors of Expected Comfort and Overall Comfort ........ 27
5.2 Factors of Expected Comfort and Overall Comfort in Using Hammer ........ 32

5.3 Factors as Predictors of Expected Comfort and Overall Comfort Experience ........... 34
CHAPTER 6: RESULTS & DISCUSSION ......................................................................40
6.1 Predicting Descriptors of Comfort in Using Hammer ................................................ 40
6.2 Identifying Factors of Comfort in Using Hammer .................................................... 42
6.3 Predicting Factors of Comfort in Using Hammer...................................................... 44
CHAPTER 7: CONCLUSION ...............................................................................47
7.1 Future Scope ........................................................................................................ 48
REFERENCES ..........................................................................................................49
APENDIX I...............................................................................................................53
APPENDIX II ............................................................................................................55

# LIST OF FIGURES

FIGURE 1: ADVERTISEMENT SLOGANS OF COMFORT IN HAND TOOL ...............................2
FIGURE 2: EMG MEASUREMENTS DURING SAWING TASK ...............................................3
FIGURE 3: ILLUSTRATION OF THE INTERACTIONS BETWEEN USER-HAND TOOL-TASK BY THE TRIANGLE WITHIN THE ENVIRONMENT (ILLUSTRATED BY THE LARGE CIRCLE) .9
FIGURE 4: NEWLY PROPOSED MODEL OF COMFORT BY VINK P. & HALLBECK S. (2012) ..........................................................................................................14
FIGURE 5: HAMMER EVALUATED IN THIS STUDY ...........................................................17
FIGURE 6: PROFESSIONAL WORKERS PERFORMING THE TASK.........................................18
FIGURE 7: UNPROFESSIONAL USERS PERFORMING THE TASK.........................................20
FIGURE 8: SCREE PLOT ......................................................................................32
FIGURE 9: BETA VALUES OF EXPECTED COMFORT PREDICTING DESCRIPTORS ...............40
FIGURE 10: BETA VALUES OF OVERALL COMFORT PREDICTING DESCRIPTORS...............41
FIGURE 11: CORRELATION COEFFICIENTS OF THE FACTORS RELATED TO EXPECTED COMFORT ..........................................................................................43
FIGURE 12: CORRELATION COEFFICIENTS OF THE FACTORS RELATED TO OVERALL COMFORT ..........................................................................................44
FIGURE 13: BETA VALUES OF THE FACTORS PREDICTING EXPECTED COMFORT .............45
FIGURE 14: BETA VALUES OF THE FACTORS PREDICTING OVERALL COMFORT...............46

# LIST OF TABLES

TABLE 1: DEFINITION OF COMFORT PROPOSED BY DIFFERENT AUTHORS ........................ 8
TABLE 2: DIFFERENT COMFORT INFLUENCING FACTORS FOR DIFFERENT TYPE OF PRODUCTS ........................ 10
TABLE 3: DEMOGRAPHY OF THE PARTICIPANTS ........................ 16
TABLE 4: HYPOTHESIS TEST SUMMARY ........................ 21
TABLE 5: CORRELATION COEFFICIENTS OF THE DESCRIPTORS WITH RESPECT TO EXPECTED COMFORT & OVERALL COMFORT ........................ 26
TABLE 6: RESULTS OF MULTIPLE REGRESSION FOR EXPECTED COMFORT AT FIRST SIGHT ........................ 27
TABLE 7: RESULTS OF MULTIPLE REGRESSION FOR OVERALL COMFORT AFTER SHORT TIME USE ........................ 29
TABLE 8: FACTOR LOADINGS OF THE DESCRIPTORS (PCA WITH VARIMAX ROTATION) ONLY THE FACTOR LOADING > 0.4 ........................ 33
TABLE 9: CORRELATION COEFFICENTS OF THE FACTORS WITH RESPECTED TO EXPECTED COMFORT AND OVERALL COMFORT ........................ 34
TABLE 10: RESULTS OF MULTIPLE REGRESSION OF THE DESCRIPTORS FOR EXPECTED COMFORT AT FIRST SIGHT ........................ 35
TABLE 11: RESULTS OF MULTIPLE REGRESSION OF THE FACTORS FOR OVERALL COMFORT AFTER SHORT TIME USE ........................ 37

# CHAPTER 1: INTRODUCTION

Almost every person in this world uses hand tools like scissors, knives, forks etc. in their daily life. A significant proportion of these people also use hand tools like hammers, chisels, pliers, screw drivers and trowels during their work. There are some jobs which cannot be completed without these non-powered hand tools like the work of carpenters, maintenance workers, surgeons. So these non-powered hand tools are always been an important element of work and production systems.

Hand tools are being used by people over a million years but the design of the tools did hardly change during the last century. So it has always been an important issue to reconsider the design of hand tools to avoid discomfort feelings of the workers during the job, to reduce musculoskeletal disorders on a longer term, to improve workers' productivity as better comfort helps to enhance job satisfaction and makes the people work more efficiently. Therefore, it is imperative to prevent workers from discomfort and this can be achieved by appropriate design of the hand tool.

In recent years, the design approaches have changed quite a lot. New notions like increase comfort, reduce biomedical loads and improve physical interactions regarding workers' functional capacities have been introduced into tool design. Now in these days of product customization it may be quite normal to order a hand tool with a fully custom-made hand grip for a hand tool. These developments on customization can make it possible to more easily adapt the design to personal preferences. This will give the opportunity to provide higher individual comfort levels in the tool design. Therefore, in the near future comfort may become an even more important issue in hand tool design with respect to these developments.

Moreover, manufacturers and distributers have already recognized comfort as a major selling factor as people would like to buy only those hand tools which are comfortable to use and free from the chance of any type of musculoskeletal disorders. The following figure 1 illustrates the different advertisement slogans of comfort in using hand tool which were collected from internet.


Figure 1: Advertisement slogans of comfort in hand tool

However, there is no widely accepted definition of comfort; there are three very common issues about comfort which are globally accepted:

1. Comfort is subjectively defined personal nature.
2. Comfort is a reaction to the environment.
3. Comfort is affected by various factors e.g., physical, physiological, psychological.

In the past, tools were designed to respond to the needs of greatest possible number of users. So the focus was always on the work-side of the tool. Very less importance was given to the handle side of the hand tool. But in recent years more attention is being given to the avoidance of discomfort in hand tool design and for that the handle side of the tool is being considered as an important part too. Different hand grips like two component grips, soft grips are being used to improve comfort level and avoid work related musculoskeletal disorders. Not only different hand grips, designers are trying to modify the tool handle design as well so that it can fit user hand more perfectly and make the user feel comfortable.

The purpose of this investigation was to gain better understanding of the descriptors that underlie comfort in using hammer. Understanding which of these descriptors are predictors of comfort. This understanding has the potential of helping designers in designing of comfortable hammer. In addition, the results can be of help to develop a questionnaire to evaluate comfort in using hand tools.

## 1.1 Comfort Measurement Techniques

As comfort is a matter of personal nature there are two methods which are often used to evaluate hand tools and they are:

1. Subjective measurement
2. Objective measurement

Subjective measurements are made when hand tools are evaluated with respect to comfort or discomfort. The most common subjective method to asses comfort is using a comfort questionnaire. In this method every subject is asked to perform any specific task with the hand tool of which comfort or discomfort level is going to evaluate. Then they are asked to fill the comfort questionnaire where each descriptor is rated on a 7-pont scale ranging from 1 (for totally uncomfortable) to 7 (for fully comfortable). Some times this rating is given on 5-point scale or 10-point scale. This method to asses comfort has some disadvantages like it fails to explain why subjects experience more or less comfort while using the hand tool and how to improve hand tool design.

In case of objective measurement technique Electromyography (EMG) is often used in hand tool evaluation to obtain muscle effort, muscle activity, muscle fatigue and physical or muscle strain. It is also used as an indirect measurement technique to estimate force requirements. An example of EMG measurement is shown in figure 2.

Figure 2: EMG measurements during sawing task

It can only predict the physical aspects in achieving total comfort but does not directly correlate to the subjective comfort rating value.

The relationship between objective measurement with comfort and discomfort experience in using hand tools is still unknown. Body posture measurement could find the relationship between joint angles and comfort as it is obtained from static posture. But these results can't explain the relationship with hand tool use which is mostly a dynamic action. So these relationships should be studied in order to find an objective measurement which can support the subjective ratings of comfort and discomfort.

## 1.2 Design and Variations in Hammer

A hammer works with greater power than any other hand tools. It delivers a blow (a sudden impact) to the intended target and basically used to drive nails, fit parts, forge metal and break apart objects. Hammers can be classified according to their shapes, sizes, structure and depending upon their use. Most of the hammers are non-powered but there are also some powered versions such as power hammers-for heavier uses. Hammers are consist of two parts i.e., head and handle. The essential part is head, a compact solid mass consists of a flat surface on one side to provide the blow to the intended target without itself deforming and the opposite side may have different shapes like 'V' shape, ball pein, cross and straight pein etc.

In the present investigation a claw hammer is used to identify the comfort predictors with the help of questionnaires. Claw hammers are mostly used as tool for pounding nails into or extracting nails from, some other object. A claw hammer roughly looks like the letter "T" with the handle being the long part and the head being the line across the top which looks like a "t". One side of the head has flat surface and the other side curves down and splits in the middle forming a "V" shape. The flat surface may be smooth or textured which is used for impacting another surface. The claw part of the head is used to remove nails from any object. The function of the handle of the hammer is not only to keep users hand away from the point of impact, it also provides a broad area that is better suited for gripping and comfort so that the user can use the tool more efficiently and feel less pain.

## 1.3 Consideration for Selecting Subjective Measurement Technique

Dumur et al. (2004) defined comfort as a mixed concept of feeling, situation, mood and perception. There is no absolute standard of feeling, mood and perception. So "truth by consensus method" is used to measure physical comfort (Lucker et al.). Comfort experience of a product is highly influenced by the human factor. Frederick A. Muckler (1992) found that empirical examples taken from several domains related to human factor show instances in which self-report (subjective) measures may be essential.

Furthermore, some sciences e.g., sociology, psychology and political science derive their data points from human observers. According to Kuijt-Evers et al. (2003) comfort is subjective, personal experience and reaction to the environment affected by various factors e.g., physical, physiological, psychological.

The objective of the current study is to identify the comfort predictors and for that subjective experience of the users is very important to study. Subjective measurement technique clearly indicates comfort as a construct of a subjectively defined personal nature (Kuijt-Evers et al.). Though, it may be useful to subjectively measured comfort experience to be supported by objective data.

## 1.4 Relevance to the Design Industry

There are three market segments can be identified in hand tool design which are named as low-price, medium-price and high-price category. For the low-price category hand tools are produced by mass production where the manufacturer tries to produce their products as cheap as possible because the hand tools from this category are mostly used by people who rarely use hand tools in and around their homes. Hence, the persons who use hand tools very rare will not be interested in comfort. Moreover, by addressing comfort in the design process the low-price hand will become more expensive and the people using hand tool from low-price category do not want to spend much money for hand tools.

The hand tools from other two categories are used by professional end-users and experienced Do-It-Yourself users. As these people use the hand tool very often and for a longer period of time comfort is an important issue for those categories. Therefore, they always try to buy hand tools that are more satisfactory to them and increase their work efficiency whether it is expensive or not does not matter.

In last decades, the focus of the design of hand tools was on the working side of the hand tool but now the design approach has changed and more attention is being paid to the avoidance of discomfort in hand tool design. Two component grips and soft grips with new materials are being used to provide comfort. So to stay ahead of competition the hand tool manufacturers need to address the problems with work-side and the hand-side simultaneously with a special attention for comfort.

## 1.5 Objectives

The key objectives of this dissertation are as follows:

### 1.5.1 Identifying the descriptors underlying comfort and discomfort

Review articles and research papers related to ‘hand tools’, ‘comfort descriptors’, ‘discomfort descriptors’, ‘satisfaction and tools’, ‘ergonomics and tools’, ‘usability and hand tools’, ‘ergonomics and hand tools’ helped to collect a list of descriptors related to comfort and discomfort in using hand tools.

### 1.5.2 Finding out whether different descriptors would underlie comfort and discomfort or not

Making of a ‘complete’ list of descriptors by ruling out the descriptors of same meaning collected from literature & rating it on a three point scale by the professional and unprofessional users of hammer for comfort and discomfort separately helped in achieving this objective.

### 1.5.3 Identifying the predicting descriptors of expected comfort at first sight & overall comfort after short time use of hammer

A comfort questionnaire for hammer containing the questions of expected comfort and overall comfort along with the descriptors & rating it on a seven point scale by the same respondents and statistical analysis of it helped in identifying.

### 1.5.4 Grouping the descriptors into factors and identifying the predicting factors of expected and overall comfort in using hammer

Use of IBM SPSS Statistics 22.0 for principle component analysis with varimax rotation & multiple regression (forward selection procedure) helped to find out expected as well as overall comfort predicting factors in using hammer.

## 1.6 Structure of Dissertation

The following seven chapters are in the dissertation report:

- **Chapter 1 – Introduction –** Discusses the background of the research, overview of the study, and it's relevance to the industry. Objectives of the research are also included in this chapter and at the end of the chapter the structure of the dissertation are described.
- **Chapter 2 – Literature Review –** This chapter covers the literature review on consequences of comfort and discomfort experiences in using different kind of products. Consequences are identified from analysis of previous literature. These factors are compiled in the tabular form and description is also given in this chapter to get the better understanding of the comfort and discomfort experiences. Different comfort models proposed by different authors are also discussed in this chapter.
- **Chapter 3 – Research Methodology –** Describes the methodology followed in conducting this research work. Discusses about the subjective measurement technique. This chapter describes the area of research. A comfort questionnaire for hammer and how it is rated are also discussed here.
- **Chapter 4 – Data collection –** Describes the procedure of data collection using comfort questionnaire for hammer. Discusses about the assumptions considered during the questionnaire survey.
- **Chapter 5 – Data analysis -** Responses from the survey are analysed in this chapter. IBM SPSS Statistical 22.0 is used for Mann-Whitney U test, multiple regression and principal component analysis.
- **Chapter 6 – Result and Discussion –** In this chapter after the analysis of the data, the results drawn from the analysis is discussed. The difference of the current study from other studies is explained in this chapter.

- **Chapter 7 – Conclusion –** This is the last chapter of the dissertation which contains what can be concluded from the results of the current study and how can it help in further studies and industries.

# CHAPTER 2: LITERATURE REVIEW

Since the last one decade or so extensive research work has been in progress in the field of minimizing discomfort and risk of musculoskeletal disorder in using hand tools the matter content available on the topic is found to be highly scattered in literature. An attempt has been made in this chapter to present the matter content in a systematic manner.

## 2.1 Comfort in Scientific Literature

A number of studies were found associated with comfort where the authors defined comfort differently, so there is no common definition of the term and the summary of the different definitions defined by different authors is given by the following table 1.

Table 1: Definition of comfort proposed by different authors

| Authors | Definition of comfort |
|---|---|
| Dumur et al. (2004) | A mixed concept of feeling, situation, mood and perception. |
| Kuijt-Evers et al. (2003) | A subjective, personal experience, reaction to the environment affected by various factors e.g., physical, physiological, psychological. |
| Keith Slater (1985) | A pleasant state of physiological, psychological and physical balance between a human being and its environment. |
| Larry G. Rechards (1980) | A state of a person involving a sense of subjective wellbeing in reaction to an environment or situation. |
| Peter Vink (2004) | A personal experience, it can never be comfortable itself. It's use makes it comfortable |
| Vink, P., & Hallbeck, S. (2012) | It is seen as pleasant state or relaxed feeling of a human being in reaction to its environment. |
| Gilman, E. W. (1989) | A state or feeling of having relief, encouragement and enjoyment. |
| M.P. de Looze et al. (2007) | 1. A construct of a subjectively defined personal nature.<br>2.Affected by factors of various nature (physical, physiological, psychological)<br>3. Reaction to the environment. |

## 2.2 Factors Affecting Comfort Experience of a Product

From these different definitions proposed by different authors it is very clear that comfort is a complex concept and is a mix of feelings, mood, perception and situation

(Dumur et al.). Comfort is basically a personal experience and a reaction to the environment. So a product can never be comfortable in itself. It only becomes comfortable (or not) in its use (Vink, P.). Interaction between product, user and its environment may affect comfort experience. User characteristics, environment characteristics and product properties also play an important role. Figure 3 illustrates these interactions.

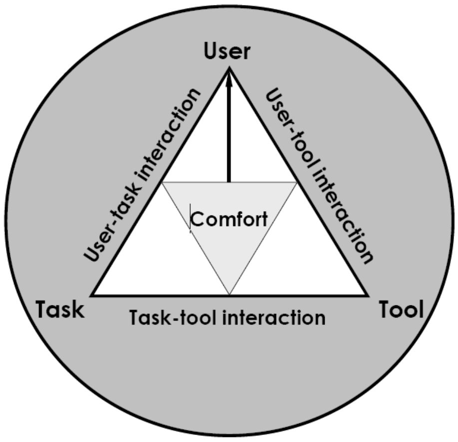



Figure 3: Illustration of the interactions between user-hand tool-task by the triangle within the environment (illustrated by the large circle)

The relationship between user-tool-task is illustrated by the triangle within the environment (illustrated by the circle) in fig. 3.

### 2.1.1 User

User is a person who experiences comfort is placed at the top of the triangle. The task a user performs, the tool he/she uses and the environment in which he/she works will influence his/her perception. There are some factors which also may affect his/her experience like user's history (Vink, P. et al.), sociological factors (Dumur et al.). In case of hand tool users, user's history may also be affected by education or experience of family members. The personal state is another aspect which also affects user's experience.

### 2.1.2 User-tool interaction

In user-tool interaction user receives two type of inputs i.e. tactile input and visual input (Vink, P. et al.). Tactile input deals with physical comfort by holding the tool in hand whereas visual input by looking at the tool (Dumur et al.). User-tool interaction is very important to improve comfort level as mismatch between handle size of the tool and hand anthropometry can decrease comfort experience (Das, B. et al.). However, visual impressions of a handle may not always meet the experience when using it. So user-tool interactions can sometimes be conflicting.

### 2.1.3 User-task interaction

Comfort experience may be affected by the task which the user has to perform. Postures and movements of the body parts involved in the task play an important role to determine comfort level (Kee D. & Karwowski W.). Physical capacity of the users is also important as it determines the physical response to external exposure (Kuijt-Evers et al.). So user-task interaction, consists of postures, body part movements and physical capacity, may affect the comfort experiences of the users.

### 2.1.4 Hand tool-task interaction

This interaction may influence comfort experience in two ways. First the comfort level is influenced by material comfort which means the tool should fulfill the basic needs (Dumur et al.). The hand tool should be suitable to perform the required task. Secondly awkward postures while performing the task influence the comfort experience (Chaffin, D.B. eta al.). Due to improper hand tool-task interaction users may have to perform the task in awkward positions which may cause discomfort experience to the users.

### 2.1.5 Work environment

Work environment of worker consists of physical work environment and social work environment. Physical work environment consists of vibration, noise, smell, temperature, humidity which is supposed to be aspects that affect the comfort experience (Vink, P., & Hallbeck, S.). Whereas social work environment deals with conformity comfort which means people want to feel they belong to a group and not outsiders (Dumur et al.).

Some authors have made specific additions to the new knowledge in the field of comfort for different products. Table 2 illustrates different factors which influences comfort in different fields.

Table 2: Different comfort influencing factors for different type of products

| Specific Addition | Author | Study | Conclusion |
|---|---|---|---|
| Sensory input | De Korte et al. (2012) | The focus was on comfortable VDU or computer work. It has been found that vibrational feedback is more comfortable than feedback via screen as it does not interfere with the primary task like word processing. | Different sensory channels can influence comfort. |
| | Vink et al. () | For airplane passengers' comfort is obviously related to knee space. However, a relationship was found with the positive attention of the crew which shows apart from the physical load, form and firmness can also influence seat comfort experience. | Soft factors like personal attention influence comfort. |

| Specific Addition | Author | Study | Conclusion |
|---|---|---|---|
| Activities | Ellegast et al. (2012) | While performing office tasks in both a naturalistic office setting and in a laboratory five different office chairs did not show much difference in the effects on the human body and discomfort. | Role of the context and specific activity influence comfort experience. |
| | Groenesteijn et al. (2012) | If the chairs are compared by activity type then the differences are visible like “swing system” chair is comfortable for computer work while for telephoning a chair with active longitudinal seat rotation is good, and a chair with a three dimensionally moveable seat is for desk work. | |
| Different body regions | Franz et al. (2012) | Various foam characteristics were tasted to define the most comfortable headrest. It has been found that for increasing comfort neck support is also required along with the head. | Material characteristics in the contact area differ according to the body region which may influence comfort experience. |
| | Kong et al. (2012) | It appeared that comfort in the palm in of the hand was more related to the force levels than at the fingers. | |
| Contour | Kamp. (2012) | The focus was on the tactile experience influencing comfort in seating. It has been found that the hard seats with high side support are appreciated by the sporty drivers and softer seats are better for more luxurious cars. | Forms following the human body contour and individual preferences influence comfort. |
| | Noro et al. (2012) | The aim was to analyze the form of cushions which appears to follow the buttock form closely and can be used in long-term static sitting in order to improve comfort experience. | Forms following the human body contour and individual preferences improves comfort experience |

The papers of these authors clear the idea about the factors of comfort and discomfort for different products. A number of descriptors underlie these factors such as irritation in hand, cramp of muscles, inflamed skin of hand, numbness in fingers which are related to different body regions; shape of the handle, styling of the handle are related to contour; good force transmission, high task performance, functional, easy in use are related to the functionality or performance of the tool; body part ache, fits the hand, nice feeling handle are related to the user-tool interaction.

M.P.Looze et al. (2004) give a brief list of descriptors related to comfort and discomfort such as reliability of the tool, force exerted from the tool, weight of the tool, handle size of the tool, offer comfortable working posture while performing with the tool, slippery handle of the tool, solid design of the tool, pressure on the hand, easy to take along, color of the tool etc.

## 2.3 Hand Tool Evaluation

An ergonomic evaluation should include estimation of force requirement, human performance and the repetitiveness of the task (Armstrong et al.). From the past years hand tool evolution studies have been carried out with several objectives. One of these objectives was to develop general predictive models of human performance with hand tools, as well as associated workplace design (Dempsey et al., McGorry et al.). Another objective was to recognize ergonomically well designed hand tools which should reduce the chance of musculoskeletal disorders and increase productivity (Kluth K. et al., Groeinesteijn et al.) and also to optimize the product characteristics and provide guidelines to the designers (Das, B. et al., Eksioglu M.).

Hand tools can be differentiated with respect to their work side, hand side or both. The work side of the hand tool can vary in shape, sharpness and blade angles for knives (Dempsey et al.), different coating materials for axes (Niemella T. et al.). The new design of the hand side of the tool i.e., handle is often studied (Harih G. & Dolsak B.). There are two types of hand tool evaluation techniques i.e., subjective method and objective method.

Subjective measurement technique is often used when hand tools are evaluated with respect to comfort or discomfort (Boyles et al.) and perceived exertion (Freund et al.). The users are asked for their ratings or preference on a 7 point scale (Dolsak B. et al. & Freund et al.) or a 5 point scale (Groeinesteijn et al.) of the evaluated tool and further according to the user satisfaction design characteristics are studied (Kumar A. et al.). This technique only shows the comfort experience but due to lack of information it fails to explain the reason behind comfort experience (Freund et al.). Despite of the limitations, as comfort is a matter of personal nature, subjective measurement is necessary to use when user’s experience is relevant to the study (Annett J.).

Objective measurement technique includes grip force and pressure measurements, electromyography, biomechanical hand models, finite element analyses, etc. So it can predict the physical aspect on perceived comfort (Dolsak B. et al.). Electromyography (EMG) is very useful and often used in hand tool evaluation studies to obtain muscle effort (Das B. et al.), muscle activity (Hmmarskjold E. & Harms-Ringdhal K.), muscle fatigue (Fellows et al.) and physical or muscular strain (Kluth K. et al.) which are really need to be evaluated for explaining perceived comfort experience because these are the factors that lead to musculoskeletal discomfort. Though it predicts the physical aspects on the perceived comfort, it does not directly correlate to the subjective comfort rating value (Kuijt-Evers et al.).

## 2.4 Different Comfort Models

The paper by De Looze et al. (2003) explained a model which shows a relationship between physical product features experience with respect to comfort and discomfort with regard to seating. According to this model the physical processes that underlie discomfort, consider exposure, dose, response and physical capacity of the human. Exposure refers to the external factors producing a disturbance of the internal state (dose) of an individual. Individual capacity is represented by the extent to which it can sustain the external exposure leads to an internal dose and response. The model concerns comfort also where physical features, psychosocial factors were considered at context level. At the seat level, the aesthetic design of the seat and at the human level, individual expectations & individual feelings or emotions were considered.

Another model was established by Moes. (2005) related to discomfort. It explains the five phases in the process of discomfort experience. According to Moes the process depends on the person who uses the product, the product features, the purpose and the usage. When a person uses any product, interaction between the product and the person results in internal body effects. These internal body effects can be perceived and interpreted. Then appreciation of the perception arises. If these factors are not appreciated then it will lead to feelings of discomfort.

The model of De Looze is more advantageous over the model of Moes as the environment is explicitly shown in the model of De Looze. Moreover, the model explains the both two processes discomfort and comfort, reflecting the prevailing concept of two distinct scales, one for discomfort and one for comfort which is not just lack of discomfort.

Being influenced by these two models a new comfort model was proposed by Vink P. & Hallbeck S. (2012) which is shown in figure 4. The use of any product by a person causes the interaction (I) with its environment which can result in internal human body effects (H) such as muscle activation, tactile sensation. Human body effects cause perceived effects (P) which may also be influenced by expectations (E).

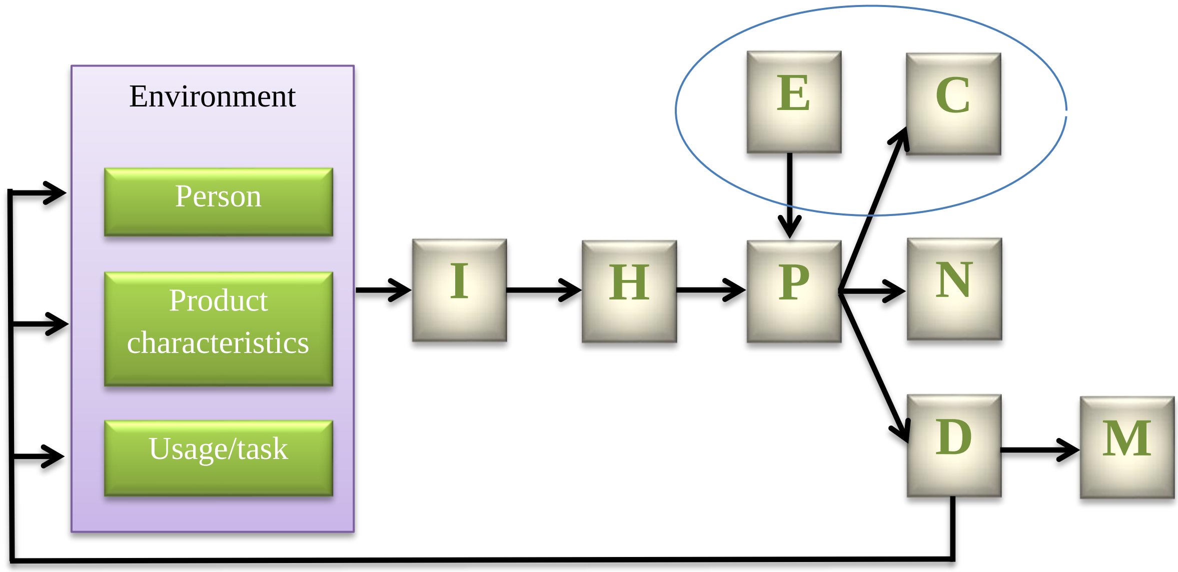



Figure 4: Newly proposed model of comfort by Vink P. & Hallbeck S. (2012)

This model interprets the perceived effects (P) as comfort (C) or no feeling (N) or discomfort (D) as there is not one form of comfort or discomfort experience, it can vary from almost uncomfortable to extremely comfortable and from no discomfort to extremely high discomfort. The discomfort could result in musculoskeletal complaints (M). The circle around E-C shows that expectations are often linked to comfort. If there is very high level of discomfort then the feedback loop to the person could help to make changes in the task/usage or in the product characteristics for better comfort.

# CHAPTER 3: RESEARCH METHODOLOGY

The current study was performed in two parts i.e., pre-study and main study to answer the research questions. All possible descriptors underlying comfort and discomfort were collected from the literature and checked whether different descriptors would underlie comfort and discomfort or not. Then in the main study the descriptors were divided into meaningful groups or factors and the relationship between these factors with expected comfort at first sight and overall comfort after short time use was studied.

## 3.1 Pre-Study

In the pre-study the main aims were to

1. Compose a 'complete' list of descriptors that could possibly underlie comfort and discomfort from the literature.
2. Find out whether the descriptors underlying comfort and the descriptors underlying discomfort are same or they are different.

The pre-study consisted of following three steps:

In the first step many searches were made for papers containing "hand tools", "ergonomics and hand tools", "comfort in hand tools", "discomfort", "comfort", "user-experience and hand tools", "usability and hand tools". All the descriptors that could possibly underlie comfort and discomfort were collected. Descriptors with the same meaning and synonyms were left out from the list.

In the second step, 20 experienced users from different carpentry shops who use hammer very often were asked to describe their feelings when experiencing comfort (Group A: n=20) while using hammer. Another 20 subjects (Group B: n=20) who use hammer seldom were asked to do the same but for discomfort experience.

In the last step, the subjects were asked to rate the 'complete' list of descriptors on a three point scale if the descriptors selected from the papers were related to comfort (Group A)/discomfort (Group B) or not. In the three point scale 1 = related to (dis)comfort, 2 = not related to (dis)comfort and 3 = do not know. The first selection was made by considering a descriptor to be a meaningful descriptor if larger majority of the subjects find it related to comfort/discomfort. Selection of the descriptors which were mentioned was made by 70% of the subjects as related to comfort or discomfort for the main study (Zhang et al.).

Appendix I shows the 'complete' list of descriptors collected from the literature and the three point scale used to rate the descriptors.

## 3.2 Main Study

The objectives of the main study were to:

1. Determine the relationship between comfort in using hammer and the descriptors collected in the pre-study.
2. Classify the descriptors into meaningful groups or factors if they can be divided.
3. Determine the relationship with these factors with expected and overall comfort.

From the literature forty six descriptors were collected related to comfort and discomfort. In the pre-study it was seen that the same descriptors were mentioned as being related to comfort and discomfort and among these forty six descriptors forty two descriptors were specified by more than 70% of the subjects as related to comfort/discomfort. So the main study was carried out on those forty two descriptors only.

### 3.2.1 Participants

A convenience sample was obtained by approaching the workers working in different carpentry shops in Jaipur where the use of hammer is very often and the unprofessional users such as the customers came to the shops who use hammer but very seldom. Twenty healthy workers from the carpentry shops and twenty unprofessional users were participated in this study. The subjects gave their written informed consent. The following table shows the demographic of the sample.

Table 3: Demography of the participants

| | Range | Mean | Standard Deviation |
|---|---|---|---|
| Age (years) | 27-58 | 43 | 11.2 |
| Stature (cm) | 160-182 | 169.8 | 8.7 |
| Weight (kg) | 54-82 | 69.1 | 9.4 |
| Hand length (cm)* | 14.6-19.4 | 18.3 | 1.4 |

*Measured from the top of the middle finger to the distal crease of the wrist

### 3.2.2 Apparatus

For the main study a comfort questionnaire was prepared based on the results of the pre-study where among forty six descriptors, forty two were identified as meaningful descriptors related to comfort in using hammer. The subjects were asked to rate these descriptors on a 7 point scale (Kuijt-Evers et al.) ranging from 1 = totally disagree to

7 = totally agree. A question about the expected comfort at first sight and a question about overall comfort after short time use were also added to the comfort questionnaire and the subjects were asked to rate these questions on the same 7 point scale with 1 = very uncomfortable, 2 = in between very uncomfortable and a little uncomfortable, 3 = a little uncomfortable, 4 = in between a little uncomfortable and a little comfortable, 5 = a little comfortable, 6 = in between a little comfortable and very comfortable, 7 = very comfortable.

The complete comfort questionnaire which was used in the main study is shown in Appendix II.

### 3.2.3 Limitations of the questionnaire

The general limitations of questionnaire techniques also apply to these questionnaires. The health conditions of the person who fills the questionnaire may affect the results. Health conditions such as work stress, mental pressure, anger, frustration, anxiety and depression may affect the response of the person filling the questionnaire. The environment and filling out situation at the time of questionnaire filling may also affect the results (M.A. Sinclair).

### 3.2.4 Experimental setting

A claw hammer with 823 g weight and 52 cm handle length was used in the current study which is shown in figure 7. The tool is different in handle shape and material from the traditional hammer with wooden handle.

Figure 5: Hammer evaluated in this study

The participants were asked to perform a specific task with this hammer in order to evaluate it on expected comfort as well as overall comfort with the help of comfort questionnaire.


Figure 6: Professional workers performing the task

Figure 6 shows different professional workers performing the task with the same hammer which is shown in figure 5.

# CHAPTER 4: DATA COLLECTION

Data may be obtained either from the primary source or the secondary source. A primary source is one that itself collects the data; a secondary source is one that makes available data which were collected by some other agency. A primary source usually has more detailed information particularly on the procedures followed in collecting and compiling the data. Many methods for collecting the data such as direct personal interview, mailed questionnaire method, indirect oral interviews schedule sent through enumerators, information from correspondents etc.

Data collection is an important part of this current study and for that data was collected by direct personal interview. Forty workers were chosen randomly. Among of them twenty were experienced workers working at different carpentry shops in Jaipur and twenty unprofessional users. Prior to data collection the analyst: (a) observed the subject during his working cycle (b) determined the fundamental tasks of the job (c) confirmed by the subject that the task is indicatively a ‘normal operation’. Snapshots of the elements of the activity were taken for further study.

## 4.1 Assumptions During Data Collection

This study required that some assumptions be made during the collection and processing of data. The following is a list of major assumptions made during data collection and processing:

1. The workers had good mental strength and physical health.
2. There were no significant differences between the employees participating in the study and those declining to participate.
3. Collecting the data using computerized format versus a traditional pen and paper had no adverse effect on the results.
4. The length of the questionnaires did not get the respondents bored.
5. The work on the day of observation was representative of typical operation with respect to production, quality and error.

## 4.2 Data Collection

The objective of the pre-study was to check whether the same descriptors underlie comfort and discomfort or not and for that data was collected by rating the ‘complete’ list of descriptors (Appendix I). The list was rated on a three point scale with 1 = related to (dis)comfort, 2 = not related to (dis)comfort, 3 = do not know.

For the main study a comfort questionnaire for hammer (Appendix II) consist of the descriptors which were rated by the majority of the respondents as meaningful descriptor related to comfort was used. The comfort questionnaire also consists of the questions for identifying the descriptors related to expected comfort experience and overall comfort experience after short time use. The same subjects participated in the pre-study were asked to rate the comfort questionnaire for hammer on a seven point scale ranging from 1 = totally disagree to 7 = totally agree.

First of all, for rating the expected comfort experience on a seven point scale ranging from 1 = totally discomfort able to 7 = totally comfortable the respondents were asked to hold the hammer into their hands. After that, the hammer was handed over to the subject and asked to perform an operation. The subjects were asked to do hammering on 2 nails to get it into a wooden beam as soon as possible without any rest break until the head of the nail touched the beam. The nails were driven into the wooden beam to a very little extent before the experiment started. The wooden beam was kept on a table, which was fixed at hip height of the subject. A rest break of at least 5 minutes was provided after completing every hammering-task and this procedure was repeated for all subjects. The time consumed by each subject for performing the whole task was also recorded.

Figure 7: Unprofessional users performing the task

After finishing the given task the subjects were asked to rate the descriptors of comfort questionnaire for hammer (Appendix II) and the overall comfort experience on a seven point scale. The meaning of the descriptors was explained whenever it was needed.

# CHAPTER 5: DATA ANALYSIS

In the pre-study the need was to see if the descriptors were rated differently between the respondents who filled in comfort questionnaire and the discomfort questionnaire and for that a non-parametric test was performed. Non-parametric methods are mathematical procedures for hypothesis testing which make no assumptions about the probability distributions of the variables being assessed. Among a number of non-parametric test methods Mann-Whitney U or Wilcoxon rank sum test was chosen for the current study as it has greater efficiency and it tests whether the two samples are drawn from the same distribution, as compared to a given alternative hypothesis. In order to carry out Mann-Whitney U test IBM SPSS 22.0 was used. The Null Hypothesis and Alternative Hypothesis taken in this case are:

$H_0$ = The distribution of the descriptor is same across the Groups i.e., Group A and Group B.

$H_1$ = There is a significant difference between the distribution of the descriptor across the Groups.

Group A: Respondents who filled the questionnaire for comfort (n = 20).

Group B: Respondents who filled the same questionnaire for discomfort (n = 20).

The results obtained by performing Mann-Whitney U test through SPSS Statistics 22.0 are as follows:

Table 4: Hypothesis Test Summary

| Null Hypothesis | Test | Sig. | Decision |
|---|---|---|---|
| The distribution of Fits the hand is the same across categories of Group. | Independent samples Mann-Whitney U test | .063[1] | Retain Null Hypothesis |
| The distribution of Functional is the same across categories of Group. | Independent samples Mann-Whitney U test | .089[1] | Retain Null Hypothesis |
| The distribution of Reliable is the same across categories of Group. | Independent samples Mann-Whitney U test | .063[1] | Retain Null Hypothesis |

| **Null Hypothesis** | **Test** | **Sig.** | **Decision** |
|---|---|---|---|
| The distribution of Easy in use is the same across categories of Group. | Independent samples Mann-Whitney U test | .063[1] | Retain Null Hypothesis |
| The distribution of Good force transmission is the same across categories of Group. | Independent samples Mann-Whitney U test | .062[1] | Retain Null Hypothesis |
| The distribution of Safe is the same across categories of Group. | Independent samples Mann-Whitney U test | .052[1] | Retain Null Hypothesis |
| The distribution of Weight is the same across categories of Group. | Independent samples Mann-Whitney U test | .061[1] | Retain Null Hypothesis |
| The distribution of Size is the same across categories of Group. | Independent samples Mann-Whitney U test | .063[1] | Retain Null Hypothesis |
| The distribution of Easy to take along is the same across categories of Group. | Independent samples Mann-Whitney U test | .063[1] | Retain Null Hypothesis |
| The distribution of Nice color is the same across categories of Group. | Independent samples Mann-Whitney U test | .065[1] | Retain Null Hypothesis |
| The distribution of Solid design is the same across categories of Group. | Independent samples Mann-Whitney U test | .063[1] | Retain Null Hypothesis |
| The distribution of High quality tool is the same across categories of Group. | Independent samples Mann-Whitney U test | .063[1] | Retain Null Hypothesis |
| The distribution of Nice feeling handle is the same across categories of Group. | Independent samples Mann-Whitney U test | .063[1] | Retain Null Hypothesis |

| Null Hypothesis | Test | Sig. | Decision |
|---|---|---|---|
| The distribution of High task performance is the same across categories of Group. | Independent samples Mann-Whitney U test | .089[1] | Retain Null Hypothesis |
| The distribution of High product quality is the same across categories of Group. | Independent samples Mann-Whitney U test | .052[1] | Retain Null Hypothesis |
| The distribution of Looks professional is the same across categories of Groups. | Independent samples Mann-Whitney U test | .063[1] | Retain Null Hypothesis |
| The distribution of Relaxed working posture is the same across categories of Groups. | Independent samples Mann-Whitney U test | .089[1] | Retain Null Hypothesis |
| The distribution of Low hand grip force is the same across categories of Groups. | Independent samples Mann-Whitney U test | .089[1] | Retain Null Hypothesis |
| The distribution of No body part ache is the same across categories of Groups. | Independent samples Mann-Whitney U test | .063[1] | Retain Null Hypothesis |
| The distribution of Good friction is the same across categories of Groups. | Independent samples Mann-Whitney U test | .052[1] | Retain Null Hypothesis |
| The distribution of Good handle roughness is the same across categories of Groups. | Independent samples Mann-Whitney U test | .075[1] | Retain Null Hypothesis |
| The distribution of No inflamed skin is the same across categories of Groups. | Independent samples Mann-Whitney U test | .063[1] | Retain Null Hypothesis |
| The distribution of No pain is the same across categories of Groups. | Independent samples Mann-Whitney U test | .062[1] | Retain Null Hypothesis |
| The distribution of No peak pressure is the same across categories of Groups. | Independent samples Mann-Whitney U test | .064[1] | Retain Null Hypothesis |

| Null Hypothesis | Test | Sig. | Decision |
|---|---|---|---|
| The distribution of No blister is the same across categories of Groups. | Independent samples Mann-Whitney U test | .065[1] | Retain Null Hypothesis |
| The distribution of No sweaty hands is the same across categories of Groups. | Independent samples Mann-Whitney U test | .063[1] | Retain Null Hypothesis |
| The distribution of No numbness is the same across categories of Groups. | Independent samples Mann-Whitney U test | .052[1] | Retain Null Hypothesis |
| The distribution of No cramped muscles is the same across categories of Groups. | Independent samples Mann-Whitney U test | .063[1] | Retain Null Hypothesis |
| The distribution of No sore muscles is the same across categories of Groups. | Independent samples Mann-Whitney U test | .052[1] | Retain Null Hypothesis |
| The distribution of No irritation is the same across categories of Groups. | Independent samples Mann-Whitney U test | .063[1] | Retain Null Hypothesis |
| The distribution of Shape is the same across categories of Groups. | Independent samples Mann-Whitney U test | .090[1] | Retain Null Hypothesis |
| The distribution of Styling is the same across categories of Groups. | Independent samples Mann-Whitney U test | .052[1] | Retain Null Hypothesis |
| The distribution of Hardness is the same across categories of Groups. | Independent samples Mann-Whitney U test | .063[1] | Retain Null Hypothesis |
| The distribution of No slippery handle is the same across categories of Groups. | Independent samples Mann-Whitney U test | .063[1] | Retain Null Hypothesis |
| The distribution of No force exerted from tool is the same across categories of Groups. | Independent samples Mann-Whitney U test | .052[1] | Retain Null Hypothesis |

| Null Hypothesis | Test | Sig. | Decision |
|---|---|---|---|
| The distribution of Weather proof is the same across categories of Groups. | Independent samples Mann-Whitney U test | .080[1] | Retain Null Hypothesis |
| The distribution of Luxurious is the same across categories of Groups. | Independent samples Mann-Whitney U test | .052[1] | Retain Null Hypothesis |
| The distribution of Pleasurable is the same across categories of Groups. | Independent samples Mann-Whitney U test | .052[1] | Retain Null Hypothesis |
| The distribution of No pressure is the same across categories of Groups. | Independent samples Mann-Whitney U test | .089[1] | Retain Null Hypothesis |
| The distribution of Satisfaction is the same across categories of Groups. | Independent samples Mann-Whitney U test | .089[1] | Retain Null Hypothesis |
| The distribution of Nice appearance is the same across categories of Groups. | Independent samples Mann-Whitney U test | .005[1] | Reject Null Hypothesis |
| The distribution of Happiness is the same across categories of Groups. | Independent samples Mann-Whitney U test | .063[1] | Retain Null Hypothesis |
| The distribution of Distraction from work is the same across categories of Groups. | Independent samples Mann-Whitney U test | .063[1] | Retain Null Hypothesis |
| The distribution of Functional color is the same across categories of Groups. | Independent samples Mann-Whitney U test | .052[1] | Retain Null Hypothesis |
| The distribution of No clammy handle is the same across categories of Groups. | Independent samples Mann-Whitney U test | .063[1] | Retain Null Hypothesis |
| The distribution of Lack of tactile feeling is the same across categories of Groups. | Independent samples Mann-Whitney U test | .051[1] | Retain Null Hypothesis |

Asymptotic significances are displayed. The significance level is .05.
[1] Exact significance is displayed for this test.

Among these forty six descriptors forty two descriptors were selected for main study except nice color, all weather proof tool, nice appearance and happiness with the performance of the tool as these descriptors were not rated by the majority (more than 70%) of the respondents.

In the main study at first the ratings of the descriptors were correlated with the expected comfort at first sight and overall comfort after short time use. The following table shows Pearson's correlation coefficients of the descriptors.

Table 5: Correlation coefficients of the descriptors with respect to expected comfort & overall comfort

| | **Expected comfort** | **Overall comfort** |
|---|---|---|
| Fits the hand | 0.568** | 0.755** |
| Functional | - | 0.734** |
| Reliable | - | 0.326* |
| Safe | - | 0.427** |
| Weight of the tool | - | 0.429** |
| Handle size of the tool | - | 0.513** |
| Easy to take along | - | 0.339* |
| Solid design | - | 0.487** |
| High quality tool | - | 0.355* |
| Nice feeling handle | 0.588** | 0.736** |
| High task performance | - | 0.623** |
| High product quality | - | 0.393* |
| Looks professional | 0.399* | - |
| Relaxed working posture | - | 0.726** |
| Low handgrip force supply | - | 0.717** |
| No body part ache | - | 0.491** |
| Good friction between handle and hand | 0.352* | 0.529** |
| Handle surface with good roughness | 0.337* | 0.364* |
| No inflamed skin | - | 0.325* |
| No pain | - | 0.395* |
| No peak pressure | - | 0.374* |
| No blisters | - | 0.484** |
| No sweaty hands | - | 0.401* |
| No numbness in fingers | - | 0.351* |
| No cramped muscles | - | 0.470** |
| No sore muscles | - | 0.475** |
| No irritations | - | 0.427** |
| Handle shape | 0.323* | 0.508** |
| No slippery handle | - | 0.453** |
| No force exerted from tool | - | 0.334* |
| Luxury tool | 0.333* | 0.361* |
| Pleasurable | - | 0.346* |
| No pressure on hand | - | 0.454** |

| | Expected comfort | Overall comfort |
|---|---|---|
| No distraction of the worker from task | - | -0.313* |
| Functional color | 0.358* | - |
| Handle does not feel clammy | - | 0.427** |
| Lack of tactile feeling | - | 0.374* |

*. Correlation is significant at the .05 level (2-tailed)
**. Correlation is significant at the .01 level (2-tailed)
-. Correlation is not significant

## 5.1 Descriptors as Predictors of Expected Comfort and Overall Comfort

After obtaining the correlation coefficients of the descriptors with expected comfort at first sight and overall comfort after short time use multiple regression (forward selection procedure) was performed. Multiple regression (forward selection procedure) was carried out to see which of the descriptors predict expected comfort at first sight and overall comfort after short time use of the hammer.

The results obtained by performing multiple regression (forward selection procedure) for expected comfort at first sight are shown in table 6.

Table 6: Results of multiple regression for expected comfort at first sight

**Variables Entered/Removed[a]**

| Model | Variables Entered | Variables Removed | Method |
|---|---|---|---|
| 1 | fitshand | . | Forward (Criterion: Probability-of-F-to-enter <= .050) |
| 2 | nicefeelingha ndle | . | Forward (Criterion: Probability-of-F-to-enter <= .050) |

a. Dependent Variable: expected

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .756[a] | .571 | .560 | .5809943 |
| 2 | .791[b] | .625 | .605 | .5505407 |

a. Predictors: (Constant), fitshand

b. Predictors: (Constant), fitshand, nicefeelinghandle

**Coefficients[a]**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | .820 | .519 | | 1.580 | .122 |
| | fitshand | .654 | .092 | .756 | 7.112 | .000 |
| 2 | (Constant) | .925 | .494 | | 1.874 | .069 |
| | fitshand | .408 | .138 | .471 | 2.958 | .005 |
| | nicefeelinghandle | .263 | .114 | .367 | 2.307 | .027 |

a. Dependent Variable: expected

From the model summary table it can be seen that the model 2 with fits the hand and nice feeling handle is having greater R square value than the model 1. So the model 2 fits better to the data and model explains most of the variability of the response data around its mean.

The coefficients table shows the standardize coefficients (beta) values for the descriptors associated with the model 1 and the model 2. The model 2 fits better to the data than the model 1 and its underlying descriptors fits i.e., hand and nice feeling handle have beta values 0.471 and 0.367 respectively.

Then the multiple regression (forward selection procedure) for overall comfort after short time use of hammer was performed. The results of multiple regression are shown in table 7.

Table 7: Results of multiple regression for overall comfort after short time use

**Variables Entered/Removed[a]**

| Model | Variables Entered | Variables Removed | Method |
|---|---|---|---|
| 1 | easyinuse | . | Forward (Criterion: Probability-of-F-to-enter <= .050) |
| 2 | relaxedworkingposture | . | Forward (Criterion: Probability-of-F-to-enter <= .050) |
| 3 | lowhandgripforce | . | Forward (Criterion: Probability-of-F-to-enter <= .050) |
| 4 | functional | . | Forward (Criterion: Probability-of-F-to-enter <= .050) |
| 5 | easytotakealong | . | Forward (Criterion: Probability-of-F-to-enter <= .050) |
| 6 | noinflamedskin | . | Forward (Criterion: Probability-of-F-to-enter <= .050) |

a. Dependent Variable: overall

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .668[a] | .447 | .432 | .8615477 |
| 2 | .745[b] | .555 | .531 | .7833450 |
| 3 | .802[c] | .643 | .614 | .7106569 |
| 4 | .832[d] | .692 | .657 | .6700132 |
| 5 | .854[e] | .730 | .690 | .6360587 |
| 6 | .872[f] | .761 | .718 | .6076389 |

a. Predictors: (Constant), easyinuse

b. Predictors: (Constant), easyinuse, relaxedworkingposture

c. Predictors: (Constant), easyinuse, relaxedworkingposture, lowhandgripforce

d. Predictors: (Constant), easyinuse, relaxedworkingposture, lowhandgripforce, functional

e. Predictors: (Constant), easyinuse, relaxedworkingposture, lowhandgripforce, functional, easytotakealong

f. Predictors: (Constant), easyinuse, relaxedworkingposture, lowhandgripforce, functional, easytotakealong, noinflamedskin

The model summary table shows the R square values for model 1, model 2, model 3, model 4, model 5 and model 6. Among these six models, model 6 has the highest R square value of 0.761 which implies that the model six fits better to the data than the other models and it explains 76.1% of the variability of the response data around its mean.

The other part of this table 7 i.e., coefficients table is shown below. The coefficients table shows the standardize coefficients (beta) values for the descriptors associated with the different models. Model 6 fits better than the other models and its underlying descriptors i.e., easy in use, relaxed working posture, low hand grip force, functional, easy to take along and no inflamed skin have the beta values of 0.266, 0.455, 0.311, 0.377, 0.245, -0.213 respectively.

**Coefficients[a]**

| Model | | Unstandardized Coefficients B | Unstandardized Coefficients Std. Error | Standardized Coefficients Beta | t | Sig. |
|---|---|---|---|---|---|---|
| 1 | (Constant) | 1.410 | .623 | | 2.265 | .029 |
| | easyinuse | .683 | .123 | .668 | 5.539 | .000 |
| 2 | (Constant) | .214 | .693 | | .309 | .759 |
| | easyinuse | .456 | .135 | .446 | 3.368 | .002 |
| | relaxedworkingposture | .517 | .173 | .397 | 2.994 | .005 |
| 3 | (Constant) | .798 | .658 | | 1.212 | .233 |
| | easyinuse | .592 | .131 | .579 | 4.519 | .000 |
| | relaxedworkingposture | .612 | .160 | .469 | 3.829 | .000 |
| | lowhandgripforce | -.453 | .151 | -.350 | -2.993 | .005 |
| 4 | (Constant) | .097 | .689 | | .140 | .889 |
| | easyinuse | .467 | .135 | .456 | 3.469 | .001 |
| | relaxedworkingposture | .567 | .152 | .435 | 3.731 | .001 |
| | lowhandgripforce | -.450 | .143 | -.348 | -3.155 | .003 |
| | functional | .277 | .118 | .263 | 2.345 | .025 |
| 5 | (Constant) | -1.191 | .878 | | -1.357 | .184 |
| | easyinuse | .355 | .137 | .347 | 2.584 | .014 |
| | relaxedworkingposture | .510 | .147 | .391 | 3.480 | .001 |
| | lowhandgripforce | -.317 | .148 | -.245 | -2.139 | .040 |
| | functional | .312 | .113 | .296 | 2.752 | .009 |
| | easytotakealong | .330 | .150 | .226 | 2.199 | .035 |
| 6 | (Constant) | -1.330 | .841 | | -1.582 | .123 |
| | easyinuse | .272 | .137 | .266 | 1.984 | .056 |
| | relaxedworkingposture | .593 | .146 | .455 | 4.070 | .000 |
| | lowhandgripforce | .378 | .131 | .311 | 2.957 | .010 |
| | functional | .397 | .116 | .377 | 3.428 | .002 |
| | easytotakealong | .358 | .144 | .245 | 2.485 | .018 |
| | noinflamedskin | -.299 | .145 | -.213 | -2.063 | .047 |

a. Dependent Variable: overall

## 5.2 Factors of Expected Comfort and Overall Comfort in Using Hammer

To divide the descriptors into factors or meaningful groups as dimension reduction tool Principal component analysis (PCA) with varimax rotation was used. Principal component analysis with varimax rotation of the descriptors revealed 8 major factors with eigenvalues greater than 1, explaining 80.703% of the variance.

The following figure shows the scree plot. It is difficult to interpret because the curve begins to tail off after four factors or components, but almost a stable plateau is reached after eight factors or components.

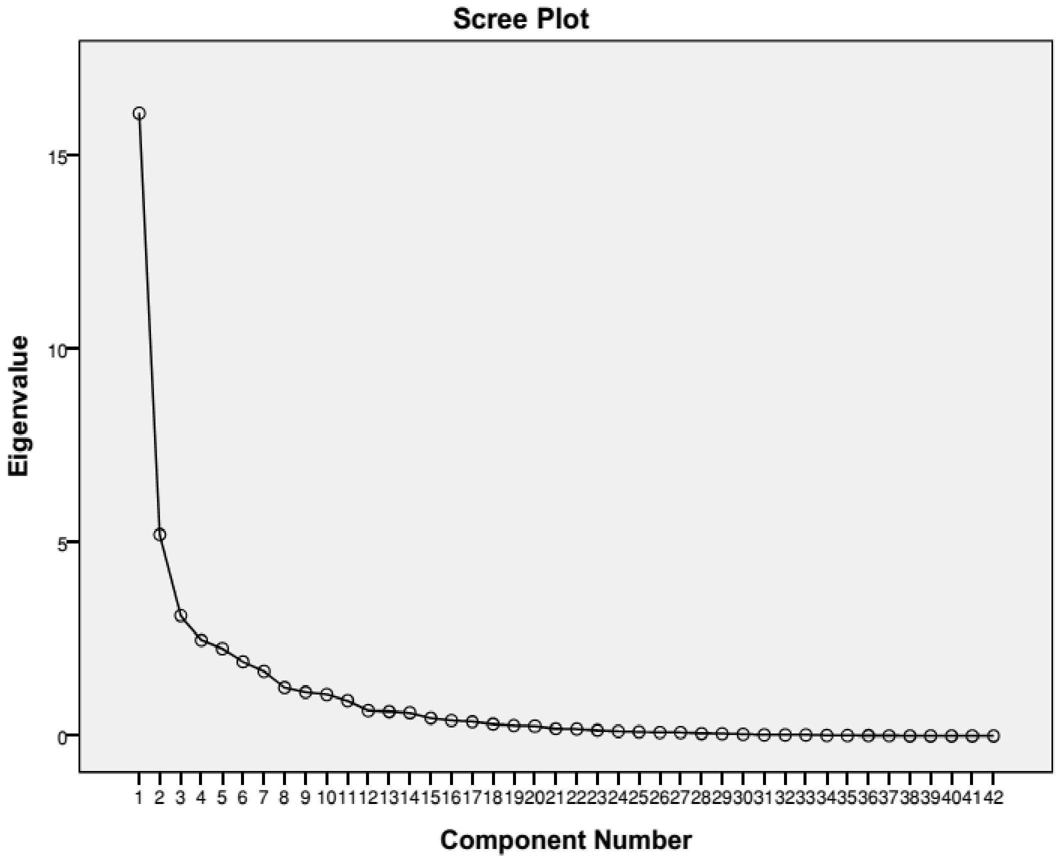



Figure 8: Scree plot

Table 6 shows the factor loadings greater than 0.4. These results suggest eight factors i.e., descriptors are divided into eight factors or components.

Table 8: Factor loadings of the descriptors (PCA with varimax rotation) only the factor loading > 0.4

| | **Factor 1** | **Factor 2** | **Factor 3** | **Factor 4** | **Factor 5** | **Factor 6** | **Factor 7** | **Factor 8** |
|---|---|---|---|---|---|---|---|---|
| Functional | 0.947 | | | | | 0.483 | | |
| Reliable | 0.913 | | | | | 0.401 | | |
| Good force transmission | 0.847 | | | | 0.487 | | | |
| High task performance | 0.833 | | | | | | | |
| Easy in use | 0.715 | | | | | | | |
| Easy to take along | 0.606 | | | 0.468 | | | | |
| Safe | 0.594 | | | | | 0.436 | | |
| High product quality | 0.555 | | | | | | | |
| Relaxed working posture | | 0.919 | | | 0.426 | | | |
| No cramped muscles | | 0.879 | | | | | | |
| Low hand grip force supply | | 0.851 | | | 0.562 | | | |
| No sore muscles | | 0.822 | | | | | | |
| No body part ache | | 0.711 | | | 0.411 | | | |
| Handle hardness | | 0.623 | | | | | | |
| No pain | | 0.557 | | | | | 0.426 | |
| Weight of the tool | | 0.4 | 0.485 | | | | | |
| Good friction between handle and hand | | | 0.846 | | | | 0.548 | |
| Good handle roughness | | | 0.799 | | | | | |
| Handle shape | | | 0.683 | | | | | |
| No slippery handle | | | 0.634 | | | | | |
| Handle size | | | 0.471 | | | | | |
| No irritation | | | 0.44 | 0.438 | | | | |
| No numbness | | | | 0.827 | | | | |
| No blister | | | | 0.749 | | | | |
| No inflamed skin | | | | 0.674 | | | | |
| No pressure on hand | | | 0.402 | 0.485 | | | | |
| Fits the hand | | | | | 0.897 | | | |
| Nice feeling handle | | | | | 0.759 | | | |
| Lack of tactile feelings | | | | 0.583 | | 0.412 | | |
| No sweaty hands | | | | 0.409 | | | 0.477 | |
| No force exerted from tool | | | | | | 0.611 | | |
| High quality tool | 0.418 | | | | | 0.887 | | |
| No distraction from work | | | | | | 0.54 | | |
| Handle does not feel clammy | | | | | | | 0.798 | |
| No peak pressure | | | | | | | 0.776 | |
| Functional color | | | | | | | | 0.792 |
| Looks professional | | | | | | | | 0.765 |
| Styling | | | | | | | | 0.724 |
| Luxury tool | | | | | | | | 0.681 |
| Solid design | | | | | | | | 0.643 |

After getting the factor scores by performing principal component analysis with varimax rotation the correlation coefficients between these factor scores and expected comfort at first sight and overall comfort after short time use were obtained. The following table 7 shows the correlation coefficients of the eight factors with expected comfort at first sight and overall comfort experience.

Table 9: Correlation coefficents of the factors with respected to expected comfort and overall comfort

| | Expected comfort | Overall comfort |
|---|---|---|
| Factor 1 | 0.084 | 0.655** |
| Factor 2 | 0.052 | 0.316* |
| Factor 3 | 0.066 | 0.146 |
| Factor 4 | 0.077 | 0.254* |
| Factor 5 | 0.199 | 0.199 |
| Factor 6 | -0.037 | -0.051 |
| Factor 7 | 0.036 | 0.065 |
| Factor 8 | 0.341* | 0.188 |

*. Correlation is significant at the .05 level (2-tailed)
**. Correlation is significant at the .01 level (2-tailed)

## 5.3 Factors as Predictors of Expected Comfort and Overall Comfort Experience

After obtaining the correlation coefficients multiple regression (forward selection procedure) was performed to identify the factors which predict expected comfort experience at first sight and overall comfort experience after short time use in using hammer.

The results of the multiple regression analysis of the factors for expected comfort at first sight is shown in table 10.

Table 10: Results of multiple regression of the descriptors for expected comfort at first sight

Variables Entered/Removed [a]

| Model | Variables Entered | Variables Removed | Method |
|---|---|---|---|
| 1 | factor8 | . | Forward (Criterion: Probability-of-F-to-enter <= .050) |
| 2 | factor5 | . | Forward (Criterion: Probability-of-F-to-enter <= .050) |

a. Dependent Variable: expected

Model Summary

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .776 [a] | .602 | .573 | .5618600 |
| 2 | .811 [b] | .659 | .622 | .5261010 |

a. Predictors: (Constant), factor8

b. Predictors: (Constant), factor8, factor5

Coefficients[a]

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 4.152 | .145 | | 28.611 | .000 |
| | factor8 | 4.804 | 1.307 | .682 | 3.676 | .001 |
| 2 | (Constant) | 3.980 | .159 | | 25.020 | .000 |
| | factor8 | 4.534 | 1.251 | .603 | 3.623 | .001 |
| | factor5 | 2.069 | 1.007 | .293 | 2.199 | .034 |

a. Dependent Variable: expected

The model summary table shows two models for predicting expected comfort. Model 1 consists of a single factor (factor 8) and model 2 consists of two factors (factor 8 and factor 5). But the R square value for model 2 is greater than the R square value of model 1. So model 2 fits better to the data than model 1 with the capability of explaining 65.9% of the variability of the response data around its mean.

The coefficients table shows the standardize coefficients (beta) values for the factors associated with the different models. Model 2 fits better than the other models and its underlying factors i.e., factor 8 and factor 5 have the beta values of 0.603 and 0.293 respectively.

The results of multiple regression (forward selection procedure) of the factors for the overall comfort after short time are shown in table 11.

Table 11: Results of multiple regression of the factors for overall comfort after short time use

Variables Entered/Removed [a]

| Model | Variables Entered | Variables Removed | Method |
|---|---|---|---|
| 1 | factor1 | . | Forward (Criterion: Probability-of-F-to-enter <= .050) |
| 2 | factor2 | . | Forward (Criterion: Probability-of-F-to-enter <= .050) |
| 3 | factor4 | . | Forward (Criterion: Probability-of-F-to-enter <= .050) |
| 4 | factor5 | . | Forward (Criterion: Probability-of-F-to-enter <= .050) |
| 5 | factor8 | . | Forward (Criterion: Probability-of-F-to-enter <= .050) |

a. Dependent Variable: overall

Model Summary

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .570 [a] | .325 | .305 | 1.5634539 |
| 2 | .664 [b] | .441 | .405 | 1.4617506 |
| 3 | .716 [c] | .513 | .474 | 1.3983483 |
| 4 | .784 [d] | .614 | .559 | 1.2901958 |
| 5 | .829 [e] | .687 | .615 | 1.2215680 |

a. Predictors: (Constant), factor1

b. Predictors: (Constant), factor1, factor2

c. Predictors: (Constant), factor1, factor2, factor4

d. Predictors: (Constant), factor1, factor2, factor4, factor5

e. Predictors: (Constant), factor1, factor2, factor4, factor5, factor8

The model summary table shows the R square values for model 1, model 2, model 3, model 4 and model 5. Among these five models, model 5 has the highest R square value of 0.687 which implies that the model five fits better to the data than the other models and it explains 68.7% of the variability of the response data around its mean.

The other part of this table 11 i.e., coefficients table is shown below. The coefficients table shows the standardize coefficients (beta) values for the descriptors associated with the different models. Model five fits better than the other models and its underlying factors i.e., factor 1, factor 2, factor 4, factor 5 and factor 8 have the beta values of 0.685, 0.437, 0.384, 0.343 and 0.256 respectively.

Coefficients [a]

| Model | | Unstandardized Coefficients B | Unstandardized Coefficients Std. Error | Standardized Coefficients Beta | t | Sig. |
|---|---|---|---|---|---|---|
| 1 | (Constant) | 4.010 | .380 | | 10.549 | .000 |
| | factor1 | 6.140 | 1.847 | .475 | 3.324 | .002 |
| 2 | (Constant) | 4.544 | .413 | | 11.009 | .000 |
| | factor1 | 6.224 | 1.727 | .481 | 3.603 | .001 |
| | factor2 | 5.877 | 2.310 | .340 | 2.544 | .015 |
| 3 | (Constant) | 4.141 | .439 | | 9.440 | .000 |
| | factor1 | 6.684 | 1.667 | .517 | 4.010 | .000 |
| | factor2 | 5.897 | 2.659 | .363 | 2.168 | .037 |
| | factor4 | 5.064 | 2.406 | .277 | 2.105 | .042 |
| 4 | (Constant) | 3.926 | .413 | | 9.518 | .000 |
| | factor1 | 6.912 | 1.540 | .534 | 4.488 | .000 |
| | factor2 | 4.039 | 2.108 | .383 | 1.916 | .064 |
| | factor4 | 6.308 | 2.267 | .345 | 2.783 | .009 |
| | factor5 | 5.820 | 2.156 | .327 | 2.700 | .011 |
| 5 | (Constant) | 4.000 | .392 | | 10.205 | .000 |
| | factor1 | 6.664 | 2.462 | .685 | -4.557 | .000 |
| | factor2 | 4.098 | 1.996 | .437 | -2.053 | .048 |
| | factor4 | 6.286 | 2.146 | .384 | 2.929 | .006 |
| | factor5 | 6.643 | 2.074 | .343 | 3.203 | .003 |
| | factor8 | 3.975 | 1.770 | .256 | 2.246 | .031 |

a. Dependent Variable: overall

.

# CHAPTER 6: RESULTS & DISCUSSION

From the user interviews, it was found that none of the respondents did add any new descriptors to the list of descriptors found from the literature. In the pre-study around forty six descriptors were collected from the literature and Mann-Whitney U test was performed. From the result of the test it was found that almost every descriptor was rated by the majority of the respondents except 'nice appearance', 'all weather proof', 'nice color' and 'happiness'. Therefore, a clear assumption can be made that comfort and discomfort have the same underlying descriptors in using hammer.

## 6.1 Predicting Descriptors of Comfort in Using Hammer

The aim of the study is to identify the predicting descriptors of expected comfort at first sight and overall comfort after short time using of hammer. The results of multiple regression (forward selection procedure) show that the expected comfort at first sight is affected by the 'nice feeling handle' of the hammer and how much it 'fits the hand' of the operator. The result also shows that 'fits the hand' is more relevant to expected comfort.

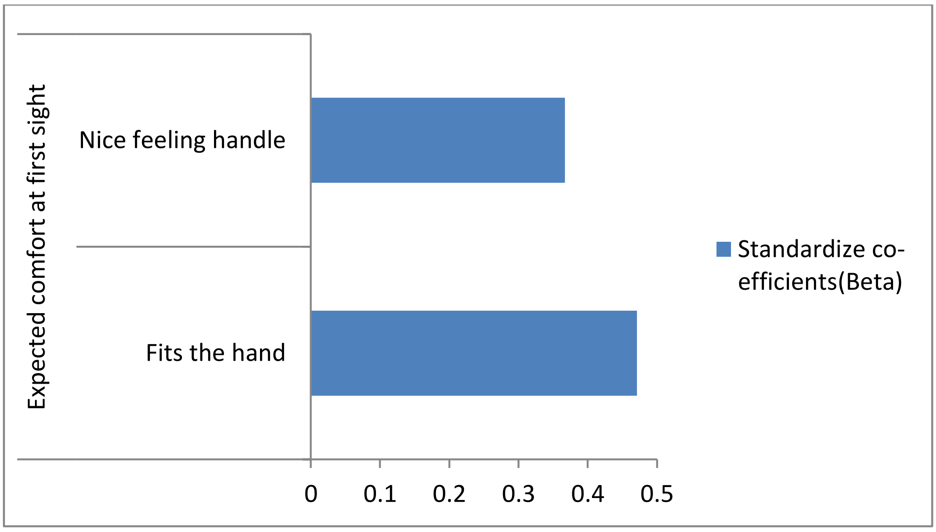



Figure 9: Beta values of expected comfort predicting descriptors

As a tool how much fits to the hand of the user is always been an user's first preference so 'fits the hand' of the operator is always an important parameter in product buying decisions, although it plays a role in overall comfort after short time use.

Six predictors of overall comfort were obtained and these are ‘easy in use’, ‘relaxed working posture’, ‘low hand grip force supply’, ‘functional’, ‘easy to take along’ and ‘no inflamed skin’. All these descriptors has their expected signs, except ‘no inflamed skin’. This descriptor has negative sign in the multiple regression but the correlation coefficient with overall comfort it has a positive sign. Probably, this is to high co-linearity between the descriptors. The results on overall comfort show that ‘relaxed working posture’ is the best descriptor as predictor.

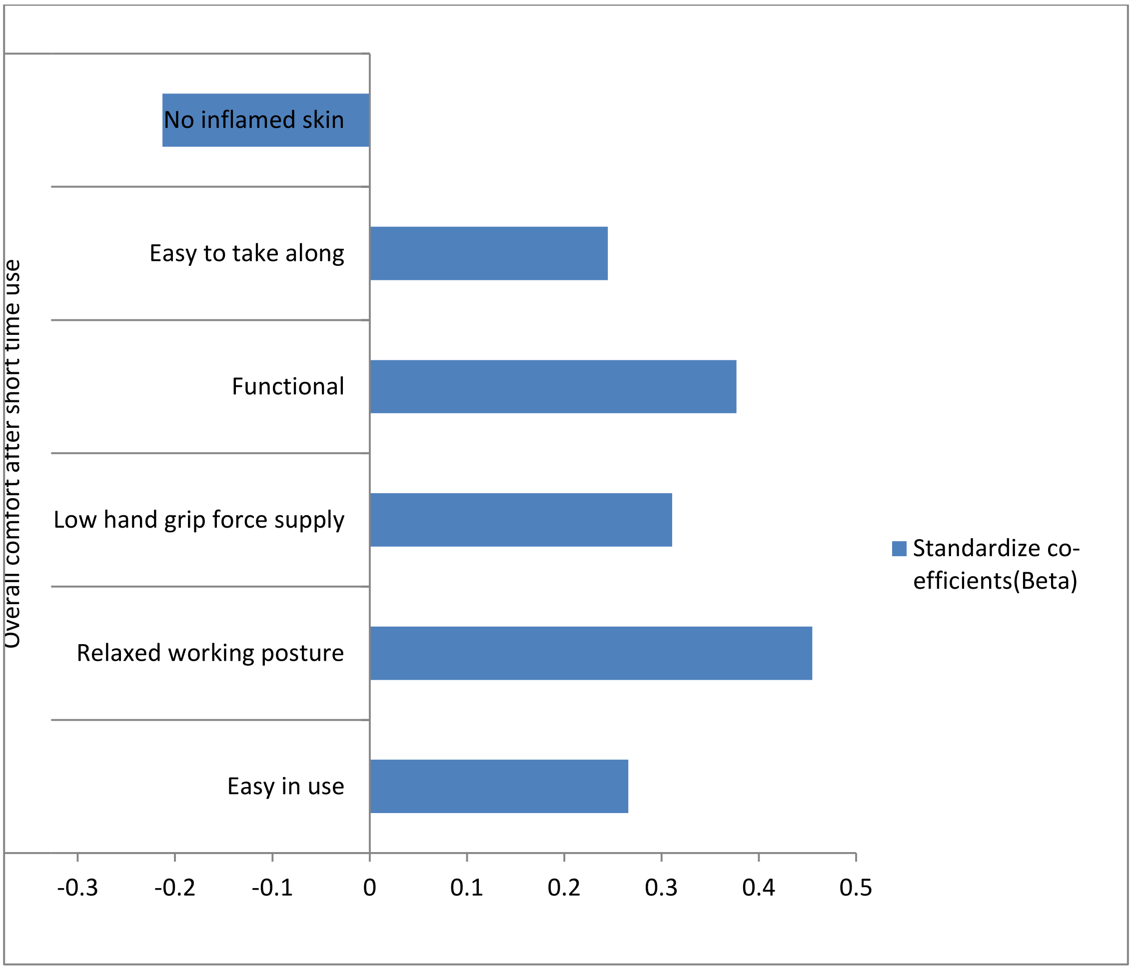



Figure 10: Beta values of overall comfort predicting descriptors

This finding illustrates that the overall comfort is highly affected by ‘relaxed working posture’ followed by ‘functional’, ‘low hand grip force supply’, ‘easy in use’, ‘easy to take along’ and ‘no inflamed skin’.

## 6.2 Identifying Factors of Comfort in Using Hammer

In the main study Principal Component Analysis (PCA) with varimax rotation was performed in order to categorize the descriptors into meaningful groups or factors. PCA of the descriptors revealed eight factors with eigenvalues greater than 1.

The first factor (Factor 1) contains descriptors as functional, reliable, good force transmission, high task performance, easy in use, easy to take along, safe, high product quality and high quality tool and this factor is labeled as 'functionality'. Relaxed working posture, no cramped muscles, low hand grip force supply, no sore muscles, no body part ache, handle hardness, no pain and weight of the tool lie under Factor 2 which is named as 'body posture and muscles'. Factor 3 contains weight of the tool, good friction between handle and hand, good handle roughness, handle shape, no slippery handle, handle size, no irritation, no pressure on hand and this factor is named as 'tool characteristics'. Factor 4 is named as 'pain in hand or fingers' and it contains no irritation, no numbness, no blister, no inflamed skin, no pressure on hand, easy to take along, lack of tactile feelings and no sweaty hands. Factor 5 underlying descriptors are good force transmission, relaxed working posture, low hand grip force supply, no body part ache, fits the hand and nice feeling handle and according to these underlying descriptors this factor is named as 'handle and hand interaction'. The next factor i.e., Factor 6 is named as 'quality' and as the name suggests the underlying descriptors are lack of tactile feeling, no force exerted from the tool, functional, reliable, high quality tool, no distraction of the worker from the task. Factor 7 is named as 'effects on palm' and no pain, good friction between handle and hand, no sweaty hand, handle does not feel clammy, no peak pressure underlie it. Functional color looks professional, styling, luxury tool and solid design underlie the last factor (Factor 8) and it is labeled as 'aesthetics'.

After getting these eight factors by PCA with varimax rotation, their correlations with expected comfort and overall comfort were obtained. The value of the correlation coefficients of the factors related to expected comfort is given in the following figure 11. It shows that 'aesthetics' and 'handle and interaction' are highly correlated to expected comfort at first sight.

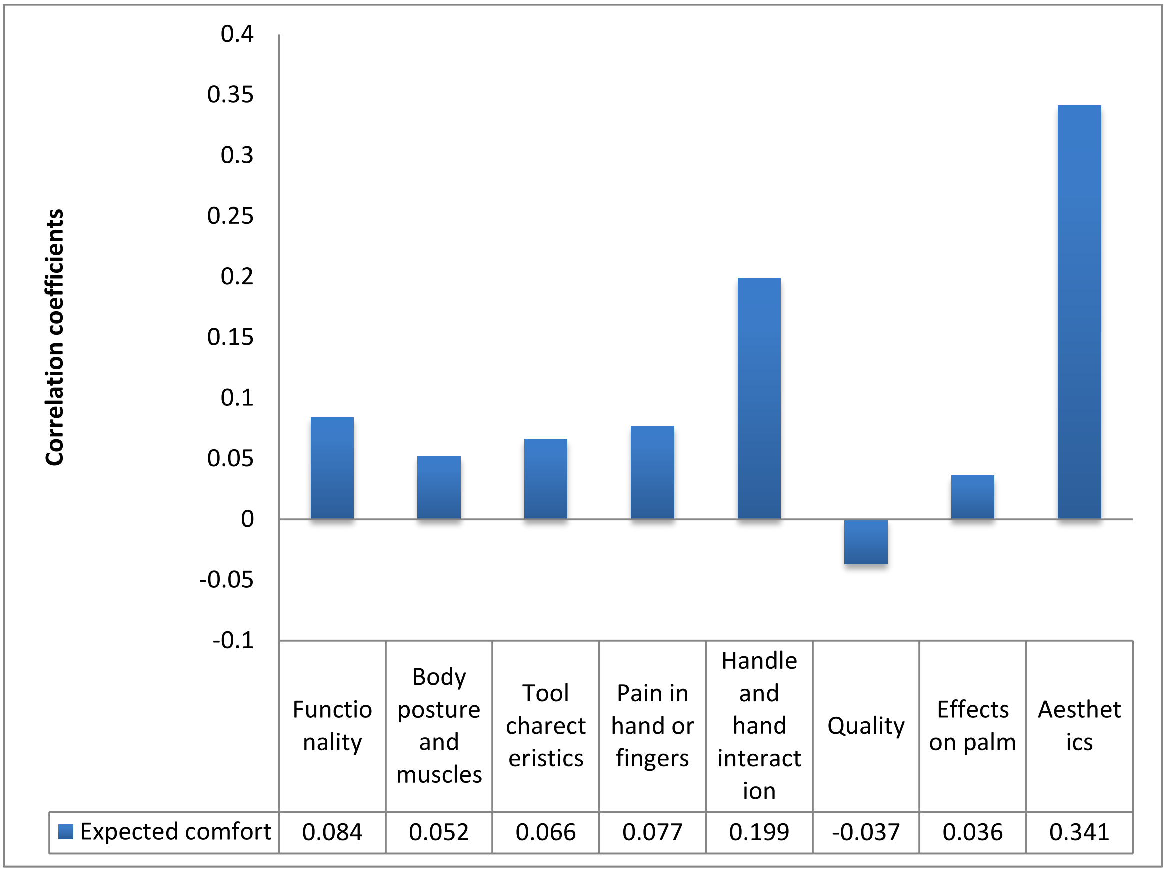



Figure 11: Correlation coefficients of the factors related to expected comfort

The result also shows how these eight factors are correlated with overall comfort in using hammer. The following figure 12 shows the values of correlation coefficients.

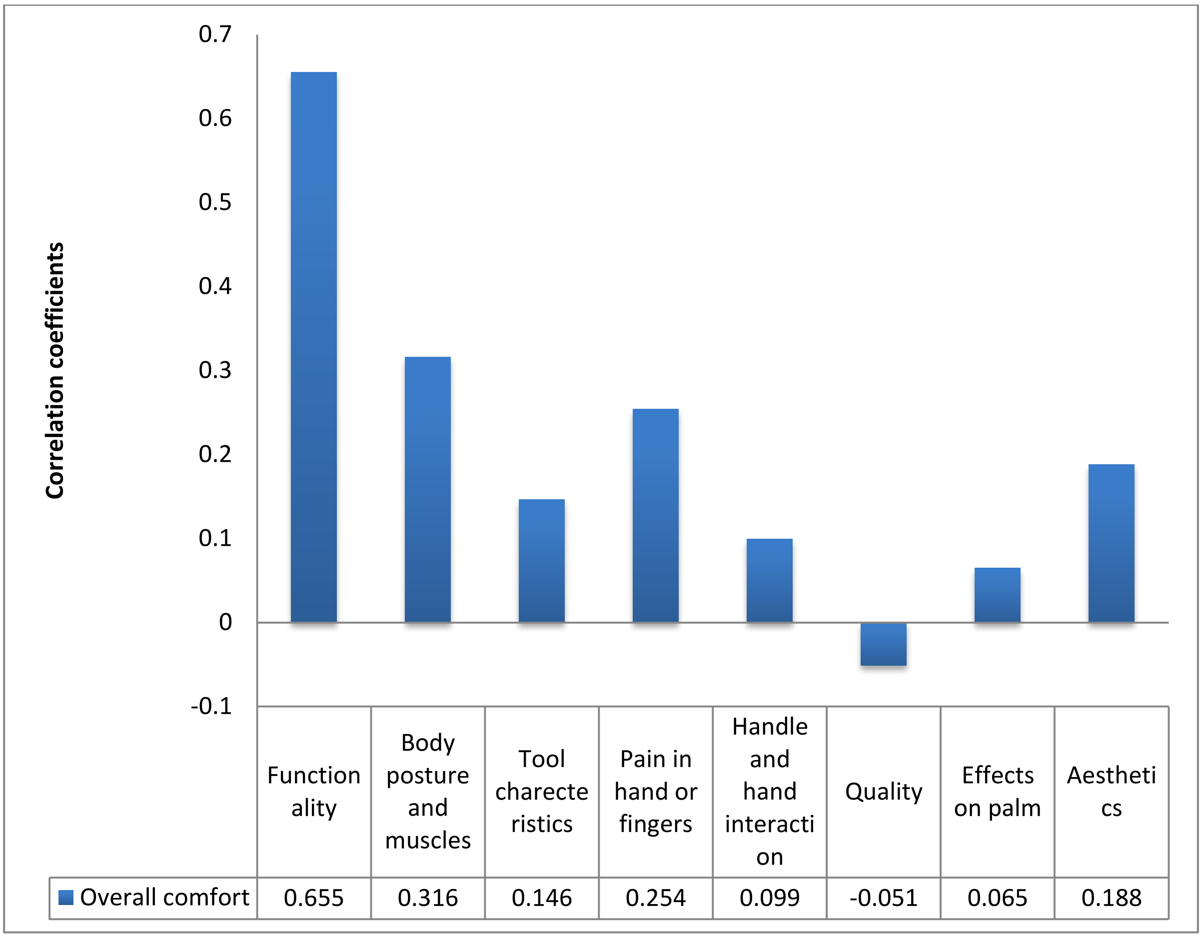



Figure 12: Correlation coefficients of the factors related to overall comfort

‘Functionality’ is highly correlated followed by ‘body posture and muscles’, ‘pain in hand or fingers’, ‘aesthetics’, ‘tool characteristics’, ‘handle and hand interaction’, ‘effects on palm’ and ‘quality’ is only negatively correlated to overall comfort after short time use of hammer.

## 6.3 Predicting Factors of Comfort in Using Hammer

To predict the factors of expected comfort at first sight and overall comfort after short time use of hammer multiple regression (forward selection procedure) was performed.

In using hammer expected comfort at first sight is predicted by ‘aesthetics’ and ‘physical interaction’. Figure 13 shows the numerical values of standardizes coefficients (beta) of ‘aesthetics’ and ‘physical interaction’ with related to the expected comfort at first sight.

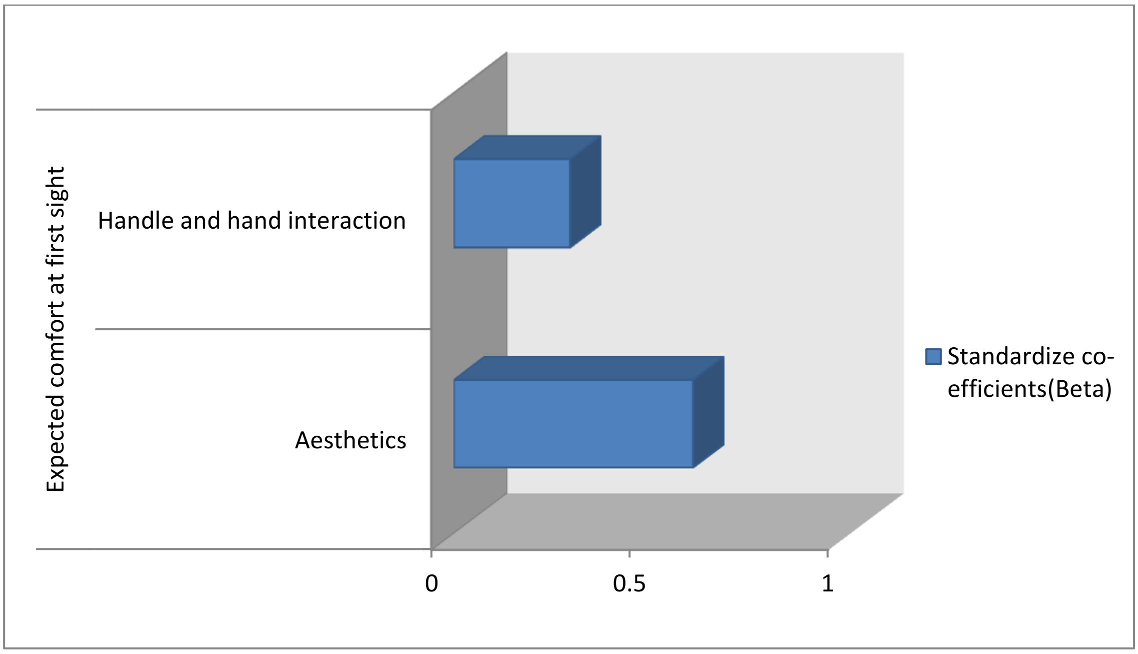



Figure 13: Beta values of the factors predicting expected comfort

From this figure it is clear that the expected comfort at first sight for hammer is highly affected by the aesthetics of the tool. Good physical interaction of hand and handle is also important for the feeling of comfort at first sight. As the expected comfort at first sight is associated with holding the hammer in hand for a few seconds and seems to be important in product buying decisions, it may help to reconsider the aesthetics of the hammer and physical interaction between handle and hand in the designing stage of a hammer.

Whereas, overall comfort is predicted by ‘functionality’, ‘body posture and muscles’, ‘ pain in hand or fingers’, ‘physical interaction’ and ‘aesthetics’ and the following figure 14 shows their standardize coefficients (beta).

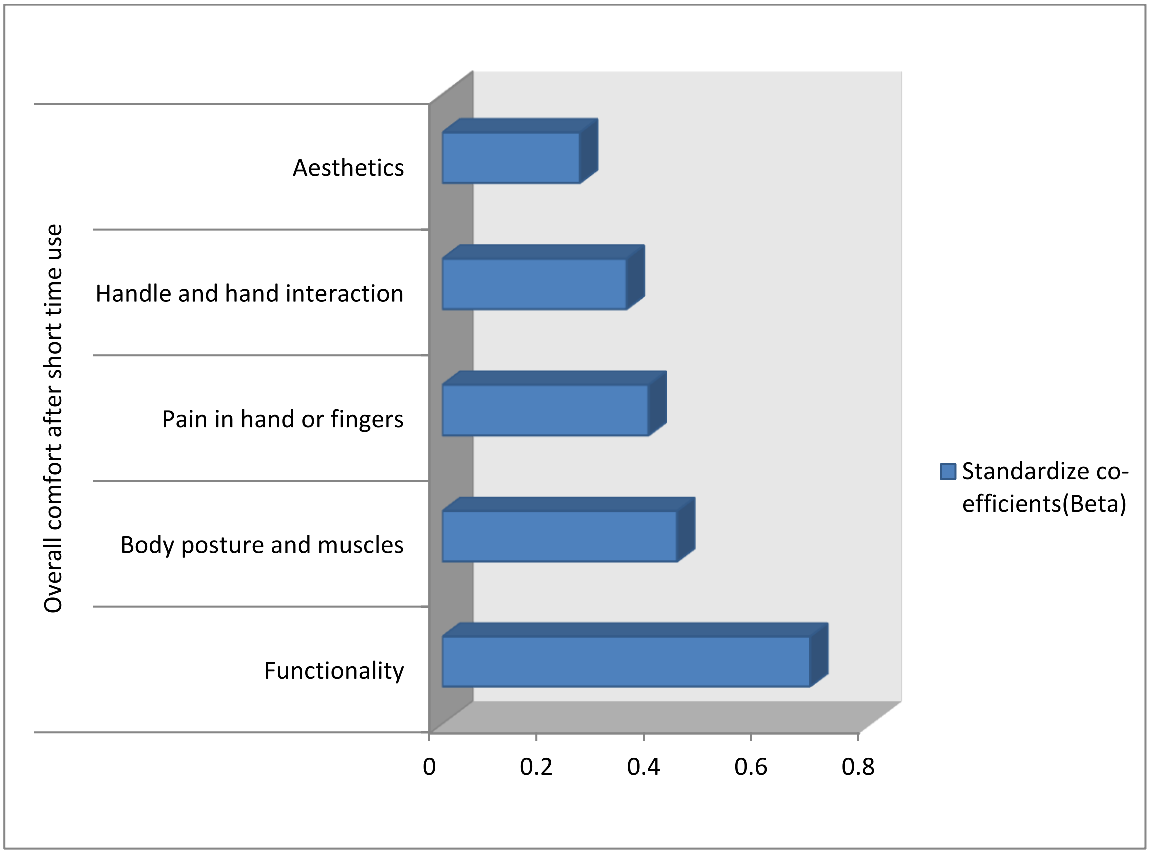



Figure 14: Beta values of the factors predicting overall comfort

From figure 14 it can be understood that ‘functionality’ is of major influence on overall comfort in using hammer. Overall comfort is less predicted by ‘aesthetics’. The factors ‘physical interaction’ and ‘aesthetics’ are common for expected comfort and overall comfort.

The result of this study is a little bit different from the other studies related to comfort where other hand tools such as screwdriver, plier, handsaw were evaluated as the number of descriptors used in the current study is more and the number of factors divided by PCA with varimax rotation is more. This implies that the relative importance of the descriptors vary between different kinds of hand tools. The prediction model is not only influenced by the type of hand tool, the properties of one of the evaluated hand tool such as diameter of the hand tool as well can influence the prediction model.

# CHAPTER 7: CONCLUSION

The results of the study may have a contribution to the discussion of the difference between comfort and discomfort. The results show that the same descriptors underlie comfort and discomfort so the argument on in using hand tools comfort and discomfort could be seen as two opposites on a continues scale is totally wrong. Furthermore, expected comfort in using hammer can be predicted by ‘physical interaction’ partially but the best predictor is ‘aesthetics’. In case of overall comfort ‘functionality’ is the best predictor followed by ‘body posture and muscles’, ‘pain in hand or fingers’, ‘handle and hand interaction’ and ‘aesthetics’. This implies that the aesthetics of a hammer is an important parameter in hammer buying decisions, although it plays a minor role in overall comfort after short time use. It is also important that whenever a hammer is evaluated on comfort, not only adverse body effects should be measured, but also the aspects of functionality of the hammer and the interaction between hand and handle of the hammer should be taken into consideration.

To provide better expected comfort the hammer should fit the hand of the user very well and make the user feel nice while holding the handle of the hammer which is a user’s first choice in hammer buying decisions. For overall comfort the hammer should provide a relaxed working posture with better functionality. The hammer should be designed in a way so that the user does not face any difficulty while using the hammer and the user can perform the task with low hand grip force supply. Mitigating the adverse body effects such as pain in hand or fingers is also important in providing overall comfort.

Therefore, in designing a hammer that provides much comfort, the designers have to focus on functionality, physical interaction and on adverse body effects for avoiding discomfort. For expected comfort ‘aesthetics’ is a very important factor and can play a major role in hammer buying decisions. But for overall comfort after short time use it is tool’s functionality. A comfortable hammer should be easy in use and functional. Additionally, the handle of the hammer should feel nice and the hammer should be able to perform the required task with low hand grip force supply.

## 7.1 Future Scope

The results of this study give the idea of inputs to develop a 'complete list' of descriptors to check whether same descriptors underlie comfort and discomfort or not. It also gives the inputs to develop a questionnaire to evaluate comfort in using hand tools.

In addition, these results can be of help to understand which factors play important role in expected comfort and overall comfort after short time use and it could help the designers in designing of a comfortable hammer.

# REFERENCES


Annett, J. (2002). Subjective rating scales: science or art?. *Ergonomics,45*(14), 966-987.

Aptel, M., Claudon, L., (2002). Integration of ergonomics into hand tool design: principle and presentation of an example. *International Journal of Occupational Safety and Ergonomics, 8* (1). 107–115.

Armstrong, T. J., Fine, L. J., Goldstein, S. A., Lifshitz, Y. R., & Silverstein, B. A. (1987). Ergonomics considerations in hand and wrist tendinitis. *The Journal of hand surgery*, *12*(5), 830-837.

Boyles, J.L., Yearout, R.D., Rys, M.J., (2003). Ergonomic scissors for hairdressing. *International Journal of Industrial Ergonomics, 32*(3). 199-207.

Chaffin, D.B., Andersson, G.B., Martin, J.M., (1999). *Occupational biomechanics*. Wiley, New York.

Das, B., Jongkol, P., & Ngui, S. (2005). Snap-on-handles for a non-powered hacksaw: an ergonomics evaluation, redesign and testing. *Ergonomics*, *48*(1), 78-97.

De Korte, E. M., Huysmans, M. A., De Jong, A. M., Van de Ven, J. G., & Ruijsendaal, M. (2012). Effects of four types of non-obtrusive feedback on computer behaviour, task performance and comfort. *Applied ergonomics, 43*(2), 344-353

.De Looze, M. P., Kuijt-Evers, L. F., & Van Dieen, J. A. A. P. (2003). Sitting comfort and discomfort and the relationships with objective measures.*Ergonomics*, *46*(10), 985-997.

Dempsey, P.G., McGorry, R.W., Leamon, T.B., O'Brien, N.V.,(2002). Bending the tool and the effect on human performance: Further investigation of a simulated wire-twisting task. *AIHA Journal, 63* (7). 586-593.

Dempsey, P. G., McGorry, R. W., & O'Brien, N. V. (2004). The effects of work height, workpiece orientation, gender, and screwdriver type on productivity and wrist deviation. *International Journal of Industrial Ergonomics*, *33*(4), 339-346.

Dumur, E., Barnard, Y., & Boy, G. (2004). Designing for comfort. *Human factors in design*, 111-127.

Eksioglu, M. (2004). Relative optimum grip span as a function of hand anthropometry. *International Journal of Industrial Ergonomics*, *34*(1), 1-12.

Ellegast, R. P., Kraft, K., Groenesteijn, L., Krause, F., Berger, H., & Vink, P. (2012). Comparison of four specific dynamic office chairs with a conventional office chair: impact upon muscle activation, physical activity and posture. *Applied ergonomics*, *43*(2), 296-307.

Fellows, G.L., Freivalds, A., (1991). Ergonomics evaluation of a foam rubber grip for tool handles. *Applied Ergonomics, 22*(4). 225-230.

Franz, M.M., Durta, A ., Zenk , R., Desmet, P.M.A.(2012). Comfort effects of a new car headrest with neck support. *Applied ergonomics, 43*(2), 336– 343.

Freund, J., Takala, E-P., Toivonen, R., (2000). Effects of two ergonomics aids on the usability of an in-line screwdriver. *Applied Ergonomics, 31*(4). 371-376.

Gilman, E. W. (1989). Webster's dictionary of English usage. *Springfield, MA: Merriam-Webster Inc*.

Groenesteijn, L., Eikhout, S.M., Vink, P., (2004). One set of pliers for more tasks in installation work: the effects on (dis)comfort and productivity. *Applied Ergonomics, 35*(5). 485-492.

Groenesteijn, L., Ellegast, R. P., Keller, K., Krause, F., Berger, H., & de Looze, M. P. (2012). Office task effects on comfort and body dynamics in five dynamic office chairs. *Applied ergonomics*, *43*(2), 320-328.

Haapalainen, M., Kivistö-Rahnasto, J., Mattila, M., (2000). Ergonomic design of non-powered hand tools: An application of quality function deployment (QFD). *Occupational Ergonomics, 2* (3). 179-189.

Hammarskjöld, E., & Harms-Ringdahl, K. (1992). Effect of arm-shoulder fatigue on carpenters at work. *European journal of applied physiology and occupational physiology*, *64*(5), 402-409.

Harih, G., & Dolšak, B. (2014). Comparison of subjective comfort ratings between anatomically shaped and cylindrical handles. *Applied ergonomics*,*45*(4), 943-954.

Eksioglu, M. (2004). Relative optimum grip span as a function of hand anthropometry. *International Journal of Industrial Ergonomics*, *34*(1), 1-12.

Kamp, I. (2012). The influence of car-seat design on its character experience.*Applied ergonomics*, *43*(2), 329-335.

Kee D. & Karwowski W. (2001). The boundaries for joint angles of isocomfort for sitting and standing males based on perceived comfort of static joint postures. *Ergonomics*, *44*(6), 614-648.

Kluth, K., Kelermann, H.G., Strasser, H., (2004). Assessment of the ergonomic quality of file handles using electromyographic and subjective methods. *Occupational Ergonomics, 4*(2). 133-142.

Kong, Y. K., Kim, D. M., Lee, K. S., & Jung, M. C. (2012). Comparison of comfort, discomfort, and continuum ratings of force levels and hand regions during gripping exertions. *Applied Ergonomics*, *43*(2), 283-289.

Kuijt-Evers, L. F. M., Bosch, T., Huysmans, M. A., De Looze, M. P., & Vink, P. (2007). Association between objective and subjective measurements of comfort and discomfort in hand tools. *Applied ergonomics*, *38*(5), 643-654.

Kuijt-Evers, L. F. M., Vink, P., & De Looze, M. P. (2007). Comfort predictors for different kinds of hand tools: Differences and similarities. *International journal of industrial ergonomics*, *37*(1), 73-84.

L.F.M. Kuijt-Evers, L. Groenesteijn, M.P. de Looze, P. Vink (2003). Identifying predictors of comfort in using hand tools. *Applied Ergonomics, 35*(1), 453-458.

Lucker, G. W., Beane, W. E., & Helmreich, R. L. (1981). The strength of the halo effect in physical attractiveness research. *The Journal of Psychology*,*107*(1), 69-75.

M.A. Sinclair, (1975). Questionnaire design. *Applied Ergonomics, 6*.2. 73-80.

Moes, N. C. C. M. (2005). Analysis of sitting discomfort, a review. *Contemporary Ergonomics*, 200-204.

Muckler, F. A., & Seven, S. A. (1992). Selecting performance measures:" Objective" versus" subjective" measurement. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *34*(4), 441-455.

Niemellä, T., Leppänen, M., Päivinen, M., Mattila, M., (2000). Evaluation of an experimental testing system for non-powered hand tools. In: Ergonomics for the New Millennium. Proceedings of the IEA 2000/HFES 2000 congress. San Diego, 28 July-4 August, 2000: (3),643-3-646.

Noro, K., Naruse, T., Lueder, R., Nao-i, N., & Kozawa, M. (2012). Application of Zen sitting principles to microscopic surgery seating. *Applied ergonomics*,*43*(2), 308-319.

Richards, L. G. (1980). On the psychology of passenger comfort. *Human Factors in Transport Research Edited by DJ Oborne, JA Levis*, *2*.

Slater, K. (1985). *Human comfort* (Vol. 1). Springfield, Ill., USA: CC Thomas.

Vink, P. (Ed.). (2004). *Comfort and design: principles and good practice*. CRC press.

Vink, P., & Hallbeck, S. (2012). Editorial: Comfort and discomfort studies demonstrate the need for a new model. *Applied ergonomics*, *43*(2), 271-276.

Vink, P., Bazley, C., Kamp, I., & Blok, M. (2012). Possibilities to improve the aircraft interior comfort experience. *Applied ergonomics*, *43*(2), 354-359.

You, H., Kumar, A., Young, R., Veluswamy, P., Mahlzahn, D.E., (2005). An ergonomic evaluation of manual calico plier designs: Effects of rubber grip, spring recoil, and work surface angle. *Applied Ergonomics, 36*(5). 575-583.

Zhang, L., Helander, M. G., & Drury, C. G. (1996). Identifying factors of comfort and discomfort in sitting. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *38*(3), 377-389.

# APENDIX I

## Complete list of descriptors

| The hammer | Related to (dis)comfort | Not related to (dis)comfort | Do not know |
|---|---|---|---|
| Fits the hand | 1 | 2 | 3 |
| Functional | 1 | 2 | 3 |
| Reliable | 1 | 2 | 3 |
| Safe | 1 | 2 | 3 |
| Weight of the tool | 1 | 2 | 3 |
| Handle size | 1 | 2 | 3 |
| Easy to take along | 1 | 2 | 3 |
| Nice color | 1 | 2 | 3 |
| Solid design | 1 | 2 | 3 |
| High quality tool | 1 | 2 | 3 |
| Nice feeling handle | 1 | 2 | 3 |
| High task performance | 1 | 2 | 3 |
| High product quality | 1 | 2 | 3 |
| Looks professional | 1 | 2 | 3 |
| Relaxed working posture | 1 | 2 | 3 |
| Low hand grip force supply | 1 | 2 | 3 |
| No body part ache | 1 | 2 | 3 |
| Good friction between handle and hand | 1 | 2 | 3 |
| Handle surface with good roughness | 1 | 2 | 3 |
| No inflamed skin of hand | 1 | 2 | 3 |
| No pain | 1 | 2 | 3 |
| No Peak pressure on the hand | 1 | 2 | 3 |
| No blisters | 1 | 2 | 3 |
| No sweaty hands | 1 | 2 | 3 |
| No numbness in fingers | 1 | 2 | 3 |
| No cramped muscles | 1 | 2 | 3 |
| No sore muscles | 1 | 2 | 3 |
| No irritation | 1 | 2 | 3 |
| Handle shape | 1 | 2 | 3 |
| Styling | 1 | 2 | 3 |

| The hammer | Related to (dis)comfort | Not related to (dis)comfort | Do not know |
|---|---|---|---|
| Handle hardness | 1 | 2 | 3 |
| No slippery handle | 1 | 2 | 3 |
| No force exerted from tool | 1 | 2 | 3 |
| All-weather proof tool | 1 | 2 | 3 |
| Luxury tool | 1 | 2 | 3 |
| Pleasurable | 1 | 2 | 3 |
| Easy in use | 1 | 2 | 3 |
| Good force transmission | 1 | 2 | 3 |
| No pressure on hand | 1 | 2 | 3 |
| Satisfaction | 1 | 2 | 3 |
| Nice appearance | 1 | 2 | 3 |
| Happy with the performance of the hammer | 1 | 2 | 3 |
| Causes no distraction of worker from task | 1 | 2 | 3 |
| Functional color | 1 | 2 | 3 |
| Handle does not feel clammy | 1 | 2 | 3 |
| Lack of tactile feeling | 1 | 2 | 3 |

# APPENDIX II

## Comfort Questionnaire

Expected comfort at first sight

| The hammer is | Very uncomfortable | • | A little uncomfortable | • | A little comfortable | • | Very comfortable |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

Comfort descriptors

| This Hammer | Totally disagree | • | Disagree somewhat | • | Agree somewhat | • | Totally agree |
|---|---|---|---|---|---|---|---|
| Fits the hand | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Is functional | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Is very reliable | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Is easy in use | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Has a good force transmission | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Is safe | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Weight of the tool | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Handle size | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Is easy to take along | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Has a solid design | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Is a high quality tool | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Has a nice feeling handle | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Offers a high task performance | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

| **This Hammer** | **Totally disagree** | **•** | **Disagree somewhat** | **•** | **Agree somewhat** | **•** | **Totally agree** |
|---|---|---|---|---|---|---|---|
| Provides a high product quality | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Looks professional | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Provides a relaxed working posture | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Needs low hand grip force supply | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Causes body part ache | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Has a good friction between handle and hand | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Has a handle surface with good roughness | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Does not cause inflamed skin of hand | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Does not cause pain | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Does not cause peak pressure on the hand | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Does not cause blisters | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Does not cause sweaty hands | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Does not cause numbness in fingers | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Does not cause cramped muscles | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Does not cause sore muscles | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Does not cause any irritation | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

| This Hammer | Totally disagree | • | Disagree somewhat | • | Agree somewhat | • | Totally agree |
|---|---|---|---|---|---|---|---|
| Handle shape | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Is stylish | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Handle hardness | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Has no slippery handle | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Exerts no force on the hand | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Is luxury tool | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Is pleasurable | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Causes no pressure on hand | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Is satisfactory tool | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Causes no distraction of worker from the task | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Has a functional color | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Handle does not feel clammy | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Lack of tactile feeling | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

Overall comfort after short time use

| I think the hand tool is: | Very uncomfortable | • | A little uncomfortable | • | A little comfortable | • | Very comfortable |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |