

DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

**ERGONOMIC CONSUMER PRODUCT DESIGN:
PRINCIPLES, EVALUATION AND
APPLICATION**

by
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June, 2019
İZMİR

ERGONOMIC CONSUMER PRODUCT DESIGN: PRINCIPLES, EVALUATION AND APPLICATION

**A Thesis Submitted to the
Graduate School of Natural and Applied Sciences of Dokuz Eylül University
In Partial Fulfillment of the Requirements for the Degree of Master of
Degree in Industrial Engineering**

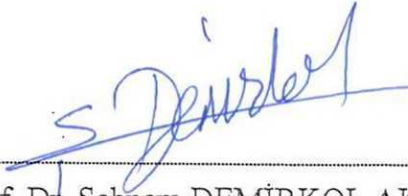
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June, 2019

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled “ERGONOMIC CONSUMER PRODUCT DESIGN: PRINCIPLES, EVALUATION AND APPLICATION” completed by SERCAN MADANLAR under supervision of ASST. PROF. DR. ŞEBNEM DEMİRKOL AKYOL and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.



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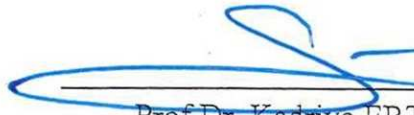
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Sercan MADANLAR

ERGONOMIC CONSUMER PRODUCT DESIGN: PRINCIPLES, EVALUATION AND APPLICATION

ABSTRACT

Product ergonomics is not only the essential factor for consumers who are looking for the best product to fulfill their requirements, but also necessary for producers which effects their sales figures and profits. The aim of this thesis is to identify and group the criteria that affect directly and indirectly to the product ergonomics and according to this, to propose Ergonomic Consumer Product Design Principles. Ergonomic Consumer Product Design Principles divided into two headlines which are primary and secondary principles. Primary and secondary principles are the criteria that affect the product ergonomics directly and indirectly, respectively. Then, the New Product Development Process model was developed with considering Ergonomic Consumer Product Design Principles, which includes ten steps and five sub-steps. After modeling the New Product Development Process, eleven pruning shears were selected, and the procedure is applied to investigate them. Throughout this thesis, the human needs of the pruning shears were identified and matched to the primary and secondary criteria. Pressure tests, case study analysis, cutting tests and some other data collecting methods were applied to the pruning shears to investigate ergonomic conditions of the products. According to the results, the ergonomic concept design ideas have been suggested. The results of the statistical analysis show that consumers' behavior can be affected by the product usage experience. The significant differences were found between gender and hand sizes of the participants in pruning shear usage. In pressure tests, unpredictable ergonomic problems were discovered that affects product ergonomics. Moderate and strong correlations were found in the human needs, which proves that Ergonomic Consumer Product Design Principles can be affected by each other. The main contribution of this thesis is implementing the Ergonomic Consumer Product Design Principles into the pruning shears design process successfully.

Keywords: Ergonomics, product design, ergonomic consumer product design principles

ERGONOMİK TÜKETİCİ ÜRÜN TASARIMI: İLKELERİ, DEĞERLENDİRME VE UYGULAMA

ÖZ

Ürün ergonomisi, sadece gereksinimlerini yerine getirmek için en iyi ürünü arayan tüketiciler için değil, aynı zamanda satış rakamlarını ve karlarını etkileyen üreticiler için de önemli olan bir faktördür. Tezin amacı doğrudan ve dolaylı olarak ürün ergonomisine etki eden kriterleri tanımlamak/gruplandırmak ve buna göre ergonomik tüketici ürünü tasarım ilkeleri önermektir. Ergonomik Tüketici Ürün Tasarım Prensipleri, birincil ve ikincil ilkeler olan iki başlığa ayrılmıştır. Birincil ilkeler ürün ergonomisini doğrudan etkileyen kriterlerdir. Öte yandan, ikincil ilkeler ürün ergonomisini dolaylı olarak etkileyen kriterlerdir. Ardından, on adımlı ve beş alt adımlı yeni ürün geliştirme süreci modeli, Ergonomik Tüketici Ürün Tasarım İlkeleri göz önüne bulundurularak geliştirilmiştir. Yeni ürün geliştirme süreci modelinin geliştirilmesini takiben, uygulama çalışması yapılmak üzere onbir adet budama makası belirlenmiştir. Bu tez kapsamında, budama makaslarının insan ihtiyaçları tespit edilmiş ve birincil ve ikincil kriterler ile eşleştirilmiştir. Ürünlerin ergonomik koşullarını araştırmak için budama makaslarına basınç testi, vaka çalışması, kesme testleri ve diğer veri toplama yöntemleri uygulanmıştır. Elde edilen sonuçlara göre ergonomik konsept tasarım fikirleri önerilmiştir. İstatistiksel analizlerden elde edilen sonuçlar, vaka çalışmasında tüketicilerin ürün seçimi konusundaki tutumlarının, ürün kullanım deneyiminden etkilendiğini ortaya koymuştur. Budama makası kullanımında katılımcıların cinsiyetleri ve el büyüklükleri arasında anlamlı farklılıklar bulunmuştur. Basınç testlerinde ürün ergonomisini etkileyen öngörülemeyen ergonomik problemler keşfedilmiştir. İnsan ihtiyaçlarında orta ve güçlü korelasyonlar bulunmuştur. Bu sonuçlar, Ergonomik Tüketici Ürünleri Tasarım İlkeleri'nin birbirinden etkilenebileceğini kanıtlamaktadır. Bu tezin literature en önemli katkısı, ergonomik tüketici ürün tasarımı ilkelerinin budama makası tasarım sürecine başarıyla uygulanması olmuştur.

Anahtar Kelimeler: Ergonomi, ürün tasarımı, ergonomik tüketici ürün tasarımı prensipleri

CONTENTS

	Page
M.Sc THESIS EXAMINATION RESULT FORM.....	ii
ACKNOWLEDGMENT	iii
ABSTRACT	iv
ÖZ	v
LIST OF FIGURES	xii
LIST OF TABLES	xiv
 CHAPTER ONE - INTRODUCTION	 1
1.1 Ergonomics.....	1
1.2 Product Design	3
1.3 Importance of the Ergonomic Product Design	4
1.4 Aim and Importance of This Thesis	5
1.5 Outline of This Thesis	6
 CHAPTER TWO - LITERATURE REVIEW	 7
2.1 Stage One: Beginning of the Literature Review	8
2.2 Stage Two: Creation of the Ergonomic Consumer Product Design Principles	18
2.3 Stage Three: Creation of the Ergonomic Consumer Product Design Methodology	18
 CHAPTER THREE -PROBLEM DEFINITION AND THESIS STRUCTURE	 20
3.1 Problem Definition	20
3.2 Thesis Structure	20

CHAPTER FOUR - PRINCIPLES OF ERGONOMIC PRODUCT DESIGN.. 23

4.1 Ergonomic Consumer Product Design Principles	23
4.1.1 Features.....	25
4.1.2 Primary Principles	29
4.1.2.1 Health.....	29
4.1.2.2 Durability	31
4.1.2.3 Comfort.....	33
4.1.2.4 Functionality	35
4.1.2.5 Usability (Easy to Use)	37
4.1.2.6 Learnability (Easy to Learn)	41
4.1.2.7 Effort- Force (Save Effort).....	43
4.1.3 Secondary Principles	44
4.1.3.1 Price- Cost.....	45
4.1.3.2 Style- Fashion	47
4.1.3.3 Product Guarantee- Warranty	48
4.1.3.4 Environmental Effect- Recyclability	50
4.1.4 Conceptual Model of Ergonomic Consumer Product Design Principles	51

CHAPTER FIVE - GENERAL METHODOLOGY 53

5.1 New Product Development Process Considering Ergonomics	53
5.1.1 Product Decision.....	56
5.1.2 Determine Target Population.....	58
5.1.2.1 Economic Environment	59
5.1.2.2 Socio- Cultural Environment	60
5.1.2.3 Technological Environment.....	60
5.1.2.4 Political- Regulatory Environment	60
5.1.2.5 Ecological Environment.....	60
5.1.3 Investigate the Target Population Needs	61

5.1.4 Translate Customer Needs into the Engineering Characteristic	61
5.1.5 Investigate Existing Product Range of the Market	64
5.1.5.1 Ergonomic Diagnosis of Similar Products.....	64
5.1.5.2 Identify the Principles to be Used.....	65
5.1.5.3 Determine Evaluation of the Principles	65
5.1.5.4 Data Collecting	66
5.1.5.5 Comparison of the Similar Products	67
5.1.6 Product Concept Generation.....	68
5.1.7 Concept Selection	71
5.1.8 Detailed Product Design (Architecture)	72
5.1.9 Testing	75
5.1.10 Production.....	77

CHAPTER SIX - AN APPLICATION OF ERGONOMIC PRUNING SHEAR DESIGN 78

6.1 Application Content	78
6.2 Product Decision	79
6.3 Determine Target Population	81
6.4 Investigate Target Population Needs.....	82
6.4.1 Right and Left Hand Usability.....	83
6.4.2 Lightweight Pruning Shear	84
6.4.3 Durability of the Pruning Shear	84
6.4.4 Adjustable Handle According to Hand Sizes	85
6.4.5 Suitable Material Usage for Handle	85
6.4.6 Suitable Hand Motion in Cutting Process	85
6.4.7 Suitable Handle Temperature	87
6.4.8 Replacement of the Pruning Shears' Parts	87
6.4.9 Hand Position at the Cutting Process (Knife Angle).....	87
6.4.10 Cutting with Minimum Effort.....	88
6.4.11 Maximum Bough Diameter to Cut	89

6.4.12 Security Lock Design	89
6.4.13 Protecting Palm Health	89
6.4.14 Protecting Wrist Health	89
6.4.15 Protecting Finger Health.....	90
6.4.16 Easy to Clean	91
6.4.17 Slippery of the Handle	91
6.4.18 Rust Protection	91
6.4.19 Bottom End Handle Distance	91
6.4.20 Smooth Cut	92
6.4.21 Price	93
6.4.22 The Service Life of the Product and Its Guarantee.....	93
6.4.23 Environmental Effect/ Recyclability	93
6.5 Translate Customer Needs into Engineering Characteristics	93
6.6 Investigate Existing Product Range of the Market.....	95
6.6.1 Ergonomic Diagnosis of Similar Products	95
6.6.2 Identify Principles to be Used.....	99
6.6.3 Determine Evaluation of Principles.....	101
6.6.4 Data Collecting and Comparison of the Similar Products.....	104
6.6.4.1 Compression Test.....	104
6.6.4.1.1 Apparatus Design.....	104
6.6.4.1.2 Experiment Design	106
6.6.4.1.3 Test Results.....	107
6.6.4.1.4 Conclusion of Compression Test.....	108
6.6.4.2 Cutting Test.....	109
6.6.4.3 Case Study- Participant Experiment of Investigating Pruning Shears	111
6.6.4.3.1 Survey Development.....	111
6.6.4.3.2 Participants.....	113
6.6.4.3.3 Procedures.....	114
6.6.4.3.4 Experiment Flow.....	115
6.6.4.3.5 Calculating Weights of Ergonomic Consumer Product Design Principles	116

6.6.4.3.6 Correlation Investigation between Survey Questions.....	125
6.6.4.3.7 Statistical Significance Investigation.....	130
6.6.4.3.8 Results.....	133
6.6.4.4 Investigating the Rest of the Human Needs and Engineering Characteristics of the Pruning Shears	144
6.6.4.4.1 Right and Left Hand Usability.....	144
6.6.4.4.2 Lightweight Pruning Shears.....	144
6.6.4.4.3 Adjustable Handle Size.....	145
6.6.4.4.4 Durability of the Pruning Shear	146
6.6.4.4.5 Suitable Motion.....	146
6.6.4.4.6 Suitable Handle Temperature	146
6.6.4.4.7 Replacement Parts.....	146
6.6.4.4.8 Knife Angle.....	146
6.6.4.4.9 Maximum Bough Diameter to Cut	146
6.6.4.4.10 Security Lock Design.....	147
6.6.4.4.11 Rust Protection.....	147
6.6.4.4.12 Bottom end Handle Distance	147
6.6.4.4.12 Price	148
6.6.4.4.13 Product Guarantee.....	149
6.6.4.4.14 Environmental Effect/Recyclability	149
6.7 Product Concept Generation	150
CHAPTER SEVEN - CONCLUSIONS	153
REFERENCES.....	157
APPENDICES	169
APPENDIX-1: Pressure Test Results Graphics	169
APPENDIX-2: Hugh Nation Hand Sizing Chart	175
APPENDIX-3: Participants Survey.....	176

APPENDIX-4: Observers' Survey	192
APPENDIX-5: Participants Criteria Ranking Matrices	193
APPENDIX-6: Correlations between Likert Questions	195
APPENDIX-7: Observers' Wrist Health data versus Likert Questions Data	196
APPENDIX-8: Correlations between Observers' Effort and Participants' Effort	197
APPENDIX-9: Gender Differences between Likert Questions	198
APPENDIX-10: Variance Test and One-way ANOVA Test Results	201
APPENDIX-11: Post- Hoc Test Results	203



LIST OF FIGURES

	Page
Figure 1.1 Interdisciplinary fields inside of ergonomics	3
Figure 2.1 Literature investigation strategies	8
Figure 3.1 Research design of the thesis	22
Figure 4.1 Comfort model, the feeling of discomfort is determined by inputs recorded by the sensors and information processing affected by the participant's history and status	34
Figure 4.2 The question that is used to evaluate the chair comfort.....	35
Figure 4.3 A model of the attributes of system acceptability	38
Figure 4.4 Summary of the usability methods	40
Figure 4.5 The conceptional model of ergonomic consumer product design principles	52
Figure 5.1 The visual representation of New Product Development Process Model	54
Figure 5.2 The procedure steps of New Product Development Process Model.....	55
Figure 5.3 Top ten startup mistakes	57
Figure 5.4 Observation areas for the future analysis.....	59
Figure 5.5 The needs-metrics matrix	63
Figure 5.6 Concept combination table for the handheld nailer	69
Figure 5.7 Example of the concept creation.....	70
Figure 5.8 Modular architecture types	74
Figure 5.9 Prototype types	77
Figure 6.1 Anvil pruner (left) and bypass pruner (right)	80
Figure 6.2 Flexion motions of four fingers and open positions of fingers (left), close positions of fingers (right).....	86
Figure 6.3 An ergonomic pruning shear knife position	88
Figure 6.4 Anterior view of the tunnel (left), cross section of tunnel (right).....	90
Figure 6.5 Full open positions of the pruning shears (left and right), holding position with the little finger (middle)	92

Figure 6.6 Group A pruning shears' names are respectively worth deluxe 1055 (A1), fiskars P68 (A2), izeltaş 6715 confort (A3), and handmade pruning shear (A4)	96
Figure 6.7 Group B pruning shears' names are respectively izeltaş 6720 hafif tip (B1), haktaş (B2), and fiskars P94 (B3)	97
Figure 6.8 Group C pruning shears' names are respectively akman (C1), raco RT53/139S (C2), izeltaş 6710 Lüks (C3), and fiskars P54 (C4).....	98
Figure 6.9 Bottom view of apparatus (top left), side view of apparatus (top right), top view of apparatus (bottom left), and side view of apparatus with cable tie (bottom right).....	105
Figure 6.10 Attachment of pruning shear to the machine with the help of the apparatus	106
Figure 6.11 Good cutting surface (top left-live bough), normal cutting surface (top middle-live bough), bad cutting surface (top right-live bough), good cutting surface (bottom left-7mm pine bough), normal cutting surface (bottom middle-7mm pine bough), and bad cutting surface (bottom right- 7mm pine bough).....	110
Figure 6.12 Evaluation areas of the palm, wrist and finger health	113
Figure 6.13 Participant posture and hand/wrist position at the cutting process.....	115
Figure 6.14 Schematic schedule of experiment for both observer and participants	116
Figure 6.15 The mean effort values of each pruning shears	134
Figure 6.16 The mean palm health values of each pruning shears	136
Figure 6.17 The mean finger health values of each pruning shears.....	137
Figure 6.18 The mean wrist health values of each pruning shears	138
Figure 6.19 The mean slippery values of each pruning shears	139
Figure 6.20 The mean easy to clean values of each pruning shears	140
Figure 6.21 The mean handle material comfort values of each pruning shears.....	141
Figure 6.22 The number of bended wrist and fail to cut according to gender and pruning shears	142

LIST OF TABLES

	Page
Table 2.1 Examination of the literature according to common and different points .	10
Table 6.1 Human needs and its relationships with ergonomic consumer product design principles and features	82
Table 6.2 Engineering characteristics and measurement units of human needs	94
Table 6.3 The first impression properties of pruning shears' (can be seen easily by consumers)	99
Table 6.4 Ergonomic consumer product design principles and human needs	100
Table 6.5 Human needs, engineering characteristics and measurement units.	103
Table 6.6 Maximum measured force of each pruning shears	107
Table 6.7 The results of multiplying distance to fulcrum and maximum measured force.....	108
Table 6.8 Scored surface area performance of each pruning shears	110
Table 6.9 RN(Cj)'s values of both matrices.....	121
Table 6.10 Normalized matrices	122
Table 6.11 RN(Kj) matrices	122
Table 6.12 RN(Qj) matrices	123
Table 6.13 Results of both matrices criteria weights and its comparison	124
Table 6.14 Reliability analysis of likert questions	126
Table 6.15 Normality analysis of the likert questions.....	127
Table 6.16 Correlation results between, pressure test, man and woman effort	135
Table 6.17 Rank of the pruning shears according to gender.....	143
Table 6.18 Weight of the pruning shears	145
Table 6.19 Bottom end handle distance of the pruning shears	148
Table 6.20 The approximate prices of the pruning shears	149

CHAPTER ONE

INTRODUCTION

1.1 Ergonomics

Ergonomics is a branch of science that is occurred from combination of the two Greek words *ergo* (work) and *nomos* (laws). The terms *Human Factors* or *Human Factors and Ergonomics (HFE)* are also used as a synonym of the *Ergonomics*. There are no differences been in these three terms (Helander, 2006). So, these are can be used interchangeably.

There are many definitions been in the Human Factors and Ergonomics (HFE) literature. The followings are from literature:

- According to the International Ergonomics Association (IEA): ‘Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance.’ (Bush, 2011, p. 3)
- National Aeronautics and Space Administration (NASA) defined that ‘Human factors is an umbrella term for several areas of research that include human performance, technology design, and human-computer interaction. The study of human factors in the Human Factors Research and Technology Division at NASA Ames Research Center focuses on the need for safe, efficient and cost-effective operations, maintenance and training, both in flight and on the ground.’ (Bush, 2011, p. 3)
- For CETENA (The Italian Ship Research Company), ‘Ergonomics is the study of human performance and its application to the design of technological systems.’ (Bush, 2011, p. 3)

It is seen that the definitions of the HFE can include some of the differences according to the institutions that make the definition. Small differences can be found in the definition of the ergonomics. It depends on the aim or product range of the institution.

Simply and according to commonly used, ergonomics is a multidisciplinary branch of science that investigates human-machine-environment relationship. Ergonomics works for understanding and improving this relationship. It is clearly seen in the literature that in ergonomic studies, a certain part of human-machine-environment relationship is taken by researchers for more specific works. For example, researchers can investigate:

- Human- task harmony
- Human- work harmony
- Environment- human harmony
- Human- product harmony
- Workplace- environment harmony
- Workplace- human harmony

These are some of the examples that the researchers do in the ergonomics works. In these ergonomics studies, researchers benefit from other disciplines. This interdisciplinary field is given in Figure 1.1 (Bush, 2011).

As can be seen in the figure, people have been at the center of ergonomics works. Interdisciplinary fields help to investigate and determine human, machine and environment features which are used in the ergonomics science for improvement of the people life.

According to Karwowski (2005, p. 438), “Traditionally, the most often cited domains of specialization within HFE are physical, cognitive and organizational ergonomics.” In this thesis, according to human- product relationship, the physical

ergonomics is the main source and application field. The aims are mitigating risk factors and improvement of the human- product relationship.

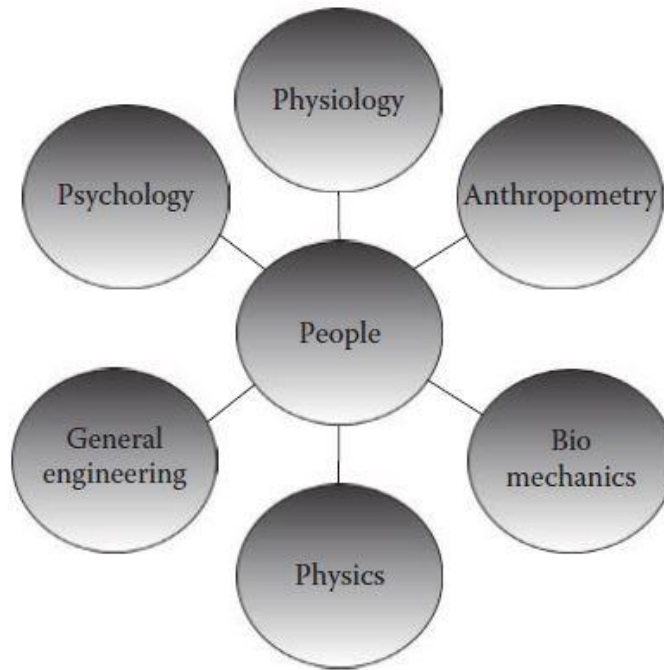


Figure 1.1 Interdisciplinary fields inside of ergonomics (Bush, 2011)

1.2 Product Design

People have been developing products for centuries to fulfill their needs. According to Lascar (2017), designing product is about the entire process of creating available products and experiences by identifying the real people's problems and thinking about possible solutions. This will ultimately lead to the best design.

As it seems, product design is not only generating product idea or drawing product shape but also includes more than that. It is also necessary to mention here about product development to demonstrate these limits. According to Ulrich & Eppinger (2015, p. 2), “product development is a set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product.” Three important functions are almost always been in the center of the product development process. These are *marketing*, ***design***, and *manufacturing*. Design function takes an important role in defining the physical form of the product to fulfill

customer needs. Engineering design (mechanical, material, electrical, software, etc.) and industrial design (aesthetics, ergonomics, user interfaces) are parts of the **design** content.

Design types may classify according to different features. Otto & Wood (2001) classified the design types into three. These are *original design*, *adaptive design*, and *variant design*. **Original design** creates an original solution for tasks or problems and includes its details. With an original design, we obtain an invention. **Adaptive design** (or synthesis) involves adapting a known system to a modified task or developing an important subsystem of an existing product. Adaptive design does not include huge changes to the system within the product operates but it can be very novel. According to Sagot, Gouin & Gomes (2003), products rarely have a unique design and properties than the other products. New products are developed with mostly include minor changes than other products. So if we want to design a new product or develop a new product, we need to investigate similar products. So we can collect important information from past works and researches. The ergonomist will compare to the products for determining the ergonomic situation. **Variant design** (or modification), includes varying parameters (size, geometry, material properties, control parameters, etc.) of specific product aspects for evolving the new and more robust design. This type of design does not change configurations of the subsystem, usually focuses on modifying the performance. To give an example, CD media is an original design, DVD media is an adaptive design and laser disc media is a variant design.

1.3 Importance of the Ergonomic Product Design

Nowadays, high product variety causes an increase in competition among companies. So, the consumers look the best product to fulfill their requirements. In the past, before industrialization, the only expectation of people from a product is that it can do its job. But now, the more product types increases to the expectations of the consumers. One of the expectations that consumers will check is ergonomics.

Ergonomic products increase to the satisfaction of the consumer. Non-ergonomic products often reduce the efficiency of the consumer from the product or lead to major problems in the future. A huge number of ergonomics researches of the products have been in the literature for determining and finding a solution to these problems. These problems will be given in the future chapter.

As a result, ergonomic products are beneficial for both consumers and producers. With ergonomic products, consumers meet their expectations without any problem and the producers increase the possibility of the preferable by the consumers. Through this, the producers can make more profit and spend on research and development (R&D). So, more ergonomic products can be found in the marketplace. The consumers may have more options and opportunities for selecting the best product to fits their requirements perfectly.

1.4 Aim and Importance of This Thesis

The aim of this thesis is to determine and apply the Ergonomic Consumer Product Design Principles and its methodology. The Ergonomic Consumer Product Design Principles will be created to cover all consumer products except single-use products like plastic bottles, pipette, etc. Thus, these principles will be applicable to all consumer products. These principles will mean also the important criteria that must be check for producing or comparing ergonomic consumer products.

Moreover, designing an ergonomic consumer product which could be used by consumers is another important aim of this thesis. The product should be designed based on some specific principles and criteria in order to be accessible and preferable to users. However, some of these principles and criteria may not directly be related to ergonomics. So, the principles divided into two main categories which are primary and secondary principles. Primary principles are directly related to the ergonomic conditions of the products. Secondary principles are directly related to human expectations (non-ergonomic expectations).

This thesis attempts to complete these following objectives:

- Proposing the conceptional model of Ergonomic Consumer Product Design Principles.
- Comparison of similar products ergonomically with the conceptional model of Ergonomic Consumer Product Design Principles.
- Proposing new ergonomic consumer product design methodology process.
- Mitigating risk factors and improvement of human- product relationship.

1.5 Outline of This Thesis

This thesis involves seven chapters including this chapter. The remainder of this thesis is as follows. In the second chapter, the relevant literature and some inspiring and important articles are placed. In the third chapter, problem definition and structure of the thesis are explained. Structure of the thesis is illustrated for better understanding of thesis chapters' content. In the fourth chapter, Ergonomic Consumer Product Design Principles are explained in more detail and the conceptional model of Ergonomic Consumer Product Design Principles are given. Also, it includes the detailed literature review that how to select these principles. In the fifth chapter, the general methodology that will be used to ergonomic product comparison and creation is given. The steps of the ergonomic consumer product design methodology are explained detail. The step and methodology creation are based on literature review and product development methods. The application of the proposed model is given in chapter six. The chosen product (hand pruner) range will be investigated according to Ergonomic Consumer Product Design Principles. Then, according to a detailed investigation, the best product concept will be suggested. In chapter seven, contributions and findings were discussed according to Ergonomic Consumer Product Design Principles and its application. Finally, future research directions are suggested.

CHAPTER TWO

LITERATURE REVIEW

From past to present, many ergonomic studies have been done to increase human-machine-environment relationship. As a result of this, many ergonomic papers, articles, conference abstracts, and books have been published by researchers. In this way, the wide variety of ergonomic sources has been placed in the literature. Into this literature, according to the thesis subject, the correct investigation strategy and ergonomic subjects should be determined.

The literature investigation was performed in three stages. The first stage includes the beginning of the literature review (resource finding and reading related to the thesis subject), the second stage includes the creation of the Ergonomic Consumer Product Design Principles with literature investigation and its proofs, and the third stage includes the creation of the ergonomic consumer product design methodology with literature investigation and its proofs. Before the explaining of the stages, the illustration of the literature review strategies is given Figure 2.1.

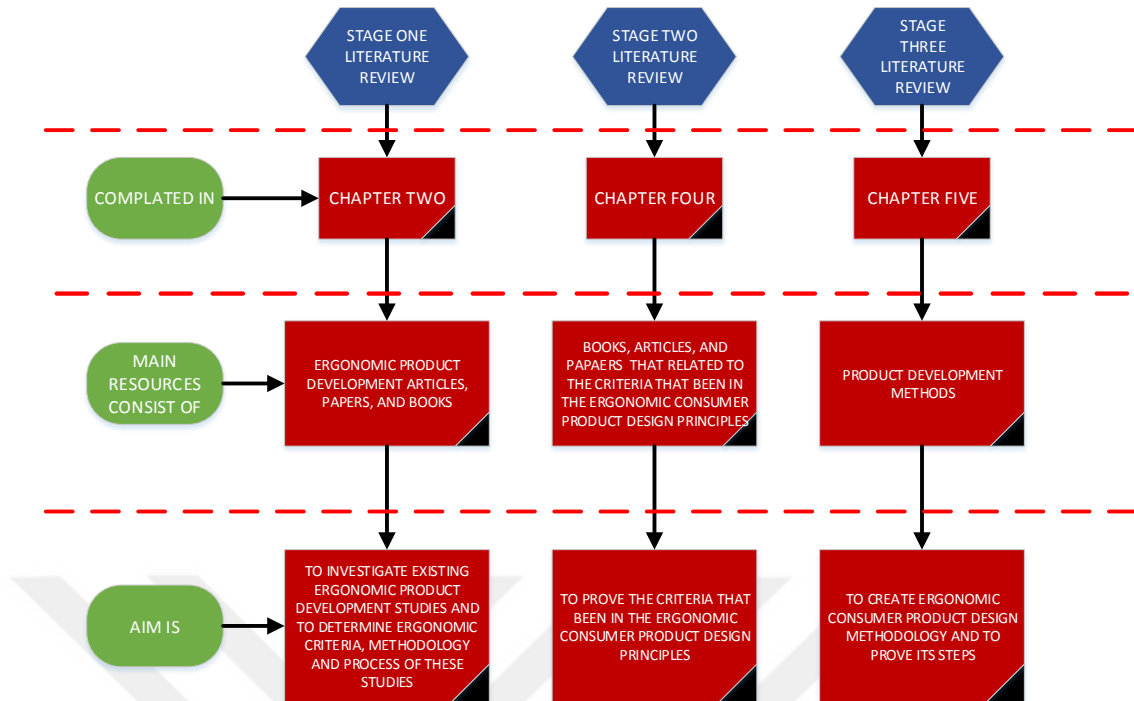


Figure 2.1 Literature investigation strategies

2.1 Stage One: Beginning of the Literature Review

According to thesis aim, in the beginning, the correct resources should be determined. Generally, environmental ergonomics studies take much place in the literature. The office ergonomics and workplace ergonomics can be given for an example of these. However, in environmental ergonomics studies, there are less (sometimes none) information been related to product ergonomics. So, in this stage, the main literature sources and information should be obtained from ergonomic product development and product ergonomic investigation articles, papers conferences, and books.

After that, the reading and investigating process of the selected literature sources has been performed. The literature content review was conducted in three ways for ergonomic product researches.

- Determine the criteria that affect the product ergonomics in each selected literature source.
- Determine the methodology of each selected literature source.
- Determination of which process has been performed to develop an ergonomic condition of the product that been in the selected literature source.

These are the main three elements that have been used to obtain common and different points of ergonomic product development studies. The examination of each study with these three steps has greatly helped in the development of ergonomic product principles and its methodology. The examination table of the literature is given in Table 2.1 with some important papers to show how the investigation outcome is created.

Table 2.1 Examination of the literature according to common and different points

Article name	Selected Reference	Year	Product	Methodology	Criteria	Process
Interactions of personal and occupational risk factors on hand grip strength of winter pruners	Çakmak & Ergül	2018	Pruning shears	1) Participants 2) Anthropometric measurements 3) Apparatus 4) Experimental design 5) Statistical analysis	Health	Different pruning shears effects were investigated
Ergonomic design and evaluation of the handle for an endoscopic dissector	Shimomura, Minowa, Kawahira & Katsuna	2016	Endoscopic dissector	1) New handle design 2) Evaluation of the experiments 3) Comparison of the old and newly designed surgical scissors with task performance and EMG	Usability, effort, task performance	New handle design was recommended
Ergonomic design and evaluation of new surgical scissors	Shimomura, Shirakawa, Sekine, Katsuna & Igarashi	2015	Surgical scissors	1) New handle design 2) Evaluation of the experiments 3) Comparison of the old and newly designed surgical scissors with task performance and EMG	Usability, effort, task performance	New handle design was recommended

Table 2.1 continues

Evaluation on an ergonomic design of functional clothing for wheelchair users	Wang, Wu, Zhao & Li	2014	Functional clothing	1) Questionnaire programme 2) Functional clothing design 3) Evaluating system	Functionality	Functional clothing was designed to wheelchair users for improving daily living activities.
Using integrated quality function deployment and theory of innovation problem solving approach for ergonomic product design	Zhang, Yang & Liu	2014	The traditional ceiling range hood and gas hob for household	1) Identification of customer satisfaction needs (CSNs). 2) Construction of the HoQ chart of QFD for identifying the key problems and the critical areas for innovation. 3) Using the TRIZ main tools and contradiction analysis to generate the innovative design alternatives. 4) Application of fuzzy group decision-making theory for the alternatives evaluation and selecting the best design alternative.	Ergonomic interactive needs: Save space, Comfort, Ergonomic affective needs: Beautiful appearance, Ergonomic performance needs: Strong suction, Multifunction, (Red criteria were selected for the investigation by authors.)	New product design(physical form change) was performed to increasing red criteria conditions.
Evaluation of ergonomics of a new effort saving via-ferrata carabiner - child vs. adult use	Lehner & Senner	2013	via-ferrata carabiner	The new carabiner development process has undefined.	effort	Old designed and new designed (physical form) carabines have been compared with EMG

Table 2.1 continues

Ergonomic evaluation of processes and products in the manufacture of upholstery	Fialho, Souza, Minette & Silva	2012	Upholstered sofas	1) Sampling and data collection 2) Ergonomic evaluation of the product 3) Ergonomic evaluation of the process	Ergonomic principles of anthropometric, armrests height, depth and width; backrest height and inclination; height, depth and seat width	Physical form of the upholstered sofas was investigated
Ergonomics principles to design clothing work for electrical workers in Colombia	Castillo & Cubilos	2012	Working clothes of the electrical workers	1) Pre-evaluation 2) Survey 3) Fieldwork 4) Characteristics of the activities reviewed	Comfort, Functionality, Usability	Physical form and product material were investigated.

Table 2.1 continues

Ergonomics and design: its principles applied in the industry	Tavares & Silva	2012	Car-rack, working station tables and artifacts	1) Problem definition 2) Tasks analysis and operators' opinions 3) Project requirements list 4) Ergonomics and Anthropometrics studies 5) Brainstorming and Sketches 6) Functional mock-ups 7) Preliminary tests 8) Revisions 9) Implementation of new products	Security, comfort, efficiency and performance.	Working station-tables were designed with changing existing products' physical form. Car-rack and assembly tools were newly designed. Different materials and physical form were used to satisfy determined ergonomic criteria.
Design and Assessment of Ergonomics of Hand-Powered Pruning Shears Based On Gender-Specific Operating Strategy	Hwang	2011	Pruning shears	1) Participant determination 2) Experimental design 3) Experimental procedures 4) Instrumentation and apparatus	Effort, usability, health, performance	2 new designed pruning shears were suggested and compared with old designed pruning shears according to muscle activity, grip force and wrist deviation

Table 2.1 continues

The Impact of Poor Assembly Ergonomics on Product Quality: A Cost–Benefit Analysis in Car Manufacturing	Falck, Örtengren & Högberg	2010	Car	1) Limitations 2) Description of Systems and Methods Used for Tracking Quality Errors 3) Analysis of Ergonomics and Quality Problems in Manufacturing Engineering 4) Action Time and Cost Analysis for Quality Errors in Production 5) Analysis of Factory-Complete Cars 6) Action Time for Corrective Measures and Cost Calculations	Work from underneath; working height, working distance, working posture or movements, hidden assembly, force, clearance, weight/force, feedback, static work, sharp edges	The project was performed to investigate the effects of the poor assembly ergonomics on product quality.
An evaluation of bag-valve-mask ventilation using an ergonomically designed facemask among novice users: A simulation-based pilot study	Bauman et al.	2010	Facemask	1) Application of participant experiment - Participant definition - Data collection - Technique definition - Statistical analysis	Performance, functionality	The new designed ergonomic facemask was evaluated and compared with baseline condition according to tidal volume

Table 2.1 continues

Can Armrests Improve Comfort and Task Performance in Laparoscopic Surgery?	Galleano, Carter, Brown, Frank & Cuschieri	2006	armrests	1) Participant experiment design - Participant definition - Task definition - Statistical analysis	task quality, task efficiency and surgeon comfort	With and without armrests were compared according to related criteria
The Effect of Ergonomic Interventions in Healthcare Facilities on Musculoskeletal Disorders	Fujishiro, Weaver, Heaney, Hamrick & Marras	2005	Ergonomic devices for healthcare facilities	1) Study design and settings 2) Intervention 3) Data collection 4) Statistical analysis	Health	Ergonomic devices were purchased and compared with baseline condition to measure MSD rate
Ergonomics in product design: safety factor	Sagot et al.	2003	The driving cabin of the new generation of high-speed trains (TGV-NG)	1) The need: the demand 2) Feasibility studies 3) Preliminary studies 4) Detailed studies 5) Industrialisation	Health, comfort, safety	Correct geometry, the final materials and technological content were investigated to increase ergonomic
Automobile seat comfort: occupant preferences vs. anthropometric accommodation	Kolich	2003	Automobile seat	Clear methodology was not given	Comfort	The physical form of the automobile seats have been compared

Table 2.1 continues

Relationship between footwear comfort of shoe inserts and anthropometric and sensory factors	Mündermann, Stefanyshyn & Nigg	2001	Shoe inserts	1) Foot shape, foot and leg alignment and foot shape measurement 2) Participant experiment 3) Data collection	Comfort, Health	6 different type of shoe inserts were investigated with participant experiment
Ergonomic evaluation of the effects of handle types on garden tools	Chang, Park & Freivalds	1999	shovel, rake and hoe	1) Subjects 2) Procedure 3) Measurement	effort, performance	According to different handle material, the effort measurement and compared have been performed with EMG
An ergonomic approach to public squatting-type toilet design	Cai & You	1998	Public toilet	1) A field survey of the usage of public toilets 2) Anthropometric investigation and experiment 3) Design development and evaluation	Sanitation, appearance, comfort, and acceptability	Rib-textured surface, the angle of inclination, angle, the distance of separation, the front fender, and the bowl were designed to improve product ergonomics according to determined criteria.

Table 2.1 continues

Ergonomic investigation of letter-carrier satchels: Part I. Field study	Dempsey et al.	1996	Letter-carrier satchels	1) Subject 2) Apparatus 3) Procedures	Ease of adjustability and handling, comfort, suitability and durability of materials, anthropometric applications, impact on other activities, ease of motion in retrieving mail, ease of motion in carrying the satchel, versatility of use in diverse climates, protection of mail from damage due to rain and snow, and defense against dog attacks.	Letter-carrier satchels' ergonomic investigation with participants
Hand-Arm Vibration: Product Design Principles	Tudor	1996	The string trimmer	1) Machine Description 2) Measurement of Vibration 3) Mechanical Design 4) Ergonomic Design Consideration	Vibration of the string trimmer	string trimmer motor and physical form is investigated, physical form change was applied

These papers will be discussed detail in the features and primary principles sections (chapter four).

2.2 Stage Two: Creation of the Ergonomic Consumer Product Design Principles

According to stage one literature review, criteria pool that effects to the product ergonomic were examined. After that, Ergonomic Consumer Product Design Principles have been created with selected criteria into the criteria pool. However, the accuracy of the Ergonomic Consumer Product Design Principles must be proven. In here, the main literature investigation was performed for proving the criteria that belong to the Ergonomic Consumer Product Design Principles. Therefore, the main focus is on the criteria investigation. The literature sources consist of the books, articles, and conferences that related to selected criteria.

2.3 Stage Three: Creation of the Ergonomic Consumer Product Design Methodology

Of course, the methodology should be designed according to ergonomic consumer product principles but it cannot contain indiscriminate steps and its ranking. So, to avoid the wrong methodology creation, the literature should be investigated. In here, the product development methods take an important role in the creation of the ergonomic consumer product design methodology. There are four methods were used to creation of the ergonomic consumer product design methodology mainly. These are:

- Illustration of the product development and design process (Sagot et. al., 2003).
- Principle description of ergonomics influence during the product development process (Falck et al., 2010).
- House of quality.
- Ulrichs' concept development phase (Ulrich & Eppinger, 2015).

With the combination of these four methods and Ergonomic Consumer Product Design Principles, the methodology and its steps were created. In addition to these four resources, other sources have been used to support the accuracy of these steps. These resources will be mentioned in chapter four.



CHAPTER THREE

PROBLEM DEFINITION AND THESIS STRUCTURE

3.1 Problem Definition

As mentioned in section 1.4, aim and importance of the thesis is to reduce risk factors and improvement of the human- product relationship. Most of products have been releasing such as consumer products with ergonomic problems. These problems can be recognized immediately or will be seen in future time by consumers. The main goal is to mitigate and realize ergonomic problems in the design steps or before the production, and minimizing the ergonomic problems that will be occurred in the future product usage by consumers. So, in this thesis, for achieving this goal, followings are developed:

- Proposing the conceptional model of Ergonomic Consumer Product Design Principles.
- Proposing the Ergonomic Consumer Product Design Methodology process.

3.2 Thesis Structure

As mentioned above (3.1), the aim of the thesis is determining the Ergonomic Consumer Product Design Principles and its methodology. Besides, to perform an application is also another objective. In the first stage, the existing studies related to ergonomics are investigated. The main resources mostly cover books and international articles. In here, determination of the ergonomics studies flows, steps and contents are performed. In the second stage, Ergonomic Consumer Product Design Principles are investigated via literature review. The common criteria that affect the product ergonomics are classified and proven with the aid of existing ergonomics studies, books, and articles. In the third stage, the features that will affects/changes of the Ergonomic Consumer Product Design Principles are classified. In here the articles that related to the ergonomic improvement of the selected products are covers to the main literature source. It was seen in these articles that the ergonomic improvement of the selected product is performed with the aid of changing/developing of product material,

physical form or technological content. In the fourth stage, the Ergonomic Consumer Product Design Principles are divided into two. These are primary principles and secondary principles. The product design will be performed for consumers. So, the other criteria that effects to the human expectation should be investigated. The primary principles cover the criteria that effects to the product ergonomic, the secondary principles cover the criteria that effects to the human expectation (non-ergonomic criteria) from products. In the fifth stage, the conceptional model of Ergonomic Consumer Product Design Principles is given. The relationship between primary principles, secondary principles and features are shown in this figure. In the sixth stage, the methodology of the ergonomic product design is developed. The main sources of the literature review of this part are product development methods and ergonomic articles/books which are used to create a methodology to fit obtained Ergonomic Consumer Product Design Principles. According to the product that will be designed ergonomically, two ways can be followed. These two ways are changed according to the selected product which is an original design or not (original design definition was given in 1.2). In following seventh and eighth stage, the application is performed according to ergonomic product design methodology. In the seventh stage, the selected product range (pruning shear) is investigated according to Ergonomic Consumer Product Design Principles. The product materials and physical forms of the product are compared. In the last stage, the best product concept is created according to the results of stage 7. The concept creation is the last operation of this thesis. The research design of this thesis is described in Figure 3.1.

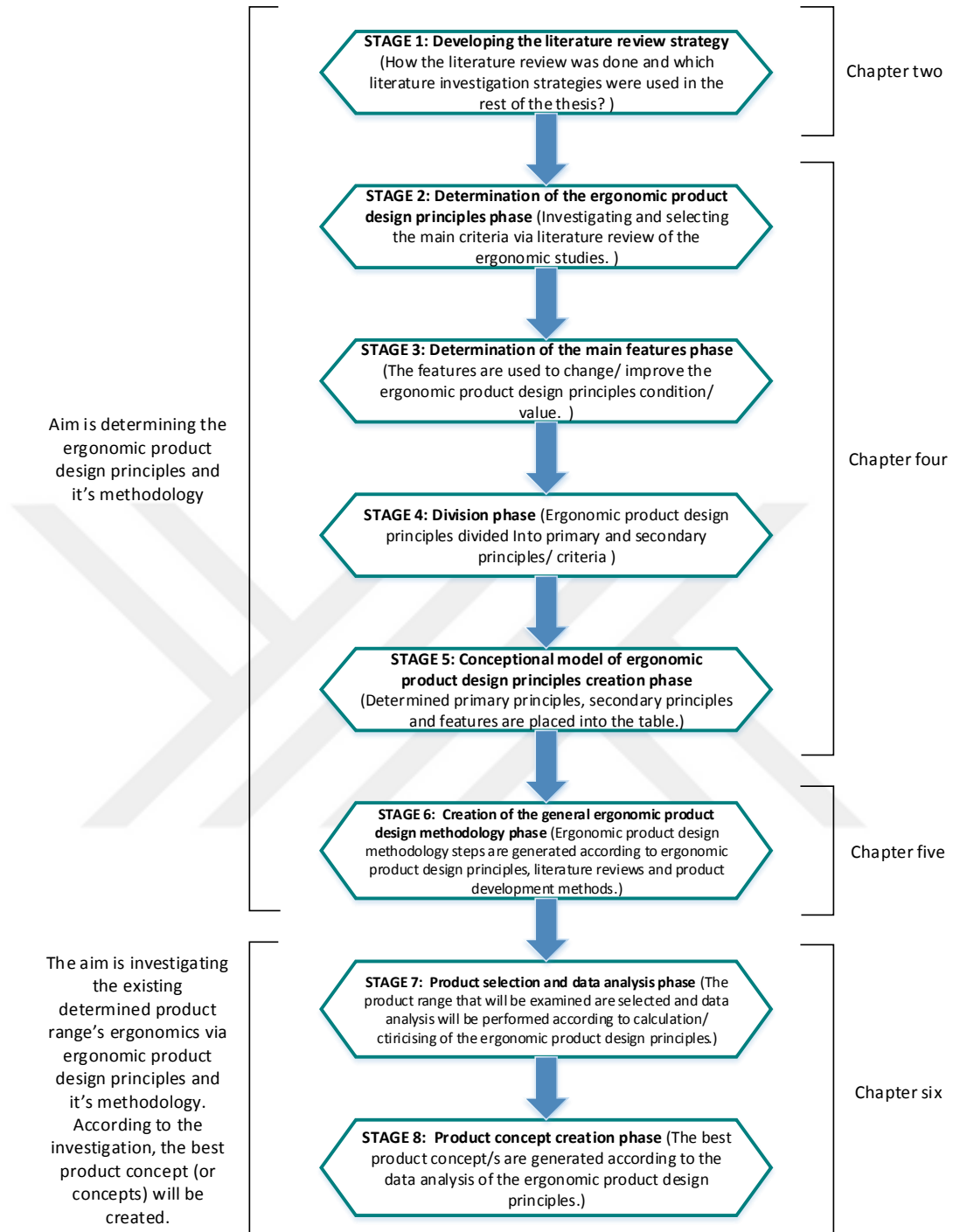


Figure 3.1 Research design of the thesis

CHAPTER FOUR

PRINCIPLES OF ERGONOMIC PRODUCT DESIGN

4.1 Ergonomic Consumer Product Design Principles

There are many criteria been at the product universe that will effect the human decisions. Some of these criteria are related to ergonomic conditions of the products. However, the other criteria might effect non-directly to the product ergonomics or human expectations. In here, main purpose is developing an ergonomic product to the consumers. Nevertheless, these products must be accessible and preferable by consumers because the product, which is not preferred by consumers for other reasons, or which can never be achieved by consumers, will not make sense even if it is very good in terms of ergonomics. So, also the other criteria that related to human expectations should be investigated. In this context, Ergonomic Consumer Product Design Principles are investigated in two headlines which are *Primary Principles* and *Secondary Principles*. Primary principles are criteria that directly effects product ergonomics, Secondary Principles are criteria that indirectly effects product ergonomics. According to a wide literature review that mentioned in chapter two, there are seven principles determined for Primary Principles. These are given below:

1. Durability
2. Health
3. Comfort
4. Usability (Easy to use)
5. Effort/ Force
6. Functionality
7. Learnability (Easy to learn)

If the producer wants to develop an ergonomic consumer product, the producer should focus these seven principles because these seven principles are directly effects of the ergonomic conditions of the product. The effects of principles on product ergonomics have been proven by the investment of the wide literature review. In the literature, when the product ergonomics is examined, the criteria often come from

some or all of these principles. In addition, these principles mean ergonomic product criteria. These principles are explained one by one in the future headline.

Secondary principles are not directly related to the product ergonomics but related to human expectations. Consumers not only searching ergonomic conditions of the products but also looking for a different feature that non-ergonomic criterion. So, if these criteria are not suitable for the consumers, it may cause the consumer to buy a different product that is less ergonomic. There are four principles are determined for secondary principles. These are given below:

1. Price/ Cost
2. Style/ Fashion
3. Product guarantee/ Warranty
4. Environmental effect/ Recyclability

These four principles should be investigated because these four principles have a strong effect on consumer choice. The effects of principles on consumer product choice have been proven by an investment of the literature. However, the secondary principles are left open-ended because there are many criteria that affect consumers' choice of products. These types of criteria cannot be limited. Researchers can add new criteria to secondary principles related to the product being compared/developed. According to the product type, new non-ergonomic criteria which the researcher finds important can be determined.

Therefore, there are eleven criteria were determined. Seven principles have been at the primary principles that directly affect the product ergonomics. Four principles have been at the secondary principles that directly affect the consumer product choice. Also, secondary principles are left open-ended. So, the researcher can expand secondary principles. The researcher can be determining an important criterion that not related to the ergonomic but related to consumer expectation.

4.1.1 Features

The principles in ergonomic product design are the criteria that should be at the desired level for a product to be ergonomic. The fact that these criteria are below the expected/required level will cause the product to be ergonomically insufficient. The level of criteria can be changed with **features** that are three. These are *product material*, *physical form of the product* and *technological content of the product*. In these properties, product material and physical form of the product are available for each product but technological content may not be found in every product. The improvement of the Ergonomic Consumer Product Design Principles level can be performed with these three features. The principles illustrate the state of product ergonomics, while the features are to change/improve the levels of these principles.

If we handle the first two features, these two features are acceptable for all tangible products because each product has a material and design. It is clear that, if we want to develop a product, we need some raw materials and product design. All products have a shape and raw material. However, technological content is an optional feature that may not be in some consumer products.

Ergonomic Consumer Product Design Principles can be improved with using these three features. Principles give information about product ergonomics. Features are the operations of the improvement of the principles.

In below, detailed information about papers which been in stage one (2.1) literature table is given. Also includes improvement of the product ergonomics with features.

- Shimomura et al. (2015, 2016) worked on surgical scissors and endoscopic dissector in both studies. The author focused on the **physical form** of both products' handle. The main reason was the improvement of the usability and task performance and reducing the muscle activity of product users.
- Çakmak & Ergül (2018) compared three different pruning shears according to grip strength. The author gives pruning shears' **physical form** and **product**

material information detail and found that these features affect the grip strength of the dominant hand.

- Zhang et al. (2014) suggested a multidisciplinary approach which integrating four methods (CSNs, HoQ, QFD and TRIZ methods). In case study, ceiling range hood and gas hob handled were investigated according to their **physical form**.
- Fialho et al. (2012) performed an ergonomic evaluation of upholstered sofas between two industries in Brazil. They evaluated 29 upholstered sofas according to its dimension. The author mainly focused on the **physical form** of upholstered sofas because the evaluation based on anthropometric variables.
- Tavares & Silva (2012) developed five new products which are two tables, two artifacts, and car-rack to improve production in the industry. Satisfactory **physical form (height)** was obtained from several tests for car-rack. The **product material** was determined for tables and artifacts to allow easy to cleaning of the material.
- Hwang (2011) investigated 3 pruning shears according to effort, usability, health, and performance. The author selected three same pruning shears. However, he performed some changes for two of them which are an addition of rubber grip-padded and thumb grip for investigating **physical form** and **product material** effects.
- Bauman et al. (2010), worked on the face mask which provides artificial ventilation to improve performance and functionality for novice users. The new ergonomic facemask was designed with changing the **physical form** of the product and compared the standard masks according to tidal volume. Results showed that the ergonomic masks achieved higher tidal volume than standard masks.
- Cai & You (1998) performed ergonomic considerations of public squatting-type toilets. The determination of the anthropometric data was investigated (dimensions of squatting posture and slope for the footsteps) to redesign squatting-type toilets. Three mockup prototypes were designed and compared according to sanitation, appearance, comfort, and acceptability. According to

results, the final mockup was obtained based on the changing **physical form** of the product.

- Tudor (1996) investigated the string trimmers' vibration effects of the hand-arm. He determined two problems which increase the hand-arm vibration. The first one is string trimmer engine; the second one is string trimmer design. He decided to change string trimmer design for reducing to the hand-arm vibration. If it did not work, he will focus on the string trimmer engine. He achieved to reduce vibration with changing string trimmer design. As a result, there are two options been here for increasing product (string trimmer) ergonomic: **the technological content** or **physical form** changing.
- Castillo & Cubillos (2012) worked on designing working clothes for electrical workers respect to ergonomics. They determined three important criteria that affect the ergonomic conditions of the product. These are comfort, functionality, and usability of the product. In here they used **physical form** and **product materials** to evaluate processes for improving product ergonomics.
- Sagot et al. (2003), investigated high-speed trains' ergonomics. They aimed to give some methodological and theoretical indicators for designing new products respect to ergonomics. They gave us ergonomic improvement methodologies and procedures with **physical form**.
- According to Falck et al. (2010), poor **product design (physical form)** and poor process design cause poor ergonomics.
- Kolich (2003) investigated automobile seat comfort with respect to ergonomics. Consumer preferences determined with using anthropometry and he compared five automobile seats according to required measurement. Of course, this ergonomic comparison of the automobile seats related to **physical form**. In this article, the author only used anthropometric values to the comparison of the automobile seats respect to ergonomics. But we know that, if we handle the automobile seat comfort, the material and technological content takes an important role. Heated seats and automatically adjustable seats (a different person can save his/her seat options and pushing one button will switch seat options automatically) directly related to **technological content**. Skin, fabric, etc. seats are types of **product material**.

- Mündermann et al. (2001) investigated footwear comfort. The aim of this research is to investigate the effect of shape and material on comfort. In here shape is related to **physical form** and material is related to **product material**.
- Dempsey et al. (1996) have performed an ergonomic investigation of letter-carrier satchels. The questionnaire takes an important role in comparing satchels. Some of the criteria that been at the questionnaire are comfort, suitability, and durability of materials, anthropometric applications, ease of motion in carrying the satchel, protection of mail from damage due to rain and snow. Four different types of letter-carrier satchels were evaluated. The participant volunteers ranked these four letter-carrier satchels according to questionnaire criteria. In here, **product material** and **physical form** are affecting criteria and participant volunteers ranking.
- According to Wang et al. (2014), suitable clothes are hard to find by people with physical disabilities. They observed daily activities of wheelchair users (managing toilet, spending time at the toilet, managing dressing and undressing). As a result, these three activities improved with developing new **physical form**.
- According to Fujihiro et al. (2005), ergonomic tool design (**physical form**) for patient lifting and handling, have been observed to reduce the symptom of disability related musculoskeletal system.
- According to Gallaeano et al. (2006), the ergonomic design (**physical form**) of the laparoscopic surgical armrests significantly reduced application errors.
- Chang et al. (1999) investigated three garden tools (shovel, rake, and hoe) and performed an ergonomic evaluation of the effects of handle types. There are three handle types determined by the author which are a conventional wood handle, solid fiberglass handle, and hollow fiberglass handle. As a result, the author compared these garden tools for measuring **product material** effects on ergonomic conditions. With different product materials, the author obtained different ergonomic measurements.
- Lehner & Senner (2013) evaluated new effort saving carabiner with respect to ergonomics. Extreme sports like climbing, the climbers need to spend less energy with using these types of products. So, the effort saver products are

necessary for climbing. At this point, effort saving via-ferrata carabiner has a new **physical form**. With this product design, the effort was reduced.

4.1.2 Primary Principles

There are seven primary principles are determined from the literature. These seven principles are directly affected by the ergonomic condition of the products. In order to produce ergonomic consumer products, these seven principles should be examined.

4.1.2.1 Health

There are three ergonomic domains defined from Federation of European Ergonomics Societies (FEES). These are physical, cognitive and organizational ergonomics. According to FEES (n.d.) “Physical ergonomics is concerned with human anatomical, anthropometric, physiological and biomechanical characteristics as they relate to physical activity”. There are some topics that related to physical ergonomics. These are relevant topics that include working postures, materials handling, repetitive movements, work-related musculoskeletal disorders, workplace layout, safety, and health. In this section health factor of ergonomic consumer products will be explained.

When we think human- product harmony, in order to optimize this harmony, we need to determine human body sizes and capabilities for a target population. Here, anthropometry is one of the branch of science that is mostly used by ergonomics. According to Bush (2011, p. 122) “this science deals with the measurement of size, mass, shape, and inertial properties of the human body.”

According to Pheasant (1996), it is less obvious that we need to figure out how to select the optimal compromise dimensions for equipment to be used by a number of users and at what point we need to adjust. We need three types of information to optimize such decisions:

- The anthropometric characteristics of the user population;

- The ways in which these characteristics might impose constraints upon the design;
- The criteria that define an effective match between the product and the user.

According to U.S. Department of Labor Occupational Safety and Health Administration (2000), we can say that if the equipment designs don't have ergonomic principles, the users may deal with many problems like vibration, awkward positions, and overexertion, etc. These problems cause of musculoskeletal disorders. According to this study (p. 2),

“MSDs, or musculoskeletal disorders, are injuries and disorders of the soft tissues (muscles, tendons, ligaments, joints, and cartilage) and nervous system. They can affect nearly all tissues, including the nerves and tendon sheaths, and most frequently involve the arms and back”.

The part of bodies that affected from MSDs are arms, back, hands, wrists, fingers, legs, neck, and shoulders. MSD takes days, months or years to recognize. Also, these types of injuries are generally developed gradually. MSDs are not happen at a single event. These single events like falls, cuts, and bruises are never included at the MSDs. The included disorders are well-known among office workers and high labor workers. These are carpal tunnel syndrome, tendinitis, sciatica, herniated discs, and low back pain.

There are many studies been in the literature about the health factors of the products. According to Koppelaar, Knibbe, Miedema & Burdorf (2013), low back pain is a very prevalent disorder for nurses. With the support of many ergonomic lifting devices, the author stated that the patient's mechanical load during the transport was reduced and the back pain was partially reduced. Fujishiro et al. (2005) purchased ergonomic tools for patient lifting and handling. As a result, they observed that these ergonomic tools reduced the symptoms that related to the musculoskeletal system. Bauman et al. (2010) founded that ergonomically designed face masks have a higher tidal volume than standard ones. The amount of air taken into the lungs is increased with this ergonomic

product design. Motamedzade, Choobineh, Mououdi & Arghami (2007) investigated the prevalence of upper limb problems in the Iranian carpet industry. Upper limb problems associated with the carpet weaving hand tools and they suggested a newly designed carpet weaving hand tools based on anthropometric dimensions and ergonomic principles to reduce upper limb MSDs. Strazdins & Bammer (2004) explained the symptom severity of upper limb musculoskeletal disorders in the gender difference according to repetitive work and poor ergonomic equipments. Bhattacharyya & Chakrabarti (2012) designed a new ergonomic basket for women workers in tea leaf plucking operation because they suffered from finger, arm, shoulder and back pains. Newly designed basket not only allows more leaf capacity but also lighter than older baskets and compatible with human anthropometry. Energy expenditure and musculoskeletal disorders reduction were observed with the newly designed basket.

According to Bush (2011), anthropometry science provides a true product design. We need to know true data of the height, body sizes, limb, weight, etc. for designing suitable product. Working on anthropometry causes ergonomics because collecting true values of the human body sizes gives as a compatible product design ideas with human body sizes.

As a result, health criteria should be considered in the design of an ergonomic product. If the health factor is not taken into consideration, the product with ergonomically insufficient design may cause musculoskeletal disorders in the users. Correct assessment of the anthropometric data for the target user in product design and accurate estimation of physical activities during product use will prevent health problems.

4.1.2.2 Durability

In this study, durability criterion is examined in order to determine how long the product can maintain its current ergonomic status. In time, problems like deterioration, functional losses and product wear will lead to ergonomic problems in consumer

products. Because of this, durability is seen as a criterion by consumers for protecting the ergonomic condition of the product in external conditions and product usage.

Coelho (2002, p. 4) stated that “the relationship of ergonomics with the design of machines, artefacts, consumer products, durable equipment, information systems, warnings and signs, documents, computer interfaces and displays, tasks, work organization, instructions and procedures.”. In this context, the author mentioned that the workers need durable equipments for doing job well and was associated with ergonomics. Also, the durable equipments mentioned here may be valid for consumer products.

Occhipinti, Colombini, Molteni & Grieco (1993) determined some criteria for ergonomic evaluation of work chairs. The wear of work chair components leads to problems like friction and sinking that causes non-ergonomic conditions. So, they considered chair durability as a criterion in ergonomic evaluation, in order to ensure that the chair components and controls were resistant to wear.

Dempsey et al. (1996) worked on an ergonomic investigation of the letter-carrier satchels. Four different types of letter- carrier satchels were compared according to ten different areas of interests. Suitability and durability of materials were considered part of those areas. In their questionnaires, participants ranked these four satchels according to suitability and durability of materials.

Dizel, Kılıç, Efe & Kasal (2017) investigated entertainment places according to ergonomic design. Wallboard choice can change according to the part of entertainment places and purpose of usage. It was stated that tile can be an ergonomic decision in order to place-action-human relationship because it fulfills the easy to clean, durability, strong and irrelevantly inexpensive features.

Zhang et al. (2014) suggested a multidisciplinary approach which integrating four methods (CSNs, HoQ, QFD and TRIZ methods). In here, customer satisfaction needs (CSNS) classified three dimensions which are ergonomic interactive needs, ergonomic

affective needs and ergonomic performance needs. Durability was seen as a CSN by authors and was included in ergonomic performance needs.

According to this information, durability is considered as a criterion for ergonomic product design. It is seen as an important criterion in terms of the expectations of the users and the protection of the existing ergonomics of the product.

4.1.2.3 Comfort

Comfort, which is defined as the pleasant feeling of being relaxed in general terms, has been an important subject in the literature for researchers. For Vink (2000), comfort is a nice situation between a human being and his/her environment according to physiological, psychological, and physical harmony. The definition of comfort concept is not clear (Helander & Zhang, 1997). Generally, it can be feelings of either comfort or discomfort in scales of ergonomic investigations.

Comfort definition discussions still ongoing and also these three topics are generally accepted (Vink, 2004):

- Comfort is a construct of a subjectively defined personal nature.
- Comfort is affected by various factors (physical, physiological, psychological).
- Comfort is a reaction to the environment.

Discomfort, no discomfort, and comfort are three output of the comfort model (Vink, 2004). The inputs of the comfort models are history+state, visual input, smell, noise, temperature/humidity, pressure/touch, and posture/movement. It is clearly seen that some of the inputs of the comfort models are related to anthropometry. Anthropometry and ergonomics has a strong connection. Therefore, ergonomics science is important to the investigation of comfort. Also, the comfort model is given in Figure 4.1 (Vink, 2004).

Ergonomics and comfort have a strong connection (Vink, 2004). Body size (related with anthropometry) and product size relationship is important because it affects

product comfort. This relationship is often investigated in ergonomics. The same author defined that “Ergonomics is the discipline that studies how the environment should be adapted to strive for optimal human performance” (p. 8). According to this, comfort or reducing discomfort is an ergonomic design outcome. Thus, ergonomics is an important discipline that increases the experience of comfort in optimizing the environment.

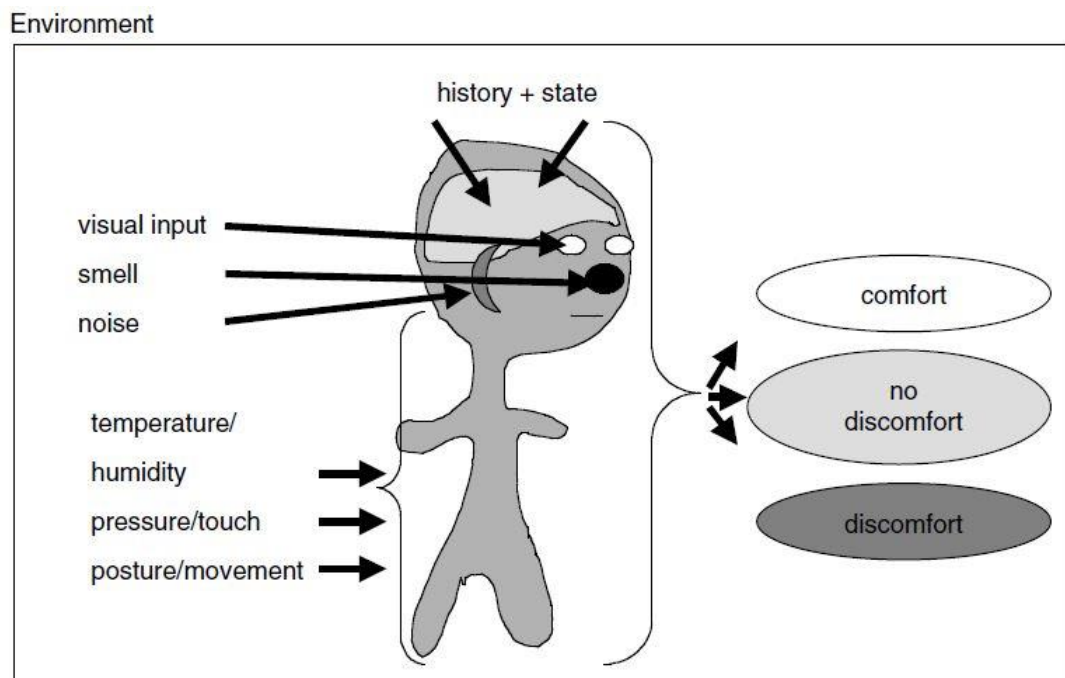


Figure 4.1 Comfort model, the feeling of discomfort is determined by inputs recorded by the sensors and information processing affected by the participant's history and status (Vink, 2004)

Many studies were performed to investigate product comfort. Castillo & Cubillos (2012) determined three concepts for evaluating working clothes which defined as comfort, functionality, and usability. In here, ergonomics applied to investigate comfort of products and also associated with comfort. Comfort is perceived by the worker in terms of visual appearance, thermal conditions, and anthropometrics. Chai & You (1998) selected the comfort as a study variable associated with effect of the footstep slope on squatting comfort in designing public squatting type toilet. According to Helander & Zhang (1997), in evaluation of the workstations and chairs, comfort and discomfort features are often measured in ergonomic studies. Galleano, Carter, Brown, Frank & Cuschieri (2006) obtained that usage of the ergonomic

laparoscopic surgical armrests significantly reduced application errors and discomfort. Tudor (1996) modified the string trimmer ergonomically to decrease hand-arm vibration and increase operator comfort. Dempsey et al. (1996) evaluated four different letter-carrier satchels with ten determined criteria and one of them is comfort. The body of discomfort map was used and applied in the questionnaire. According to Vink (2004), designing furniture for use at home, comfortable is an important criterion.

According to Vink (2004), ordinary people need to participate in the investigation and designing (furniture) because it is hard to guess human behavior and comfort experience. Thus, differences between academic things and common understanding can be seen with participant experiments. The real and end users need to use for obtaining useful ideas and information (Vink, 2004). Particularly in ergonomic fields, if the object is supporting to the user, the public has to participate to investigate. Mostly questionnaire is a good way to measure comfort and has been using by researchers. Likert scale is used commonly for measuring product comfort in researches and an example is given in Figure 4.2.

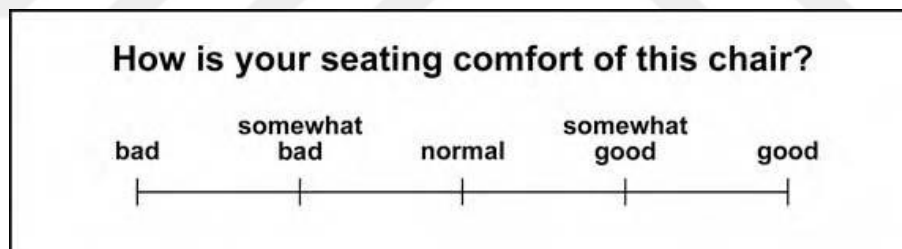


Figure 4.2 The question that is used to evaluate the chair comfort (Vink, 2004)

According to the definitions and examples mentioned above, there is a strong relationship between comfort and ergonomics. Although comfort is not well-defined, comfort is seen as one of the important product criteria sought by the users. Therefore, comfort is included in the Ergonomic Consumer Product Design Principles.

4.1.2.4 Functionality

Nart (2008) defined product functionality as an elimination of the product and service victimization. Product functionality is a technical matter (McNamara &

Kirakowski, 2006) and the level of functionality of the product can be determined by looking at the physical properties of the product. Here, the physical properties can be expressed numerically, such as the dimensions of the product; the hardness of the material used, but can also be expressed by the properties of the device, such as the locking mechanism and the anti-vibration.

According to Pheasant (1996), functional activity can be determined with the measurement of task performance and efficiency. Ergonomics is a branch of science that ensures the connection between product and user, and the goal between the product and the potential user is to provide the best possible match. For a successful match, the author stated that functional effectiveness is an important criterion. In addition, Castillo & Cubillos (2012) also noted that functionality is related to product performance and the ability to use the product appropriately.

Many definitions and researches about functionality and performance have been made in the literature. According to Yüreğir & Nakibboğlu (2007), performance measurement is a method that how the tasks are carried out objectively within a program for fulfilling the product, services or processes. Kim, Kara & Hauschild (2012) specified that having different technologies may cause different levels and types of functionality at the product comparisons. As a rebound effect, technological development can affect the expectations and behaviors of consumers towards demanding higher performance or functionality. Huang, Soutar & Brown (2003), used a questionnaire for measuring to product performance goal. Güner & Hasgöl (2012) stated that human performance can be severely affected by both physical and mental workload and that heavy workload can often lead to fatigue and stress in man. This leads to a decrease in performance.

Product functionality has been investigating in ergonomic studies. Kın (2007) stated that handle design for most of tools has a critical importance for success of the process and the functionality of the hand tools and grasping the objects are related to hand dimensions (Nag A., Nag P. K. & Desai, 2001). For a good ergonomic design, features such as the diameter of the handle, shape, length, texture, material, and balance must

be considered (Stanton, 1998). Wang et al. (2013) worked on people that have physical disabilities in their studies. The wheelchair users investigated in this study. The purpose of the study is ergonomic design of the functional clothing. They determined three important requirements from questionnaires. One of the important features related to functionality is, the inner side of the elbow re-designed for giving to elbow more flexibility. It is clearly that this new design increases the functionality of the wheelchair users. Another study about clothing design, Neves, Brigatto, Medola & Paschoarelli (2015, p. 6339) said that "..., more specifically in fashion design, biomechanics and ergonomics can contribute to the professional guidance with respect to the adequacy of products to the physical characteristics and functional needs of the user during the use of certain piece of clothing". If the ergonomically design adapted to user suitably, it offers comfort, quality, and functionality between user and product. Castillo & Cubillos (2012) investigated to working clothes. In here, ergonomics used for investigating to functionality of the working clothes. The functionality of the working clothes must fulfill to the complex worker actions. Good functionality gives good comfort for workers.

As a result, functionality can be determined by measurement of product performance and the physical properties of the product also affect the level of functionality of the product. Poor product performance negatively affects the relationship between the user and the product. Therefore, functionality is included in Ergonomic Consumer Product Design Principles.

4.1.2.5 Usability (Easy to Use)

According to Simões-Marques & Nunes (2012, p. 155),

"Usability is a quality or characteristic of a product that denotes how easy this product is to learn and to use; but it is also an ergonomic approach, and a group of principles and techniques aimed at designing usable and accessible products, based on user-centred design."

Usability will be affected positively to ergonomic objectives of design like a reduction of the negative effects on human health, safety and performance (ISO 9241, 1998). At the same source, it is stated that product usability must provide three important features. These are effectiveness, efficiency, and satisfaction.

According to Nielsen (1993), in a user interface, it is important to notice that usability is not one single property or one-dimensional property. Usability has multiple components that determined at the system acceptability model attributes. This model is created by Nielsen and given in Figure 4.3.

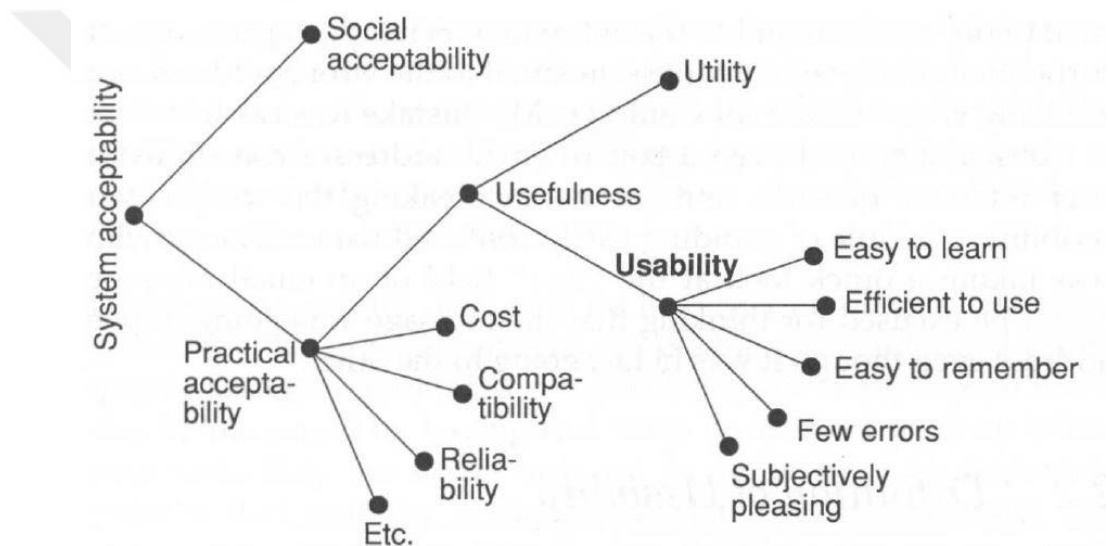


Figure 4.3 A model of the attributes of system acceptability (Nielsen, 1993)

It is clearly seen that usability has five usability attributes at the model of system acceptability.

- Learnability: Some work with the user's system to be able to begin to learn the system quickly should be easy.
- Efficiency: The use of the system must be effective, so that when the user learns the system a high level of productivity is possible.
- Memorability: The system should be easy to remember, so that the normal user can return to the system without having to learn everything again after a period of inactivity.

- Errors: The system must have a low error rate, so users can make a few errors when using the system, so they can easily get rid of them if they make mistakes. In addition, destructive errors should not occur.
- Satisfaction: Must be nice to use the system, so users will be satisfied as using subjective; they like it.

These five components identified by the author are defined as characteristics that affect availability. Similarly, According to Lastrucci, Infante & Pascale (2009), if the product is usable, it provides some properties that are given below:

- Provides user's needs and expectations.
- The user can understand, learn and use easily.
- The product can be attractive.
- The user's work correctly and quickly with provide satisfaction.

From this, it can be seen that the usability definitions and contents of Nielsen (1993), ISO 9241 (1998) and Lastrucci et al. (2009) have similarities.

User testing with real participants is the primal method of usability measurement and it ensures direct information about product usage and exact problems (Nielsen, 1993). The same author determined that reliability and validity are the real issues of usability testing that the researchers should pay attention most. The tests should give the same result if the test were to be repeated for reliability checking. Also, the tests should give exact results for validity checking. Even though usability test forms are the milestone of the measurements but several other methods also can be used to gather additional data and also can be performed with low cost. The author illustrated a table to provide a good, quick overview of the methods that include 10 methods. This table is given in Figure 4.4.

These methods can be combined with each other for using new projects. There are many ways been here for combining these methods and about each new project

properties may need a different combination. The person in charge can determine the best combination for the project to measuring to the usability.

<i>Method Name</i>	<i>Lifecycle Stage</i>	<i>Users Needed</i>	<i>Main Advantage</i>	<i>Main Disadvantage</i>
Heuristic evaluation	Early design, "inner cycle" of iterative design	None	Finds individual usability problems. Can address expert user issues.	Does not involve real users, so does not find "surprises" relating to their needs.
Performance measures	Competitive analysis, final testing	At least 10	Hard numbers. Results easy to compare.	Does not find individual usability problems.
Thinking aloud	Iterative design, formative evaluation	3–5	Pinpoints user misconceptions. Cheap test.	Unnatural for users. Hard for expert users to verbalize.
Observation	Task analysis, follow-up studies	3 or more	Ecological validity; reveals users' real tasks. Suggests functions and features.	Appointments hard to set up. No experimenter control.
Questionnaires	Task analysis, follow-up studies	At least 30	Finds subjective user preferences. Easy to repeat.	Pilot work needed (to prevent misunderstandings).
Interviews	Task analysis	5	Flexible, in-depth attitude and experience probing.	Time consuming. Hard to analyze and compare.
Focus groups	Task analysis, user involvement	6–9 per group	Spontaneous reactions and group dynamics.	Hard to analyze. Low validity
Logging actual use	Final testing, follow-up studies	At least 20	Finds highly used (or unused) features. Can run continuously.	Analysis programs needed for huge mass of data. Violation of users' privacy.
User feedback	Follow-up studies	Hundreds	Tracks changes in user requirements and views.	Special organization needed to handle replies.

Figure 4.4 Summary of the usability methods (Nielsen, 1993)

According to Bhise (2012), if the product is designed well, the product which has usability problems or the absence of ergonomics can be noticed rapidly. These usability problems usually come up after usage because in showrooms or product overviews, the ergonomic characteristic of the product is not generally noticed and the customer does not have an opportunity to use them. If the customer gets a chance to try the product, generally the customer will have a short time to investigate them. The problems which are come up at the beginning of the usage can be noticed but long-term problems cannot be determined at the first impression. Generally, the first impression is performed at the prototype stage by the manufacturer.

In the vehicles, all user interfaces and services should be designed for easy to use (Bhise, 2012). For example, the problem of cleaning the wire wheels has specified by the customer and any designers did not realize this problem before the colleague came and told about the problem. A customer has suggested that the ergonomic engineers

should work to designing the wheel covers for easier cleaning. The ergonomics engineers must interact with the users and determine the needs and create solutions. So we can say that with this case, any problem that came up between product and users can affect the usability of the product.

Many studies have been conducted on usability. Chamorro-Koc, Popovic & Emmison (2009) worked on the relationship between human experience and people's understanding of product usability. The findings show that human experience is critical for understanding product context of use and its usability. Shimomura et al. (2015, 2016) investigated and redesigned the handle of the surgical scissors and endoscopic dissector to improve the usability of these products. Castillo & Cubillos (2012) investigated the working clothes of the electrical workers according to comfort, functionality, and usability of the product. According to Nunes (2006), not only the characteristic or quality of product can be defined as usability, but also it is an ergonomic approach to create useful and easy to use products based on user-centered design. Scapin & Bastien (1997) defined those ergonomic criteria which are called a set of usability dimensions to summarize research work conducted on design and assessment.

As a result, the usability definitions and characteristics made by the authors have similarities and it can be seen that these features are associated with ergonomics. Therefore, the usability criterion was taken as one of the Ergonomic Consumer Product Design Principles.

4.1.2.6 Learnability (Easy to Learn)

Learnability is defined as the ease and speed by which users can understand how the product should be used (Srivastava, Chandra & Lam, 2009). As mentioned usability section, learnability is an attribute of the usability. Learnability and usability have a strong relationship but the learnability criterion focuses on the speed and ease of learning how to use the product effectively.

Nowadays, consumers expecting the products that the learning of product usage should be easy and takes short time because the consumers do not want to spend much time to learn full features of the product. They want to adapt quickly to the product. Consumers do not prefer the products which do not have easy to learn, responding to their needs, save time and benefitting easily properties (Evcil & İslim, 2012).

According to Bhise (2012), if the product is well designed or satisfies ergonomic requirements, one of the expected effect should be easy to learn. For example, in designing the driver interface, the users will not prefer to use what they do not understand. Also, the same author stated that the owner of the “easy to use” product rarely uses manuals of the product.

Easy to learn products are works expected way (Bhise, 2012). As we know, ergonomics examines the relationship between human-machine-environment. The product should come naturally for people. These naturally fit between product and human increases the performance. In here the performance meets these features (Bhise, 2012, p. 8):

- Reduces operation/task completion time and errors.
- Reduces learning and training.
- Makes product more enjoyable, less difficult and less boring.

It is clearly seen that the easy to learn is an important feature for designing ergonomic products.

Karwowski, Soares & Stanton (2011) stated that the ease of learning and the others (ease of use, high efficiency, comfort, safety, and compliance) are ergonomic measurement units and these units are the main determinants for acceptance in the product market. Bhise (2012) specifies the primary goals that the ergonomic engineers have to work with the vehicle design team to produce ergonomic vehicles. In here, easy to learn, easy to find and use, no distracting and safe, comfortable, and convenient attributes should be placed in minimum acceptable levels of ratings.

Therefore, easy to learn or learnability criterion was included in the ergonomic consumer product principles because it is essential for product ergonomics and consumers.

4.1.2.7 Effort- Force (Save Effort)

When the effort is examined for product ergonomics, it is mostly focused on the physical force that the user will spend. Mental effort can also be examined when it is necessary. Users expect to achieve minimum energy consumption and maximum efficiency during product usage. For example, mountain climbing is one of the most energy-consuming and challenging sport. For this purpose, climbers should use their energy in the most efficient way and should use their equipment with minimum effort.

Handle design of the products effects the transmission of the force. According to Pheasant (1996, p. 86),

“The purpose of a handle is to facilitate the transmission of force from the musculoskeletal system of the user; to the tool or object he is using; in the performance of the task or purpose for which he is using it.”

According to this, if we optimize handle design, we can optimize force transmission.

Reducing the effort consumption of product usage is seen as a popular research area in ergonomics. Bhise (2012) determined some ergonomic goals for ergonomic automotive design process that are comfort, convenience, safety-minimization of physical and mental effort. For example, operating control panel, reading and understanding the display should be able to perform with minimal mental and physical effort by drivers. Humans naturally want to protect their energy and reduce effort. That's the main reason that the people want to reduce their mental and physical effort when they using a product. As an example from cars, most of the drives like options that reduce the movements and forces such as automatic transmissions, power mirrors, remote key fobs, power steering, etc.

Lehner & Senner (2013) evaluated a newly designed effort saving carabiner with ergonomic and user-friendliness condition. The comparison of new and old designed carabiners were performed by using electromyography at the two scenarios to measure force. After the measurement, the new effort saving carabiner was reduced muscle activities of the participants. Chang, Park & Freivalds (1999) investigated effects of the handle types on garden tools respect to ergonomic evaluation. Grip force, muscular effort, and worker's subjective ratings can be fit on the ergonomic evaluation of the handle types because modifying tool handles may improve shoveling performance. According to Rasmussen, Boocook & Paul (2012), at the saw designing or comparing, the muscle activation becomes an excellent criterion in ergonomic design because it offers an opportunity to compare different scenarios at the tool or workplace designing process. Shimomura et al. (2015, 2016) redesigned and evaluated surgical scissors and endoscopic dissector ergonomically to reduce effort and muscle activity and to improve task performance and usability of the products.

The measurement of the effort can be performed with subjective and objective methods. Likert scale is the most preferable subjective method for force measurement. On the other hand, electromyography, force-sensing gloves and different type of force measuring dynamometers can be used to measure force in objective methods. We can say that objective force measurement methods are more reliable than subjective force measurement methods. However, the combination of the subjective and objective methods would give a better solution.

Consequently, it is seen that consumers prefer to perform minimum effort while the usage of the product because the effort is seen as a criterion that affects attention and performance. In many studies, reducing effort was the main reason for designing ergonomic products. Therefore, the effort is determined as the criterion for Ergonomic Consumer Product Design Principles.

4.1.3 Secondary Principles

Secondary principles are the criteria that interact indirectly with ergonomics. In other words, these principles do not directly affect product ergonomics. However, it

affects consumers' purchase preferences. The main reason for the inclusion of these principles is designing ergonomic product for consumers. It is necessary to design ergonomic products that include accessibility and preferability properties because not only the product ergonomic is the only important factor but also the other factors affect consumer expectations and purchase behavior.

It is hard to clarify exact secondary principles because of the different variety of consumers' expectation and behavior might be defined and can be changed from consumer to consumer. Also, these expectations might be changed according to the different type of products. Therefore, secondary principles were left open-ended. So, the designer can able to add more criteria that determined as important for the product that will be designed. However, four criteria were determined that should be taken into consideration. These are price/cost, fashion /design, product warranty/guarantee and environmental effect /recyclable of the product. The detailed descriptions of these four criteria are given below.

4.1.3.1 Price- Cost

Tomassi & Ierulli (1995, p. 1) defined that “the full price that people pay is a composite of the time, money, and effort they must give to obtain the good”. Price is an important factor that generally people will check first when they decided to buy a product. Also, cost is affecting price directly because price is determined by sum of the amount of the wanted profit and cost.

According to Eroğlu (2005), the price has great importance in terms of the perception of marketing activities within customer behaviors as well as providing the best benefit from the limited budget of the customer. Moon, Park & Kim (2015) specified that if the consumer needs to choose a product between similar price and functionality, they usually tend to buy a product that more attractive aesthetic value. According to Eski (2007), if the consumer need to buy a product and the determined important criteria by consumer is same for comprising products, the consumers check to the price of the product and the consumer will select the cheapest one. Economic behavior can be formulated in three ways Eski (2007):

- Maximization principle: Achieving the highest possible result with certain economic opportunities.
- The principle of minimization: Providing a certain end result from the beginning, using the lowest possible economic resources and goods.
- Optimization principle: To achieve the best possible economic result with certain and limited economic opportunities.

According to Duman & Yağcı (2006), marketing research shows that consumers do not have detailed information about product prices but compare them by holding reference prices in their minds. Consumers generally judge the prices that meet with judgments such as low-high, cheap-expensive, economical-high price rather than fully knowing market prices because the consumers generally do not find or know the cost and profit of the product. The only thing that the consumer can do easily is comparing to similar products' prices.

Most people have a psychological limit according to the level of the product selling price. This limit is not usually obvious, but it might mean that the value of a product is much higher than its value. In order not to exceed this limit, producers have to keep product production costs low. Generally, producers need innovation for creating an ergonomic consumer product that this innovation directly related to research and development. A company which wants to be innovative has three options to develop production performance, technological assets and abilities (OECD/Eurostat/EU, 1997). These three options are given below:

- strategic
- R&D
- non-R&D

These three applications have a cost for producers. So, the ergonomic consumer product has more expensive than the other similar products. If the producers want to create and sell an ergonomic consumer product, there are two important things that the producers have to attentive for determining the selling price.

- Producers shouldn't exceed the psychological limit of money that can be given to a product.
- When the ergonomic product is first sold, it will be more expensive than other products. So, the producers need to convince the customers that why should pay more money.

As a result, these two important conditions should be considered by the manufacturers when an ergonomic product design is desired. Otherwise, the desired level of product sales will not be performed by companies.

4.1.3.2 Style- Fashion

Fashion is not only an important way for the expression of social identity, political ideas, and aesthetic pleasure (Breward, 2003) but also the most popular style or genre in a given period (Bici, 2007). Fashion trends and forecasts play an important role in capturing the design that will be accepted by the market. So, the social status indicator and the other attractive tools can be included in the scope of fashion.

An object must be visible to go into the scope of fashion (Bici, 2007). If the producers desire to produce an ergonomic product, also the producer should need to investigate a fashion of the society. Fashion is affected by human's preferences. People desire to use products that suit themselves. Perchance a producer can design an acceptable ergonomic consumer product, but if the product design, color or image is not suitable for people, the people will not prefer the product. So, fashion can determine the product shape, design, color or style.

At the design subject, understanding of the cause of the purchasing by consumers is an important criterion. Purchasing is not only related meet of the requirements but also handle the social and psychological factors. Moon et al. (2015) said that when the consumer had to make a choice between two products with similar prices and functionality, they generally preferred to buy the product that includes a more attractive aesthetic value. Kotler & Rath (1989) wanted the product to have a pleasant or different appearance. On the other hand, some products designed with a good style

may not satisfy the users due to performance problems. According to Bici (2007), people's products are seen by society as part of their social identity. As a result, both industrial and fashion designers work on the basis of 'image' and social identity that people will have in society.

According to Aktaş (2008), nowadays, big-sized people complain not only to want clothes that fit their body but also demanding the clothes that look fashionable. Big-sized people demand to wear appropriate, stylish, fashionable and comfortable clothes. But, large body clothes producers firstly need to aim at producing ergonomic products considering the anthropometric structure, mobility and body measurements of the customer. After that, they need to focus on the fashion of the clothes. We can extend to this definition for the products that have a fashion criterion.

As a result, both industrial and fashion designers should work on the basis of the image and social identity that people will have in society. Therefore, in some cases, the ergonomics of the product is not sufficient to satisfy the customer. Even if the products meet ergonomic, there may be a dissatisfaction as the product does not meet their expectations. As a result, the designer should design an ergonomic product that people can choose by taking into account the present day fashion and time.

4.1.3.3 Product Guarantee- Warranty

If a company produces thousands of products, it is difficult to sure of the products' quality control. The results of the lack of quality control can be like:

- Cars might be recalled by the manufacturers,
- The software and hardware problems might arise after the launch of mobile phones,
- Unnoticed problems in the production might cause the inability (not working, problematic working) of some products.

In addition, the problems that occur in the logistics operations of products may affect product quality in the same way. Therefore, companies should take precautions

and make the right service and service investments. That is why the best solution is that manufacturers should provide a guarantee for their products.

D'Astous & Guevremont (2008, p. 307) said that "Product warranties essentially focus on reducing the uncertainty surrounding product quality because they guarantee that the product will be replaced or the customer's money refunded if it does not perform as it should". This ensures that the product can be used during the warranty period by consumers.

Çelik & Bengül (2008) declared that warranties on products affect the customers' loyalty of the brands in direct and indirect ways. Heiman, McWilliams & Zilberman (2001) defined that reimbursement warranties or full repayments are offered to encourage purchases by retailers. Furthermore, Heydari, Choi & Radkhah (2017) stated that the refund option in the products purchased would increase the demand and the number of customers. The same author specified that the situations where the customer cannot understand the quality of the products, the money back guarantee will reduce the risks and increase the confidence. This can also indicate that the product can be of good quality.

There are many warranty types such as repair, parts replacement and product exchange. However, these types of warranties take time for investment of the problematic product. Mostly the consumers need to wait during this time and firms mostly do not offer any temporary product for using. In this time, the firms will be investigated a problematic product and they are tried to find a reason for the problem. If they find a manufacturing defect, firms will repair or change to the product. The firms always will choose the least costly solution. Some products repair cost is much more expensive than the manufacturing of the new product. According to this, sometimes firms might not repair the problematic product. They probably offer a new product for users. Otherwise, the manufacturer changes to the problematic parts of the product or repair to the product. If the manufacturer finds a user failure at the product, most firms take to the repairing cost.

Based on this, the guarantee of a product indicates that the manufacturer trusts their product. The customer receives the assurance that the product can be used during the warranty period.

4.1.3.4 Environmental Effect- Recyclability

In the mid-eighties, research activities have focused on environmentally friendly production methods and they gave particular importance to the careful use of natural resources (Abele, Anderl & Birkhofer, 2005). Products that do not harm the environment, have the possibility of recycling, and use natural resources as little as possible are defined as green products (Hussein & Cankül, 2010). Abele et al. (2005) consider that some products are a good option for developing environmentally friendly products. These products are complex products that consume high energy and resource. Reducing energy and resource consumption has a positive impact on users and the environment.

Nowadays, with the effect of increasing environmental problems, the purchasing behavior of consumers has started to turn towards green buying behavior (Korkmaz, Atay & Yıldırım, 2017) and many investigators have examined these consumers' purchasing behavior. Çolakoğlu, Türk, Başar & Gül (2013) defined that having an environmentally friendly feature is not enough for consumers but also the other features like design and saving should be placed at a high level. However, people who identify themselves as green consumers prefer products that have a positive impact on their environment, as well as fulfilling their needs.

The resource consumption and firm costs might be reduced with recycling. Thanks to the recyclable products, the environmental damage has been reducing day by day. Nowadays, our chances of using a non-environmental product are close to impossible. The laws which are determined by the governments with the line of environmentalist organizations' pressures and actions make pressure on businesses to comply with these laws (Çakır, 2017). For example, since January of 2019 Turkey in order to reduce the harmful effects on the environment of plastic bags, plastic bags in supermarkets started

to sell with money and observed that the number of plastic bags taken from the market reduced the result of this law.

In line with the information given above, it can be said that, although consumers have some inconsistent behaviors about green products, the preferability of green products increases day by day. Consumers not only expect their products to meet their own needs and expectations from the product but also expect them to make a positive contribution to the environment. Consequently, the effect of an ergonomically designed product on the environment should also be investigated.

4.1.4 Conceptual Model of Ergonomic Consumer Product Design Principles

Based on the explanations above in chapter 4, it can be seen that primary principles, secondary principles and features are related to each other. When designing a product, it is necessary to identify and define these relationships in a good way. In this study, a conceptual model showing the principles of ergonomic product design has been formed and this model is given in Figure 4.5.

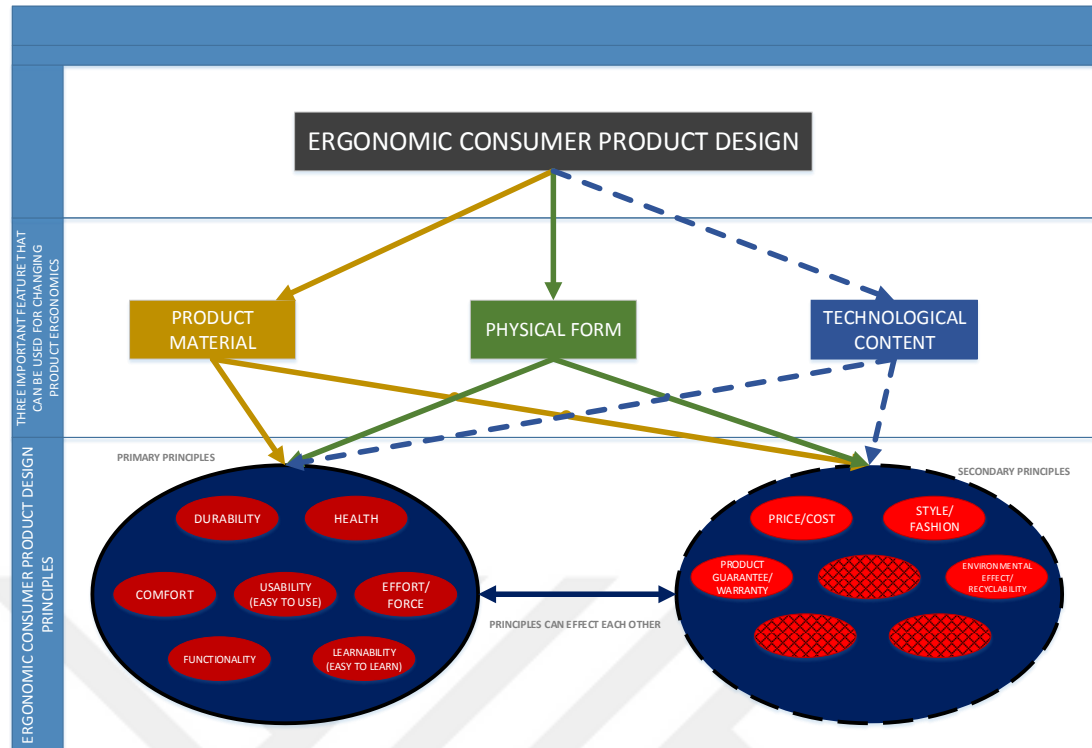


Figure 4.5 The conceptual model of ergonomic consumer product design principles

The primary and secondary principles are given in blue large ellipses. The primary principles' blue ellipse covered with a black line that shows the defined boundary of the primary principles. Also, the secondary principles' blue ellipse covered with a striped black line that illustrates the open-ended situation. Striped red ellipses are found in secondary principles. These striped red ellipses are included to illustrate examples of open-ended criteria. The criteria can be added by the researchers should be specified in such a way that they can be distinguished from the criteria that need to be examined precisely or in a different way. The other four criteria, which do not contain a striped line, are the secondary principles that must be examined. Three features are used to change criteria given in the middle. Principles are developed with the help of these features. The reason why the technological content is drawn with a striped line is not every consumer product has a technological structure. If there is no technological content been in the selected product, this feature is removed. As a result, while developing a completely new product or modifying existing products, it is possible to examine the principles and features of ergonomic product design in a holistic and systematic manner with the help of this conceptual model.

CHAPTER FIVE

GENERAL METHODOLOGY

5.1 New Product Development Process Considering Ergonomics

The general methodology of the ergonomic consumer product design was developed with a literature review of the product development methods and Ergonomic Consumer Product Design Principles which were defined in chapter 2 and 4. Also, it can be defined as a New Product Development Process Considering Ergonomics. The other product development methods are not fully fitted in the Ergonomic Consumer Product Design Principles. Thus, for creating the correct methodology, the combination of the Ergonomic Consumer Product Design Principles and four methods was used. These four methods are given below:

- Illustration of the product development and design process (Sagot et al., 1998).
- Principle description of ergonomics influence during the product development process (Falck et al., 2010).
- House of quality.
- Ulrichs' concept development phase (Ulrich & Eppinger, 2015).

Most of the product development methods were investigated in the literature but these four methods take an important role for the creations of the New Product Development Process Considering Ergonomics. As a result of this combination, the New Product Development Process Model and its steps were defined. The visual representation of the New Product Development Process Model and its' procedures are given in Figures 5.1 and 5.2, respectively.

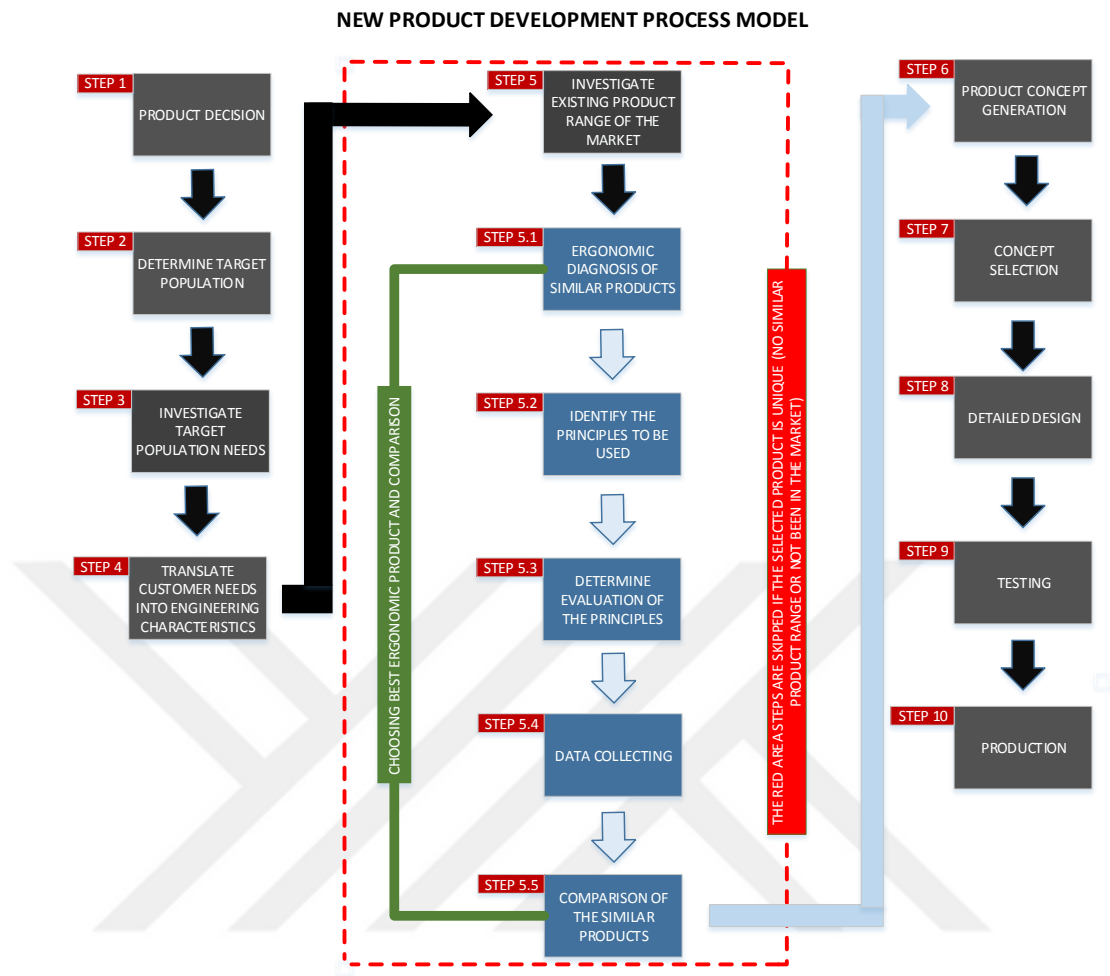


Figure 5.1 The visual representation of New Product Development Process Model

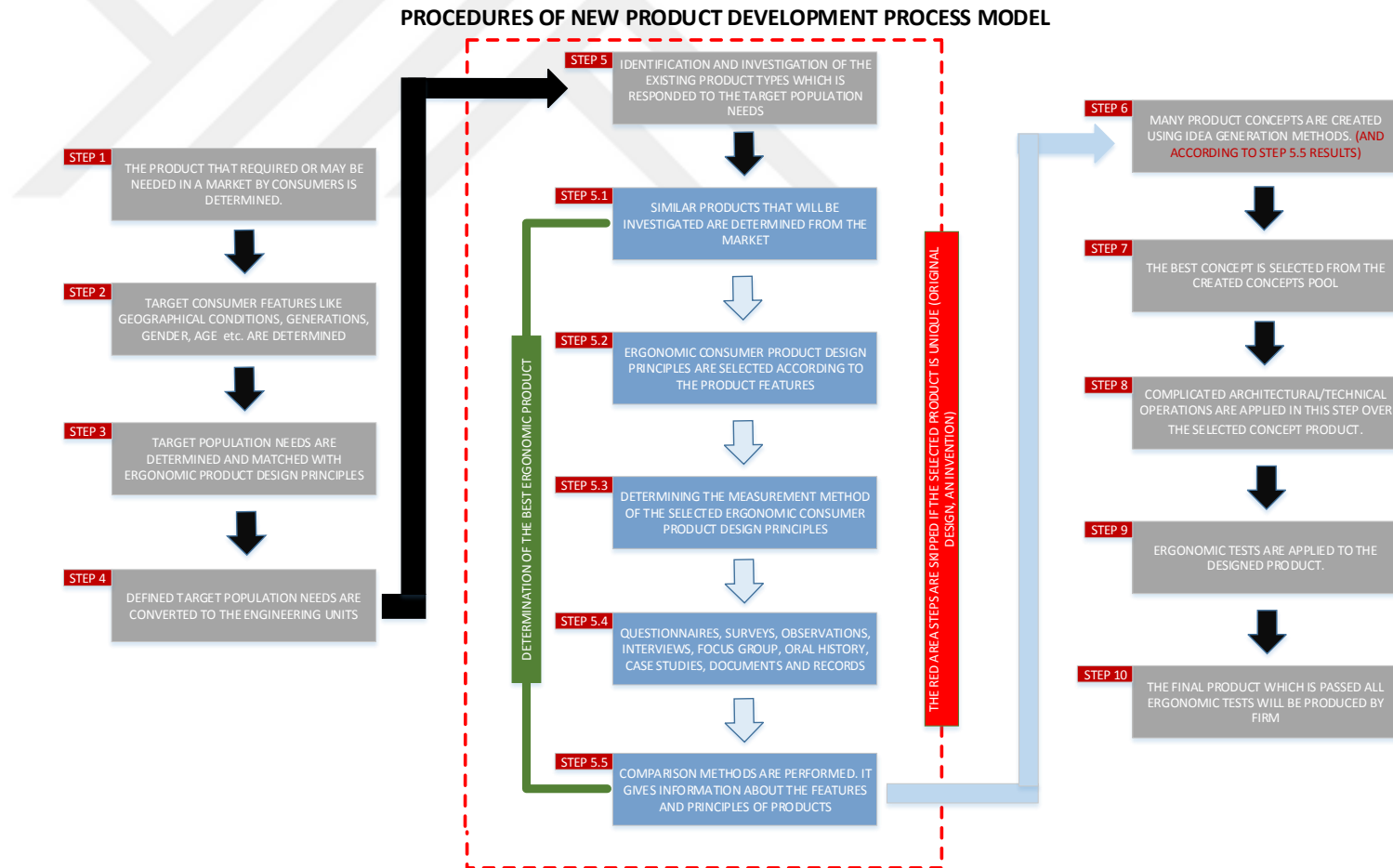


Figure 5.2 The procedure steps of New Product Development Process Model

This model is contained ten steps and five sub-steps. As mentioned in chapter three, mostly, the newly designed products generally developed with minor changes in the existing products. So that, step five (Investigate existing product range of the market) can be used mostly in the ergonomic consumer product design operation. If the product that will be developed is planned as an invention, the existing product range cannot be found. So, the existing products cannot be investigated. That's why the ergonomic consumer product design methodology contains two ways. If the product that will be developed is planned as an invention, the "investigate existing product range of the market" step is skipped otherwise the step five is performed. The step five and its sub-steps were covered into the red area that can be seen in the illustration of the ergonomic consumer product design methodology above. Step five contains five sub-steps that can be used for comparing similar product range and investigating the product features that the good ones can be seen. Investigate existing product range of the market really helps to create product concept and detailed design of the product because the best features of the Ergonomic Consumer Product Design Principles are determined. In below, each step of the ergonomic consumer product design methodology are explained in detail.

5.1.1 Product Decision

First of all, the researcher should have to determine the product which is demanded by the market. According to Ries (2011), building something that nobody wants is the ultimate form of waste. This situation causes a big time and money loss for firms because the usage of unnecessary products will not make any sense to consumers. Also, according to an investigation was performed by Garplid (2013) shows that in top ten startup mistakes, the "building something nobody wants" has taken the biggest part of the pie chart (36 percent). The pie chart of the top ten startup mistakes is given in Figure 5.3.

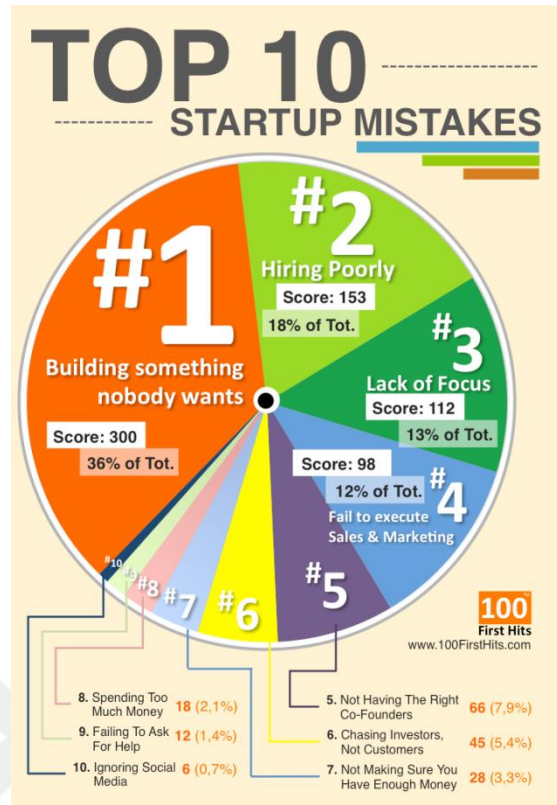


Figure 5.3 Top ten startup mistakes (Garplid, 2013)

There have some of the differences between old invented product and newly invented products. In the new product development stage (an invention), the researcher can determine some of the milestones that are related to ergonomic conditions. But after usage, these milestones might be changed by consumers because the ergonomic requirements are mostly determined by consumers. Sometimes, it is hard to find any ergonomic problems in old invented products because the old invented products mostly modified by firms according to consumers' feedbacks, long-term usage results or ergonomic tests, etc. However, product improvement within ergonomic still can be performed because a huge number of products have been producing into the market. The products that wait for an ergonomic solution are easily identified by market research.

According to Liem & Brangier (2012), the presence of market-pull and technology-push innovations has effects for ergonomics with other fields of study in terms of focal areas and integration. Basically, market-pull is a need of society. According to Ryan (2013), market pull meets to the need/requirement of a new product or solution to a

problem. The identification of the needs is determined by customers or market researches. In the market pull, needs of society are often met by modifying existing products. According to Liem & Brangier (2012, p. 5244), "in market-pull innovation, consumers and users play a central role in the search for new inspiration or knowledge that could trigger innovation". It is based on the understanding of specific customer needs. These unsatisfactory customer needs are the source of the innovations and it causes to the new demands for problem-solving (Brem & Voigh, 2009).

Technology push is an invention that is come up with research and development activities. The new technology invention drives new product development. According to Ryan (2013), technology push generally does not include market research. It starts with a company that develops innovative technology and applies it to a product. After, the company markets the product. So, according to Walsh, Kirchhoff & Newbert (2002), technology push can be described as creative/destructive with grand/new improvement, the market pull can be defined as a replacement or modification.

Technology push and market pull definitions need to minor modifications for Ergonomic Consumer Product Design Principles. According to an outline of the thesis, market pull meets to ergonomic needs/requirements of a new product or solution of the problem and technology push is an invention that drives to new ergonomic product development. With technology push, the milestones of the product ergonomic features can be investigated and guessed carefully. With a market pull, the consumers' feedbacks and ergonomic problems can be evaluated carefully.

5.1.2 Determine Target Population

Basically, the target population or target group is the classification of customers who share common areas when purchasing a product. Many classifications have performed in the literature which can be like geographical conditions, generation, gender, income rate, etc. According to Sagot et al. (2003), it is essential to characterize the population of future users at the early steps of the product design process. Depends on the situation, the target population range can be extended or narrowed. The researcher determines to classifications of the population. So the observation areas are

interchangeable. According to Porta (n.d.), specific demographics to target and psychographics of your target should be investigated. The specific demographics factors of the target population can be like age, location, gender, income level, education level, marital or family status, occupation, and ethnic background. The psychographics factors of the target population can be like personality, attitudes, values, interests/ hobbies, lifestyles and behavior.

For the more systematic and structured investigations, observation areas of the Future Analysis (Brandenburg, 2002) also can be used. The classification of the observation areas were determined by Aeberhard (1996). These five observation areas can be suitable to investigate the target population or the researcher can change some of the areas. The figure of the observation areas is given in Figure 5.4.

In here the center of the application area can be defined as customers and these areas can be regulated into the customer features.

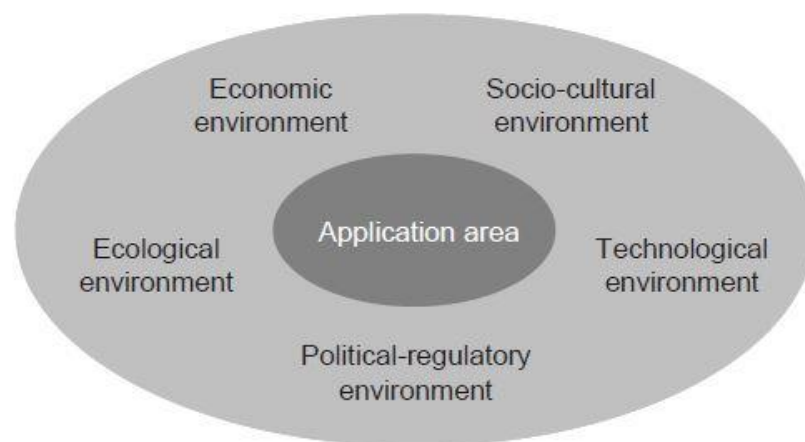


Figure 5.4 Observation areas for the future analysis (Eversheim, 2009)

5.1.2.1 *Economic Environment*

In this section, the purchasing power of the population can be investigated. It should be determined which revenue group are suitable for the product. Generally, customers have a psychological limit price that effects on product buying. Exceeding this limit may cause different products selection behavior by customers.

5.1.2.2 Socio- Cultural Environment

According to Eversheim (2009), determination of the future customer wishes is an indirect approach that related to socio-cultural environment analysis. Consumers direct or base their needs on the existing social value system, which can change continuously. Indicators for this change are social trends that are typically defined and named by trend researchers. Thus, the trend of the target population should be investigated. Also, the needs and expectations of the consumers change according to nationalities. So, cultural differences or cultural features of the target population needs to be well examined.

5.1.2.3 Technological Environment

The increasing sensitivity of the population to the indirect consequences of new technologies, especially in terms of ecological and social impact, is becoming more and more important to estimate or quantify possible technology results (Eversheim, 2009). This sensitivity also might be investigated if it will be defined as an important factor by the manufacturer.

5.1.2.4 Political- Eegulatory Environment

Political-legal environment includes the activities of the country as well as the developments foreseen by entities with legislative authority (Eversheim, 2009). The legalization authority or requirements like country-specific product requirements etc. also should be investigated.

5.1.2.5 Ecological Environment

Eco-friendly products become more preferable by customers day by day. So the discussion of the ecological demands like non-renewable materials consumption, producing environmentally friendly products, and the importance of environmental concerns are essentials for strategic success.

5.1.3 Investigate the Target Population Needs

In this step, the expected needs from the product are investigated. According to Watkins, Meirers & Visser (2012), need assessments are commonly used for guiding strategic decisions that directed from a society needs with direct and indirect clients. Generally, the target population needs can be determined by customer feedbacks or internet sources but for more, data collection tools and techniques also can be used.

After that, according to gathered target population needs, the evaluation of the Ergonomic Consumer Product Design Principles is performed. Within the primary principles, the dominant criteria and the other criteria comparisons can be determined. So, the researcher might focus on the dominant principles more than others. On the other hand, primary principles are directly related to the ergonomic conditions of the product. Therefore, the researchers should not miss any primary principles to investigation of the target population needs. Within the secondary principles, the dominant criteria also can be determined but secondary principles are open-ended. So the new criteria might be added at this stage. New criteria also can be gathered from the data collection tools and techniques.

Therefore, in this step, the target population needs are determined. After that, according to target population needs, the primary and secondary criteria are investigated and target population needs are placed as sub-criteria below the related primary and secondary criteria.

5.1.4 Translate Customer Needs into the Engineering Characteristic

According to Chan & Wu (2002), quality function deployment is a general notion which provides a means of translating customer needs into the suitable engineering requirements for each step of the production and product development. Zhang et al. (2014) stated that House of Quality (HoQ) is a primary chart that is used to quality function deployment. In House of Quality, the customer requirements are converted into the technical requirements (engineering characteristics). Consequently, translate customer needs into the engineering characteristics is a part of the House of Quality

that critical to the defining correctness of customer requirements input. The need-metrics matrix can be performed to the determining and matching customer needs and engineering characteristics. According to Ulrich & Eppinger (2015), a few guidelines should be taken into account when creating a list of metrics:

- Metrics should be complete.
- Metrics should be dependent, not independent variables.
- Metrics should be practical.
- Some needs cannot be easily translated into quantifiable metrics.
- The metrics should include the popular criteria for comparison in the marketplace.

The need-metrics matrix can be created in many ways. An engineering characteristic can fulfill more than one of the customer needs. In the same way, a customer need can be fulfilled by more than one engineering characteristics. An example of the need-metrics that illustrated by Ulrich & Eppinger (2015) is given in Figure 5.5.

Need		Metric	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
		Attenuation from dropout to handlebar at 10 Hz																										
		Spring preload																										
		Maximum value from the Monster																										
		Minimum descent time on test track																										
		Damping coefficient adjustment range																										
		Maximum travel (26-in. wheel)																										
		Rake offset																										
		Lateral stiffness at the tip																										
		Total mass																										
		Lateral stiffness at brake pivots																										
		Headset sizes																										
		Steertube length																										
		Wheel sizes																										
		Maximum tire width																										
		Time to assemble to frame																										
		Fender compatibility																										
		Installs pride																										
		Unit manufacturing cost																										
		Time in spray chamber without water entry																										
		Cycles in mud chamber without contamination																										
		Time to disassemble/assemble for maintenance																										
		Special tools required for maintenance																										
		UV test duration to degrade rubber parts																										
		Monster cycles to failure																										
		Japan Industrial Standards test																										
		Bending strength (frontal loading)																										

Figure 5.5 The needs-metrics matrix (Ulrich & Eppinger, 2015)

According to Ulrich & Eppinger (2015), process of establishing the target specifications includes four steps:

1. Prepare list of matrix.
2. Collect competitive benchmarking information.
3. Set ideal and marginally acceptable target values.
4. Reflect on the results and the process.

Also in this matrix, human needs and engineering characteristic are classified according to Ergonomic Consumer Product Design Principles. With this method, which human needs represent to the Ergonomic Consumer Product Design Principles and its value calculation can be performed.

The values or properties of engineering characteristics can be investigated and determined in this step but if the product has a similar type of existing product range in the market, the investigation of the existing products must be performed at the next step. The value or properties of engineering characteristics might be determined better after the investigating existing product range of the market.

5.1.5 Investigate Existing Product Range of the Market

According to Sagot et al. (2003), the design of a product infrequently consists of a development an entirely new product. However, the design of a product is mostly having performed with modification or upgrade of the existing products. So, the investigation of the existing products gives high information about the product features and the product that will be developed.

This step is also can be performed for determining the good ergonomic products in the market for consumers and also gives ergonomic features of these products. This part consists of five sub-steps in itself. The first step is an ergonomic diagnosis of similar products in the identified product range. After, determination of the principles to be used is performed. Then, the evaluation methods of the Ergonomic Consumer Product Design Principles (human needs and engineering characteristics evaluation methods) are determined. Later, the data collecting process is performed with data collection tools and techniques. At last, the comparison of similar products is performed with decision-making tools or statistical evaluation methods.

5.1.5.1 Ergonomic Diagnosis of Similar Products

As mentioned before, the product decision is performed at the first step of the New Product Development Process Model. In this step of 4.5.1, the products that fulfill the customer needs in the existing market are investigated according to selected and defined product at step 1.

Product material, the physical form of the product and technology content of the product are the main three features of Ergonomic Consumer Product Design

Principles. The products that will be investigated are needed to choose with respect to the ergonomic product design features. For example, materials of the product can be like metal, plastic, polymer, and iron. Thus, the differentiation of the materials between products can be compared. Also, it can be performed for the physical form of the product and technology content. The more different material, physical form, and technological content that products have, the more diversity comparison can be obtained. The best and worst features can be compared.

5.1.5.2 Identify the Principles to be Used

First of all, principles in ergonomic consumer product design are the criteria that should be at the desired level for a product to be ergonomic. The main goal is investigating and comparing the products according to the Ergonomic Consumer Product Design Principles. However, sometimes there is no point in comparing some criteria because the fact that some of the criteria are the same for all products does not require the examination of that criterion. For example, if we are comparing the different type of shovels, the investigation of the easy to learn criteria will not make any sense. We can explain the easy to learn criterion that if the products can be used properly at the first usage without product manuals, the product has a good level of easy to learn. If all products can be used without product manual, according to easy to learn principles, the comparison of the products is illogical. Therefore, easy to learn principles are removed for the comparison. All principles should be investigated like this for identification of the Ergonomic Consumer Product Design Principles. The essential principles are determined and proceed to the next step.

5.1.5.3 Determine Evaluation of the Principles

A similar type of product comparison should respect to the Ergonomic Consumer Product Design Principles. In this step, we need to define evaluation methods of the human needs that represent the related primary or secondary criteria. Human needs also can be defined as sub-criteria of the Ergonomic Consumer Product Design Principles that gives the condition of the primary and secondary criteria's level.

Different human needs can be measured with different type of units. The determination of the types of units and evaluation methods should be defined in this step.

Some human needs' sub-criteria values can be measured exactly but sometimes cannot because of the type of data which might be subjective. For example, the durability of the concrete can be measured properly with the pressure test. Each determined concretes are tested and after that, all values of the durability criteria for each product are measured. On the other hand, the comfort of the product cannot be measured exactly because there is no technique been in the literature about the absolute measurement of comfort. If the criteria have not an absolute measurement technique, we might use some types of scales like Likert scale for this type of measurements.

Therefore, the measurement methods may vary according to the type of data. Objective and subjective data measurements techniques should be defined properly.

5.1.5.4 Data Collecting

The measurement of the criteria's human need values of each product is performed in this step. Many data collecting techniques have been in the literature.

The most common techniques that can be used for these types of investigations can be like:

- Questionnaires
- Surveys
- Observation
- Interviews
- Focus Group
- Ethnographies
- Oral history
- Case studies
- Documents and records

Besides the measurement of the criteria's human needs and criteria weights also can be determined in this step. Some of these methods might be fitted to gather data for calculating criteria weights. Many weight determination methods can be used with subjective and objective data for calculation. Therefore, the researcher might select the correct data collecting method for calculation of own criteria's human needs and criteria weights.

5.1.5.5 Comparison of the Similar Products

After the determination of the criteria's human needs values of each product, the comparison should be performed in the selected product range. Many decision-making tools and techniques had been in the literature. Some of these methods are nominal group technique, multi-criteria analysis, tabletop analysis, pair-wise comparison, 2x2 matrix decision aids, fishbone diagrams, scenarios, root cause analysis, fault tree analysis, concept mapping, future wheel, performance pyramids, etc. (Watkins et al., 2012). Especially in questionnaires and surveys, statistical methods also take an important part of the comparisons and investigating relations between the groups of values. Some of these methods are ANOVA, MANOVA, regression, correlation, etc. However, the statistical method selection can be changed according to the distribution of the data. Normal distribution and non-normal distribution techniques are different. So, the distribution of the collected data should be identified.

The ergonomic comparison of existing products provides many benefits for the researcher. These are:

- Gives important features about product material, physical form and technological content of the good product ergonomics.
- Identification of the criteria weights can be performed according to consumers' behavior with data collection methods. This provides a rank of the Ergonomic Consumer Product Design Principles according to consumers' behavior. So the researcher or manufacturer can be focused on the important criteria first.
- It helps the generation of product concepts.

- Comparison of the existing products gives the rank of these products from best to worst. This provides the determination of best ergonomic product or products for consumers and researchers.

5.1.6 Product Concept Generation

Investigating the existing product range according to Ergonomic Consumer Product Design Principles gives us the most important features of the investigated product. In the concept creation step, the best-obtained features of the Ergonomic Consumer Product Design Principles will be selected to the creation of the concept.

According to Ulrich & Eppinger (2015), technology, working principles, and form of the product are an approximate description of the product concept. It is a succinct illustration of how the product will satisfy customer requirements.

Product concepts are created with a reunion of the subunit parts or determined components. Each engineering characteristics can be performed with a variety of the subunit parts. Each engineering characteristic and its subunit parts are determined. For example, the cup can be produced with material like glass, metal, and plastic. These are the subunit parts of the cup characteristic. This combination of the engineering characteristics and its subunit parts can be illustrated in the table. The table (Ulrich & Eppinger, 2015) is given in Figure 5.6.

Convert Electrical Energy to Translational Energy	Accumulate Energy	Apply Translational Energy to Nail
Rotary motor with transmission	Spring	Single impact
Linear motor	Moving mass	Multiple impacts
Solenoid		Push nail
Rail gun		

Figure 5.6 Concept combination table for the handheld nailer (Ulrich & Eppinger, 2015)

Many concepts can be created with a different combination of these subunit parts of components. An illustrative example of the concept creation is given in Figure 5.7.

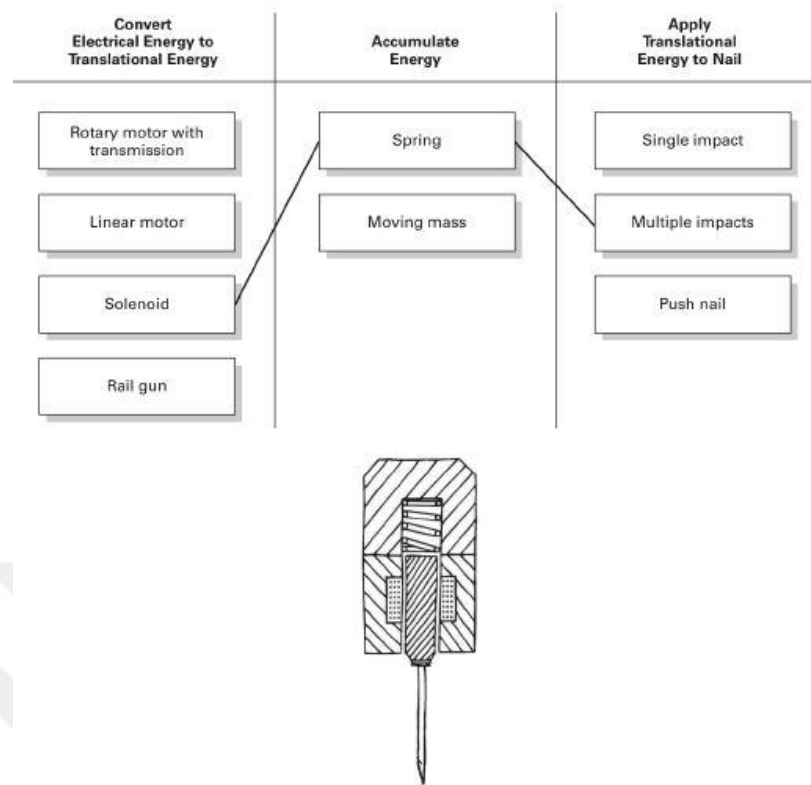


Figure 5.7 Example of the concept creation (Ulrich & Eppinger, 2015)

The numbers of possible concepts are created at this step with this method. The example was given above are related to the technological content of the product. Also, the other features which are product material and physical form can be illustrated like this.

In here, according to step 5, the components can be ranked under each headline of the concept creation figure is given above. For all that, the best and alternative combinations can be created with the matching of the features. Thus, the rough appearance of the product is obtained. This rough product is called product concept and it helps to how the final product can be seen. Many product concepts are generated at this step for choosing the best product concept or more than one can be selected. Concept selection will be given in the next step.

5.1.7 Concept Selection

Determined concepts are investigated and selected in this step. Many methods can be used to selecting a concept. Some of the methods were given by Ulrich & Eppinger (2015). These are:

- *External decision*: Concepts are presented to the customers, clients or some of the external entities for concept elimination.
- *Product champion*: The experienced member of the product development team is selected a concept with an individual choice.
- *Intuition*: Feelings it the main source of the choosing concept at this method.
- *Multivoting*: The all team members are voted for a few concepts. The most voted concepts are selected.
- *Web-based survey*: Online survey tools are used in this step. There are many platforms on the internet where people can participate in the survey.
- *Pros and cons*: The strength and weak features of the concepts are listed by team members. Each team selects the best concept found in group decisions.
- *Prototype and test*: The firm produces prototype for each concept. The selection is done by team members based on the test data.
- *Decision matrices*: The team determines criteria and its values for each concept. The determination of the criteria weights can be determined.

Prototyping of the product concept is more effective selection method than the others because, with prototyping, the tangible product will be obtained. The tangible product concept can be investigated better. Also, some of the tests can be applied by the team members for observing weak and strength features if it is needed. Small differences cannot be measured without prototyping and its effects cannot be intuited. But the prototype product concept that will be created is not a final product. So, it won't perform the real performance of the product. Also, other methods can be used to select concepts. The other methods are much easier to apply than prototyping. Therefore, the prototyping might be selected as the last option of the concept selection

step. Prototyping gives better observation and ideas for the concept product but it takes much time and also has costs than other methods.

5.1.8 Detailed Product Design (Architecture)

In this step, the selected concept product will be converted to the final product because concept products have a rough appearance. Nevertheless, the concept product gives us hints the general appearance of the product and how the final product can be looked. But it cannot be the final product because exact architecture and dimensions not defined.

According to Ulrich & Eppinger (2015), product architecture is a designation method that the functional elements of a product are transformed into physical building blocks of the product. Detailed design and testing of these blocks are provided by architectural decisions. With the designation of the building blocks to teams, individuals and suppliers allow the simultaneous development of different part of the product.

A product can be investigated in two terms like functional and physical (Ulrich & Eppinger, 2015). Functional elements contribute to the overall performance of the product via individual operations and transformations. Store paper and communicate with host computer can be given as an example of functional elements for printers. Functional elements are generally defined in the schematic form before they are converted to components, specific technologies or physical working principles. The physical elements of a product contribute to the product's function ultimately that are parts, components, and subassemblies. The physical elements are defined as more detail in this step. Generally, in product concept creation step some physical elements are defined and the rest of the physical elements are defined in the detailed design phase.

According to Ulrich & Eppinger (2015), *chunks* are physical building blocks that the combination of the several blocks creates the physical elements of the product. Each chunk has a function for a product that is created of a collection of components.

As a result, product architecture is the scheme that functional elements of the product are lined up to physical chunks and by which the chunks interact.

Modularity is the characteristic of the product architecture that is highly important (Ulrich & Eppinger, 2015). If the functions of the product are designated to different chunks, the design of that is called modular architecture. If the different functions of the product are designated to one chunk, the design of that is called integral architecture. Two of the modular architecture properties are given below:

- Chunks or more than one chunk designate one functional element.
- The interaction of the chunks is well defined and mostly meets the primary function of the product.

Three of the integral architecture properties are given below:

- Functional elements of the product are implemented using more than one chunk.
- A single chunk designated many functional elements.
- The interaction between chunks are weakly defined and might be meet randomize the primary functions of the product.

According to Ulrich & Eppinger (2015), modular architectures can be divided into three types. These are slot-modular architecture, bus-modular architecture, and sectional-modular architecture. Each type of modular architecture is a one-to-one mapping of well-defined interfaces and parts of functional elements. In slot-modular architecture, the interfaces between the chunks are of a different type than the others, so that various chunks in the product cannot be replaced. The automobile radio can be given an example of slot-modular architecture. In the bus modular architecture, there is a common bus, where the other chunks are connected via the same interface. Expansion card of the computer can be given an example of the bus-modular architecture. In a sectional-modular architecture, there is no single element been to

attach the chunks that, the chunks attach each other and all interfaces are the same type. The figure of the modular architecture types is given in Figure 5.8.

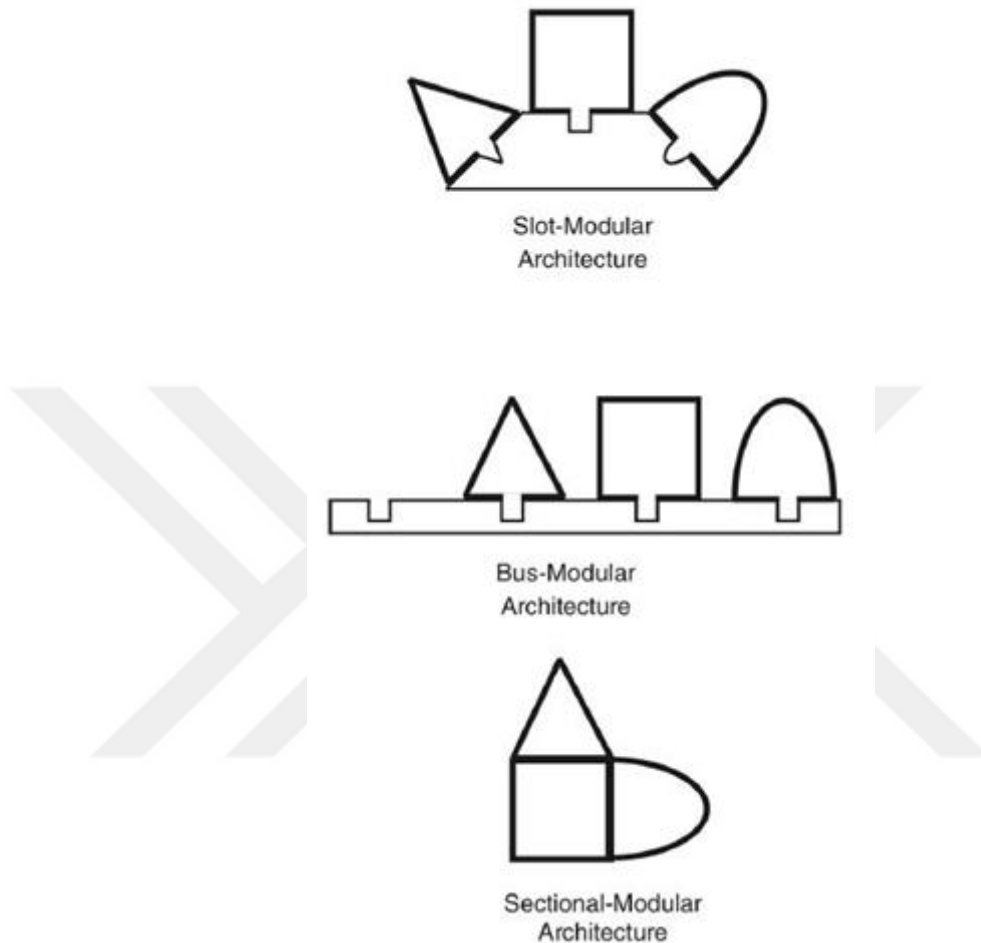


Figure 5.8 Modular architecture types (Ulrich & Eppinger, 2015)

In concept generation step, the rough product is determined. So, the chunks and modular architecture can be seen roughly in the detailed design step. In here, according to “investigate existing product range of the market” step and its substeps (if step 5 is available to investigate), the product features like material and physical form is determined detail. Ergonomic Consumer Product Design Principles take a primary role in determining features of the product and its chunks. All chunks of the concept product are drawn detailed (dimensions, shapes, etc.) with 2D or 3D computer-aided systems according to the result of the Ergonomic Consumer Product Design Principles result. After that, the chunks are attached according to the selected type of modular

architecture. Also, the materials of the chunks are determined with the result of step 5. Finally, if the detail designed product is approved by the management team, the ergonomic tests will be applied to the detail designed product in the next step.

5.1.9 Testing

After the detailed design is finished, ergonomic tests should be performed for measuring the ergonomic performance of the designed product because an ergonomic product should provide all primary criteria.

According to Chitale & Gupta (2011), testing is used to measure the proficiency of the product or design. The test is an important way of showing what a product or design can do because it gives direct and concrete results. Testing is performed to demonstrate compliance with a specific requirement, investigate ideas and check the feasibility or concept. Some of the testing methods are given by Chitale & Gupta (2011). These are:

- Scale model test (carried out on reduced size part)
- Development tests
- Prototype test
- Proof tests
- Acceptance tests
- Model test

Creating a prototype gives the best testing applications for developing an ergonomic consumer product because consumer products are tangible products. So, before the mass production, the prototype product should be tested according to Ergonomic Consumer Product Design Principles.

According to Ulrich & Eppinger (2015), a prototype is an approach along one or more output dimensions of the product. The prototypes can be classified two dimensions that the first one is divided into physical prototypes and analytic prototypes. The physical prototypes are tangible that represent the approximate product. For testing and experimentation of the prototype, the development team

actually will be building an artifact. Analytical prototypes are not tangible, generally mathematical or visual manner. In here, interesting aspects of the product are measured without build. Computer simulations, computer models of three-dimensional geometry, and system of equations encoded within a spreadsheet can be given an example of the analytical prototypes. The second dimension is divided into comprehensive prototype and focused prototype. Comprehensive prototypes closely represent the daily use of the prototype; this is a real-size version of the product. On the other hand, the focused prototype has few attributes than the final product. Generally, one or a few attributes that the focused prototype have been. The illustration of the types of prototypes is given in Figure 5.9 (Ulrich & Eppinger, 2015).

The prototype is pre-version of the final product or the prototype is the closest model of the final product. The main reason for the creation of the prototype is testing the product that how far the expectations and calculations of the Determined Ergonomic Consumer Product Design Principles values are met.

Most of the product features will be obtained in the previous steps. The ergonomic tests are performed to the detailed product design with two ways. The first one is testing prototypes with some of the participants. The second one is the prototypes are tested in related machines that give us specific values. The measurement tests and participant applications can be alterable by the variety of the product type. The researcher will be developed measurement tests and participant applications according to selected product type and its Ergonomic Consumer Product Design Principles.

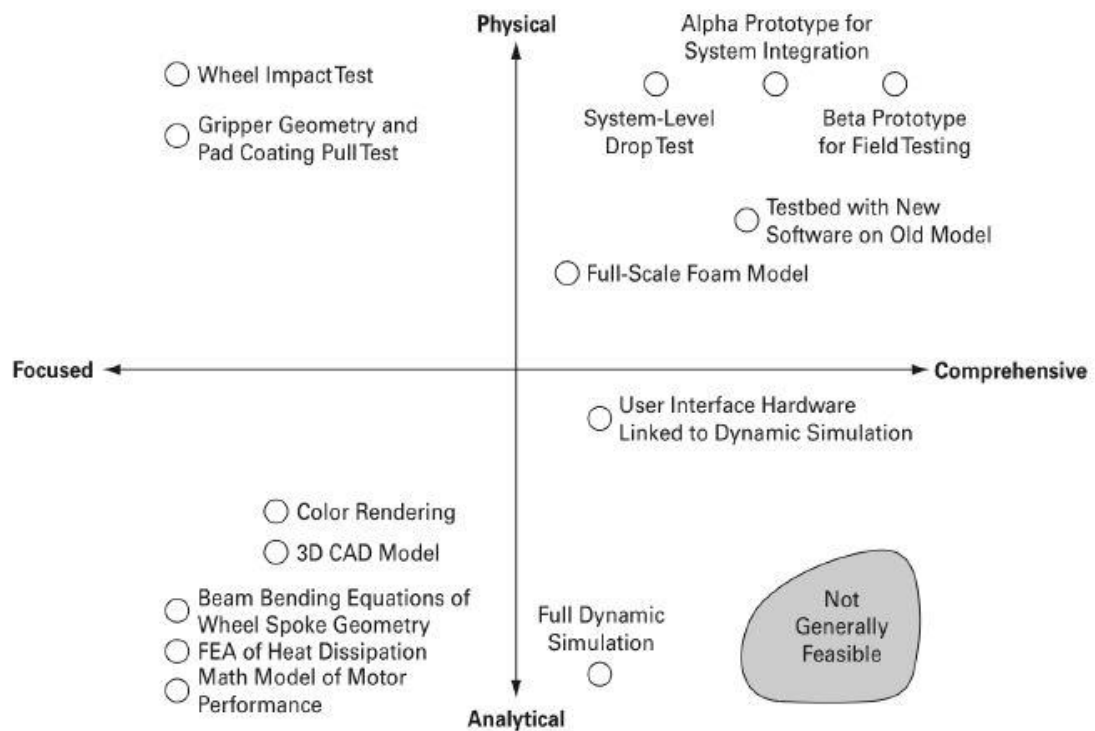


Figure 5.9 Prototype types (Ulrich & Eppinger, 2015)

5.1.10 Production

If the detail designed prototype can success all the ergonomic and other defined tests, the product will be produced by firms. Product development is wide definitions that include improvements, customer feedback, logistics, manufacturing, testing, scheduling, concept/industrial design, costing, market analysis, product specifications, etc. Besides product design includes all the engineering and industrial design works like simulation, 3D Cad modeling, design calculations, industrial design, user experience, etc. The product design is a part of a product development process. Therefore, the production process is mostly related to the product development process.

CHAPTER SIX

AN APPLICATION OF ERGONOMIC PRUNING SHEAR DESIGN

6.1 Application Content

The application of ergonomic pruning shear design contains the first six steps of the New Product Development Process Model which start from Product Decision step and ends with Concept Creation step. Pruning shear consumer product which is selected for application has wide existing product range. So, Investigate Existing Product Range of the Market step (step 5) and its sub-steps are also performed in this application.

An application also includes participant experiment, force measurement experiment and cutting experiment were performed to obtain:

- Values of defined human needs and its comparisons.
- Ergonomic features of pruning shears.
- Weights of selected Ergonomic Consumer Product Design Principles (primary and secondary criteria).

These three experiments are given detailed in the step 5. If it is necessary to summarize the application steps, in step 1, the pruning shear is selected as a product that will be designed. In step 2, potential target population is defined. Also, target populations are classified according to age, hand size, gender et cetera. In step 3, human needs are defined according to the pruning shear products. In step 4, these human needs will be translated into the engineering characteristics and investigated detail. Step 5 is also included because many types of different pruning shears been in the market. In step 5.1, different type of pruning shears are selected for the ergonomic investigation. In step 5.2, the related principles are selected for pruning shears investigation. Also, these principles were matched with human needs. In step 5.3 the evaluation methods are defined and applied into the selected human needs. In here participant experiment, force measurement experiment, cutting experiment and the

other data collecting methods were selected. In step 5.4, selected data collecting methods are applied to the pruning shears and consumers for collecting data. In step 5.5, statistical and other comparison methods are performed into gathered data. These methods give important features about product ergonomics of pruning shears. In the last step of this application which is step 6, many product concepts will be created according to investigate human needs and engineering characteristics.

6.2 Product Decision

Except for disposable products and food products, Ergonomic Consumer Product Design Principles model were developed to design ergonomic products for consumer. In here, pruning shear has selected as a product to be designed for thesis application. There are many reasons why pruning shear was chosen as the product to be designed. These are given below:

- Pruning shear is a common product can be found easily in the market (bypass pruning shears).
- There are many different types of pruning shears been in the market.
- Pruning shears are very suitable for applying Ergonomic Consumer Product Design Principles.
- Consumers are expecting a lot of "human needs" from pruning shears.
- Participant experiments can be performed much easier than other complex consumer products.
- Ergonomic tests can be applied.
- Viticulture is very common in Turkey.

Pruning shear is a consumer product that is used for cutting vineyards, flowers, bough et cetera. Small size pruning shears are generally used with one hand for cutting thin boughs. The mechanical structure of pruning shear is similar to a scissor in many ways. The blade is located in front of the pruning shears and blade is moved and cut boughs with the flexion and extension movements of the hand into the pruning shears' handle. However, there is only one blade and one supportive part been in the pruning

shears. The supportive part is not sharpness. The cutting is performed with move of the cutter knife.

There are two different types of pruning shears been in the market according to blade movements. These are bypass pruners and anvil pruners. Anvil pruners are used for cutting dry boughs. When the pruning shear is closed, there is no gap between the cutting blade and the supporting part. The cutter blade fits exactly on the supporting part. However, bypass pruners are used for cutting live boughs. When the pruning shear is started to close, the cutting blade passes to the supportive part. Bypass pruning shears should not be used in the dry boughs because the blade will be lost its sharpness easily. Therewithal, anvil pruning shears should not be used in the live boughs because it cannot cut the live bough correctly. The figure of the anvil and bypass pruning shears are given in Figure 6.1.

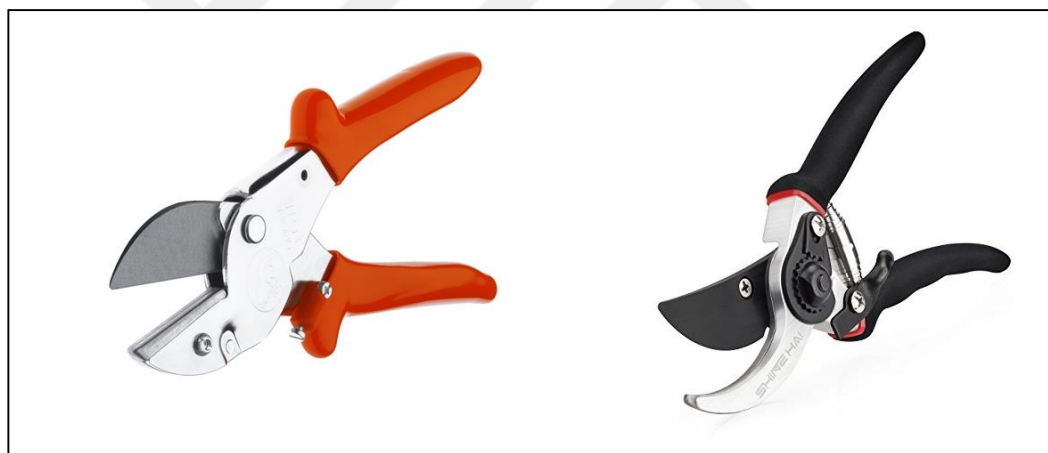


Figure 6.1 Anvil pruner (left) and bypass pruner (right) (Google images, 2019)

These are the hand-powered pruning shears. Also, electrical pruning shears been in the market but these products generally not suitable for consumers. These types of products are mostly used for professional vineyard workers because continuous usage of the hand-powered pruning shears causes might cause musculoskeletal hand-wrist disorders.

In Turkey, anvil pruning shears are not common in the marketplace. Unlike, bypass pruning shears are can be found easily in the marketplaces. Therefore, bypass pruning shear was selected to design and investigate according to New Product Development Process Model.

6.3 Determine Target Population

The classification of the target population is included gender, hand size, income rate, regions of Turkey, left-handed/ right-handed, age and effort. These are given below:

- *Gender*: Both male and female consumers are targeted for pruning shear design. Pruning shear design should be fitted to both male and female consumers.
- *Age*: Consumers aged between 18 and 65 are targeted.
- *Hand Size*: In 2005, the average length of the male hand was measured as 195.54mm and the standard deviation was calculated as 10.46. On the other hand, the average length of the female hand was measured as 180.27mm and the standard deviation was calculated as 10.62 (Güleç et al., 2009).
- *Income rate*: Middle-Income consumers are targeted.
- *Grip Force*: The mean value of grip force was measured as 27.59 ± 9.92 kg (Narin, Demirbüken, Özyürek & Eraslan, 2009). The grip force value can be changed according to gender.
- *Regions*: In Turkey, the high vineyards rates been in Southeast Anatolia Region and Aegean Region which are 35.04% and 27.48% (Semerci, Kızıltuğ, Çelik & Kiracı, 2015).
- *Left-handed/right-handed users*: Both left-handed and right-handed consumers are targeted.

6.4 Investigate Target Population Needs

Basically, human needs are consumer expectations by the product. According to pruning shears, 23 human needs were determined for consumers. These human needs were matched with Ergonomic Consumer Product Design Principles and features. The human needs table is given in Table 6.1.

Table 6.1 Human needs and its relationships with ergonomic consumer product design principles and features

HUMAN NEEDS	RELATED PRINCIPLES	RELATED FEATURES
Right and left hand usability	Functionality	Physical form
Lightweight pruning shear	Usability (Easy To Use), Effort/ Force	Product material
Durability of the pruning shear	Durability	Physical form, product material
Adjustable handle according to hand sizes	Comfort, Usability (Easy To Use), Functionality	Physical form
Suitable material usage for handle	Comfort	Physical form, product material
Suitable hand motion in cutting process	Comfort, Usability (Easy To Use)	Physical form
Suitable handle temperature	Comfort, Usability (Easy To Use)	Product material
Replacement of the pruning shears' parts	Functionality	Physical form
Hand position at the cutting process (knife angle)	Health, Comfort, Usability (Easy To Use)	Physical form, product material
Cutting with minimum effort	Health, Comfort, Usability (Easy To Use), Effort/ Force	Physical form, product material
Maximum bough diameter to cut	Functionality	Physical form, product material
Security lock design	Health, Usability (Easy To Use), Functionality	Physical form, product material
Protecting palm health	Health	Physical form, product material
Protecting wrist health	Health	Physical form
Protecting finger health	Health	Physical form, product material
Easy to clean	Usability (Easy To Use)	Physical form, product material
Slippery (Handle)	Health, Comfort, Usability (Easy To Use)	Physical form
Rust protection	Durability	Product material

Table 6.1 continues

Bottom end handle distance	Comfort, Usability (Easy To Use)	Physical form
Smooth cut	Durability, Functionality	Product material
Price	Price/ Cost	Physical form, product material
Service life of the product/ guarantee	Product Guarantee/Warranty	Physical form, product material
Environmental effect/ recyclability	Environmental Effect/Recyclability	Product material

It is clearly seen in the table that one human need can be related to more than one Ergonomic Consumer Product Design Principles. The most effective criteria were matched with human needs. Least effective relationships between criteria and human needs were not matched because the effect is insignificant. Learnability criteria were not taken into consideration. It was mentioned before that the mechanical structure between pruning shears and scissors are similar. Thus, consumers will not check the product manuals for learning the product usage. Also, style/fashion criteria were not taken consideration because consumers will not interest in the appearance of the pruning shears. The technological content feature was not investigated because the pruning shears that will be designed has not included any technological content. The designing operations will be performed with the physical form and material determination for pruning shears.

6.4.1 Right and Left Hand Usability

Pruning shear that will be designed should compatible with both hands. Classical pruning shears are compatible with both hands. However extra design or mechanical part additions might hinder both hand usability of pruning shears.

There are some differences between left-handed and right-handed users in the usage of pruning shears. In pruning operation, both left and right hand fingers close in the opposite direction. For example, movable handle types are only suitable for right-handed consumers. Left-handed consumers cannot use properly this product because of the opposite finger moves. Thumb can only reach inside of the pruning shears. So,

pruning shear mechanisms which placed in the one side that managed by thumb not suitable for both left and right hand. Therefore, according to target consumers' dominant hand, these considerations should be investigated.

6.4.2 Lightweight Pruning Shear

According to Hwang (2011), tool weights should be as little as possible. Grip force and grip force control are affected by the weight of objects (Chang et al., 1999). Also, lighter tools require less force than heavy tools (Hwang, 2011). The same author clarified that in precision works, hand tools should not be more than 0.4 kg. Not optimized hand tool weight causes the fatigue effect that decreases the performance of the product. Also, might be caused the hand and wrist problems.

The selection of the correct size pruning shear and product materials helps the optimizing pruning shears' weight. Light materials should be used to reduce product weight. Also, the optimum length of the pruning shear should be defined considering the more length might be caused more weight.

6.4.3 Durability of the Pruning Shear

The durability of the pruning shears' blade directly related to the size and material of the blade. Mostly steel is used for pruning shears' blade. Steel can be a different value of hardness (HCR). Basically, hardness can be defined as a resistance of the penetration against an object. Therefore, more hardness causes tough steel. Also the thin of blade and size of the blade also affects the durability of the blade. If the pruning shear blades bend or damaged in the cutting process, it affects the sharpness of the blade. The sharpening of the blades might fix the blade but it will never reach the first sharpness. It has experienced that the Fiskars P54 blade was damaged in the cutting 2 cm thick pine tree. The blade was sharpened. However, it could not reach the old performance. So, the blade was changed with the new one. So, the pruning shear reached the old performance.

Other parts of pruning shears durability also related with the material quality and physical form of the pruning shears.

6.4.4 Adjustable Handle According to Hand Sizes

Different consumers have a different size of hands. So, it is essential to use the adjustable handle design. Many pruning shears can adjustable according to hand size. However, generally, it is hard to change and understand because demount operation should be performed. This operation generally causes the misalignments or incorrectly sized pruning shears because consumers might not know the complicated adjust operations. Therefore the adjustable handle mechanism should be designed according to consumers understanding.

6.4.5 Suitable Material Usage for Handle

The handle material should be suitable for the human hand. Handle material affects handle comfort that good quality materials will be better for consumers. The different type of materials may minimally affect the transmission of the force. The best material can be determined according to the measurement of force. However, these differences can be only measured with EMG or other sensitive measurement techniques. But in this content, material comfort is taken into consideration. The definition of comfort concept is not clear (Helander et al., 1997). So, the comfort of the materials can be measured with scoring or other subjective methods.

6.4.6 Suitable Hand Motion in Cutting Process

The pruning operation is performed with flexion and extension of the four fingers which are index, middle, ring and little finger. The thumb is located here in a passive position and does not make any contribution to the cutting process. In below extension and flexion motions of fingers are given detail into the classic pruning shear.

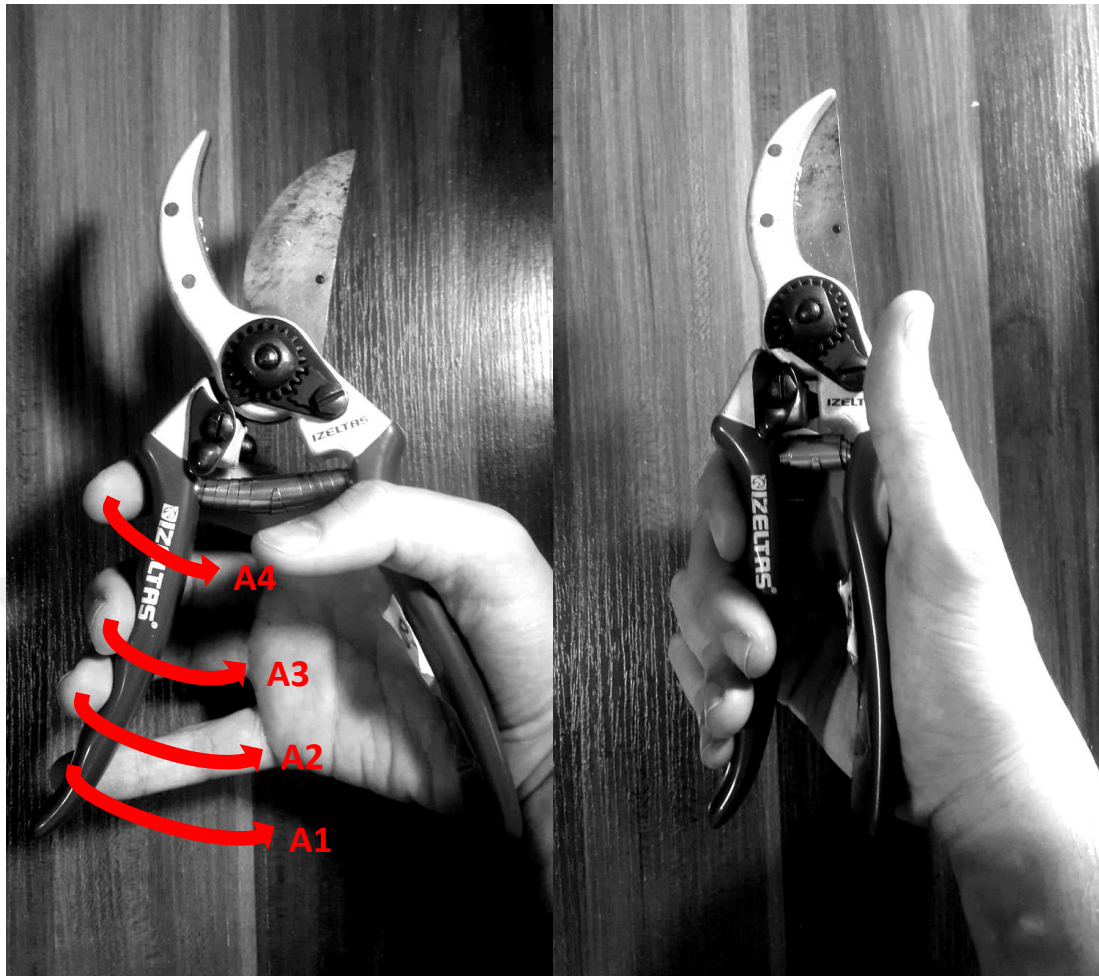


Figure 6.2 Flexion motions of four fingers and open positions of fingers (left), close positions of fingers (right) (Personal archive, 2019)

It can be seen clearly in Figure 6.2 that,

- Fingers perform a round motion.
- Fingertips take a straight position in the left figure. Then after the flexion, fingertips take a down position in the right figure.
- Fingers move different distance.
- The position of the fingers into the handle change with the flexion move.

Index finger and middle finger is more powerful fingers than ring finger and little finger (Li, Latash & Zatsiorsky, 1998). Also, ring finger is more powerful than little finger. It is clearly seen in the figure that, powerful fingers (index and middle finger)

close the fulcrum of pruning shears and moves short distance than less powerful fingers. To make better use of strong fingers, the distance traveled should be increased for strong fingers and, if possible, increased in distance with the fulcrum. The finger movements should be same and straight. The position of the fingers should not change in the flexion and extension movements because this situation might cause finger health problems.

6.4.7 Suitable Handle Temperature

The handle material of pruning shears should keep its temperature across external environments. In too hot or too cold environmental conditions, the handle material should compatible with hand temperature. This situation does not cause the major hand health problems but might decrease the comfort and performance of the pruning shears.

6.4.8 Replacement of the Pruning Shears' Parts

It is essential that the parts of pruning shears can be replaceable because as parts of the pruning shear become old, many problems will arise. These problems decrease the ergonomic condition of pruning shears. Besides, the replacement of the pruning shears' parts should be performed easily. Sometimes, it is hard to figure out which products have replaceable parts or not. The replacement cannot be performed properly by consumers if the hand pruner is hard to replacement.

6.4.9 Hand Position at the Cutting Process (Knife Angle)

The wrist angle affects the hand grip strength (Kınalı et al., 2016, Eryiğit, 2012). So, in the pruning process, the wrist angle should be compatible with the pruning shear. The pruning shears should look like an extension of the arm. Otherwise, the wrist position can change and pruning shears performance might reduce because of the bad ergonomic design. Blades angles of pruning shear should be designed as in Figure 6.3.



Figure 6.3 An ergonomic pruning shear knife position (Personal archive, 2019)

The different type of knife angle can be determined by designers according to the type of pruning operation. The consumers, who are pruning near the ground, might need more angled pruning shears. Interestingly, the classical type of pruning shears still have been producing by firms. However, this situation decreases the pruning shears' performance. Therefore, the knife angle might be in a wide range but the angle should be compatible with consumers' wrist and hand. Also, consumers' requests should be investigated.

6.4.10 Cutting with Minimum Effort

According to Hwang (2011), the risk of musculoskeletal hand-wrist disorders increases with the result of hand-powered pruning shears usage. Cramp of the hand or forearm also occurred by repetitive movements (Muggleton, Allen & Chappell, 1999) which can be seen in the pruning operation. Also, grip force may cause the work-related musculoskeletal disorders (Kung & Fathallah, 2006). So, the required force for pruning should be as low as possible.

The most important factor that affects the effort is the sharpness of the blade because it directly contacts with the bough. Then, the handle should fit the consumers' hand that the force transmission can be applied properly.

6.4.11 Maximum Bough Diameter to Cut

Generally, it is difficult to cut larger than 20 mm thick bough with a pruning shear. The material, sharpness, bough type and size of the blade directly affect the maximum bough diameter in pruning operation.

6.4.12 Security Lock Design

The security lock should be used with one hand, especially with the thumb. The easy to use criterion is really important because generally, the pruning shears' blade is really sharp. So, the lock system should be used with safe way.

The location of the security lock is also important that it might be reduced the performance of the pruning shear because in pruning operation the security lock might touch the hand and causes discomfort situation.

6.4.13 Protecting Palm Health

Palm is a part of the hand that meets the force during the pruning operation. Flexion movements of the fingers push the handle toward the palm. So, palm meets the most of force. Palm is the most sensitive part of the hand in the pruning shear usage. The health of palm is directly affected by the effort, handle design and handle material. The combination of these three factors should be optimized surely in the design of pruning shears. The lack of one factor of these can cause palm health problems. The palm health problems will occur in a short time if the product did not design ergonomically.

6.4.14 Protecting Wrist Health

Every end of the cut, a shock wave occurs as a result of striking the handles of the pruning shear. This shock wave directly affects the wrist and causes pressure and

vibration. The shock wave should be as little as possible. Otherwise, it might be contributing to Carpal Tunnel Syndrome. Carpal tunnel is a narrow tunnel that, the limitation of available space in the canal causes the nerve compression that termed carpal tunnel syndrome (Clippinger, 2006). The cause of this condition not well understood that repetitive finger or wrist flexion, prolonged exposure to vibration and repetitive gripping creates high risk of the carpal tunnel syndrome. The location of the tunnel in the wrist and hand is given in Figure 6.4.

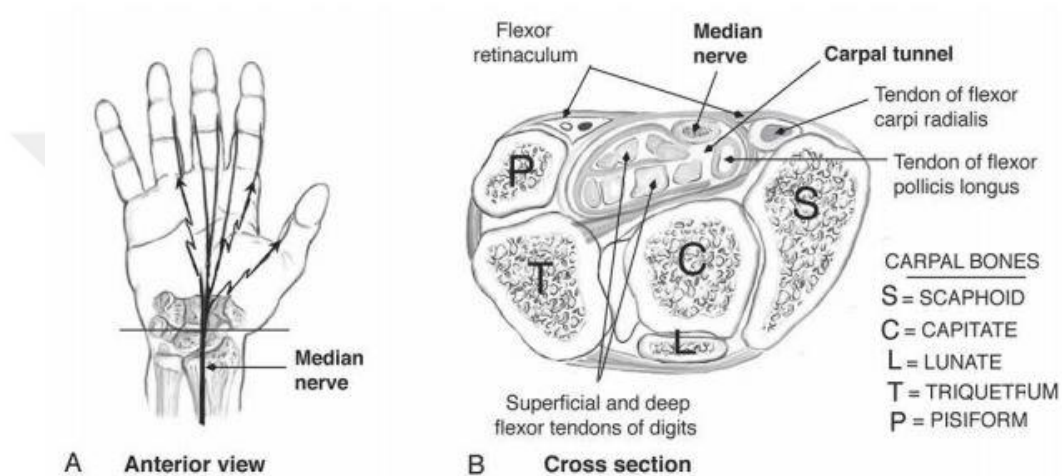


Figure 6.4 Anterior view of the tunnel (left), cross section of tunnel (right) (Clippinger, 2006)

The position of the pruning shears in the hand exactly places the top of this tunnel. So, force, repetitive motions and shock waves of the pruning shears directly affects this tunnel. The reduction of these effects prevents the musculoskeletal wrist-hand disorders. Shock absorbers are good options to reduce shock and pressure on the hand and wrist.

6.4.15 Protecting Finger Health

The flexion of fingers except for thumb on the pruning shear performs the pruning operation. The health of these four fingers is affected by force and slippery. Slippery increases the friction on the fingers. This might be causing surface finger problems. On the other hand, excessive force might cause the crushing of the fingers. Lastly, the design of the handle should compatible with finger anthropometry.

6.4.16 Easy to Clean

Bypass pruning shears are used for cutting live bough. The self liquid and other contents of live bough stick to the pruning shears' blade in pruning operation. So, these contents should be cleaned by consumers, otherwise, the performance of the pruning shear will be decreased. Also, dirty blades might cause the rough cutting area of the bough. The blade can be cleaned in many ways, but the cleaning should be easy and realizable. Special coatings of the pruning shears' blade ease the cleaning.

6.4.17 Slippery of the Handle

The slippery of the pruning shears is directly affected by handle materials. The slippery of the pruning shears causes hand problems because of the friction between handle and hand. Also, it decreases the performance of the pruning shears because the position of the pruning shear in the hand changes and awkward positions may occur into the hand and wrist. The correct material usage will prevent the slippery of the handle.

6.4.18 Rust Protection

The pruning shears' blade mostly is manufactured with steel. However, pruning shears' blade might rust over time. In here stainless steel usage is a good option for rust protection. Also, rust protection sprays and covering over the pruning shears' blade with other materials are provided rust protection. Rust decreases the pruning shear performance with reduction of the opening and closing fluency of handle. Also, rust might give damage to the plants and causes the disease.

6.4.19 Bottom End Handle Distance

The bottom end handle distance should be compatible with the length of little finger and hand. The long bottom end handle distance causes the extra force that the consumer should expend in the non-pruning operations. An illustrative example is given in Figure 6.5.



Figure 6.5 Full open positions of the pruning shears (left and right), holding position with the little finger (middle) (Personal archive, 2019)

As seen above, in the middle picture, the consumer should expend more energy to holding correct positions of the pruning shears because the full open size of the pruning shear which can be seen in the left causes the non-effective usage. So, consumers will not prefer to reach handle with the little finger constantly. The correct bottom end distance size given in the right of the picture. In relaxed mode, consumers will not consume extra energy to holding pruning shears. Also, it affects the pruning shear performance, comfort, and usability.

6.4.20 Smooth Cut

A smooth cut is needed for plants' health. For live bough, the cutting area should be smooth because the rough area causes the plant diseases. It affects the quality of plants and their harvest. The smooth cut is directly related with the pruning shears' blade. The blade should be durable and sharp.

6.4.21 Price

There are many types of pruning shears been in the market that has a variety of prices. Competitive prices are generally preferable by consumers. However, the quality of the product might be affected by price. The quality parts of the pruning shear will be more expensive than other pruning shears' parts. Also, it is directly related to the determined target population. The price should be balanced according to the targeted population.

6.4.22 The Service Life of the Product and Its Guarantee

The service life of the product and its guarantee shows the product quality. The consumers expecting from producers that the guarantee or warranty of the product as much as possible. Also, high-quality pruning shears reduce the guarantee costs of firms because the problems will be seen very rare.

6.4.23 Environmental Effect/ Recyclability

The parts of the pruning shears should not give any damage to the environment. Some consumers investigate the environmental effects of the product that affects the purchase decision. Also, recyclable materials give less damage to the environments. So, this environmental effect and recyclability are taken as a human need for consideration.

6.5 Translate Customer Needs into Engineering Characteristics

In this section, defined human needs' engineering characteristics and metrics will be given. However, proper metrics will be determined after the existing product range investigation. If there is no existing product couldn't be in the market, the metric determination would be performed in this step. However, many types of pruning shears been in the market and also, existing product range investigation will give us important features about product ergonomic of pruning shears. Therefore, ergonomic metrics of human needs will be defined exactly after the existing product range investigation. The engineering characteristics and its metrics are given in Table 6.2.

Table 6.2 Engineering characteristics and measurement units of human needs

HUMAN NEEDS	RELATED PRINCIPLES	ENGINEERING CHARACTERISTICS
Right and left hand usability	Functionality	Compatible handle physical form for both hands
Lightweight pruning shear	Usability (Easy To Use), Effort/ Force	Total mass
Durability of the puning shear	Durability	Hardness and sizes of the blade
Adjustable handle according to hand sizes	Comfort, Usability (Easy To Use), Functionality	Adjustment Mechanism
Suitable material usage for handle	Comfort	Raw material selection
Suitable hand motion in cutting process	Comfort, Usability (Easy To Use)	Handle Design
Suitable handle temperature	Comfort, Usability (Easy To Use)	Thermal conductivity of handle material
Replacement of the pruning shears' parts	Functionality	Modular structured pruning shear
Hand position at the cutting process (knife angle)	Health, Comfort, Usability (Easy To Use)	Knife position according to handle
Cutting with minimum effort	Health, Comfort, Usability (Easy To Use), Effort/ Force	Sharp knife usage and power gear design
Maximum bough diameter to cut	Functionality	The size of pruning shears
Security lock design	Health, Usability (Easy To Use), Functionality	Lock mechanism
Protecting palm health	Health	Compatible handle design
Protecting wrist health	Health	Compatible handle design
Protecting finger health	Health	Compatible handle design
Easy to clean	Usability (Easy To Use)	Cleanable material usage
Slippery (Handle)	Health, Comfort, Usability (Easy To Use)	Suitable handle design and material usage
Rust protection	Durability	Stainless material usage
Bottom end handle distance	Comfort, Usability (Easy To Use)	Compatible handle design
Smooth cut	Durability, Functionality	Suitable blade sharpness and sizes
Price	Price/ Cost	Cost
The Service Life of the Product and Its Guarantee	Product Guarantee/Warranty	Quality pruning shears
Environmental efect/ recyclability	Environmental Effect/Recyclability	Green material usage

6.6 Investigate Existing Product Range of the Market

As mentioned before, investigate existing product range of the market includes 5 sub-steps that provides an ergonomic comparison of the selected product range and ergonomic features of products. **4th and 5th sub-steps will be investigated in the same headlines.** In here some selected pruning shears will be investigated and compared according to determined human needs and Ergonomic Consumer Product Design Principles. Also, this step includes participant experiment, force measurement experiment and cutting experiment will be performed to obtain:

- Values of defined human needs and its comparisons.
- Ergonomic features of pruning shears.
- Weights of selected Ergonomic Consumer Product Design Principles (primary and secondary criteria).

6.6.1 Ergonomic Diagnosis of Similar Products

In the market, 11 pruning shears with different characteristics were selected to the comparison. 11 pruning shears were separated 3 groups that each pruning shear was coded according to group name and number. The groups were created with randomization that there are no common features been in the grouped pruning shears. The selection of pruning shears was performed according to different type of pruning shears' designs and materials. Thus, a larger and detailed comparison was made. The selected 11 pruning shears are given according to its groups in Figures 6.6, 6.7 and 6.8, respectively.



Figure 6.6 Group A pruning shears' names are respectively worth deluxe 1055 (A1), fiskars P68 (A2), izeltaş 6715 confort (A3), and handmade pruning shear (A4) (Google images, 2019)

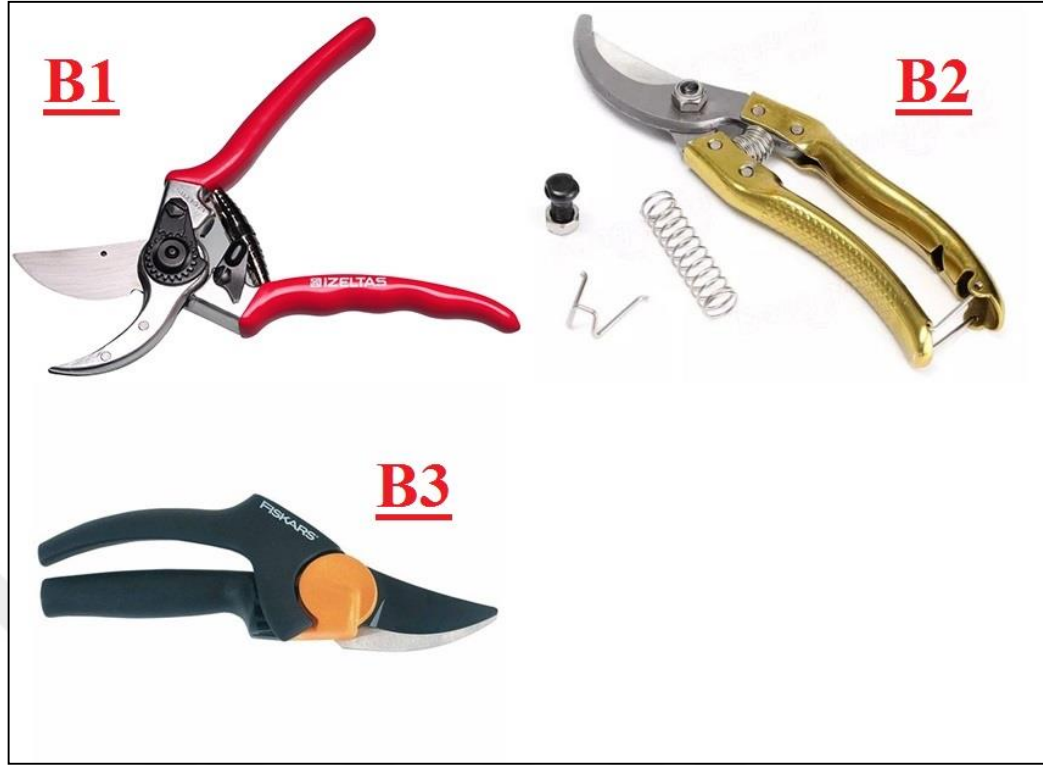


Figure 6.7 Group B pruning shears' names are respectively izeltaş 6720 hafif tip (B1), haktaş (B2), and fiskars P94 (B3) (Google images, 2019)



Figure 6.8 Group C pruning shears' names are respectively akman (C1), raco RT53/139S (C2), izeltaş 6710 Lüks (C3), and fiskars P54 (C4) (Google images, 2019)

All pruning shears will be compared according to their properties and these properties will be given detail in next steps. Table 6.3 depicts the properties that the user could have seen in the first impression.

Table 6.3 The first impression properties of pruning shears' (can be seen easily by consumers)

Pruning shears	Weight	Hand Type	Handle Material
Fiskars P54	132g	Small	Tough plastic
Fiskars P68	193g	Small and Large	Tough plastic
Fiskars P94	274g	Small	Tough plastic
İzeltaş 6715 Confort	294g	Small and Large	PVC isolation (covered)
İzeltaş 6710 Lüks	397g	Large	PVC isolation (covered)
İzeltaş 6720 Hafif tip	250g	Large	PVC isolation (covered)
Akman	170g	Small and Large	Plastic isolation (Not well defined)
Worth Deluxe 1055	186g	Small and Large	Strengthen nylon
Raco RT53/139S	213g	Small	Plastic isolation (Not well defined)
Haktaş	220g	Small and Large	Metal
Hand made pruning shear	301g	Large	Wood

6.6.2 Identify Principles to be Used

As mentioned in 6.4, the determined human needs were matched with Ergonomic Consumer Product Design Principles and features. Easy to learn and style/fashion criteria were not taken into consideration because these criteria do not make any differences into the pruning shear and consumers purchase decision. The other criteria were matched with human needs. One criterion might be matched with more than one human need. Also, one human need can belong with more than one criterion. The table is given in Table 6.4.

Table 6.4 Ergonomic consumer product design principles and human needs

HUMAN NEEDS	RELATED PRINCIPLES	RELATED FEATURES
Right and left hand usability	Functionality	Physical form
Lightweight pruning shear	Usability (Easy To Use), Effort/ Force	Product material
Durability of the pruning shear	Durability	Physical form, product material
Adjustable handle according to hand sizes	Comfort, Usability (Easy To Use), Functionality	Physical form
Suitable material usage for handle	Comfort	Physical form, product material
Suitable hand motion in cutting process	Comfort, Usability (Easy To Use)	Physical form
Suitable handle temperature	Comfort, Usability (Easy To Use)	Product material
Replacement of the pruning shears' parts	Functionality	Physical form
Hand position at the cutting process (knife angle)	Health, Comfort, Usability (Easy To Use)	Physical form, product material
Cutting with minimum effort	Health, Comfort, Usability (Easy To Use), Effort/ Force	Physical form, product material
Maximum bough diameter to cut	Functionality	Physical form, product material
Security lock design	Health, Usability (Easy To Use), Functionality	Physical form, product material
Protecting palm health	Health	Physical form, product material
Protecting wrist health	Health	Physical form
Protecting finger health	Health	Physical form, product material
Easy to clean	Usability (Easy To Use)	Physical form, product material
Slippery (Handle)	Health, Comfort, Usability (Easy To Use)	Physical form
Rust protection	Durability	Product material
Bottom end handle distance	Comfort, Usability (Easy To Use)	Physical form
Smooth cut	Durability, Functionality	Product material
Price	Price/ Cost	Physical form, product material
Service life of the product/ guarantee	Product Guarantee/Warranty	Physical form, product material
Environmental effect/ recyclability	Environmental Effect/Recyclability	Product material

The more human needs are matched with the primary criterion, the greater the impact on product ergonomics. According to the amount of match here, some criteria can be given more importance than others. Also, the criteria importance can be determined with the weight determination methods. According to this importance, the designer can be focused on the most important primary or secondary criteria.

6.6.3 Determine Evaluation of Principles

The evaluations of principles are performed with investigating human needs. According to all human needs results, we can take consideration of Ergonomic Consumer Product Design Principles. The combination of human needs shows the Ergonomic Consumer Product Design Principles situation. Also, the weight of these principles should be determined. So, we can obtain the most important and the least important criteria for investigated products.

There are 23 human needs and engineering characteristics were determined for pruning shears. Some of the human needs can be determined easily with objective data measurement methods. However, some of them cannot be measured with numerical. In these types of measurements, Likert scale or other methods can be performed to obtain data. The evaluations procedures of human needs are given below:

- *Right and left hand usability:* The evaluation is performed with available or not.
- *Lightweight pruning shear:* The evaluation is performed by measuring pruning shears' weight.
- *Durability of the product:* Durability is evaluated with investigating pruning shears' blades.
- *Adjustable handle according to hand sizes:* The evaluation is performed with available or not.
- *Suitable material usage for handle:* The different types of handle materials are compared with five-point Likert scale.

- *Suitable hand motion in cutting process:* Angle of hand motions is compared.
- *Suitable handle temperature:* The handle temperatures are compared.
- *Replacement of the pruning shears' parts:* The evaluation is performed with available or not.
- *Hand position at the cutting process (knife angle):* The knife angles are investigated according to hand position.
- *Cutting with minimum effort:* The evaluation is performed with the combination of the seven-point Likert scale, compression tests and Quick Exposure Check (David, Woods, Li & Buckle, 2008).
- *Maximum bough diameter to cut:* The evaluation is performed with a comparison of the maximum cutting diameters.
- *Security lock design:* The evaluation is performed according to the position of the security lock.
- *Protecting palm health:* The evaluation is performed with five-point Likert scale.
- *Protecting wrist health:* The evaluation is performed with five-point Likert scale.
- *Protecting finger health:* The evaluation is performed with five-point Likert scale.
- *Easy to clean:* The evaluation is performed with five-point Likert scale.
- *Slippery (Handle):* The evaluation is performed with five-point Likert scale.
- *Rust protection:* The evaluation is performed with availability of stainless material usage.
- *Bottom end handle distance:* The evaluation is performed with the measuring maximum bottom end handle distance.
- *Smooth cut:* The evaluation is performed with three-point Likert scale.
- *Price:* The evaluation is performed with the comparison of pruning shears price.
- *The Service Life of the Product and Its Guarantee:* The evaluation is performed with comparison of the guarantee years.

- *Environmental effect/ recyclability:* The evaluation is performed with material decomposition and recyclability percents.

Table 6.5 Human needs, engineering characteristics and measurement units

HUMAN NEEDS	ENGINEERING CHARACTERISTICS	MEASUREMENT UNITS
Right and left hand usability	Compatible handle physical form for both hands	available or not available
Lightweight pruning shear	Total mass	gram
Durability of the pruning shear	Hardness and sizes of the blade	hardness value and sizes
Adjustable handle according to hand sizes	Adjustment Mechanism	available or not available
Suitable material usage for handle	Raw material selection	5 point likert scale
Suitable hand motion in cutting process	Handle Design	angle of handle motion
Suitable handle temperature	Thermal conductivity of handle material	Celsius
Replacement of the pruning shears' parts	Modular structured pruning shear	available or not available
Hand position at the cutting process (knife angle)	Knife position according to handle	knife angle
Cutting with minimum effort	Sharp knife usage and power gear design	7 point Likert scale, compression tests (Newton)
Maximum bough diameter to cut	The size of pruning shears	Milimeter
Security lock design	Lock mechanism	The location of the security lock
Protecting palm health	Compatible handle design	5 point likert scale

Table 6.5 continues

Protecting wrist health	Compatible handle design	5 point likert scale
Protecting finger health	Compatible handle design	5 point likert scale
Easy to clean	Cleanable material usage	5 point likert scale
Slippery (Handle)	Suitable handle design and material usage	5 point likert scale
Rust protection	Stainless material usage	available or not available
Bottom end handle distance	Compatible handle design	Milimeter
Smooth cut	Suitable blade sharpness and sizes	3 point likert scale
Price	Cost	TL
The Service Life of the Product and Its Guarantee	Quality pruning shears	Year
Environmental effect/ recyclability	Green material usage	Material decompose

6.6.4 Data Collecting and Comparison of the Similar Products

This part includes respectively compression test, cutting test, case study (Participant Experiment of Investigating Pruning Shears) and investigating the rest of human needs and engineering characteristics of the pruning shears.

6.6.4.1 Compression Test

The compression test was performed to measure minimum cutting effort of each pruning shears. The compression test was conducted in Dokuz Eylül University Mechanical Engineering laboratory. SHIMADZU AG-X 100 kN was used to measure cutting forces.

6.6.4.1.1 Apparatus Design. An apparatus is designed to fit the pruning shears in the machine properly. The visual representation of the apparatus is given in Figure 6.9.



Figure 6.9 Bottom view of apparatus (top left), side view of apparatus (top right), top view of apparatus (bottom left), and side view of apparatus with cable tie (bottom right) (Personal archive, 2019)

The pruning shear is connected to the apparatus with a cable tie. The cable ties can adjustable for different pruning shears handle size. Also, other advantages are the cable ties do not give any damage to the pruning shears' handle and easy to use. After the pruning shear is attached to the apparatus, the hinge is placed on the empty parts to prevent it from bending left or right. Then the apparatus with pruning shears is placed on the machine as in Figure 6.10.

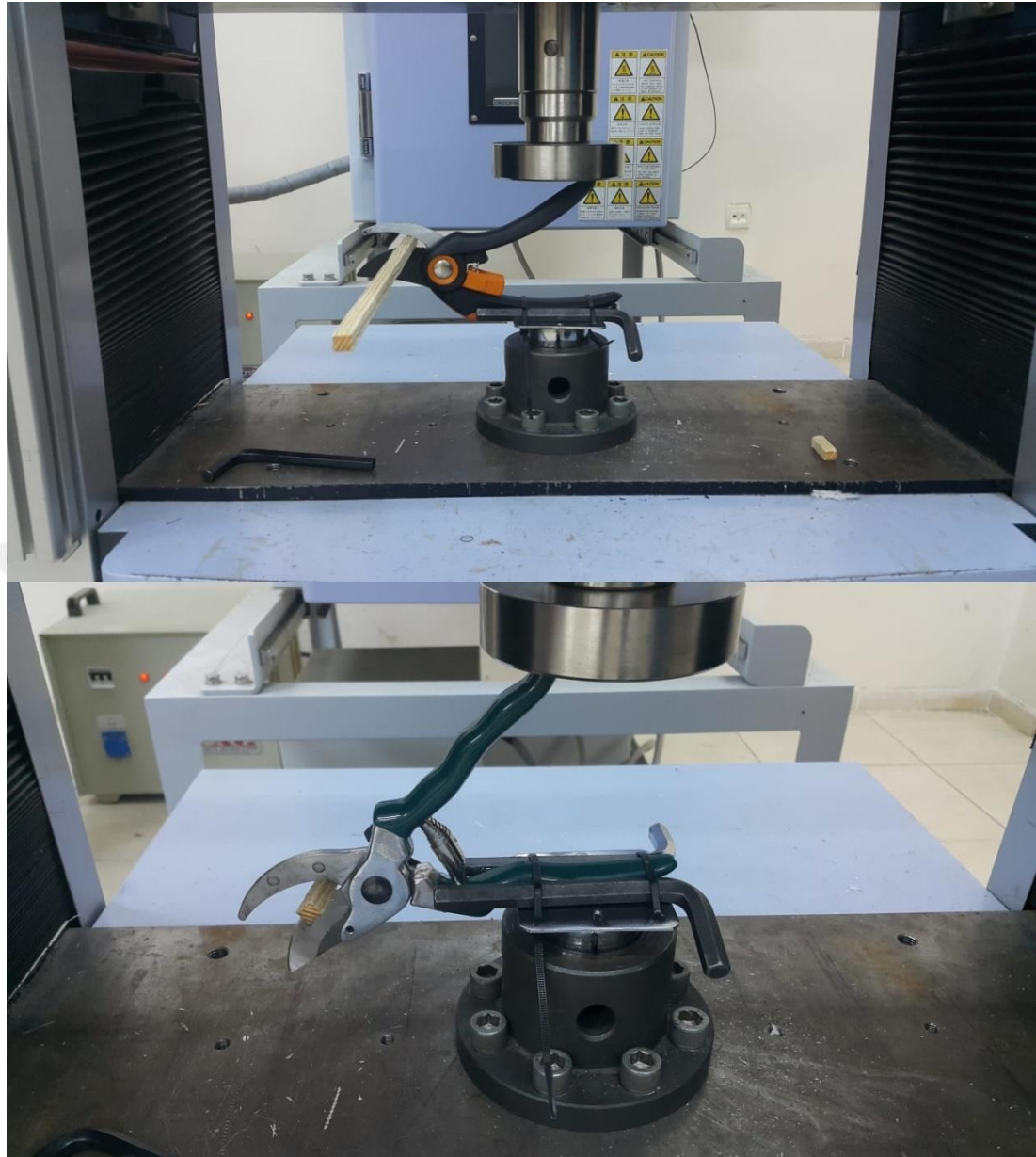


Figure 6.10 Attachment of pruning shear to the machine with the help of the apparatus (Personal archive, 2019)

6.6.4.1.2 Experiment Design. 7mm identical pine tree bough was used for cutting. The identical boughs were obtained from cutting the single big pine billet. The pine tree boughs were kept on water one day because only live bough can be cut by bypass pruning shears. With this method, the content of pine tree bough will be similar that of a live bough. One day of keeping on the water was measured enough that more than one day would not affect the content of pine tree bough.

The speed of the pusher has been set on 10mm/min. The pusher presses from the tip of the pruning shears' handle. When the pine tree bough is attached to the tip of the pruning shear the push starts. Then, the push ends with the pine tree bough being cut off.

6.6.4.1.3 Test Results. Each pruning shears cut the pine tree one time. With this test, stroke-force graphics and maximum calculated force were obtained for each hand pruners. The maximum calculated force for each hand pruners is given in Table 6.6 and force-stroke graphics of each pruning shears are given in Appendix-1.

Table 6.6 Maximum measured force of each pruning shears

Pruning shears	Group and no	Maximum measured force
Worth Deluxe 1055	A1	141.176N
Fiskars P68	A2	129.271N
İzeltaş 6715 Confort	A3	92.5541N
Hand made pruning shear	A4	143.925N
İzeltaş 6720 Hafif tip	B1	81.6981N
Haktaş	B2	90.8534N
Fiskars P94	B3	81.8253N
Akman	C1	132.3064N
Raco RT53/139S	C2	141.811N
İzeltaş 6710 Lüks	C3	192.467N
Fiskars P54	C4	81.9842N

The results that given in Table 6.6 shows that the maximum force that pushes from the end of the pruning shears. The following results in Table 6.7 are obtained by multiplying the distances to the fulcrum of the pruning shears.

Table 6.7 The results of multiplying distance to fulcrum and maximum measured force

Pruning shears	Group and no	Maximum measured force	Distance to fulcrum	Force* distance
Worth Deluxe 1055	A1	141.176N	11cm	1552.936 N*cm
Fiskars P68	A2	129.271N	11.7cm	1512.4707 N*cm
İzeltaş 6715 Confort	A3	92.5541N	14.7cm	1360.54527 N*cm
Hand made pruning shear	A4	143.925N	13cm	1871.025 N*cm
İzeltaş 6720 Hafif tip	B1	81.6981N	13.3cm	1086.58473 N*cm
Haktaş	B2	90.8534N	13cm	1181.0942 N*cm
Fiskars P94	B3	81.8253N	12.8cm	1047.36384 N*cm
Akman	C1	132.3064N	12.8cm	1693.52192 N*cm
Raco RT53/139S	C2	141.811N	12cm	1701.732 N*cm
İzeltaş 6710 Lüks	C3	192.467N	13cm	2502.071 N*cm
Fiskars P54	C4	81.9842N	10.8cm	885.42936 N*cm

6.6.4.1.4 Conclusion of Compression Test. According to force-stroke graphics,

- As can be seen in the C2 graph, spring of the pruning shear causes this result because the spring of the pruning shear storing and releasing power. So the movement of the spring is not fluent.
- The pine tree boughs were not found identical in 100% because of the bumpy charts. However, this situation does not affect the solution. The effect is minor.
- In C1 graph, the bough jammed to the pruning shears blade caused the excessive force. That's why maximum force was taken 132.3064N.

Multiplying four fingers' power and its distance to the fulcrum should be more than the calculated force*fulcrum distance. Otherwise, the cutting process cannot be performed because enough force could not be applied.

6.6.4.2 Cutting Test

The aim is investigating the surface of the cutting area because the rough or crushed surface of the plants might be suffered by diseases. There were 10 cuts have performed on thin, medium and thick boughs with each pruning shears. Thin bough diameter was defined as 5mm and smaller. Medium bough diameter was defined as between more than 5mm and 10mm. Thick bough diameter was defined as more than 10mm. The live boughs were used to investigating cutting surface. The pruning shears have scored according to bad, normal and good ratings. These three ratings can be defined as:

- *Good*: The cutting surface of the bough is smooth and clean after the cutting process.
- *Normal*: The cutting surface of the bough might be a little bit rough or the bottom area of the bough surface might not be cut properly in this situation.
- *Bad*: Mostly, the pruning shear crushes the bough in the cutting process in this situation. Therefore, broken and crushed cutting surface is obtained.

For better understanding, the visual representation of the cutting surface is given in Figure 6.11. The cutting surface of the boughs are illustrated with 7mm identical pine boughs and live boughs. The 7mm identical boughs were obtained from cutting the single big pine billet. The pine tree boughs were kept on water one day because only live bough can be cut by bypass pruning shears. With this method, the content of pine tree bough will be similar that of a live bough. One day of keeping on the water was measured enough that more than one day would not affect the content of pine tree bough. It was included the visual representation because participant experiment was performed with these 7mm identical boughs. That's why it is essential to specify the cutting surface of the 7mm identical boughs.



Figure 6.11 Good cutting surface (top left-live bough), normal cutting surface (top middle-live bough), bad cutting surface (top right-live bough), good cutting surface (bottom left-7mm pine bough), normal cutting surface (bottom middle-7mm pine bough), and bad cutting surface (bottom right-7mm pine bough) (Personal archive, 2019)

The experiment was performed with the live boughs. Ten cuts were performed with all pruning shears in thin, medium and thick bough. According to experiment, results are given in Table 6.8.

Table 6.8 Scored surface area performance of each pruning shears

Pruning shears	Group and no	Thick	Medium	Thin
Worth Deluxe 1055	A1	Normal	Good	Good
Fiskars P68	A2	Bad	Good	Good
İzeltaş 6715 Confort	A3	Good	Good	Good
Hand made pruning shear	A4	Bad	Normal	Good
İzeltaş 6720 Hafif tip	B1	Good	Good	Good
Haktaş	B2	Good	Good	Good
Fiskars P94	B3	Good	Good	Good
Akman	C1	Normal	Good	Good
Raco RT53/139S	C2	Good	Good	Good
İzeltaş 6710 Lüks	C3	Bad	Normal	Good
Fiskars P54	C4	Bad	Good	Good

According to results, each pruning shears perform well on thin branches. A4 and C3 have big blades that start to crush bough when the thickness is increased. The other pruning shears which scored badly are not suitable to cut thick boughs because of the sizes and sharpness of the blades. The good size of blades can approximate 5cm length because good scored pruning shears mean blades size was calculated approximate 5cm.

6.6.4.3 Case Study- Participant Experiment of Investigating Pruning Shears

The purpose of this participant experiment was to compare 11 pruning shears according to ergonomic conditions. This experiment was performed with real participants to measure subjective data of the pruning shears' human needs. Also, consumers' behavior was calculated according to Ergonomic Consumer Product Design Principles. The data was collected with the survey.

6.6.4.3.1 Survey Development. There are two types of survey have developed for participants and observer. The participant survey includes 4 parts.

- *Part 1:* This section includes the name and surname, age, gender, height, and weight questions. Also, the hand size is measured in this step. For measuring hand size, Hugh Nation's Hand Sizing Chart was used. The Hugh Nation's Hand Sizing Chart is given Appendix-2.
- *Part 2:* This section includes nine Ergonomic Consumer Product Design Principles that the participant should rank from best to worst according to their pruning shear selecting behavior. This ranking was taken from the participants before the experiment.
- *Part 3:* This section includes 7 Likert questions for each pruning shears that these 7 Likert questions are answered for each 11 pruning shears. In other words, the participants answer a total of 77 Likert questions. These questions are:
 - *Effort:* 7 point Likert scale is used from very low to very high.
 - *Palm health:* 5 point Likert scale is used from too bad to too good.
 - *Finger health:* 5 point Likert scale is used from too bad to too good.

- *Wrist health*: 5 point Likert scale is used from too bad to too good.
- *Slippery of the handle*: 5 point Likert scale is used from too bad to too good.
- *Easy to clean*: 5 point Likert scale is used from too bad to too good.
- *Handle material comfort*: 5 point Likert scale is used from too bad to too good.
- *Part 4*: In here, according to section 3 experience, participants are asked if they want to change their rankings in section 2. Participants keep their section 2 ranking or can make a new ranking.

The participant survey is given Appendix-3 and palm, finger and wrist health are evaluated according to the determined areas of the hand that areas given in Figure 6.12.

The observer survey includes 4 questions for the observer. These 4 questions are answered by the observer for each pruning shears usage. So the observer answers total of 44 questions for each participant. The questions are given below:

- *Question 1*: Effort (7 point Likert scale is used from very low to very high).
- *Question 2*: Wrist health according to shock effect of pruning shear (from too bad to very good).
- *Question 3*: Back position in cutting process (static position or not).
- *Question 4*: Wrist- hand position in cutting process (straight or deviated/bended).

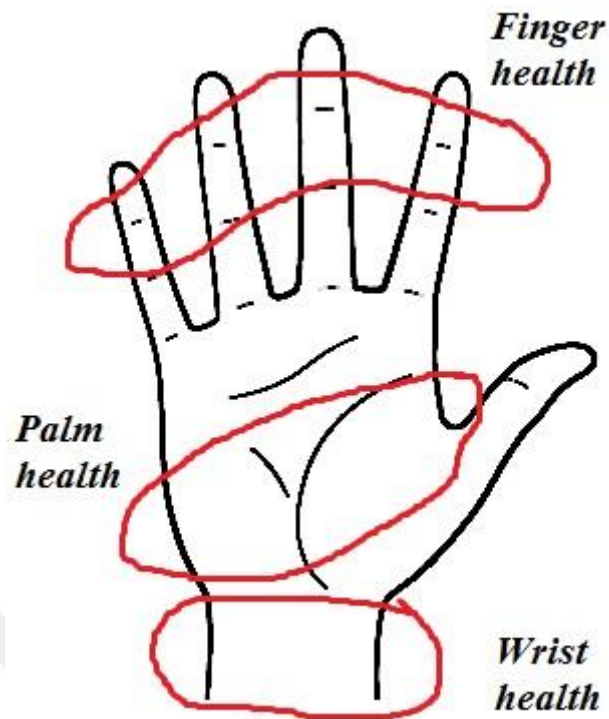


Figure 6.12 Evaluation areas of the palm, wrist and finger health

Question 3 and 4 were taken from Quick Exposure Check (David et al., 2008) to investigate hand, wrist and back positions of the cutting process. Question 1 is the same with the participant question that provides a double check for these answers. The observer survey is given Appendix-4.

6.6.4.3.2 Participants. Some participation requirements have been determined for the experimental study. The participants who meet these requirements can be a participant in this experimental study.

- The dominant arm should be the right arm.
- Without anatomical disorders.
- Not interested in bodybuilding (professional).
- Has no recent arm/ muscle pain.
- People aged between 18-40.

The experiment was performed with 15 male and 17 female participants who met these requirements above. Fourth grade Industrial Engineering students from Dokuz Eylül University were selected as participants for the experiment. All students were taking the “IND 4900 Ergonomic Assessment and Job Safety” and also all students had a background about ergonomic risk assessment. Thus, the evaluation of the pruning shears were performed properly by participants.

6.6.4.3.3 Procedures. 7mm identical pine tree bough was used for cutting. The identical boughs were obtained from cutting the single big pine billet. The pine tree boughs were kept on water one day because only live bough can be cut by bypass pruning shears. With this method, the content of pine tree bough will be similar that of a live bough. One day of keeping on the water was measured enough that more than one day would not affect the content of pine tree bough.

The pruning shears were grouped to prevent fatigue effect of the participants. At the end of the last pruning shears, the fatigue effect will begin and the performance will decrease. Each participant used the pruning shears with a different row. The fatigue effect was eliminated with the giving pruning shears in a different row. Three groups were created which the ranking combinations are equal to six. These combinations are given below.

- A-B-C (7 participant)
- A-C-B (6 participant)
- B-A-C (6 participant)
- B-C-A (6 participant)
- C-A-B (7 participant)
- C-B-A (6 participant)

The cutting was performed with a sitting position. The wrist and back should be straight position. The front arm and back arm should make an angle of 90 degrees from the elbow. The illustration is given in Figure 6.13.



Figure 6.13 Participant posture and hand/wrist position at the cutting process (Personal archive, 2019)

6.6.4.3.4 Experiment Flow. Firstly, participants read the introduction of the survey. Then, participants fill the part 1 that includes personal information. Also, hand size is measured with Hugh Nation's Hand Sizing Chart. In part two, participants rank from best to worst the Ergonomic Consumer Product Design Principles according to pruning shears. The best criterion takes 1 and the worst criterion takes 9. Then, in part 3, the row of pruning shears are determined and gives to the participant respectively. The participant cuts the identical bough five times and then scores. The scoring is also resting time that takes two minutes. In addition, during the cutting process, the observer investigates the participant and fills his own survey in resting time. This cycle is repeated 11 times then the cutting process finishes. Lastly, in part 4, according to pruning shears' usage experience, the participants are asked if they want to change the rank they made in the second part. The participants change their criteria rank or not. The schematic schedule of the experiment is given in Figure 6.14.

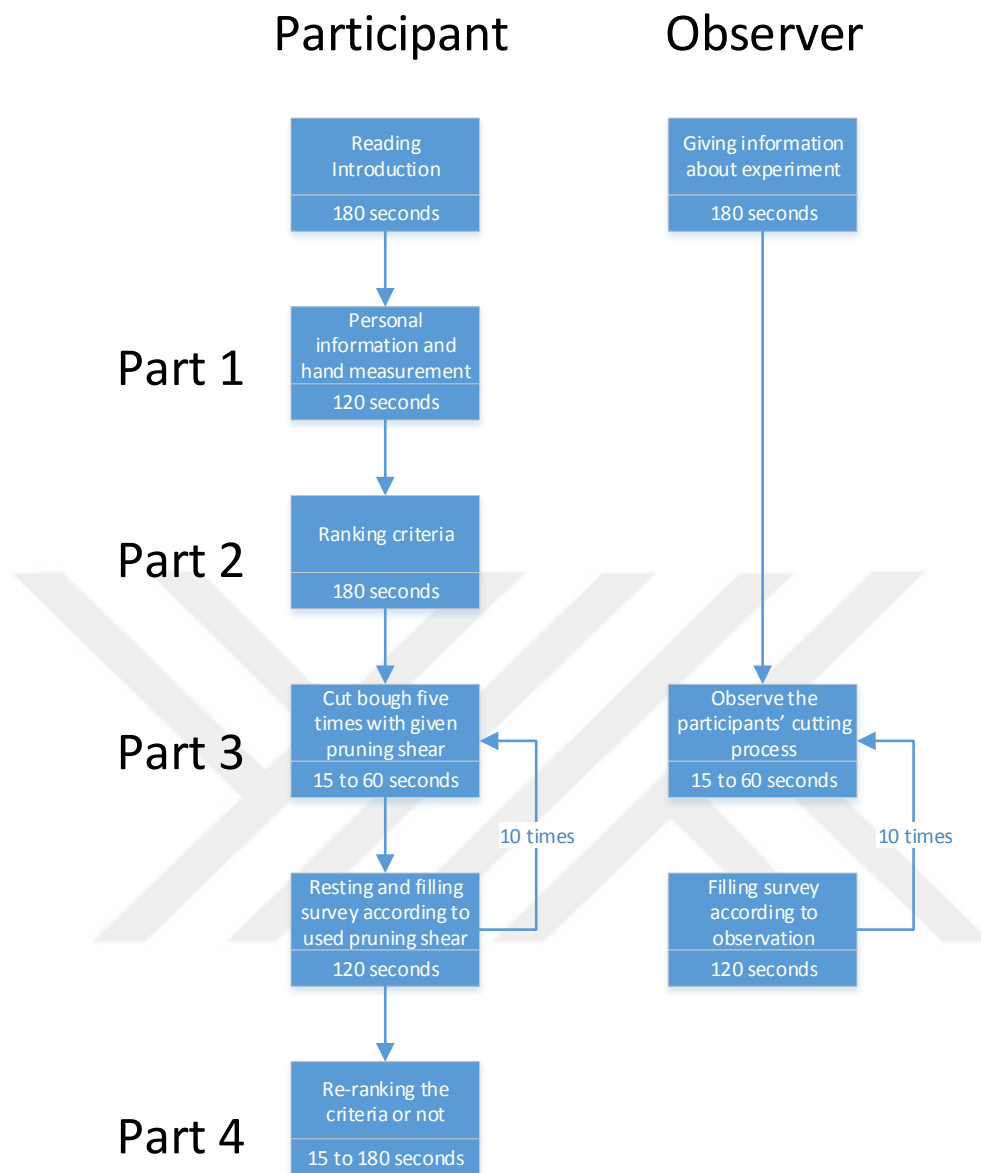


Figure 6.14 Schematic schedule of experiment for both observer and participants

6.6.4.3.5 Calculating Weights of Ergonomic Consumer Product Design Principles.

As mentioned before, there were nine Ergonomic Consumer Product Design Principles determined for pruning shears which are durability, health, comfort, usability (easy to use), effort/force, functionality, price/cost, product guarantee, and environmental effect/recyclability. All participants did not have any experience to usage of pruning shears. In other words, all participants created their first impression during the experiment. In the experiment, we have collected the rank of Ergonomic Consumer Product Design Principles two times, before and after the cutting process. The ranking was performed by the participants according to participants' pruning shear behavior.

Participants ranked these criteria from best to worst. The best one was scored with “1” and the worst one was scored with “9”. The first rankings were collected from participants in part 2 of the survey. Then the cutting experiment was performed by consumers. Finally, according to their pruning shear usage experience, we have asked them in the part 4 of the survey that if they want to change their ranking. The participants have two options that they can keep their first ranking or they can re-rank their criteria. Thence, we have obtained two groups of rankings that they represent before (group 1) and after (group 2) usage of the pruning shears’ criteria ranking. Additionally, if the participants do not change the first ranking, the rank of the criteria is taken in the same row for group two. Otherwise, the re-ranked criteria row is taken for group two. With this fiction, criteria weights were calculated for both groups and compared. That gives us the differences between before and after usage weights of criteria according to pruning shear usage experience.

The Rough SWARA (Zavadskas, Stevic, Tanacko & Prentkocskis, 2018) method was used to calculate criteria weighs that gives us the criteria weights with interval numbers. The reason for choosing this method is the relative comparison between criteria do not be determined by participants. It is hard to determine the relative comparison between criteria with percent by participants. For example, the percent of relative comparison between comfort and health cannot be defined properly by participants because there is no method or way to determine exact percents. Also, the biggest advantage of this method is that the weight calculation has been performed only taking the rankings from the participants. Ranking type weight calculation method was selected in this experiment because the methods like AHP takes too much time if the criteria number is high, and the more criteria might cause inconsistency between participant answers.

Before the Rough SWARA steps, explaining the rough numbers is essential. According to Zavadskas et al. (2018, p. 99) and Voćkić, Stojic & Stevic (2018, p. 217), “In the rough set theory, any vague idea can be represented as a couple of exact concepts based on the lower and upper approximations”. U is the universe that contains all the objects, arbitrary object of U is defined as Y , R is a set of t classes $\{G_1, G_2, \dots, G_3\}$

that cover all the objects in U , $R=\{G_1, G_2, \dots, G_t\}$. If these classes are ordered as $G_1 < G_2 < \dots < G_t$, then $\forall Y \in U$, $G_q \in R$, $1 \leq q \leq t$, by $R(Y)$ meaning the class to which the object belongs. The lower approximation ($\underline{Apr}(G_q)$), upper approximation ($\overline{Apr}(G_q)$) and boundary region ($\overline{Bnd}(G_q)$), of class G_q are defined as (Zavadskas et al., 2018, Voćkić et al., 2018):

$$\underline{Apr}(G_q) = \{Y \in U / R(Y) \leq G_q\}, \quad (6.1)$$

$$\overline{Apr}(G_q) = \{Y \in U / R(Y) \geq G_q\}, \quad (6.2)$$

$$\overline{Bnd}(G_q) = \{Y \in U / R(Y) \neq G_q\} = \{Y \in U / R(Y) > G_q\} \cup \{Y \in U / R(Y) < G_q\} \quad (6.3)$$

Then G_q can be represented as $(RN(G_q))$, which is determined by its corresponding lower limit

$$\underline{Lim}(G_q) = \frac{1}{M_L} \sum R(Y) | Y \in \underline{Apr}(G_q) \quad (6.4)$$

$$\overline{Lim}(G_q) = \frac{1}{M_U} \sum R(Y) | Y \in \overline{Apr}(G_q) \quad (6.5)$$

$$RN(G_q) = [\underline{Lim}(G_q), \overline{Lim}(G_q)] \quad (6.6)$$

Where M_L , M_U are the numbers of objects that contained in $\underline{Apr}(G_q)$ and $\overline{Apr}(G_q)$ respectively. These six formulas will be used to the Rough SWARA method to calculate RNs from the decision making matrix.

The Rough SWARA methods steps are given below respectively (Zavadskas et al., 2018, Voćkić et al., 2018):

Step 1: Determine criteria for decision-making matrix.

Step 2: The number of participants (k) who should rank the determined criteria (c_n) from best to worst. Then, the pair-wise comparison matrix is obtained.

Step 3: Individual responses are converted to group rough matrix. These calculations are performed with the usage of (6.1) – (6.6) equations:

$$RN(C_j) = [c_j^L, c_j^U]_{1 \times m} \quad (6.7)$$

Step 4: $RN(C_j)$ normalization to obtain the matrix $RN(S_j)$:

$$RN(S_j) = [s_j^L, s_j^U]_{1 \times m} \quad (6.8)$$

The elements of matrix $RN(S_j)$ are obtained with the following equation:

$$RN(S_j) = \frac{[c_j^L, c_j^U]}{\max[c_j^L, c_j^U]} \quad (6.9)$$

The first element of matrix $RN(S_j)$, i.e. $[s_j^L, s_j^U] = [1.00, 1.00]$, because $j=1$. For other elements $j>1$, the equation (6.9) can be calculated using the following equation:

$$RN(S_j) = \left[\frac{c_j^L}{\max(c_j^U)}, \frac{c_j^U}{\max(c_j^L)} \right]_{1 \times m} \quad (6.10)$$

Step 5: Calculate the matrix $RN(K_j)$ with following equation:

$$RN(K_j) = [k_j^L, k_j^U]_{1 \times m} \quad (6.11)$$

by applying the following equation:

$$RN(K_j) = [s_j^L + 1, s_j^U + 1] \quad (6.12)$$

Step 6: Recalculated weights $RN(Q_j)$ are determined with following equation:

$$RN(Q_j) = [q_j^L, q_j^U]_{1 \times m} \quad (6.13)$$

The elements of matrix $RN(Q_j)$ with the next equation (6.14):

$$RN(Q_j) = \left[q_j^L = \begin{cases} 1.00 & j=1 \\ \frac{q_{j-1}^L}{k_j^U} & j>1, \end{cases}, q_j^U = \begin{cases} 1.00 & j=1 \\ \frac{q_{j-1}^U}{k_j^L} & j>1, \end{cases} \right] \quad (6.14)$$

Step 7: Relative weight values $RN(W_j)$ calculation with following equation:

$$RN(W_j) = [w_j^L, w_j^U]_{1 \times m} \quad (6.15)$$

Lastly, individual weight values of criteria are calculated with the last equation:

$$[w_j^L, w_j^U] = \left[\frac{[q_j^L, q_j^U]}{\sum_{j=1}^m [q_j^L, q_j^U]} \right] \quad (6.16)$$

Thus, the interval values of criteria are calculated.

As determined before, there were nine Ergonomic Consumer Product Design Principles determined for pruning shears which are durability, health, comfort, usability (easy to use), effort/force, functionality, price/cost, product guarantee, and environmental effect/recyclability. 15 male and 17 female participants were ranked these criteria. However, 3 participants ranked wrong these criteria. So these 3 participants were removed that total of 29 participants' ranking was evaluated. There was two pair-wise comparison matrix were created which are "criteria ranking before experiment" and "criteria ranking after experiment". These matrices were given in Appendix-5.

After the ranking, $RN(C_j)$'s were calculated with using the formula (6.1) – (6.6). The formulas were applied into the two pair-wise comparison matrices then the complete matrix c_j was obtained.

Table 6.9 RN(Cj)'s values of both matrices

Criteria ranking before experiment				Criteria ranking after experiment		
RN(C3)	1	1		RN(C4)	1	1
RN(C4)	2.03409962	3.950037		RN(C2)	1.83957643	4.105976
RN(C2)	2.27080005	5.137818		RN(C3)	1.93895904	4.492734
RN(C1)	2.85075374	5.87582		RN(C5)	2.20332724	5.054361
RN(C5)	2.95468964	6.051102		RN(C6)	3.41219778	6.133617
RN(C6)	3.01399391	6.189997		RN(C1)	4.17864221	6.328594
RN(C7)	4.09324783	6.624034		RN(C7)	5.15606421	6.946405
RN(C8)	7.35043779	8.422926		RN(C8)	7.49278637	8.284157
RN(C9)	7.62401902	8.892341		RN(C9)	7.99643282	8.946407

Both matrices were ranked according to from low to high. Then these matrices were normalized according to (6.9) and (6.10). The normalized matrices are given in Table 6.10.

Table 6.10 Normalized matrices

Criteria ranking before experiment				Criteria ranking after experiment		
RN(S3)	1	1		RN(S4)	1	1
RN(S4)	0.22874736	0.518104		RN(S2)	0.20705089	0.626787
RN(S2)	0.25536582	0.673899		RN(S3)	0.23114461	0.815263
RN(S1)	0.32058528	0.770698		RN(S5)	0.29017807	0.932368
RN(S5)	0.33227353	0.793689		RN(S6)	0.30075769	0.960182
RN(S6)	0.33894267	0.811907		RN(S1)	0.30679427	0.982221
RN(S7)	0.4603116	0.868838		RN(S7)	0.41665147	1.051094
RN(S8)	0.82660321	1.104788		RN(S8)	0.74820066	1.33654
RN(S9)	0.85736915	1.166359		RN(S9)	0.77604847	1.411026

$RN(K_j)$ values were obtained to sum with +1 for each $RN(S_j)$ values except [1,1] values of both matrices. The new obtained matrices are given in Table 6.11 according to (6.12):

Table 6.11 $RN(K_j)$ matrices

Criteria ranking before experiment				Criteria ranking after experiment		
RN(K3)	1	1		RN(K4)	1	1
RN(K4)	1.228747	1.518104		RN(K2)	1.205622	1.513476
RN(K2)	1.255366	1.673899		RN(K3)	1.21673	1.561842
RN(K1)	1.320585	1.770698		RN(K5)	1.246281	1.632077
RN(K5)	1.332274	1.793689		RN(K6)	1.381404	1.767044
RN(K6)	1.338943	1.811907		RN(K1)	1.467075	1.791427
RN(K7)	1.460312	1.868838		RN(K7)	1.576328	1.868688
RN(K8)	1.826603	2.104788		RN(K8)	1.837519	2.035982
RN(K9)	1.857369	2.166359		RN(K9)	1.893815	2.1188

After that, according to (6.13) and (6.14), $RN(Q_i)$ values were calculated for both matrices. The matrices are given in Table 6.12.

Table 6.12 $RN(Q_j)$ matrices

Criteria ranking before experiment				Criteria ranking after experiment		
$RN(q_3)$	1	1		$RN(q_4)$	1	1
$RN(q_4)$	0.65871627	0.813837		$RN(q_2)$	0.66073068	0.829448
$RN(q_2)$	0.39352213	0.648287		$RN(q_3)$	0.42304573	0.681702
$RN(q_1)$	0.22224119	0.490909		$RN(q_5)$	0.25920697	0.546989
$RN(q_5)$	0.12390172	0.368474		$RN(q_6)$	0.14668958	0.395966
$RN(q_6)$	0.06838193	0.275198		$RN(q_1)$	0.0818842	0.269902
$RN(q_7)$	0.03659062	0.188452		$RN(q_7)$	0.04381909	0.171222
$RN(q_8)$	0.01738447	0.10317		$RN(q_8)$	0.02152234	0.093181
$RN(q_9)$	0.00802474	0.055547		$RN(q_9)$	0.0101578	0.049203

Finally, the weights of criteria were calculated with (6.16). The result and comparison of both matrices are given in Table 6.13.

Table 6.13 Results of both matrices criteria weights and its comparison

	Criteria ranking before experiment				Criteria ranking after experiment			Comparison
		Lower	Upper			Lower	Upper	
Durability	w1	0.056350998	0.19413		w1	0.020280356	0.101963	↓
Health	w2	0.099780625	0.256365		w2	0.163643939	0.313347	↑
Comfort	w3	0.253557848	0.39545		w3	0.10477623	0.257532	↓
Usability (easy to use)	w4	0.167022681	0.321832		w4	0.247671166	0.377778	↑
Effort	w5	0.031416254	0.145713		w5	0.064198094	0.206641	↑
Functionality	w6	0.017338776	0.108827		w6	0.03633078	0.149587	↑
Price/cost	w7	0.00927784	0.074523		w7	0.010852724	0.064684	↔
Product guarantee/warranty	w8	0.004407969	0.040799		w8	0.005330463	0.035202	↔
Environmental effect/recyclability	w9	0.002034736	0.021966		w9	0.002515794	0.018588	↔

These matrices represent the consumers' attitude of pruning shears usage before and after experiments values. Of the participants, 58.62% changed the benchmark rankings after the pruning shear test, and 41.38% did not change the benchmark rankings. Pruning shear is not a well-known product by consumers. So all consumers did not any experience before using pruning shears. The aim of the experiment was to investigate the effect of product usage experience on the user's Ergonomic Consumer Product Design Principles. It is clearly seen that the product usage experience affects the user's Ergonomic Consumer Product Design Principles attitude. After the product usage experience, health, usability (easy to use), effort and functionality criteria significantly increased. On the other hand, durability and comfort criteria significantly decreased. The last three criteria which are price/cost, product guarantee/warranty, and environmental effect/recyclability are the criteria that the participants did not interest. It is clearly seen that in these products, primary principles are much more effective in choosing product than secondary principles. The designer can focus on the most important criteria's human needs with this way for their investigation.

6.6.4.3.6 Correlation Investigation between Survey Questions. After the data collection, the relationship between Likert questions were investigated according to participants' answers and observer' answers. However, before the correlation investigation, reliability analyses of the questions are essential. Reliability analysis was performed with IBM SPSS. Each participant has answered total of 77 questions for 11 pruning shears that each pruning shear includes 7 same questions. The mean of these 7 questions was performed because of the elimination of the fatigue effect. Fatigue effect decreases the participant performance towards to end of the experiment. So, as mentioned before each participant has used the pruning shears with the different row. Thus the mean of these questions eliminates the fatigue effects. Cronbach's Alpha was used to calculate the reliability of the questions. The result is given in Table 6.14.

Table 6.14 Reliability analysis of likert questions

Reliability Statistics		Case Processing Summary				Item-Total Statistics				
Cronbach's Alpha	N of Items			N	%		Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
.926	7	Cases	Valid	32	100.0	Effort	18.67329545472	5.478	.767	.928
			Excluded ^a	0	0.0	Palm_Health	19.54261363647	6.565	.868	.907
			Total	32	100.0	Finger_Health	19.36079545469	6.375	.831	.909
		a. Listwise deletion based on all variables in the procedure.				Wrist_Health	19.44318181822	6.896	.787	.915
						Slippery	19.10511363650	6.536	.760	.916
						Easy_to_clean	19.32670454553	6.943	.698	.922
						Comfort_material	19.49715909113	6.477	.831	.909

It is clearly seen that the result of the reliability analysis very powerful that is 92.6%. Also, if any question is deleted, the reliability analysis results will not change with a great rate.

The normality analysis of both participants and observer questions also should be performed to determination of the correlation method. Also, observers' Likert questions were added to the calculation. The hypotheses are:

*Ho: The **Likert answers data** are not significantly different than the normal population (null hypothesis).*

*H_a: The **Likert answers data** are significantly different than the normal population (alternative hypothesis).*

The normality analysis was performed with IBM SPSS and the result is given in Table 6.15.

Table 6.15 Normality analysis of the likert questions

Tests of Normality						
	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Comfort_material	0.106	32	.200*	0.975	32	0.65
Easy_to_clean	0.117	32	.200*	0.952	32	0.161
Slippery	0.123	32	.200*	0.965	32	0.363
Wrist_Health	0.1	32	.200*	0.97	32	0.5
Finger_Health	0.084	32	.200*	0.97	32	0.488
Palm_Health	0.12	32	.200*	0.977	32	0.718
Effort	0.125	32	.200*	0.96	32	0.272
Effort_obs	0.097	32	.200*	0.977	32	0.694
Wrist_obs	0.1	32	.200*	0.974	32	0.621
*. This is a lower bound of the true significance.						
a. Lilliefors Significance Correction						

It is clearly seen that for all 9 Likert questions, for Shapiro-Wilk tests, the significance levels are bigger than 0.05. So, we accepted the null hypothesis and we can say that all Likert questions answers have a normal distribution.

According to normality test results, Pearson's Correlation Coefficients were performed for participants Likert questions' data. The correlation results table is given in Appendix-6. According to correlations results:

- Between *effort* and *palm health*, the Pearson Correlation was measured 0.730. So, we can say that there is a strong relationship between the variables.
- Between *effort* and *finger health*, the Pearson Correlation was measured 0.687. So, we can say that there is a moderate relationship between the variables.

- Between *effort* and *wrist health*, the Pearson Correlation was measured 0.670. So, we can say that there is a moderate relationship between the variables.
- Between *effort* and *slippery*, the Pearson Correlation was measured 0.601. So, we can say that there is a moderate relationship between the variables.
- Between *effort* and *easy to clean*, the Pearson Correlation was measured 0.600. So, we can say that there is a moderate relationship between the variables.
- Between *effort* and *material comfort*, the Pearson Correlation was measured 0.671. So, we can say that there is a moderate relationship between the variables.
- Between *palm health* and *finger health*, the Pearson Correlation was measured 0.855. So, we can say that there is a strong relationship between the variables.
- Between *palm health* and *wrist health*, the Pearson Correlation was measured 0.781. So, we can say that there is a strong relationship between the variables.
- Between *palm health* and *slippery*, the Pearson Correlation was measured 0.723. So, we can say that there is a strong relationship between the variables.
- Between *palm health* and *easy to clean*, the Pearson Correlation was measured 0.558. So, we can say that there is a moderate relationship between the variables.
- Between *palm health* and *material comfort*, the Pearson Correlation was measured 0.748. So, we can say that there is a strong relationship between the variables.
- Between *finger health* and *wrist health*, the Pearson Correlation was measured 0.853. So, we can say that there is a strong relationship between the variables.
- Between *finger health* and *slippery*, the Pearson Correlation was measured 0.606. So, we can say that there is a moderate relationship between the variables.

- Between *finger health* and *easy to clean*, the Pearson Correlation was measured 0.578. So, we can say that there is a moderate relationship between the variables.
- Between *finger health* and *material comfort*, the Pearson Correlation was measured 0.701. So, we can say that there is a strong relationship between the variables.
- Between *wrist health* and *slippery*, the Pearson Correlation was measured 0.574. So, we can say that there is a moderate relationship between the variables.
- Between *wrist health* and *easy to clean*, the Pearson Correlation was measured 0.505. So, we can say that there is a moderate relationship between the variables.
- Between *wrist health* and *material comfort*, the Pearson Correlation was measured 0.651. So, we can say that there is a moderate relationship between the variables.
- Between *slippery* and *easy to clean*, the Pearson Correlation was measured 0.672. So, we can say that there is a moderate relationship between the variables.
- Between *slippery* and *material comfort*, the Pearson Correlation was measured 0.775. So, we can say that there is a strong relationship between the variables.
- Between *easy to clean* and *material comfort*, the Pearson Correlation was measured 0.706. So, we can say that there is a strong relationship between the variables.

The comparison between observer wrist health Likert question and the other participant questions, there is no correlation has founded. The reason might be that the observer's wrist health investigation was performed according to the shock wave of the pruning shear into the wrist. The SPSS result is given in Appendix-7.

Lastly, the comparison between observers' effort question and participants' effort question were compared. The SPSS result is given in Appendix-8. According to

results, between *observers' effort* and *participants' effort*, the Pearson Correlation was measured 0.824. So, we can say that there is a strong relationship between the variables. Also, we can say that the effort results were collected with observer, participant and pressure tests that the results are compatible.

6.6.4.3.7 Statistical Significance Investigation. In this section, it is desired to understand whether hand size and gender factors differ depending on the 7 participants' Likert questions. As mentioned before, Likert questions' answers have a normal distribution. For gender, the differences between man and woman into the Likert questions' answers were investigated. In this condition, the analysis was performed with Independent-Samples T Test because there was two group been in the analysis which are man and woman. The following hypothesis is tested using Independent-Samples T Test.

*Ho: The differences between perceptions of **man** and **woman** groups on the 7 Likert questions answers factors are not statistically significant (null hypothesis).*

*Ha: The differences between perceptions of **man** and **woman** groups on the 7 Likert questions answers factor are statistically significant (alternative hypothesis).*

The Independent-Samples T-Test was performed with IBM SPSS. The results table is given in Appendix-9. According to results for all seven criteria, equal variances were assumed. So, we can accept the Independent-Samples T Test results. As a result, the responses of **man** and **woman** groups are significantly different between **effort, palm health, finger health, slippery, and material comfort** because p-values of these criteria are smaller than 0.05. So, Ha hypothesis is accepted (Ho is rejected) for these criteria. On the other hand, the responses of **man** and **woman** groups are not significantly different between **wrist health** and **easy to clean** because p values of these criteria are bigger than 0.05. So, Ho hypothesis is accepted (Ha is rejected) for these criteria.

There are 5 different hand size groups were obtained from survey results. However, only one participant has large size hand. So, for performing statistical tests, large size

hand transferred into the medium hand size group. Therefore, the statistical analysis between 4 different hand sizes groups were compared according to Likerts question answers. It is suitable to apply one-way ANOVA because more than 2 groups were obtained in the hand sizes. The following hypothesis is tested using one-way ANOVA.

*Ho: The differences between perceptions of **medium, small, xsmall** and **xxsmall** groups on the Z Likert questions answers factors are not statistically significant (null hypothesis).*

*Ha: The differences between perceptions of **medium, small, xsmall** and **xxsmall** groups on the Z Likert questions answers factor are statistically significant (alternative hypothesis).*

The one-way ANOVA test was performed with IBM SPSS. The results table is given in Appendix-10. According to results for all seven criteria, equal variances were assumed. So, we can accept the one-way ANOVA results. As a result, the responses of **medium, small, xsmall** and **xxsmall** groups are significantly different between **effort, palm health, material comfort, easy to clean** and **slippery** because p-values of these criteria are smaller than 0.05. So, Ha hypothesis is accepted (Ho is rejected) for these criteria. On the other hand, the responses of **medium, small, xsmall** and **xxsmall** groups are not significantly different between **finger health** and **wrist health** because p values of these criteria are bigger than 0.05. So, Ho hypothesis is accepted (Ha is rejected) for these criteria.

It is essential to investigate which types of hand sizes cause significantly different in the one-way ANOVA test. So, the post-hoc test was performed between **effort, palm health, material comfort, easy to clean** and **slippery**. The results table is given in Appendix-11.

Tukey HSD test was applied to the **effort**. According to results:

- Medium-xsmall, medium-xxsmall, and small-xxsmall are significantly different in the **effort** because p-values of these hand sizes are smaller than 0.05. So, Ha hypothesis is accepted (Ho is rejected) for these hand sizes.

- Medium-small, small-xsmall, and xsmall-xxsmall are not significantly different in the **effort** because p-values of these hand sizes are bigger than 0.05. So, H_0 hypothesis is accepted (H_a is rejected) for these hand sizes.

LSD test was applied to the **palm health**. According to results:

- Medium-xxsmall and small-xxsmall are significantly different in the **palm health** because p-values of these hand sizes are smaller than 0.05. So, H_a hypothesis is accepted (H_0 is rejected) for these hand sizes.
- Medium-small, medium-xsmall, small-sxsmall, and xsmall-xxsmall are not significantly different in the **palm health** because p-values of these hand sizes are bigger than 0.05. So, H_0 hypothesis is accepted (H_a is rejected) for these hand sizes.

Tukey HSD test was applied to the **material comfort**. According to results:

- Medium-xxsmall, small-xxsmall, and xsmall-xxsmall are significantly different in the **material comfort** because p-values of these hand sizes are smaller than 0.05. So, H_a hypothesis is accepted (H_0 is rejected) for these hand sizes.
- Medium-small, medium-xsmall, and small-xsmall are not significantly different in the **material comfort** because p-values of these hand sizes are bigger than 0.05. So, H_0 hypothesis is accepted (H_a is rejected) for these hand sizes.

Tukey HSD test was applied to the **easy to clean**. According to results:

- Medium-xxsmall, small-xxsmall, and xsmall-xxsmall are significantly different in the **easy to clean** because p-values of these hand sizes are smaller than 0.05. So, H_a hypothesis is accepted (H_0 is rejected) for these hand sizes.

- Medium-small, medium-xsmall, and small-xsmall are not significantly different in the **easy to clean** because p-values of these hand sizes are bigger than 0.05. So, Ho hypothesis is accepted (H_a is rejected) for these hand sizes.

Tukey HSD test was applied to the **slippery**. According to results:

- Medium-xxsmall, small-xxsmall, and xsmall-xxsmall are significantly different in the **slippery** because p-values of these hand sizes are smaller than 0.05. So, H_a hypothesis is accepted (H_o is rejected) for these hand sizes.
- Medium-small, medium-xsmall, and small-xsmall are not significantly different in the **slippery** because p-values of these hand sizes are bigger than 0.05. So, Ho hypothesis is accepted (H_a is rejected) for these hand sizes.

6.6.4.3.8 Results. 15 male and 17 female participants have performed the experiment. The mean age of the participants was calculated 23 and the standard deviation of the age was calculated 2.015. The mean height of the participants was calculated 167.75cm and the standard deviation of the height was calculated 28.201. The mean weight of the participants was calculated 67.718kg and standard deviation of the weight was calculated 13.374. According to the hand sizing chart measurements, 1 male participant has a large hand, 12 male participants have medium hand and 2 male participants have a small hand. For female measurements, 5 female have a small hand, 9 female have xsmall hand and 3 female has xxsmall hand.

The pruning shears effort values were gathered from a 7-point Likert scale. 15 male and 17 female filled the effort scale according to the usage of each pruning shears. The evaluation was made from the mean of the Likert scales' results because the fatigue effects needed to be eliminated. In the effort graphic, high value means less effort. For statistical calculations, the effort values were changed reverse. Each pruning shears' Likert scale results are given in Figure 6.15.

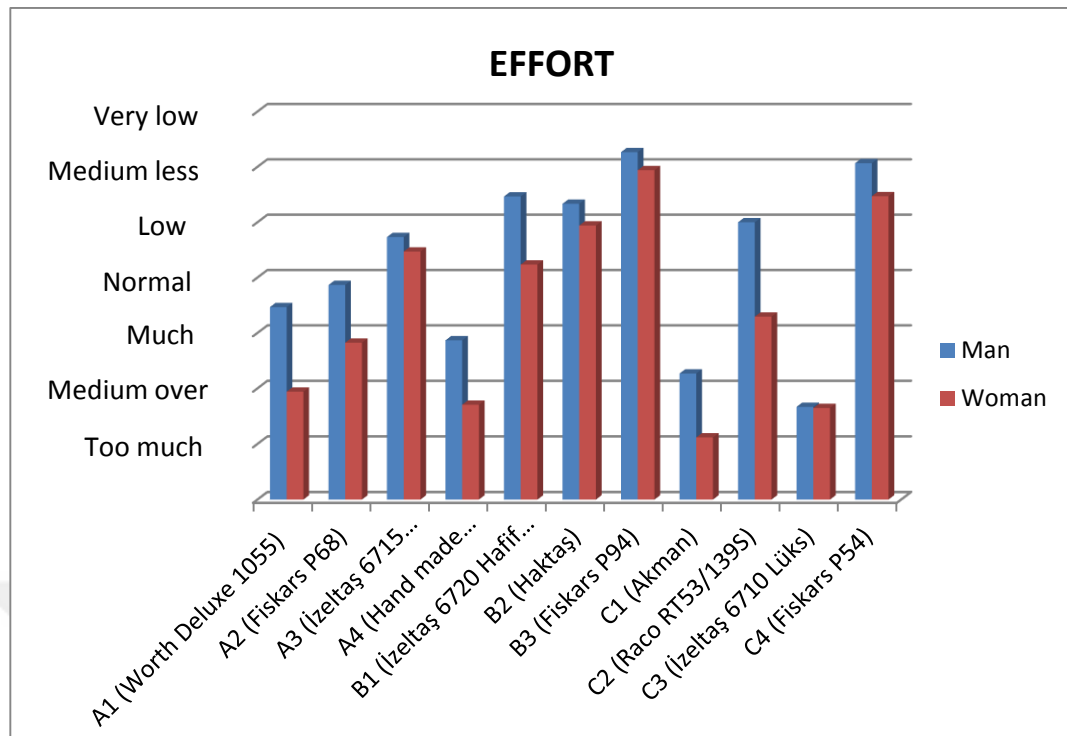


Figure 6.15 The mean effort values of each pruning shears

The correlations between Likert scale, effort values, and pressure tests also investigated. Pearson Correlation test was performed because all groups have a normal distribution. According to results, we can say that there is a strong relationship between the variables. As mentioned before, the Likert scale effort values were changed reverse. That's why in the table that pressure test between man and woman correlations value calculated minus. The Pearson Correlation results are given in Table 6.16.

Table 6.16 Correlation results between, pressure test, man and woman effort

Correlations				
		Pressure_test	Effort_man	Effort_woman
Pressure_test	Pearson Correlation	1	-.890**	-.819**
	Sig. (2-tailed)		.000	.002
	N	11	11	11
Effort_man	Pearson Correlation	-.890**	1	.944**
	Sig. (2-tailed)	.000		.000
	N	11	11	11
Effort_woman	Pearson Correlation	-.819**	.944**	1
	Sig. (2-tailed)	.002	.000	
	N	11	11	11
**. Correlation is significant at the 0.01 level (2-tailed).				

The palm health of the pruning shears were measured with 5-point Likert scale. The participants have evaluated palm health according to the amount of pressure and pain in the determined area of the palm. The evaluation was made from the mean of the Likert scales' results because the continuous usage can affect the pressure and pain feelings. Each pruning shears' Likert scale results are given in Figure 6.16.

Palm health is directly affected by effort because the four fingers push the pruning shears' handle towards to palm and all effort are met by the palm. The more effort is applied the more pressure is felt by palm. However design and material also can affect the palm health but the effects are less than effort.

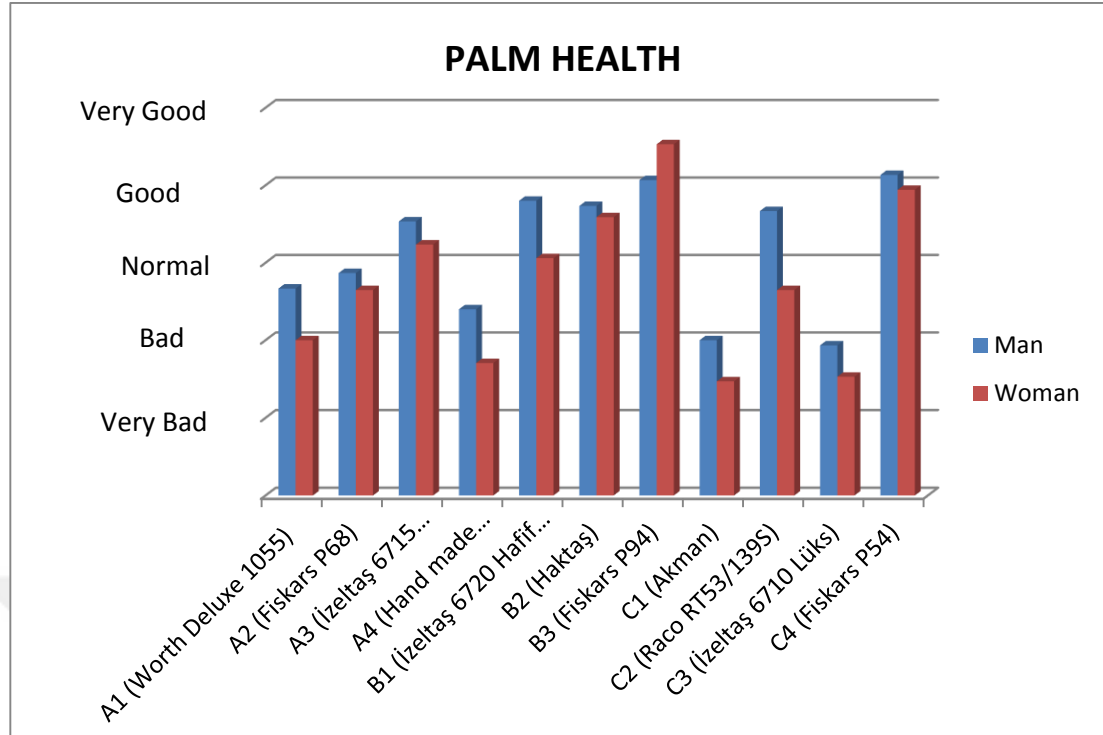


Figure 6.16 The mean palm health values of each pruning shears

The finger health of the pruning shears were measured with 5-point Likert scale. The participants were evaluated finger health according to the amount of pressure and pain in the determined area of the finger. The evaluation was made from the mean of the Likert scales' results because the continuous usage can affects the pressure and pain feelings. Each pruning shears' Likert scale results are given in Figure 6.17.

As it can be seen in Figure 6.17, the first two pruning shears are Fiskars P94 and Fiskars P54. The reason for these results is the rotating handle structure of the Fiskars P94. The rotating handle type reduces the friction between fingers and handle because the handle moves with the fingers. The other pruning shear which is Fiskars P54 also has a different type of handle structure that the fingers move together with the same direction. This situation reduces the fingers slippery in the handle. Therefore, the first two pruning shears are the best for both male and female consumers.

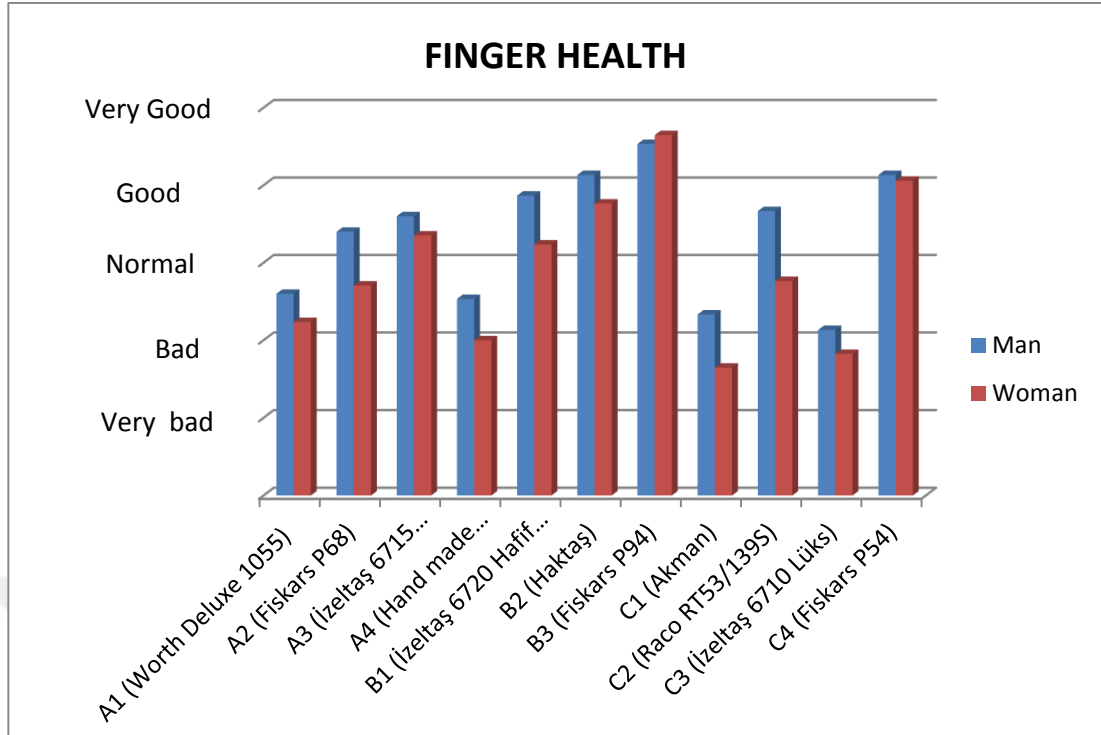


Figure 6.17 The mean finger health values of each pruning shears

The wrist health of the pruning shears were measured with 5-point Likert scale. The participants were evaluated wrist health according to amount of pressure in the wrist. The evaluation was made from the mean of the Likert scales' results because the continuous usage can effect the pressure and pain feelings. Each pruning shears' Likert scale results are given in Figure 6.18.

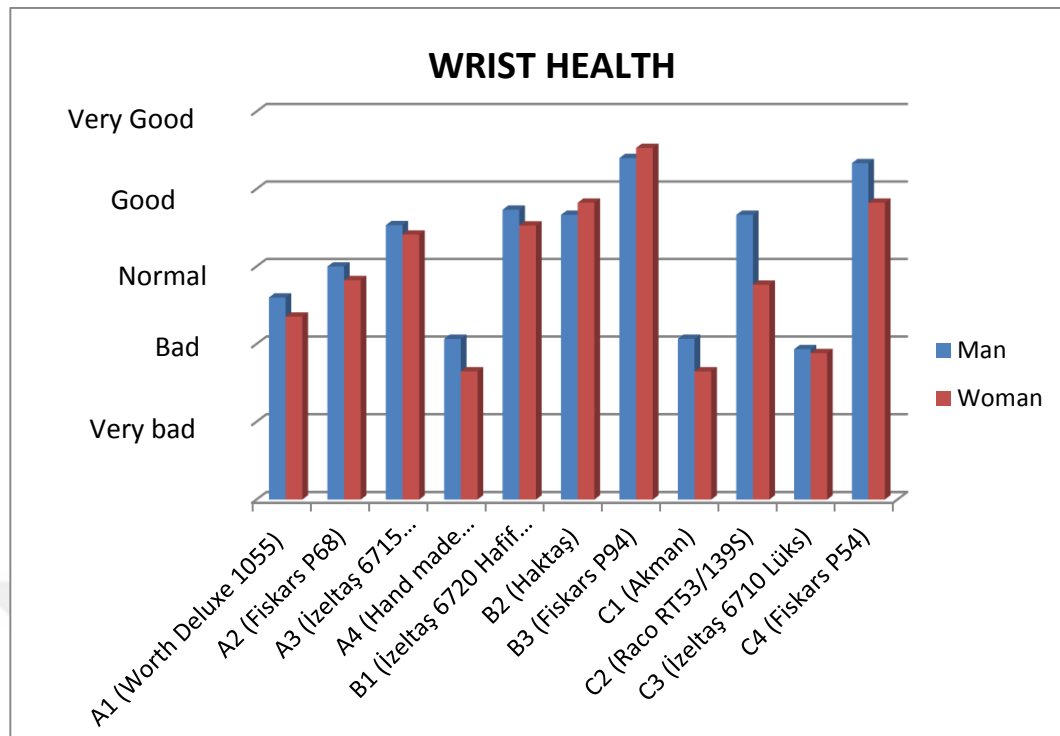


Figure 6.18 The mean wrist health values of each pruning shears

As can be seen above, the more effort consumption pruning shears which are hand-made pruning shear, Akman and İzeltaş 6710 were scored badly by both male and female participants. The wrist health is directly related to repetitive motions and pressure on the wrist. In these pruning shears, only İzeltas 6720 has shock absorber that really reduces the pressure on the wrist at the end of the cut. However, the other Fiskars P94 and P54 were scored better than İzeltas 6720 because of the low effort consumption. But, shock absorber should essential for pruning shears.

The slippery (handle) of the pruning shears were measured with 5-point Likert scale. The participants were evaluated slippery according to handle material. The material of the handle directly affects the slippery of the pruning shear. The each pruning shears' Likert scale results are given in Figure 6.19.

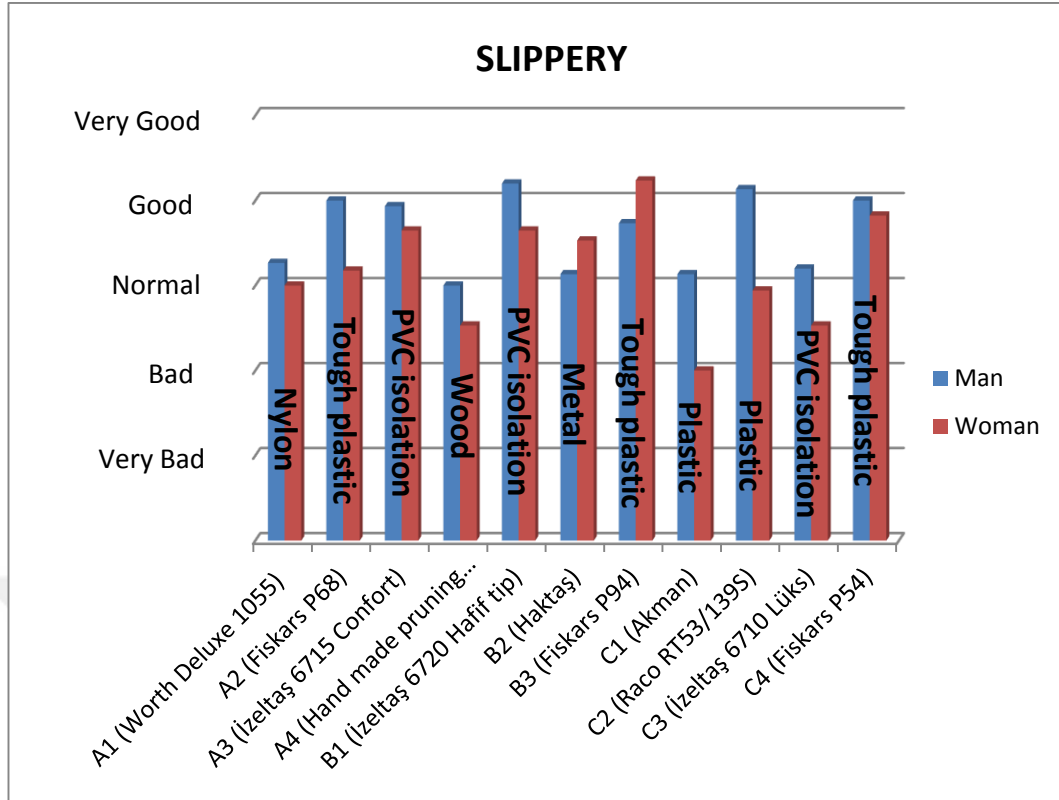


Figure 6.19 The mean slippery values of each pruning shears

As can be seen above, generally the results have been between normal and good scale. Akman and Raco pruning shears' materials were not well defined and Akman took the worst score by women participants. The other materials might be used for pruning shears' handle.

The easy to clean of the pruning shears were measured with 5-point Likert scale. The participants were evaluated easy to clean according to checking the blade areas of the pruning shear. The wet bough might cause to make blades dirtier because sell-fluid of boughs and its' soft content can adhesion to the blades. So, this might cause a reduction in the performance of pruning shears. All blades were made with steel. The each pruning shears' Likert scale results are given in Figure 6.20.

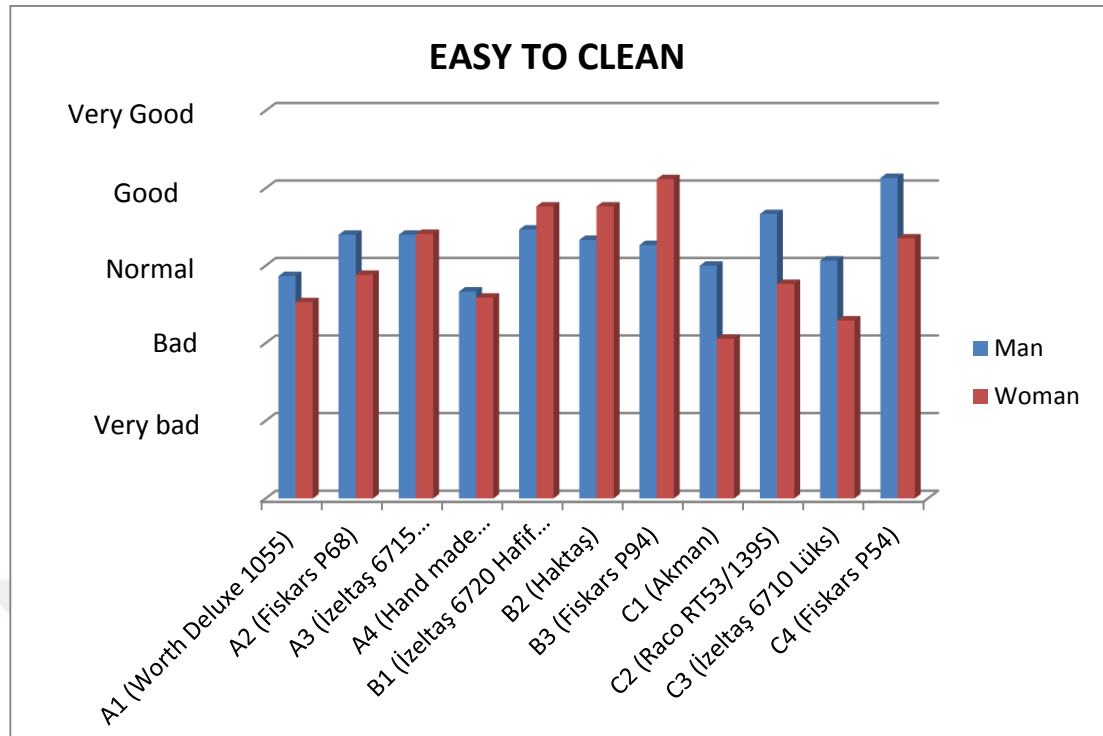


Figure 6.20 The mean easy to clean values of each pruning shears

We can say for “easy to clean” that, the results are generally close to each other because all pruning shears have steel blades. Also, the blade surface might be covered with another material that keeps the blades clean.

The handle material comfort of the pruning shears were measured with 5-point Likert scale. The participants were evaluated handle material comfort according to handle material type. There are seven different types of handle material been that these are tough plastic, PVC isolation (covered), strengthen nylon, metal, wood, and two undefined plastic material. The each pruning shears’ Likert scale results are given in Figure 6.21.

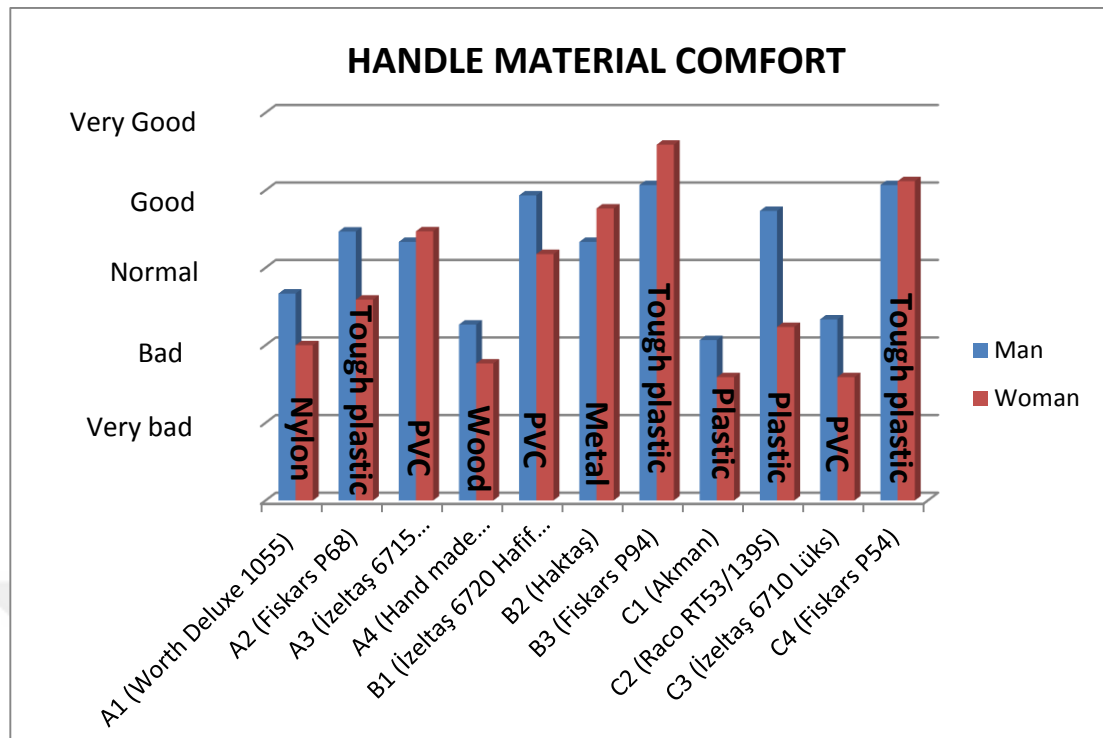


Figure 6.21 The mean handle material comfort values of each pruning shears

It is clearly seen that there are huge differences been in the material comfort of the pruning shears. Tough plastics were generally high scored. Also, PVC and metal are good options for consumers. Woods and undefined plastics have taken low scored by consumers. Not only the handle comfort is affected by material but also other effects might be causes the differentiation of the handle comfort. As seen above with İzeltaş 6700 and İzeltaş 6720, both pruning shears handle covered with the same material but the handle material comfort effects are felt different. That's why the correlations were calculated to investigate relationships between Likert questions.

According to the observer survey, the back position of the participants was statically observed in the use of all pruning shears. However, some participants could not finish the 5 cuts in some pruning shears. This situation also caused the wrist to bend. Observed bended wrists and fail to cut graphic is given in Figure 6.22.

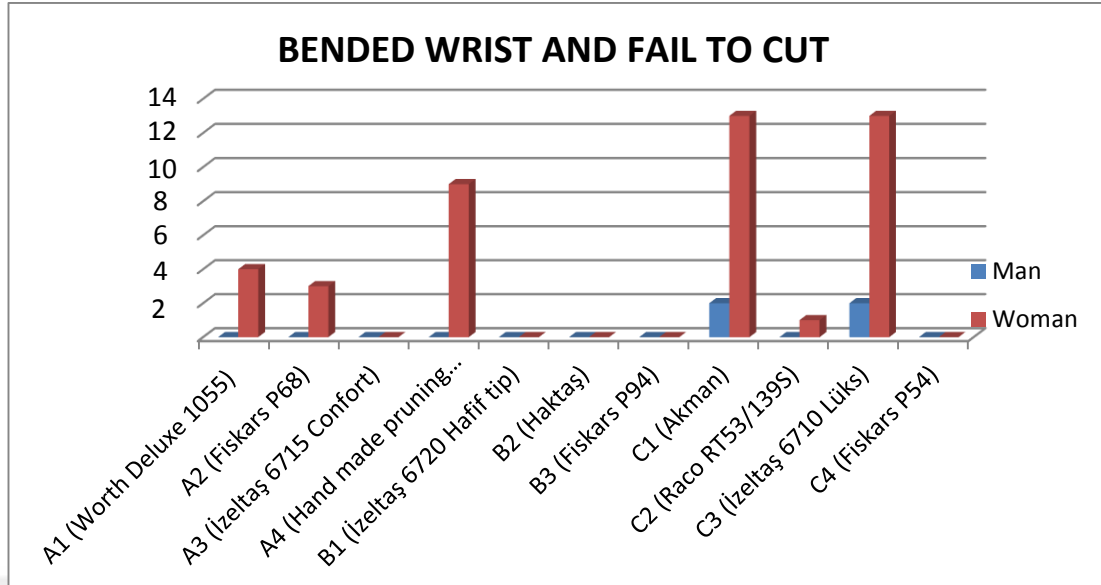


Figure 6.22 The number of bended wrist and fail to cut according to gender and pruning shears

Only 4 male participants could not finish the cutting process with Akman and İzeltaş 6710 pruning shears. On most of woman, participants could not finish the cutting process with hand-made pruning shear, Akman and İzeltaş 6710. Only two types of pruning shears could not be cut by male participants. For woman participants, six types of pruning shears could not be cut. Also, this situation causes a bended wrist.

According to participants' scoring, the total score of each pruning shear was calculated. The ranking of the pruning shears were divided according to gender. The calculation was performed with the sum of all Likert scale values of each pruning shears that the participants gave. The rank of pruning shears from best to worst is given in Table 6.17.

Table 6.17 Rank of the pruning shears according to gender

Rank	MAN	Score	Rank	WOMAN	Score
1	B3 (Fiskars P94)	554	1	C4 (Fiskars P54)	463
2	C4 (Fiskars P54)	486	2	B3 (Fiskars P94)	455
3	B2 (Haktaş)	462	3	B1 (İzeltaş 6720 Hafif tip)	427
4	A3 (İzeltaş 6715 Confort)	425	4	C2 (Raco RT53/139S)	413
5	B1 (İzeltaş 6720 Hafif tip)	419	5	B2 (Haktaş)	400
6	A2 (Fiskars P68)	334	6	A3 (İzeltaş 6715 Confort)	391
7	C2 (Raco RT53/139S)	330	7	A2 (Fiskars P68)	360
8	A1 (Worth Deluxe 1055)	273	8	A1 (Worth Deluxe 1055)	302
9	A4 (Hand made)	237	9	A4 (Hand made)	267
10	C3 (İzeltaş 6710 Lüks)	226	10	C1 (Akman)	253
11	C1 (Akman)	196	11	C3 (İzeltaş 6710 Lüks)	244

It is clearly seen that male and female participants' decisions have differentiation. For woman participants, the best pruning shear is determined as Fiskars P54 which is the smallest pruning shear in the compared pruning shears pool. For male participants, the best pruning shear is determined as Fiskars P94 which is bigger than Fiskars P54 and also has a movable handle. İzeltaş 6710 is the biggest pruning shear that placed 10th for males and 11th for females. This shows that the biggest pruning shears not suitable for females. Also, Akman is the cheapest pruning shear that, the blade was bent so quick that the participants did not cut the boughs properly.

According to scoring pruning shears, up to 5th row, the male participants' scores are bigger than the female participants'. However, after the 5th row, the female participants' scores will be bigger than the male participants'.

We can say that tough plastic, PVC and metal handle materials are matched with the consumers' expectation.

Haktaş and Raco pruning shears also can be classified in the low price products that, for male participants, Haktaş placed in the 3rd row. For female participants, Raco placed in the 4th row. The both Fiskars P94 and P54 are expensive pruning shears. If the participants want to prefer a low price product, female consumers will select the Raco and male consumers will select the Haktaş. Both pruning shears' sizes can be defined as similar that the main difference is handle material. In this condition, male participants will prefer the metal handle and the female participants will prefer the plastic handle.

6.6.4.4 Investigating the Rest of the Human Needs and Engineering Characteristics of the Pruning Shears

In this section remaining the rest of the human needs and engineering characteristics of the pruning shears are investigated.

6.6.4.4.1 Right and Left Hand Usability. Most of the pruning shears are suitable to use with both hands. However, the new design apparatus might deny both hand usage. All the 11 pruning shears can be used with both hands except Fiskars P94. The movable handle design causes a better movement for the right hand but it denies the left-hand usability. There is no option to lock this movable handle. The left-hand users should check the pruning shears' features properly.

6.6.4.4.2 Lightweight Pruning Shears. The pruning shears' weights also an important factor that affects performance and fatigue. The more weight the pruning shears has, the less performance the consumer to perform. The all 11 pruning shears weights are given in Table 6.18.

Table 6.18 Weight of the pruning shears

Pruning shears	Weight (gram)
Fiskars P54	132
Akman	170
Worth Deluxe 1055	186
Fiskars P68	193
Raco RT53/139S	213
Haktaş	220
İzeltaş 6720 Hafif tip	250
Fiskars P94	274
İzeltaş 6715 Confort	294
Hand made pruning shear	301
İzeltaş 6710 Lüks	397

According to the weights table and participant experiments results, Fiskars P54 took the first place both weight row and women's results. On the other hand, hand-made pruning shear and İzeltaş 6710 placed in the last rows in weight table, men's and women's results.

6.6.4.4.3 Adjustable Handle Size. Adjustable pruning shears handle is an important function that the consumer can adjust the pruning shears handle according to their handle comfort and sizes. However, very few pruning shears have this function either it is hard to adjust hand size because sometimes the consumer needs to disassemble the pruning shear. Only one pruning shear has the easy to manage hand size function that is Fiskars P68. The consumer can easily adjust the pruning shears' handle according to their hand size.

6.6.4.4.4 Durability of the Pruning Shear. The most important and sensitive part of the pruning shears is the blade. The durability of the blade is related to material of the blade. Akmans' blade was damaged too much during the participant experiments. The sharpness of the blade was completely disappeared. The other pruning shears prevented their sharpness during the participant experiment.

6.6.4.4.5 Suitable Motion. Only Fiskars P54 and P94 have suitable hand motion. Other pruning shears have a classical handle that movements are the same for all.

6.6.4.4.6 Suitable Handle Temperature. Metal is a material that conducts heat well. So, in the cold or hot temperatures, the handle might disturb the consumers' handle comfort. The other materials are suitable for cold or hot temperatures.

6.6.4.4.7 Replacement Parts. Part replacement is an essential function that the pruning shears should have. In time, pruning shears parts getting old. So, these parts should be replaced with the new ones. Hand-made pruning shear, İzeltaş 6710, Akman, Haktaş and Worth Deluxe 1055 pruning shears parts cannot be changed with the new ones. Also, this process should be performed easily because the wrong adjustment of the pruning shears' parts causes the reduce performance and comfort of the product.

6.6.4.4.8 Knife Angle. The knife of the pruning shears should compatible with the wrist and forearm of the consumer. Hand-made pruning shear, İzeltaş 6710, İzeltaş 6720 and Raco have classical straight blade.

6.6.4.4.9 Maximum Bough Diameter to Cut. Some producers are defined to the maximum bough diameter that generally changes between 10cm to 25cm. However, the maximum bough diameter to cut is directly related to the knife sizes because Fiskars P54 blade became dysfunctional in the 2cm bough cutting process because the blade was bended. Also, it was defined by the firm that the maximum diameter to cut 20mm. The Fiskars P54 blade is the smallest blade in the 11 pruning shears. Therefore, it depends on the pruning shears blade sizes.

6.6.4.4.10 Security Lock Design. Each pruning shears have a security lock because these products are really dangerous for consumers. The pruning shears blade is mostly very sharp and can injure people dangerously. Worth Deluxe 1055 security lock is located on the top of the pruning shear. However, this lock is closed by pruning shear in the cutting operations because of the functional problem. In the case study, the participants mostly reopened the blades lock because it closed by itself. On the other hand, some security locks are located into the bottom end of the pruning shear. This location reduces the hand comfort significantly because at the end of the cut, sometimes the lock mechanism hits the consumers' palm that gives pain. Also, consumers need to use both hands to open and close the security lock. The other security locks are located inside of the pruning shears that the thumb can reach easily. This location is good for easy to manage this security lock. Also can be performed the locking only one hand. All Fiskars pruning shears, Raco, İzeltaş 6720 and İzeltaş 6715 have a good security lock design.

6.6.4.4.11 Rust Protection. Rusting is directly related to the amount of usage and the material structure of the pruning shears' blade. The blade coverage and rust protection sprays might delay to rusting. In 11 pruning shears, these blades structures are not well defined. So, this part of the investigation was skipped.

6.6.4.4.12 Bottom end Handle Distance. This distance should suitable for consumers hand sizes. The more distance the pruning shears have, the more energy consumption is performed by consumers because they need to spend energy on holding the pruning shear. The adjustable handle is an important property for managing this distance. However, if the pruning shear does not have the adjustability function, the selecting suitable bottom end handle distance is essential. The table of all 11 pruning shears bottom end handle distance is given in Table 6.19.

Table 6.19 Bottom end handle distance of the pruning shears

Pruning shears	Bottom end handle distance(mm)
Fiskars P54	95
Fiskars P94	100
Fiskars P68	110
El yapımı bahçe makası	137
İzeltaş 6715 Confort	139
Raco RT53/139S	140
Akman	145
İzeltaş 6710 Lüks	155
Worth Deluxe 1055	163
Haktaş	170
İzeltaş 6720 Hafif tip	171

For example, Fiskars P54 does not have an adjustability function. However, the bottom end handle distance is suitable for most of the consumers. Therefore, this distance is also as important as an adjustable handle size.

6.6.4.4.12 Price. Price is an important criterion that consumers generally checks firstly. The consumers generally prefer moderate prices in the product range. The most expensive products might provide the best ergonomics but if the price is not accessible for consumers, the product will not be selected by consumers. The approximate prices of all 11 pruning shears are given in Table 6.20.

Table 6.20 The approximate prices of the pruning shears

Pruning shears	Group and no	Cost(TL)
C1 (Akman)	C1	12.6
B2 (Haktaş)	B2	37.5
A4 (Hand made pruning shear)	A4	38.94
A1 (Worth Deluxe 1055)	A1	39.99
C2 (Raco RT53/139S)	C2	48.8
C3 (İzeltaş 6710 Lüks)	C3	74
A3 (İzeltaş 6715 Confort)	A3	125
B1 (İzeltaş 6720 Hafif tip)	B1	139
A2 (Fiskars P68)	A2	160
C4 (Fiskars P54)	C4	170
B3 (Fiskars P94)	B3	198

6.6.4.4.13 Product Guarantee. Product guarantee was determined less important criterion by consumers in the case study. However, it shows the product quality and consumers product usage time. Both İzeltaş and Fiskars product guarantees only cover the label and material failures in the production of pruning shears. Consumers' failures are not guaranteed. Also, other products do not have any product guarantees.

6.6.4.4.14 Environmental Effect/Recyclability. The pruning shears blades are mostly made of steel. The steel is a material that can recyclable by firms. So, we can say that the pruning shears blades are environmental products. However, different material types have been using into the pruning shears handle. All handle materials can recyclable but the most environmental handle material types are wood and metal. The waste of PVC, plastic, and nylon might give damage to the environment.

6.7 Product Concept Generation

The existing product range investigation of the pruning shears have provided an enormous amount of product features and human expectations. These features help to create concept generations. According to the results of the criteria weights, the main focusing of the Ergonomic Consumer Product Design Principles are usability (easy to use), health, comfort, effort, and functionality. The less important Ergonomic Consumer Product Design Principles are durability, price/cost, product guarantee/warranty, and environmental effect/recyclability. Also, the main focusing criteria are investigated with human needs and engineering characteristics.

The product concepts are generated as a sectional-modular architecture which includes three different parts that are handle, body, and knife. That means these three parts can separable easily. Also, it allows for much more flexible pruning shear concepts.

The pruning shears security lock should be placed in the nut part that, most of the pruning shears have this type of security lock. However, in the concept, the security lock also provides the adjusting bottom end handle distance. The case study has shown that most of the male participants have medium hand size, and woman participants hand sizes can be changed between small, xsmall and xxsmall sizes. Xxsmall sizes can be added to the xsmall group. So, the three levels of adjustment should be developed into the security lock. So the pruning shear can be suitable for both hand sizes.

PVC and tough plastics were obtained most scored pruning shears' handle by the participants. The sectional-modular architecture is selected because it allows changing handle materials. Also, these materials are light weighted that contributes to the reduction of the pruning shears' weights. Therefore, the consumer can select the best material for own handle comfort. Many types of modular structured handle type should be provided by firms that the consumer can select the suitable one according to slippery, handle temperature et cetera.

The movable handle design also should be taken into consideration because it reduces the friction between handle and fingers that provide a positive contribution for finger health. Nevertheless, the movable handle denies both hand usage feature. It was seen in the Fiskars P94 that the pruning shear only can be used with the right hand because the movable handle (the handle moves with the fingers) movement is not independent. In here the independent handle movement should be applied to the movable handle. Besides the lock mechanism should be applied to the handle that opens and closes the handle movement. So it provides both hand usage and movable handle usage.

The angle between pruning shears' body and pruning shears' blade should be 15 degrees to provide product ergonomics. Nevertheless, classical pruning shears also been in the market. Moreover, the 30 degrees knife angles pruning shears can be seen in the market. So the adjustability also should be performed on the knife angle. The consumers can change the knife angle according to their comfort and behavior.

The blade sizes also important that is related to the durability and maximum bough diameter to cut. Very large or very small pruning shears' blade shows poor performance on thick boughs. The approximately the optimum pruning shear blades' size was defined 4 to 5 centimeter.

The pressure tests have shown that the pruning shears' springs might reduce the smooth movement of the pruning shear. Also, it might reduce the performance of the product or might increase the effort. So, the spring is also an important factor that should be checked before the usage.

The correlation results showed that approximately 0.70 Pearson correlation calculated between effort-palm health, effort-wrist health, and effort- finger health. Thus, the reduction of effort helps to protect the health of the fingers, palms, and wrists. The important factor that affects effort is the sharpness of the pruning shear. Also, it provides smooth cut performance. However, the blade material should be high quality and durable because bended or rusted pruning shears' blade increases the effort. Also,

material comfort and design are seen as an important factor. The area between thumb and index finger should be designed suitably. In here the soft materials might be used to this area.

Lastly, suitable handle motion should be applied to the pruning shears handle design. However, modular structured pruning shear might not be designed with this handle motions. So, classical handle motion also takes into consideration. Thus, many types of concepts can be created with these provided information.



CHAPTER SEVEN

CONCLUSIONS

Product ergonomics is not only the essential factor for consumers who are looking for the best product to fulfill their requirements, but also necessary for producers which effects their sales figures and profits. For this perspective, it is essential to make ergonomic products for consumers but it should also be accessible for consumers.

By searching the relevant literature comprehensively, it is observed that most of the relevant work which involves improvement of product ergonomics are studied only product-oriented improvements. For our best knowledge, there is not any study on structured principles that can be applied to all consumer products except disposable ones. Moreover, the product ergonomics is not only the most important feature but also the product should be accessible for consumers. With this purpose, Ergonomic Consumer Product Design Principles are proposed.

The most important criteria that affect product ergonomics are investigated in the relevant literature. However, it was seen that the other criteria that affect the product ergonomics non-directly should be also taken into consideration. So, both of the criteria are applied to the Ergonomic Consumers Product Design Principles. Ergonomic Consumer Product Design Principles are the criteria that affect product ergonomics directly and indirectly. Ergonomic Consumer Product Design Principles are composed of two fundamental groups that classify direct and indirect criteria that affect product ergonomics which are called primary and secondary principles, respectively, in the relevant literature. Seven criteria (durability, health, comfort, usability, effort/force, functionality, and easy to learn) are determined for the primary principles and four criteria (price/cost, style/fashion, product guarantee/warranty, and environmental effect/recyclability) are determined for the secondary principles which should be taken into consideration in the product design process. Primary principles should provide the desired ergonomic level for the product, otherwise, ergonomic problems might be occurring in the future. It is much more difficult to set consumers' non-ergonomic criteria as secondary principles, so the secondary principles left open-

ended. Thus the researcher can add more criteria into the secondary principles according to its product design.

The features which improve product ergonomics are identified such as product material, physical form, and technological content. Technological content is not available for some products. So this is an also optional feature according to the product type. However, the rest of them are valid for all consumer products.

In this study, the New Product Development Process with considering Ergonomic Consumers Product Design Principles is proposed. The process includes ten steps and five sub-steps, which searches existing product range of the market in order to give some ergonomic product features. This step can be skipped if the product that will be designed does not have any existing product range in the market. So this step is optional.

This application carried out an ergonomic pruning shears design concept and aims to demonstrate applying Ergonomic Consumer Product Design Principles and New Product Development Process. Pruning shear is a consumer product which has a great variety at the market. After selecting the product to be designed, the target population is determined and classified. The classifications are performed to investigate human needs and these needs have matched to the related Ergonomic Consumer Product Design Principles. Then, the engineering characteristics of human needs are defined.

Eleven pruning shears are selected for the existing product investigation. This investigation provides a comparison of the pruning shears and also demonstrates an enormous amount of product ergonomics features. Some evaluation methods are performed in order to compare the shears. Firstly, the pressure test is applied and the minimum effort level for using shears is determined. As a result of pressure test, an appropriate data that will be used for comparison is gathered and also, it is observed that the pruning shears' spring might affect the fluency of the pruning shears handle movement. So, the existing product investigations demonstrate an important ergonomic feature that affects product performance. In cutting test, the cutting surface

of the bough was investigated and the results showed the differences in the cutting surface.

The statistical results of the implementation show that there are some moderate and strong correlations between human needs, which means that the Ergonomic Consumer Product Design Principles can be affected by each other. Moreover, statistical significance is observed between hand sizes and genders in pruning shear usage. This situation shows that the classification and definition of the target population are essential.

The effort of the pruning shears has been investigated via three ways which are pressure tests, Likert scale of participant surveys' and Likert scale of observer surveys'. These three data sets are studied in SPSS. The results show that these three data sets were strongly correlated with each other. Therefore, the Likert scales can provide good results in the subjective and objective data calculations in the ergonomic product design process.

The determination of the Ergonomic Consumer Product Design Principles weights is also performed. Pruning shear is a product that is not commonly using by consumers. So, in the case study, the rank of the determined Ergonomic Consumer Product Design Principles is collected from participants both before and after the experiment. All participants did not have any pruning shear experience. So, the product usage experience effects on the participants can be investigated. The results show that the product experience is affecting the consumers' behavior and Ergonomic Consumer Product Design Principles priority.

These results have provided important ergonomic features about the pruning shears that the concept properties can be determined suitable for consumers' ergonomic expectations. So the product concepts can be developed better.

In future research, the selected product would be produced and compared to the existing products. Tangible products might perform better performance than the other

existing products. Also, long term product usage observation should be performed which shows whether a long term ergonomic problems may occur or not. Long term ergonomic investigations may reduce the accuracy of the investigation because the consumers' behavior and physiological are not stable. However, with the best fiction, it gives better results than short term investigations.



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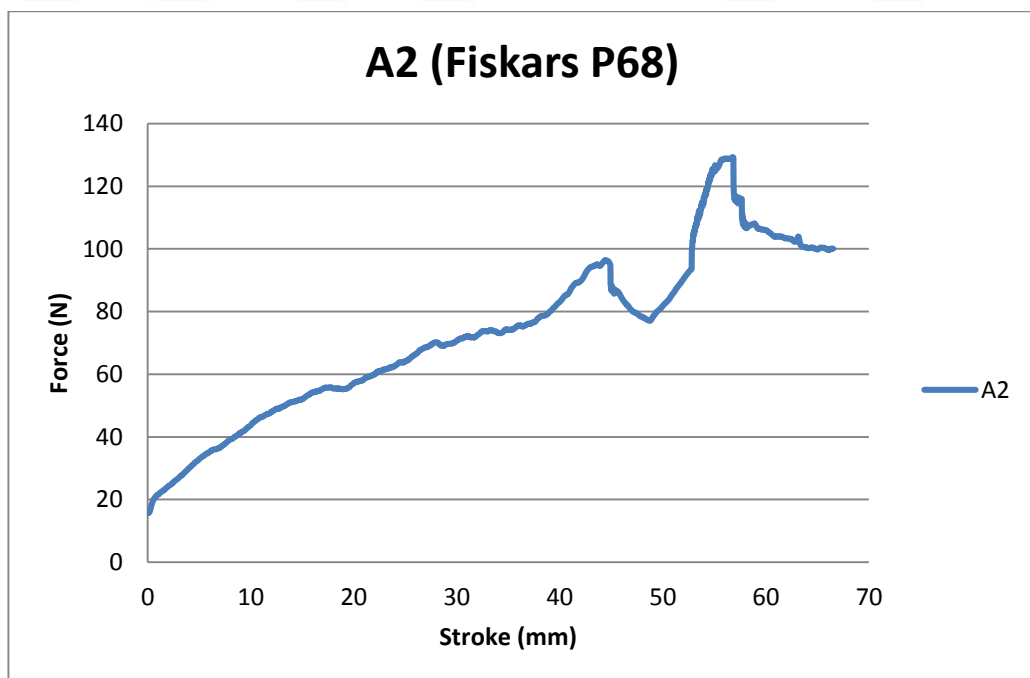
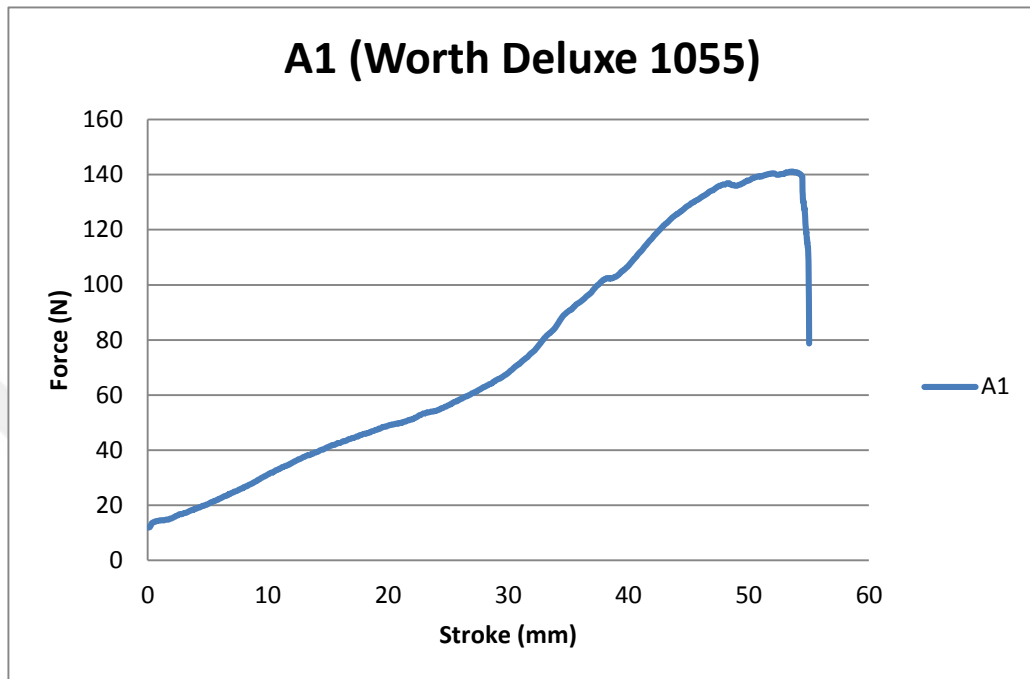
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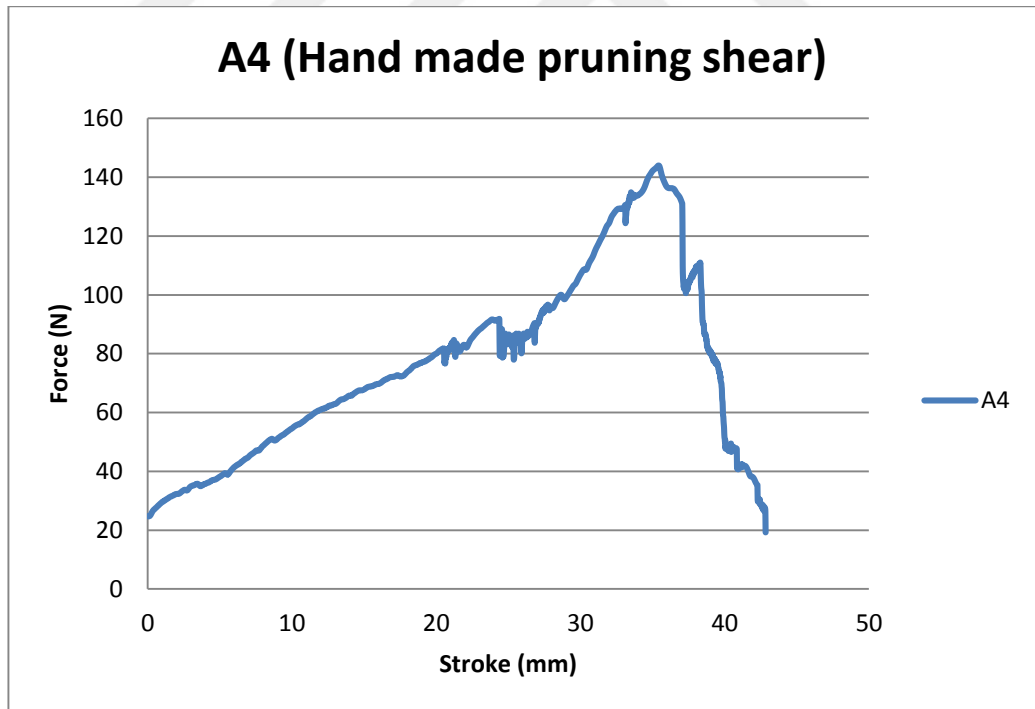
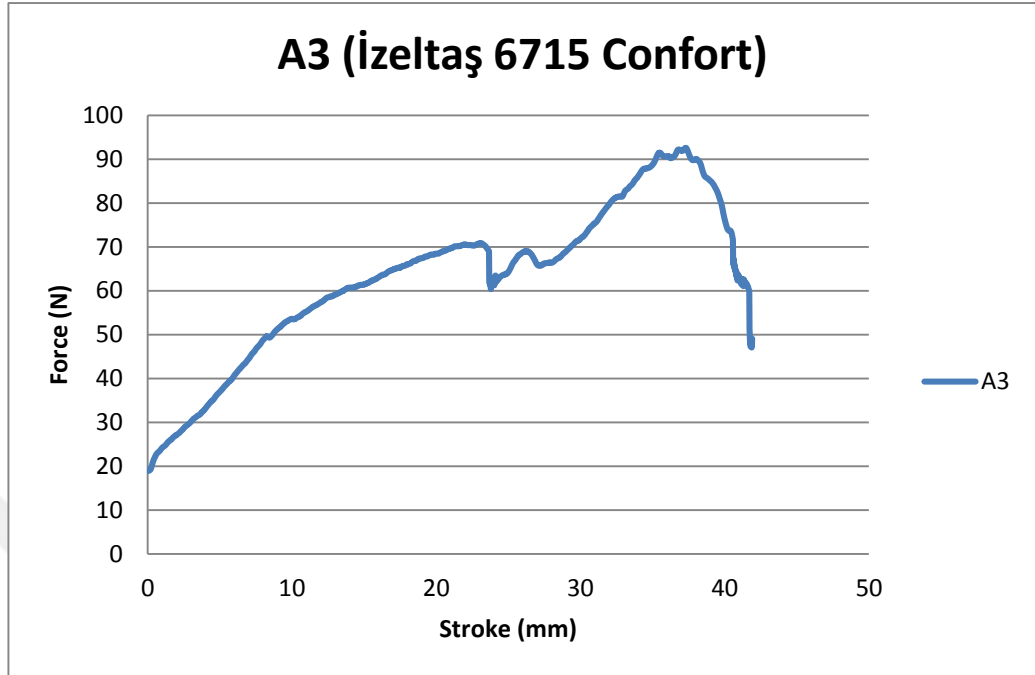
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APPENDICES

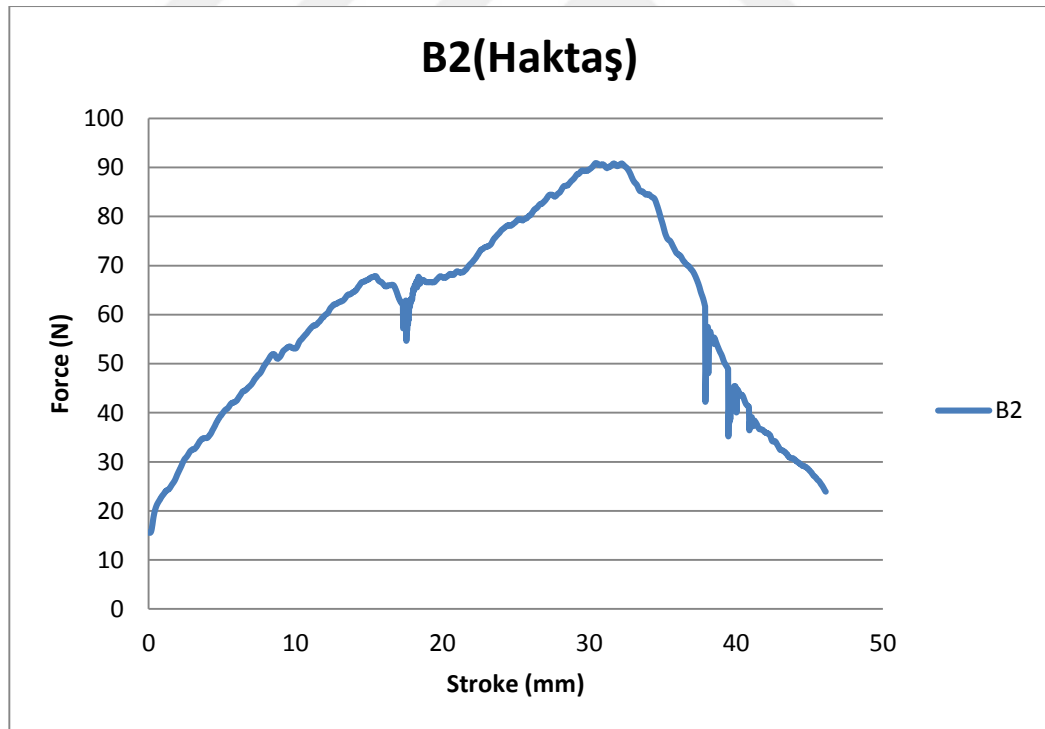
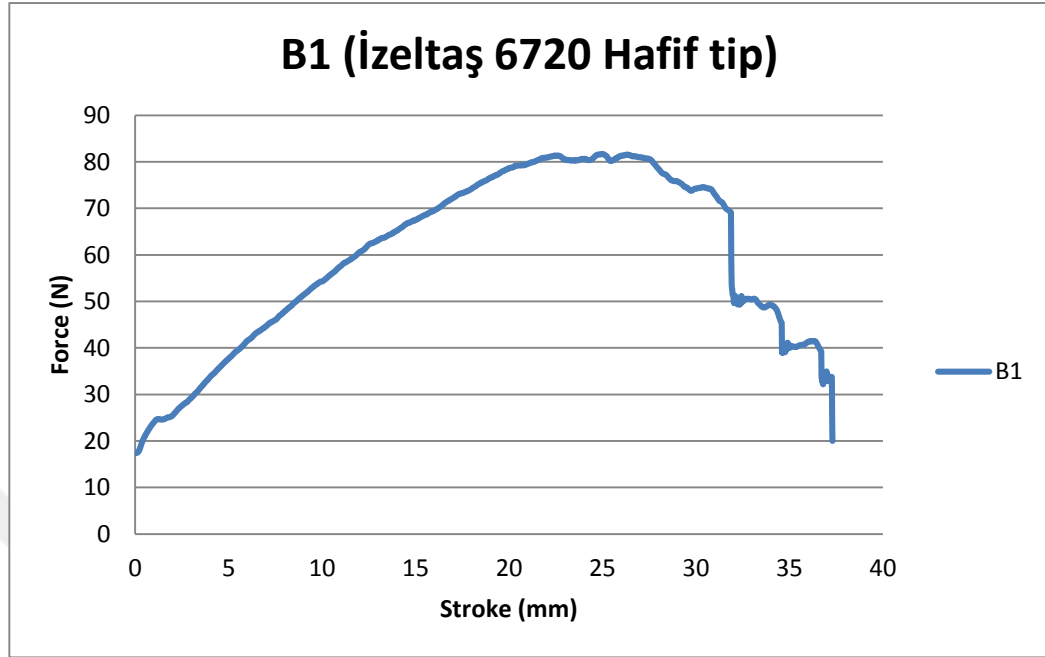
APPENDIX-1: Pressure Test Results Graphics



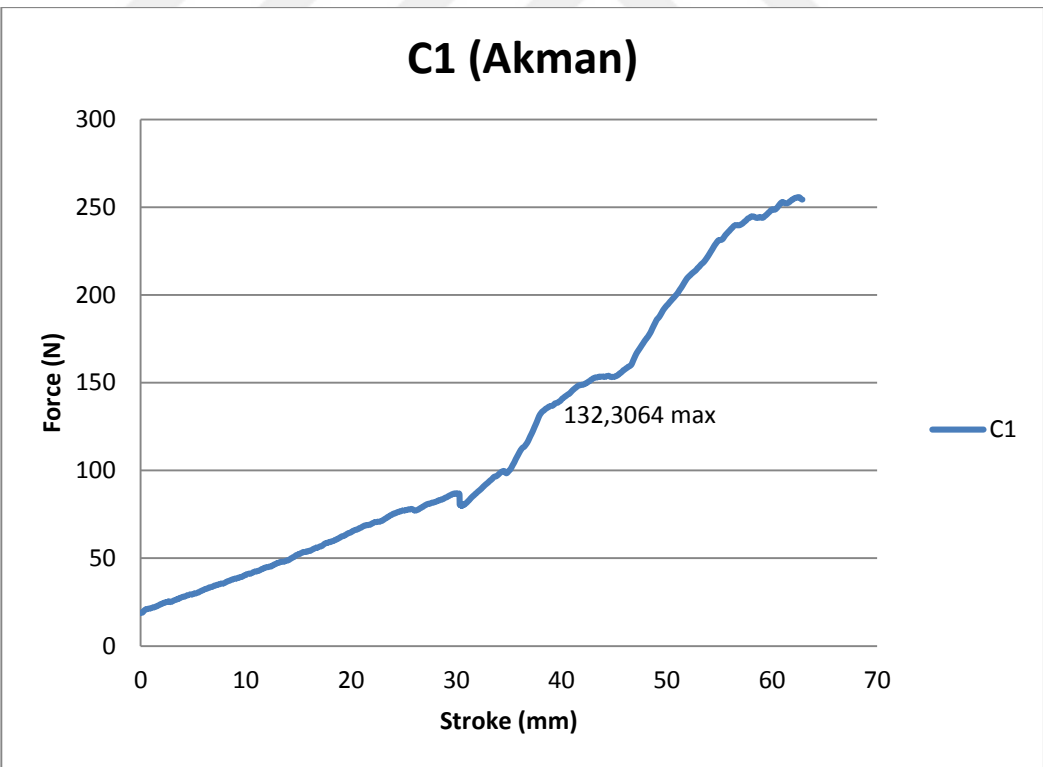
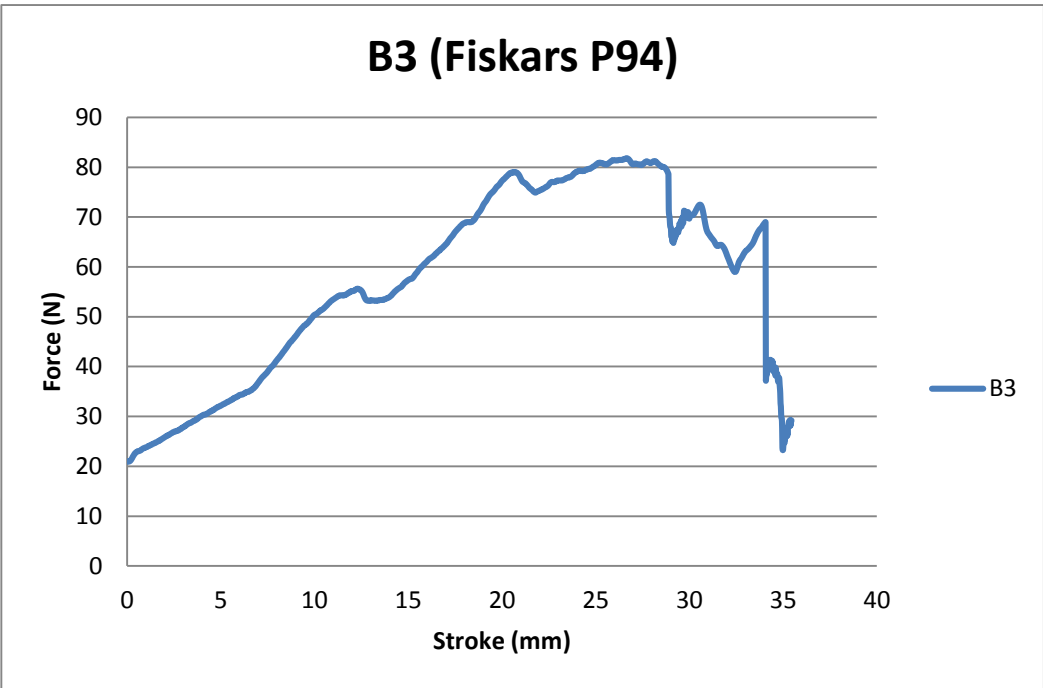
APPENDIX-1: Continues



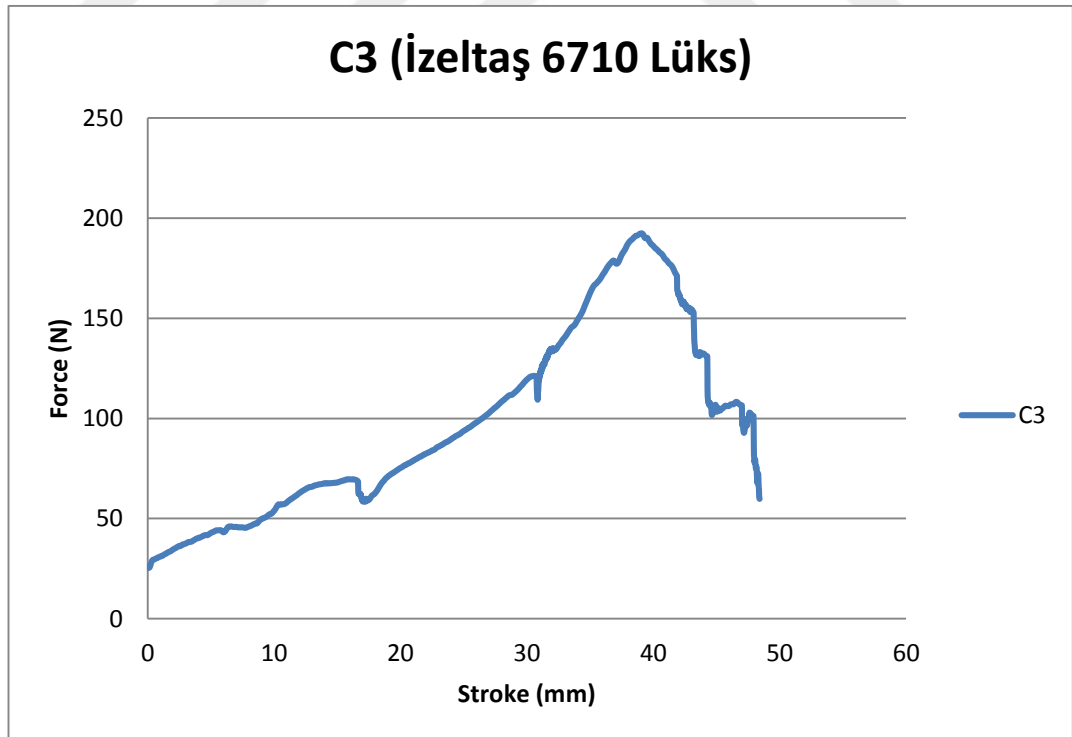
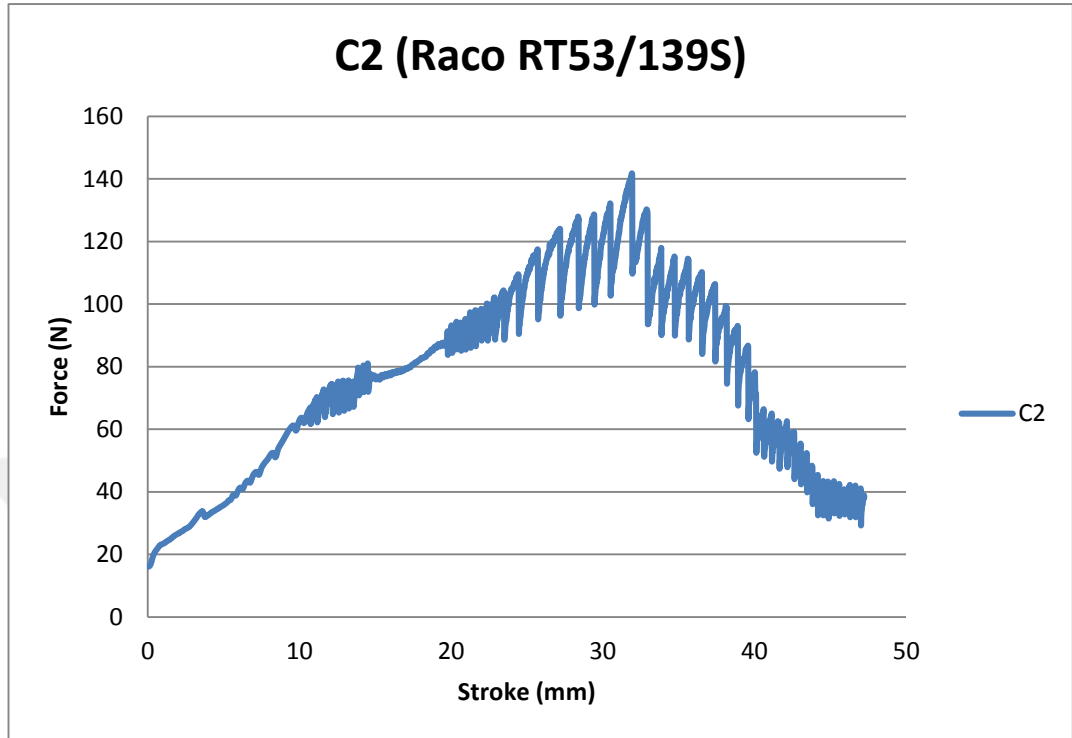
APPENDIX-1: Continues



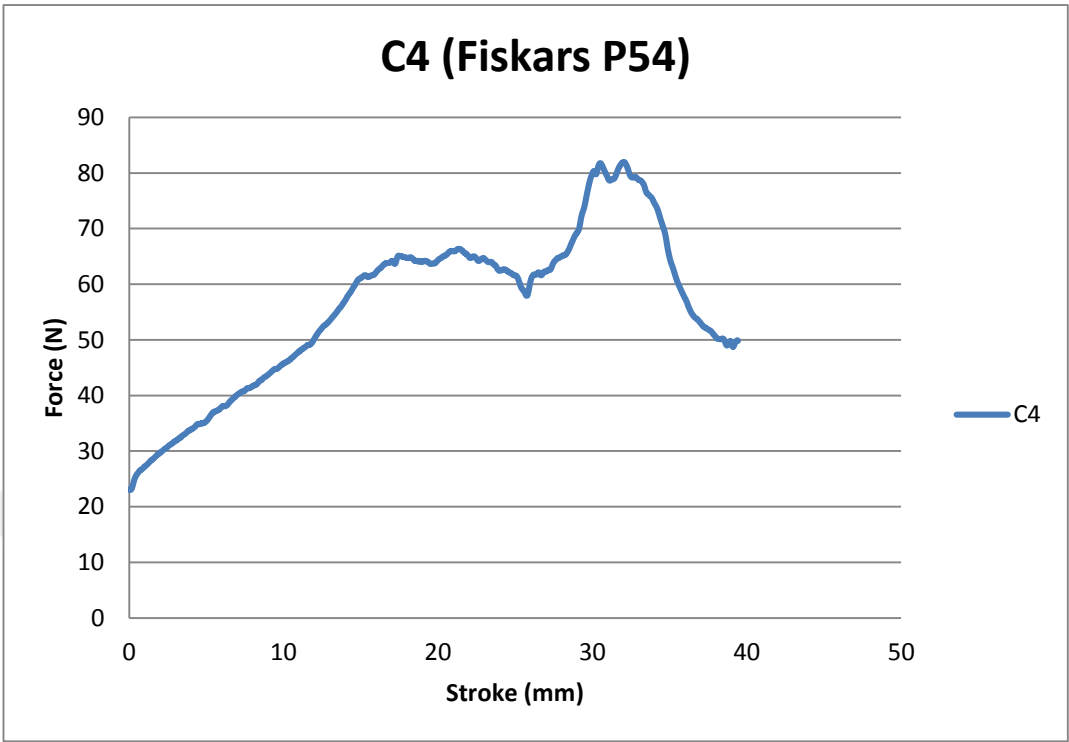
APPENDIX-1: Continues



APPENDIX-1: Continues



APPENDIX-1: Continues



APPENDIX-2: Hugh Nation Hand Sizing Chart

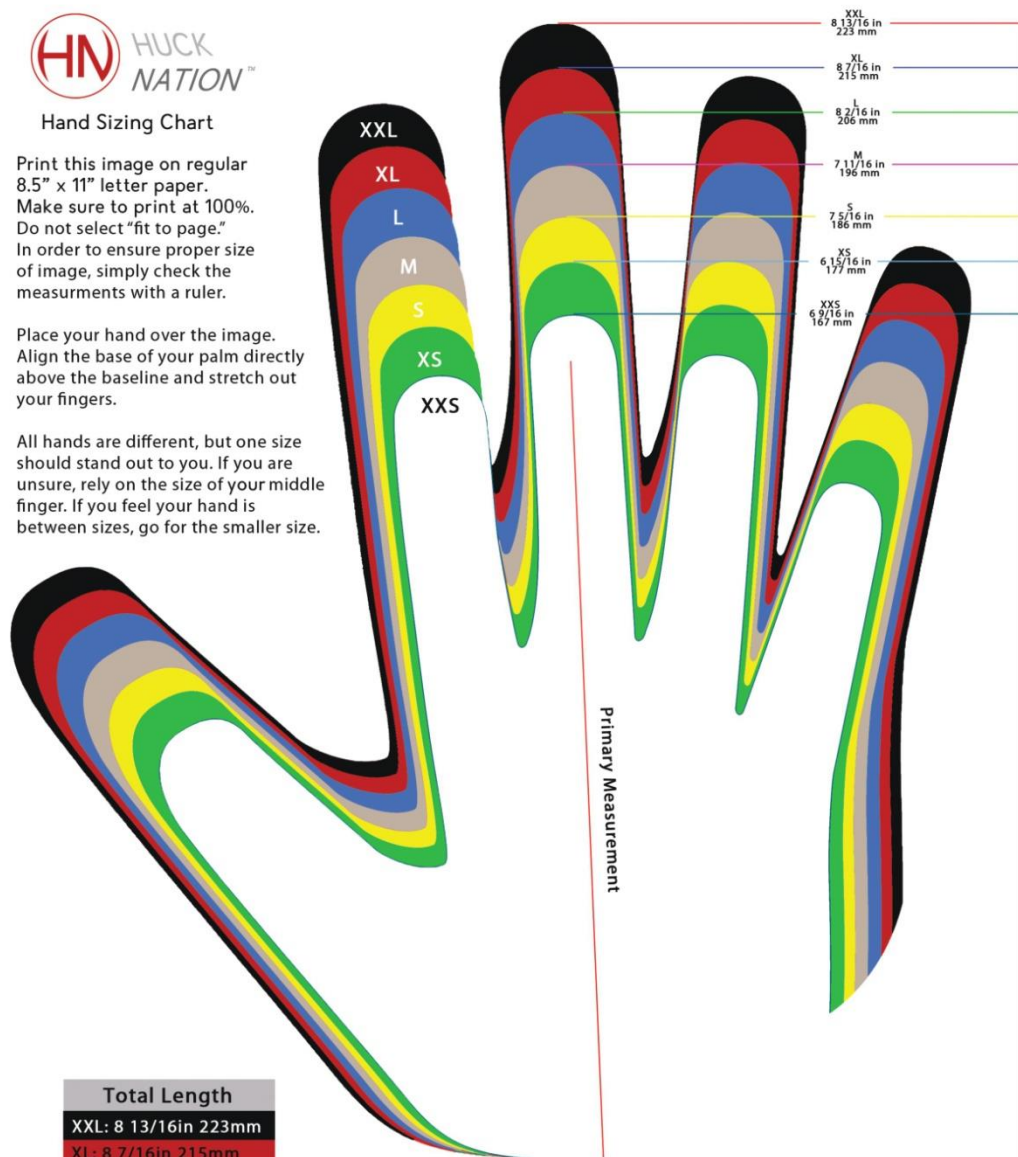


Hand Sizing Chart

Print this image on regular 8.5" x 11" letter paper. Make sure to print at 100%. Do not select "fit to page." In order to ensure proper size of image, simply check the measurements with a ruler.

Place your hand over the image. Align the base of your palm directly above the baseline and stretch out your fingers.

All hands are different, but one size should stand out to you. If you are unsure, rely on the size of your middle finger. If you feel your hand is between sizes, go for the smaller size.



Total Length	
XXL:	8 13/16in 223mm
XL:	8 7/16in 215mm
L:	8 2/16in 206mm
M:	7 11/16in 196mm
S:	7 5/16in 186mm
XS:	6 15/16in 177mm
XXS:	6 9/16in 167mm

We want to do our best to ensure you have a great experience with your gloves. If your gloves do not fit when you receive them, contact us at info@hucknation.com.

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APPENDIX-3: Participants Survey

The case study was performed with Turkish participants. So, the survey was written in Turkish Language.

**DOKUZ EYLÜL ÜNİVERSİTESİ, ENDÜSTRİ MÜHENDİSLİĞİ
“ERGONOMİK TÜKETİCİ ÜRÜN TASARIMI: İLKELERİ,
DEĞERLENDİRME VE UYGULAMA” İSİMLİ YÜKSEK LİSANS TEZ
UYGULAMASI İÇİN VERİ TOPLAMA ARACI**

Sayın katılımcı;

Bu çalışma, Dokuz Eylül Üniversitesi Endüstri Mühendisliği Bölümünde yürütülen “Ergonomik Tüketici Ürün Tasarımı: İlkeleri, Değerlendirme ve Uygulama” başlıklı Yüksek Lisans Tezi kapsamında oluşturulan anket sorularını içermektedir. Anket uygulamalı olup, bahçe makaslarının ergonomik olarak değerlendirilmesiyle ilgili bazı soruları kapsamaktadır. Katılımcının ürünleri belirli bir süre kullanması ve her bir makas için belirlenen soruları kullanım deneyimine göre cevaplaması istenmektedir.

Katılım Koşulları

1. Dominant kolu sağ kol olan
2. Anatomik rahatsızlıkları olmayan
3. Vücut geliştirme sporu ile ciddi olarak ilgilenmeyen (yarışmalara katılmayan)
4. Yakın zamanda kol gücü gerektiren işler yapmayan/ kas ağrısı bulunmayan
5. 18-40 yaş arası kişiler

Bu çalışmaya katılabilirler.

Gizlilik Politikası

1. Bu çalışmaya katılan kişilerin verdikleri bilgiler ve cevaplar üçüncü firma, kurum veya kişilerle kesinlikle paylaşılmayacaktır.

2. Bu yüksek lisans tezinden üretilecek dokümanlarda, çalışmaya katılan kişilerin ismi yayınlanmayacaktır. Sadece verilen ve ölçümlenen cevaplara göre ürünlerin ergonomik olarak değerlendirilmesi ile ilgili istatistiksel sonuçlar yayınlanıp paylaşılacaktır.
3. Ankete katılan kişiler eğer isterlerse çalışmanın sonuçları geri bildirimle paylaşılacaktır.

Gösterdiğiniz ilgi ve destek için çok teşekkür ederiz. Sorular 2. sayfadan başlayacaktır.

Sercan Madanlar- Dokuz Eylül Üniversitesi Endüstri Mühendisliği Bölümü Yüksek Lisans Öğrencisi,

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E-mail: sebnem.demirkol@deu.edu.tr

ÖNEMLİ NOT: Bu anket soruları Dokuz Eylül Üniversitesi Endüstri Mühendisliği bölümünde yürütülen “Ergonomik Tüketici Ürün Tasarımı: İlkeleri, Değerlendirme ve Uygulama” başlıklı yüksek lisans tezi kapsamında oluşturulmuştur ve tüm hakları saklıdır. İzinsiz şekilde kopyalanması ve çoğaltılması kesinlikle yasaktır.

Birinci Kısım

Adınız Soyadınız:

Yaşınız:

Cinsiyetiniz: ☐ Kadın ☐ Erkek

Boyunuz:

Kilonuz:

İkinci Kısım

Bahçe makası satın alma kararınızda aşağıda verilen kriterlerin önem düzeyini en önemliden en önemsizye doğru sıralayınız. (1 den 9'a kadar. 1 en önemli, 9 en önemsiz)

- Ürün sağlamlığı _____
- El, kol, bilek sağlığı _____
- El konforu _____
- Kullanım kolaylığı _____
- Harcanan efor _____
- Ürün işlevselliği _____
- Ürün fiyatı _____
- Ürünün garanti süresi _____
- Ürünün geri dönüştürülebilirliği _____

Üçüncü kısım

Bu kısımda her bir ürünün kullanımından sonra (her bir makas ile 7mm çapındaki tahta çubuklar üzerinde 5 kesim yapılacaktır) edindiğiniz deneyime göre her bir bahçe makası ile ilgili 7 soruyu cevaplamanız istenmektedir. Bu soruların cevapları 1 den 5 e kadar ve 1 den 7 ye kadar oluşturulan skala ile toplanacaktır. Toplamda 11 tane bahçe makası bulunmaktadır. Dolayısıyla 55 tane kesim ve 77 tane işaretleme yapmanız gerekmektedir.

Sorular ile ilgili önemli açıklama!

1. Harcanan efor: Bahçe makası ile yapılacak kesim işleminde katılımcıların kesim sırasında harcadıkları eforu ve zorlanmayı göz önünde bulundurarak değerlendirme yapması beklenmektedir.
2. Avuç içi sağlığını katılımcının ürün kullanım sırasında avucunda oluşan baskıya göre değerlendirmesi beklenmektedir.
3. Parmak sağlığını katılımcının ürün kullanım sırasında parmağında oluşan baskıya göre değerlendirilmesi beklenmektedir.

4. Bilek saęlıęı: Bahe makası kullanımı sırasında dalın kesilmesi ile aniden oluřan kapanma sonucu bir řok kuvveti oluřmaktadır ve bu kuvvet bileęi etkilemektedir. Katılımcıların, rn kullanım sırasında bileęinde hissettikleri řok kuvvetine gre bilek saęlıęını deęerlendirmeleri beklenmektedir.
5. Kesim sırasında rnn elden kayıp kaymaması: Katılımcının rn kullanım sırasında rnn elden kayıp kaymamasına gre deęerlendirmesi beklenmektedir.
6. Kolay temizlenme: rnn sapına ve bıak kısmına bakarak tahmini olarak rnlerin kolay temizlenip temizlenmeyeceęini deęerlendirmesi beklenmektedir.
7. El konforunun sap malzemesine gre deęerlendirilmesi: Burada katılımcıdan, el konforunu, makasın sap malzemesine gre deęerlendirmesi beklenmektedir.



1.Makas/ Grubu ve numarası:

	<u>Çok Az</u>	<u>Orta Az</u>	<u>Az</u>	<u>Normal</u>	<u>Fazla</u>	<u>Orta Fazla</u>	<u>Çok Fazla</u>
<u>Harcanan Efor</u>	()	()	()	()	()	()	()

	<u>Çok Kötü</u>	<u>Kötü</u>	<u>Normal</u>	<u>İyi</u>	<u>Çok iyi</u>
Avuç İçi Sağlığı					
Parmak Sağlığı					
Bilek Sağlığı					
Sapın Kaygan Olmaması					
Kolay Temizlenme					
El Konforu (Sap malzemesine göre)					

2.Makas / Grubu ve numarası:

	<u>Çok Az</u>	<u>Orta Az</u>	<u>Az</u>	<u>Normal</u>	<u>Fazla</u>	<u>Orta Fazla</u>	<u>Çok Fazla</u>
<u>Harcanan Efor</u>	()	()	()	()	()	()	()

	<u>Çok Kötü</u>	<u>Kötü</u>	<u>Normal</u>	<u>İyi</u>	<u>Çok iyi</u>
Avuç İçi Sağlığı					
Parmak Sağlığı					
Bilek Sağlığı					
Sapın Kaygan Olmaması					
Kolay Temizlenme					
El Konforu (Sap malzemesine göre)					

3.Makas / Grubu ve numarası:

	<u>Çok Az</u>	<u>Orta Az</u>	<u>Az</u>	<u>Normal</u>	<u>Fazla</u>	<u>Orta Fazla</u>	<u>Çok Fazla</u>
<u>Harcanan Efor</u>	()	()	()	()	()	()	()

	<u>Çok Kötü</u>	<u>Kötü</u>	<u>Normal</u>	<u>İyi</u>	<u>Çok iyi</u>
Avuç İçi Sağlığı					
Parmak Sağlığı					
Bilek Sağlığı					
Sapın Kaygan Olmaması					
Kolay Temizlenme					
El Konforu (Sap malzemesine göre)					

4.Makas / Grubu ve numarası:

	<u>Çok Az</u>	<u>Orta Az</u>	<u>Az</u>	<u>Normal</u>	<u>Fazla</u>	<u>Orta Fazla</u>	<u>Çok Fazla</u>
<u>Harcanan Efor</u>	()	()	()	()	()	()	()

	<u>Çok Kötü</u>	<u>Kötü</u>	<u>Normal</u>	<u>İyi</u>	<u>Çok iyi</u>
Avuç İçi Sağlığı					
Parmak Sağlığı					
Bilek Sağlığı					
Sapın Kaygan Olmaması					
Kolay Temizlenme					
El Konforu (Sap malzemesine göre)					

5.Makas / Grubu ve numarası:

	<u>Çok Az</u>	<u>Orta Az</u>	<u>Az</u>	<u>Normal</u>	<u>Fazla</u>	<u>Orta Fazla</u>	<u>Çok Fazla</u>
<u>Harcanan Efor</u>	()	()	()	()	()	()	()

	<u>Çok Kötü</u>	<u>Kötü</u>	<u>Normal</u>	<u>İyi</u>	<u>Çok iyi</u>
Avuç İçi Sağlığı					
Parmak Sağlığı					
Bilek Sağlığı					
Sapın Kaygan Olmaması					
Kolay Temizlenme					
El Konforu (Sap malzemesine göre)					

6.Makas / Grubu ve numarası:

	<u>Çok Az</u>	<u>Orta Az</u>	<u>Az</u>	<u>Normal</u>	<u>Fazla</u>	<u>Orta Fazla</u>	<u>Çok Fazla</u>
<u>Harcanan Efor</u>	()	()	()	()	()	()	()

	<u>Çok Kötü</u>	<u>Kötü</u>	<u>Normal</u>	<u>İyi</u>	<u>Çok iyi</u>
Avuç İçi Sağlığı					
Parmak Sağlığı					
Bilek Sağlığı					
Sapın Kaygan Olmaması					
Kolay Temizlenme					
El Konforu (Sap malzemesine göre)					

7.Makas / Grubu ve numarası:

	<u>Çok Az</u>	<u>Orta Az</u>	<u>Az</u>	<u>Normal</u>	<u>Fazla</u>	<u>Orta Fazla</u>	<u>Çok Fazla</u>
<u>Harcanan Efor</u>	()	()	()	()	()	()	()

	<u>Çok Kötü</u>	<u>Kötü</u>	<u>Normal</u>	<u>İyi</u>	<u>Çok iyi</u>
Avuç İçi Sağlığı					
Parmak Sağlığı					
Bilek Sağlığı					
Sapın Kaygan Olmaması					
Kolay Temizlenme					
El Konforu (Sap malzemesine göre)					

8.Makas / Grubu ve numarası:

	<u>Çok Az</u>	<u>Orta Az</u>	<u>Az</u>	<u>Normal</u>	<u>Fazla</u>	<u>Orta Fazla</u>	<u>Çok Fazla</u>
<u>Harcanan Efor</u>	()	()	()	()	()	()	()

	<u>Çok Kötü</u>	<u>Kötü</u>	<u>Normal</u>	<u>İyi</u>	<u>Çok iyi</u>
Avuç İçi Sağlığı					
Parmak Sağlığı					
Bilek Sağlığı					
Sapın Kaygan Olmaması					
Kolay Temizlenme					
El Konforu (Sap malzemesine göre)					

9.Makas / Grubu ve numarası:

	<u>Çok Az</u>	<u>Orta Az</u>	<u>Az</u>	<u>Normal</u>	<u>Fazla</u>	<u>Orta Fazla</u>	<u>Çok Fazla</u>
<u>Harcanan Efor</u>	()	()	()	()	()	()	()

	<u>Çok Kötü</u>	<u>Kötü</u>	<u>Normal</u>	<u>İyi</u>	<u>Çok iyi</u>
Avuç İçi Sağlığı					
Parmak Sağlığı					
Bilek Sağlığı					
Sapın Kaygan Olmaması					
Kolay Temizlenme					
El Konforu (Sap malzemesine göre)					

10.Makas / Grubu ve numarası:

	<u>Çok Az</u>	<u>Orta Az</u>	<u>Az</u>	<u>Normal</u>	<u>Fazla</u>	<u>Orta Fazla</u>	<u>Çok Fazla</u>
<u>Harcanan Efor</u>	()	()	()	()	()	()	()

	<u>Çok Kötü</u>	<u>Kötü</u>	<u>Normal</u>	<u>İyi</u>	<u>Çok iyi</u>
Avuç İçi Sağlığı					
Parmak Sağlığı					
Bilek Sağlığı					
Sapın Kaygan Olmaması					
Kolay Temizlenme					
El Konforu (Sap malzemesine göre)					

11.Makas / Grubu ve numarası:

	<u>Çok Az</u>	<u>Orta Az</u>	<u>Az</u>	<u>Normal</u>	<u>Fazla</u>	<u>Orta Fazla</u>	<u>Çok Fazla</u>
<u>Harcanan Efor</u>	()	()	()	()	()	()	()

	<u>Çok Kötü</u>	<u>Kötü</u>	<u>Normal</u>	<u>İyi</u>	<u>Çok iyi</u>
Avuç İçi Sağlığı					
Parmak Sağlığı					
Bilek Sağlığı					
Sapın Kaygan Olmaması					
Kolay Temizlenme					
El Konforu (Sap malzemesine göre)					

Dördüncü Kısım

Anketin son kısmında, katılımcıdan ürünlerin kullanımından elde ettiği deneyime göre ikinci kısımda yaptıkları sıralamayı değiştirmek isteyip istemediği öğrenilmek istenmektedir.

Bahçe makası kullanım deneyiminden sonra kriterlerin önem düzeyi ile ilgili sıralamanızda bir değişiklik yapmak ister misiniz?

Evet_____

Hayır_____

Eğer değişiklik yapmak isterseniz yeni sıralamayı yapınız. (1 den 9'a kadar. 1 en önemli, 9 en önemsiz)

- Ürün sağlamlığı _____
- El, kol, bilek sağlığı _____
- El konforu _____
- Kullanım kolaylığı _____
- Harcanan efor _____
- Ürün işlevselliği _____
- Ürün fiyatı _____
- Ürünün garanti süresi _____
- Ürünün geri dönüştürülebilirliği _____

Anket burada sona ermiştir. Vakit ayırdığınız için çok teşekkür ederiz.

APPENDIX-4: Observers' Survey

	<u>Cok Az</u>	<u>Orta Az</u>	<u>Az</u>	<u>Normal</u>	<u>Fazla</u>	<u>Orta Fazla</u>	<u>Cok Fazla</u>
<u>Harcanan Efor</u>	()	()	()	()	()	()	()

	Çok Kötü	Kötü	Normal	İyi	Çok iyi
Bilek Sağlığı	()	()	()	()	()

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

Yes ()

No ()

Is the task performed with (select worse case situation)

An almost straight wrist? ()

A deviated or bent wrist? ()

APPENDIX-5: Participants Criteria Ranking Matrices

Criteria ranking before experiment	Criteria/ Participants	E 1	E 2	E 3	E 4	E 5	E 6	E 7	E 8	E 9	E 10	E 11	E 12	E 13	E 14	E 15	E 16	E 17	E 18	E 19	E 20	E 21	E 22	E 23	E 24	E 25	E 26	E 27	E 28	E 29
	C ₁ Durability	4	4	3	2	1	6	9	5	7	2	1	3	5	6	4	2	3	4	7	4	6	4	6	4	1	7	5	4	7
	C ₂ Health	5	3	7	6	6	2	1	4	3	1	4	4	2	2	7	3	2	7	4	5	2	6	5	3	2	1	1	6	4
	C ₃ Comfort	1	2	1	5	2	3	3	6	9	4	7	5	3	3	1	1	1	1	3	2	5	1	2	2	3	2	2	3	3
	C ₄ Usability (easy to use)	2	5	2	4	3	5	4	1	4	3	5	1	1	4	3	4	4	3	5	3	1	2	3	1	5	3	3	2	1
	C ₅ Effort	6	6	4	3	4	2	7	8	2	6	3	6	7	1	2	5	5	2	6	6	3	3	1	5	8	5	6	7	2
	C ₆ Functionality	7	1	6	7	5	4	8	2	8	5	2	2	4	5	5	7	6	5	1	1	4	7	4	6	4	6	7	1	5
	C ₇ Price/cost	2	7	5	1	7	7	2	3	6	7	6	7	6	7	6	6	7	6	2	7	7	5	8	7	6	4	4	5	6
	C ₈ Product guarantee/warranty	9	8	8	8	9	9	5	7	5	8	8	8	9	8	8	8	8	8	9	9	8	8	7	8	7	9	8	8	8
	C ₉ Environmental effect/recyclability	8	9	9	9	8	8	6	9	1	9	9	9	8	9	9	9	9	9	8	8	9	9	9	9	8	8	9	9	9

APPENDIX-5: Continues

Criteria ranking after experiment		Criteria/ Participants	E 1	E 2	E 3	E 4	E 5	E 6	E 7	E 8	E 9	E 10	E 11	E 12	E 13	E 14	E 15	E 16	E 17	E 18	E 19	E 20	E 21	E 22	E 23	E 24	E 25	E 26	E 27	E 28	E 29
	C 1	Durability	2	4	5	3	6	6	9	5	7	2	5	6	5	6	7	5	4	6	4	4	6	4	6	6	4	7	6	7	6
	C 2	Health	3	3	3	1	5	2	1	4	3	1	2	3	2	2	2	3	5	4	6	5	2	6	5	4	1	1	1	4	1
	C 3	Comfort	4	2	4	4	4	3	3	6	9	4	3	2	3	3	1	1	1	1	7	2	5	1	2	2	3	2	2	2	3
	C 4	Usability (easy to use)	5	5	1	6	1	5	2	1	4	3	4	4	1	4	3	2	2	3	1	3	1	2	3	1	2	3	3	1	4
	C 5	Effort	6	6	2	5	2	2	4	8	2	6	1	1	7	1	4	4	3	2	2	6	3	3	1	3	5	5	4	3	2
	C 6	Functionality	1	1	6	7	3	4	6	2	8	5	6	5	4	5	6	6	6	7	3	1	4	7	4	5	6	6	7	5	5
	C 7	Price/cost	7	7	7	2	7	7	5	3	6	7	7	7	6	7	5	7	7	5	5	7	7	5	8	8	7	4	5	6	7
	C 8	Product guarantee/warranty	8	8	8	8	8	9	7	7	5	8	8	8	9	8	8	8	8	8	9	9	8	8	7	7	8	9	8	8	8
	C 9	Environmental effect/recyclability	9	9	9	9	9	8	8	9	1	9	9	9	8	9	9	9	9	9	8	8	9	9	9	9	9	8	9	9	9

APPENDIX-6: Correlations between Likert Questions

Correlations								
		Effort	Palm_Health	Finger_Health	Wrist_Health	Slippery	Easy_to_clean	Comfort_material
Effort	Pearson Correlation	1	.730**	.687**	.670**	.601**	.600**	.671**
	Sig. (2-tailed)		0	0	0	0	0	0
	N	32	32	32	32	32	32	32
Palm_Health	Pearson Correlation	.730**	1	.855**	.781**	.723**	.558**	.748**
	Sig. (2-tailed)	0		0	0	0	0.001	0
	N	32	32	32	32	32	32	32
Finger_Health	Pearson Correlation	.687**	.855**	1	.853**	.606**	.578**	.701**
	Sig. (2-tailed)	0	0		0	0	0.001	0
	N	32	32	32	32	32	32	32
Wrist_Health	Pearson Correlation	.670**	.781**	.853**	1	.574**	.505**	.651**
	Sig. (2-tailed)	0	0	0		0.001	0.003	0
	N	32	32	32	32	32	32	32
Slippery	Pearson Correlation	.601**	.723**	.606**	.574**	1	.672**	.775**
	Sig. (2-tailed)	0	0	0	0.001		0	0
	N	32	32	32	32	32	32	32
Easy_to_clean	Pearson Correlation	.600**	.558**	.578**	.505**	.672**	1	.706**
	Sig. (2-tailed)	0	0.001	0.001	0.003	0		0
	N	32	32	32	32	32	32	32
Comfort material	Pearson Correlation	.671**	.748**	.701**	.651**	.775**	.706**	1
	Sig. (2-tailed)	0	0	0	0	0	0	
	N	32	32	32	32	32	32	32
**. Correlation is significant at the 0.01 level (2-tailed).								

APPENDIX-7: Observers' Wrist Health data versus Likert Questions Data

		Effort	Palm_Health	Finger_Health	Wrist_Health	Slippery	Easy_to_clean	Comfort_material	Wrist_obs
Wrist_obs	Pearson Correlation	.180	.286	.021	.013	.050	.052	-.070	1
	Sig. (2-tailed)	.324	.112	.909	.945	.786	.778	.704	
	N	32	32	32	32	32	32	32	32
**. Correlation is significant at the 0.01 level (2-tailed).									

APPENDIX-8: Correlations between Observers' Effort and Participants' Effort

Correlations			
		Effort	Effort_obs
Effort	Pearson Correlation	1	.824**
	Sig. (2-tailed)		.000
	N	32	32
Effort_obs	Pearson Correlation	.824**	1
	Sig. (2-tailed)	.000	
	N	32	32
**. Correlation is significant at the 0.01 level (2-tailed).			

APPENDIX-9: Gender Differences between Likert Questions

Group Statistics					
	Gender	N	Mean	Std. Deviation	Std. Error Mean
Effort	Man	15	4.27272727267	.526735059359	.136002407517
	Woman	17	3.41711229947	.679586365016	.164823903805
Palm_Health	Man	15	3.16363636367	.357414300720	.092283975626
	Woman	17	2.75935828882	.418997692892	.101621867334
Finger_Health	Man	15	3.35757575760	.351194061361	.090677916729
	Woman	17	2.93048128341	.524728788359	.127265424659
Wrist_Health	Man	15	3.18181818200	.303462894693	.078353782489
	Woman	17	2.93048128347	.440146261007	.106751148521
Slippery	Man	15	3.61212121213	.415841370658	.107369780215
	Woman	17	3.18716577541	.479400654856	.116271737468
Easy_to_clean	Man	15	3.29696969707	.340959592251	.088035388168
	Woman	17	3.04812834229	.469215151568	.113801390062
Comfort_material	Man	15	3.20606060600	.375562021447	.096969696969
	Woman	17	2.80748663094	.478766442884	.116117918471

APPENDIX-9: Continues

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Effort	1.854	0.183	3.94	30	0	0.855615	0.217159	0.412117	1.299112
			4.004	29.549	0	0.855615	0.21369	0.418922	1.292308
Palm_Health	1.345	0.255	2.915	30	0.007	0.404278	0.138675	0.121065	0.687491
			2.945	29.974	0.006	0.404278	0.137271	0.123923	0.684633
Finger_Health	1.581	0.218	2.667	30	0.012	0.427094	0.160159	0.100006	0.754183
			2.733	28.094	0.011	0.427094	0.156266	0.107047	0.747142

APPENDIX-9: Continues

Wrist_Health	Equal variances assumed	2.383	0.133	1.855	30	0.073	0.251337	0.135495	-0.02538	0.528054
	Equal variances not assumed			1.898	28.447	0.068	0.251337	0.13242	-0.01972	0.522395
Slippery	Equal variances assumed	0.126	0.726	2.661	30	0.012	0.424955	0.159714	0.098776	0.751135
	Equal variances not assumed			2.685	29.995	0.012	0.424955	0.158264	0.101736	0.748175
Easy_to_clean	Equal variances assumed	1.729	0.198	1.695	30	0.1	0.248841	0.146776	-0.05091	0.548597
	Equal variances not assumed			1.73	29.008	0.094	0.248841	0.143878	-0.04542	0.543102
Comfort_material	Equal variances assumed	0.421	0.521	2.594	30	0.015	0.398574	0.153626	0.084827	0.712321
	Equal variances not assumed			2.635	29.629	0.013	0.398574	0.151283	0.089451	0.707697

APPENDIX-10: Variance Test and One-way ANOVA Test Results

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Effort	1.542	3	28	.225
Palm_Health	.457	3	28	.715
Wrist_Health	2.570	3	28	.074
Comfort_material	.858	3	28	.474
Easy_to_clean	1.731	3	28	.183
Slippery	.624	3	28	.605
Finger_Health	2.615	3	28	.071

APPENDIX-10: Continues

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
Effort	Between Groups	9.106	3	3.035	10.621	.000
	Within Groups	8.002	28	.286		
	Total	17.107	31			
Palm_Health	Between Groups	1.478	3	.493	3.120	.042
	Within Groups	4.422	28	.158		
	Total	5.900	31			
Wrist_Health	Between Groups	.597	3	.199	1.297	.295
	Within Groups	4.295	28	.153		
	Total	4.892	31			
Comfort_material	Between Groups	3.027	3	1.009	7.282	.001
	Within Groups	3.881	28	.139		
	Total	6.908	31			
Easy_to_clean	Between Groups	2.494	3	.831	7.389	.001
	Within Groups	3.150	28	.112		
	Total	5.644	31			
Slippery	Between Groups	3.102	3	1.034	6.528	.002
	Within Groups	4.435	28	.158		
	Total	7.537	31			
Finger_Health	Between Groups	1.535	3	.512	2.367	.092
	Within Groups	6.051	28	.216		
	Total	7.586	31			

APPENDIX-11: Post- Hoc Test Results

Multiple Comparisons						
Dependent Variable: Effort						
Tukey HSD						
(I) Hand Size (J) Hand Size		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
M	S	.486513486253	.250612974770	.234	-.19773802009	1.17076499259
	XS	1.003108003094*	.231807594078	.001	.37020104537	1.63601496082
	XXS	1.599067598872*	.342402508504	.000	.66420206594	2.53393313181
S	M	-.486513486253	.250612974770	.234	-1.17076499259	.19773802009
	XS	.516594516841	.269400853022	.244	-.21895375100	1.25214278468
	XXS	1.112554112619*	.368892310528	.026	.10536316655	2.11974505869
XS	M	-1.003108003094*	.231807594078	.001	-1.63601496082	-.37020104537
	S	-.516594516841	.269400853022	.244	-1.25214278468	.21895375100
	XXS	.595959595778	.356383830042	.357	-.37707930121	1.56899849277
XXS	M	-1.599067598872*	.342402508504	.000	-2.53393313181	-.66420206594
	S	-1.112554112619*	.368892310528	.026	-2.11974505869	-.10536316655
	XS	-.595959595778	.356383830042	.357	-1.56899849277	.37707930121

*. The mean difference is significant at the 0.05 level.

APPENDIX-11: Continues

204

APPENDIX-11: Continues

Multiple Comparisons						
Dependent Variable: Easy_to_clean						
Tukey HSD						
(I) Hand_Size (J) Hand_Size		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
M	S	.006993006912	.157241755856	1.000	-.42232597948	.43631199330
	XS	.077700077769	.145442721579	.950	-.31940386873	.47480402427
	XXS	.976689976436*	.214833137415	.001	.39012857425	1.56325137862
S	M	-.006993006912	.157241755856	1.000	-.43631199330	.42232597948
	XS	.070707070857	.169029808601	.975	-.39079697241	.53221111412
	XXS	.969696969524*	.231453597654	.001	.33775653233	1.60163740672
XS	M	-.077700077769	.145442721579	.950	-.47480402427	.31940386873
	S	-.070707070857	.169029808601	.975	-.53221111412	.39079697241
	XXS	.898989898667*	.223605418857	.002	.28847743490	1.50950236243
XXS	M	-.976689976436*	.214833137415	.001	-1.56325137862	-.39012857425
	S	-.969696969524*	.231453597654	.001	-1.60163740672	-.33775653233
	XS	-.898989898667*	.223605418857	.002	-1.50950236243	-.28847743490
*. The mean difference is significant at the 0.05 level.						

APPENDIX-11: Continues

Multiple Comparisons						
Dependent Variable: Slippery						
Tukey HSD						
(I) Hand Size (J) Hand Size		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
M	S	.227772227670	.186579125854	.619	-.28164691966	.73719137500
	XS	.370629370718	.172578687552	.163	-.10056421783	.84182295927
	XXS	1.097902098051*	.254915615544	.001	.40190304180	1.79390115431
S	M	-.227772227670	.186579125854	.619	-.73719137500	.28164691966
	XS	.142857143048	.200566533745	.891	-.40475198598	.69046627207
	XXS	.870129870381*	.274637037031	.018	.12028518872	1.61997455204
XS	M	-.370629370718	.172578687552	.163	-.84182295927	.10056421783
	S	-.142857143048	.200566533745	.891	-.69046627207	.40475198598
	XXS	.727272727333*	.265324584805	.049	.00285394180	1.45169151287
XXS	M	-1.097902098051*	.254915615544	.001	-1.79390115431	-.40190304180
	S	-.870129870381*	.274637037031	.018	-1.61997455204	-.12028518872
	XS	-.727272727333*	.265324584805	.049	-1.45169151287	-.00285394180

*. The mean difference is significant at the 0.05 level.

APPENDIX-11: Continues

Multiple Comparisons						
Dependent Variable: Palm_Health						
LSD						
(I) Hand_Size	(J) Hand_Size	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
M	S	.073926073846	.186296606187	.695	-.30768522476	.45553737245
	XS	.348096347957	.172317367465	.053	-.00487977821	.70107247413
	XXS	.671328671179*	.254529620195	.013	.14994837937	1.19270896298
S	M	-.073926073846	.186296606187	.695	-.45553737245	.30768522476
	XS	.274170274111	.200262834228	.182	-.13604954576	.68439009398
	XXS	.597402597333*	.274221179342	.038	.03568597514	1.15911921953
XS	M	-.348096347957	.172317367465	.053	-.70107247413	.00487977821
	S	-.274170274111	.200262834228	.182	-.68439009398	.13604954576
	XXS	.323232323222	.264922828108	.233	-.21943748990	.86590213634
XXS	M	-.671328671179*	.254529620195	.013	-1.19270896298	-.14994837937
	S	-.597402597333*	.274221179342	.038	-1.15911921953	-.03568597514
	XS	-.323232323222	.264922828108	.233	-.86590213634	.21943748990
*. The mean difference is significant at the 0.05 level.						