



DEGREE PROJECT IN DESIGN AND PRODUCT REALISATION,
SECOND CYCLE, 30 CREDITS
STOCKHOLM, SWEDEN 2017

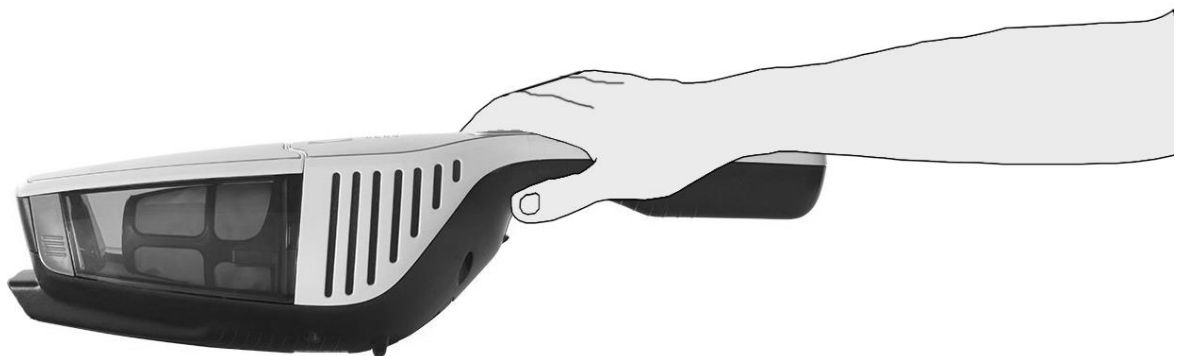
Ergonomic guidelines for designing handheld products

a case study of hand-held vacuum cleaners

LESYA ELAM

Ergonomic guidelines for designing handheld products a case study of handheld vacuum cleaners

Lesya Elam



Master of Science Thesis MMK 2017: 173 IDE 305
KTH Industrial Engineering and Management
Machine Design
SE-100 44 STOCKHOLM



KTH Industriell teknik
och management

Examensarbete MMK 2017: 173 IDE 305

Ergonomiska riktlinjer för design av handhållna produkter en case study av handhållna dammsugare

Lesya Elam

Godkänt 2018-05-	Examinator Claes Tisell	Handledare Stefan Ståhlgren
	Uppdragsgivare Electrolux AB	Kontaktperson Esbjörn Svantesson

Sammanfattning

För en industridesigner finns det inga detaljerade riktlinjer eller vägledningar för utformning av vardagliga produkter, men i varje hem finns ett antal konsumentprodukter som bör anpassas till användarens antropometri och fysik: från en vattenkokare till dammsugare och diskmaskiner. Att kalla en viss design "ergonomisk" är populärt men betyder inte nödvändigtvis att en produkt är utformad med avseende på belastningen i muskler, leder eller antropometriska mätningar. Begreppet ergonomi används ofta för att beskriva designval som inte tar hänsyn till konventionella ergonomiska metoder.

Syftet med detta examensarbete är att sammanfatta och utveckla riktlinjer för konstruktionen samt förbättringsförslag för utformningen av små handhållna produkter med ergonomi i fokus baserat på en studie av handdammsugare. Riktlinjerna är avsedda för att vara användbara för att designa andra liknande produkter för hushållsbruk, där ergonomi kan förbättra slutanvändarens komfortkänsla och bidra till mindre belastade positioner för handleden och underarmen.

De ergonomiska riktlinjerna för utformning av handhållna produkter utvecklades med Electrolux handdammsugare som huvudobjekt för studien och baseras på omfattande litteraturforskning och användarstudier som inkluderar kvantitativa undersökningar, kvalitativa intervjuer och mätstudier.



KTH Industrial Engineering
and Management

Master of Science Thesis MMK 2017: 173 IDE 305

**Ergonomic guidelines
for the design of handheld products
a case study of handheld vacuum cleaners**

Lesya Elam

Approved 2018-05-	Examiner Claes Tisell	Supervisor Stefan Ståhlgren
	Commissioner Electrolux AB	Contact person Esbjörn Svantesson

Abstract

For an industrial designer, there are no detailed guidelines or guides for designing everyday life products, yet in every home, there are a number of consumer products that should be adapted to the user's anthropometrics and physics: from an electric kettle to vacuum cleaners and dishwashers. To call a certain design "ergonomic" is popular but does not necessarily mean that a product was designed with regards to strain in muscles, joints or anthropometric measurements. The term "ergonomics" is often misused to describe design choices that do not take conventional ergonomic practices into account.

The purpose of this master thesis is to summarize and develop design guidelines as well as improvements for the design of small handheld products with ergonomics in focus based on a study of handheld vacuum cleaners. The guidelines are meant to be useful for designing other similar products for domestic use as well, where ergonomics can improve the comfort feeling of the end user and contribute to less heavily loaded positions of the wrist and forearm.

The Ergonomic guidelines for the design of handheld products were to be developed with Electrolux handheld vacuum cleaners as the main research subject and were based on extensive literature research and user studies including quantitative surveys, qualitative interviews, and measurement studies.

PREFACE

I would like to express my sincere gratitude towards all who helped me to make this master thesis project happen and all who volunteered to participate in the user studies and shared their insights during the interviews, tests and a survey.

I would especially like to thank Stefan Ståhlgren and Teo Enlund for their wisdom, inspiration, and guidance during this thesis and through the years at KTH. Additionally, I would like to thank Jörgen Eklund for inspiring me to study ergonomics and for all the help he provided during the project.

I would like to thank my industrial supervisor at Electrolux Esbjörn Svantesson for his guidance, support and for trusting me to choose the subject for this work freely.

Lesya Elam

Stockholm, October 2017

NOMENCLATURE

The list below presents used notations and abbreviations.

Notations

<i>Symbol</i>	<i>Description</i>
----------------------	---------------------------

<i>V</i>	<i>Volt</i>
<i>m</i>	Mass (Kg)
<i>T</i>	Torque (Nm)
<i>r</i>	Position (m)

Abbreviations

<i>B&D</i>	Black & Decker
<i>CM</i>	Centre of mass
MVC	Maximal Voluntary Contraction

TABLE OF CONTENTS

PREFACE	5
NOMENCLATURE	7
TABLE OF CONTENTS	8
1. INTRODUCTION	10

1.1	Background	10
1.2	Purpose	12
1.3	Delimitations	12
1.4	Research Design	13

| **2. FRAME OF REFERENCE** | **14** |

2.1	Dust	14
2.2	Cleaning Habits and Target Group	15
2.3	Anthropometry and Ergonomic Factors	16
2.4	Hand Tool Ergonomics	19

| **3. METHODOLOGY** | **23** |

3.1	Existing Product	23
3.2	Population and Anthropometric Data	25
3.3	Calculations for the Torque Load on the Wrist	26

| **4. USER STUDIES** | **29** |

4.1	Contextual Interviews	29
4.2	Survey	31
4.3	Clustering and a Customer Journey Map Scenario	34
4.4	MAXIMAL VOLUNTARY CONTRACTION	39

| **5. RESULT** | **42** |

5.1	Ergonomic design guidelines and recommendations	43
-----	---	----

| **6. DISCUSSION AND CONCLUSIONS** | **46** |

6.1	Discussion	46
-----	------------	----

REFERENCES

47

1. INTRODUCTION

This chapter contains the description of this Thesis project's background as well as descriptions of the project's purpose, delimitations and methods used.

1.1 Background

This section presents the history behind the origin of handheld vacuum cleaners worldwide and within Electrolux, in order to provide an insight to handheld vacuum cleaners as well as the case company. This section also gives a short background on the ergonomic perspective for this study.

1.1.1 Ergonomics in Product Design and Hand Tools

With origins in the Greek language, Ergonomics denote for “ergon” – work and “nomos” – law and is a growing field of research that stands for the science of work for all aspects of human activity (International Ergonomics Association, 2017). Ergonomics is applied in production, work environment, work safety, for preventing work-related musculoskeletal problems, management, and organization as well as product and process design.

For an industrial designer, there are no detailed guidelines or guides for designing everyday life products, yet in every home, there are a number of consumer products that should be adapted to the user's anthropometrics and physics: from an electric kettle to vacuum cleaners and dishwashers. Typical design work is often about creating products that “feel” good or possess an interesting design element. To call a certain design “ergonomic” is popular but does not necessarily mean that a product was designed with regards to strain in muscles, joints or anthropometric measurements. The term “ergonomics” is often misused to describe design choices that do not take conventional ergonomic practices into account.

This thesis will investigate who is the primary user for handheld vacuum cleaners and how the design can be adapted to the user. Based on this case study and extensive literature research, ergonomic guidelines for the design of handheld products will be developed with Electrolux handheld vacuum cleaners as the main research subject. Hand tools have existed as long as humans have: from early human primates using the hand tools for digging and cutting to the wide variety of commercial products for all kind of function we are used to today. The diversity and variation of the hand tools in the commercial products imply, along with other insights, that there is no optimal form yet found and that there is not enough research, testing, and evaluation available in this area (Kumar et al., 2008).

1.1.2 History of the Handheld Vacuum Cleaners

The first handheld cordless unit for vacuum cleaning was introduced to the market in 1974 as a part of Black & Decker's 4-product set. That set included a drill, a shrub trimmer, a lantern and a handheld vacuum cleaner called “Spotvac”: all made in the company's typical black and orange colours (Gantz, 2012), see Figure 1. All the products were powered by Ni-cad batteries placed in a detachable handle that could be attached to all four products. This set was meant to be sold to male users, and this product did not reach the typical customers of the cleaning industry.



Figure 1 Black & Decker's Mod 4 set of tools including the Spotvac handheld vacuum cleaner

Later, in 1979, B&D launched “Dustbuster,” the first cordless handheld vacuum cleaner, this time addressed to female users, see Figure 2. Major improvements were made from the Spotvac, both in engineering and industrial design regarding increasing power, battery time, changing the paper bag to plastic dirt cup and using an “Almond” color scheme; typical for all household products at the time (Gantz, 2012). This product was to become an icon for cleaning products as it was not made to be hidden in a closet, but to be constantly charged at plain sight and to be a part of the kitchen interior.



Figure 2 Dustbuster, B&D, 1979

1.1.3 Electrolux and Handheld Vacuum Cleaners: a Case Study

Electrolux AB is a leading developer and producer of products in home appliances, implementing thoughtfully designed solutions into homes. Electrolux has a wide range of products with a global distribution network. This Master Thesis is carried out for the Small appliances department. Small appliances stand for 7 percent of Electrolux' total sales and include products such as ordinary vacuum cleaners and handheld, cordless, battery empowered products for dust cleaning and accessories (Electrolux, 2017).

Handheld vacuum cleaners are popular for its mobility and easy access when cleaning up minor spills and crumbs. The product consists of two main parts: the first one containing the motor, fan, electronics and batteries and the second one containing the filter and dirt receptacle.

In 2004 the “Ergorapido” was launched, a stick cleaner 2-in-1 with a handheld unit (Electrolux, 2017). Later in 2006, it was followed by “Rapido,” a cordless handheld vacuum cleaner, see Figure 3 and 4.



Figure 3 Ergorapido 2016 Figure 4 Rapido 2016

These products were developed with growing urbanization in mind and a change in cleaning habits: a new need to clean smaller spaces following a growing compact living trend. Ergorapido and Rapido are the main objects used in user studies and measurements for this thesis project and serve as the main objects of study for the case study which this thesis is based upon.

1.2 Purpose

The purpose of this master thesis is to summarize and develop design guidelines and improvements for the design of small handheld products with ergonomics in focus based on a study of handheld vacuum cleaners. The guidelines are meant to be useful for designing other similar products for domestic use as well, where ergonomics can improve the comfort feeling of the end user and contribute to less heavily loaded positions of the wrist and forearm.

Electrolux handheld vacuum cleaners, which this study is based upon, are examined from biomechanical and ergonomic points of view as well as with a user experience perspective in favor of bringing two disciplines together: user studies, as part of product development and ergonomics.

1.3 Delimitations

This project was limited only to handheld units for vacuum cleaning. All evaluations were made with Electrolux' handheld vacuum cleaners of the models Ergorapido and Rapido. The focus group used both recent and older models as a part of the user studies.

The user studies were composed considering everyday use, storage, user experience, perceived comfort and discomfort for the use of handheld units. Extra attention was allocated to the handle and holding posture: the position of the wrist, overarm, forearm and shoulder, rotation of the wrist and whether or not users have experienced an increased load in the wrist joint.

For the biomechanical calculations and late-stage user studies, the choice of the handheld vacuum cleaner was limited to Ergorapido hand-unit only to gather data that accessibly could be compared.

1.4 Research Design

To develop the guidelines and improvements for the design of small handheld products, the first step is establishing the frame of reference where several areas of importance will be explored; mainly through an extensive literature review in relevant areas as well as through conducting an interview. First, research is made on the topic of dust as a way of understanding the role of the vacuum cleaner and the effects of dust are also investigated. Investigations on typical cleaning habits and the target group are also conducted in order to understand how and where the products are used. Lastly, the subjects of anthropometry and various ergonomic factors are presented as they are used later in the thesis.

The frame of reference is followed by the methodology where information needed to reach a further conclusion is gathered. The chapter starts by presenting some existing products currently on the market featuring a product autopsy on such a product to give a better understanding of the product. Further, followed by the gathering of the population- and anthropometric data to get an understanding the physical characteristics of a typical user. Consequently, to examine the load on the human wrist when using a handheld vacuum cleaner, calculations on the torque load on the wrist during usage were conducted.

The next part of the thesis consists of the user studies, beginning with contextual interviews where subjects were interviewed on their cleaning habits and perceptions on their handheld products. Followed by a quantitative survey targeting a larger number of users spanning 17 questions on several aspects such as their profile, cleaning habits, and product experience. The main insights gathered during the contextual interviews and the survey were then compiled into clusters in order to create a customer journey map; highlighting key comments and insights. Based on some of the interactions with the interview group and the survey results, a measurement study was conducted to measure the maximal voluntary contraction (MVC) to investigate further what users typically perceive as heavy.

The ergonomic guidelines for further product development are presented in the results section. The guidelines utilize the results obtained with the processes and methods described in the previous chapters.

Lastly, the results of the thesis are discussed and reflected upon in the next part where suggestions for future work and research are also discussed.

The writing process of the thesis was conducted continuously throughout the project. Furthermore, the thesis was designed using an iterative approach; improvements and changes to all chapters were conducted during the research process.

2. FRAME OF REFERENCE

This chapter presents a summary for the research of existing solutions, knowledge and research in three different fields: dust, existing products and ergonomics. A number of specialists were interviewed from different fields. A short summary of their insights is presented in the corresponding sections.

2.1 Dust

To understand what dust is and if any particles in it are dangerous, how they should be collected, what happens to them after the treatment plant purification and whether there is an impact on human health, a literature review and an interview were conducted.

2.1.1 What is Dust?

Dust collecting is one of the primary targets in home cleaning. Dust is a broad designation for a range of different particles. The household dust mostly consists of dead, rejected skin cells from humans and animals, but depending on the household's activities it can also contain paper fibers, fibers from fabrics, construction materials, insect residues, pollen grains, and fungus. In an average room with normal activity, the amount of dust varies from 0,05 to 1,00 mg/m³ (Illustrerad vetenskap, 2017).

Swedish wastewater treatment plants recommend collecting the dust dry and dispose it as household waste instead of rinsing the dust off with water. This is claimed due to dangerous particles from electronics, plastic, furniture, and textiles that attaches to the dust. (Stockholm vatten och avfall, 2015).

2.1.2 Interview with an Expert – Dust as a Part of Wastewater

Stockholm Vatten och Avfall, Stockholm Water and Waste, is the largest water and waste management company in Sweden, working continuously with environmental requirements and sustainable waste treatment for the city of Stockholm.

An environmental chemist Cajsa Wahlberg from Stockholm Water and Waste was interviewed about the dust, its collection, treatment as well as the environmental and health impact.

The full interview can be found in Appendix A, the main insights from the interview were:

- Dust contains dangerous particles: heavy metals and organic compounds from flame retardants, electronics, textiles, construction materials, floor, etc.
- When collected dry, the dust and the particles in it are incinerated with the rest of the household waste. With wet cleaning, all the particles from the dust end up in the wastewater.
- All the particles from the dust water can be purified and end up in the sludge.
- Swedish water and waste treatment plants are selling the sludge to agriculture and mining industries and want to sell as clean sludge as possible.
- There is no information about crops absorbing heavy metals from the sludge when it is used as fertilizer.
- The most dangerous particles are being banned by the EU-legislation, but new chemicals and treatment methods are being developed all the time, and it takes time to evaluate the eventual danger and ban the substance.

2.2 Cleaning Habits and Target Group

According to Statistics Sweden (Statistiska centralbyrån) women spend less time cleaning at home and men spend in average more in Sweden in statistics from 1990 to 2010 (Statistiska centralbyrån, 2010). Figure 5 presents how many minutes men and women spend on average per weekday, for cleaning that does not include dishwashing, laundry or household maintenance. Even though men's time for cleaning has increased and women's has declined, women still clean at a much higher rate.

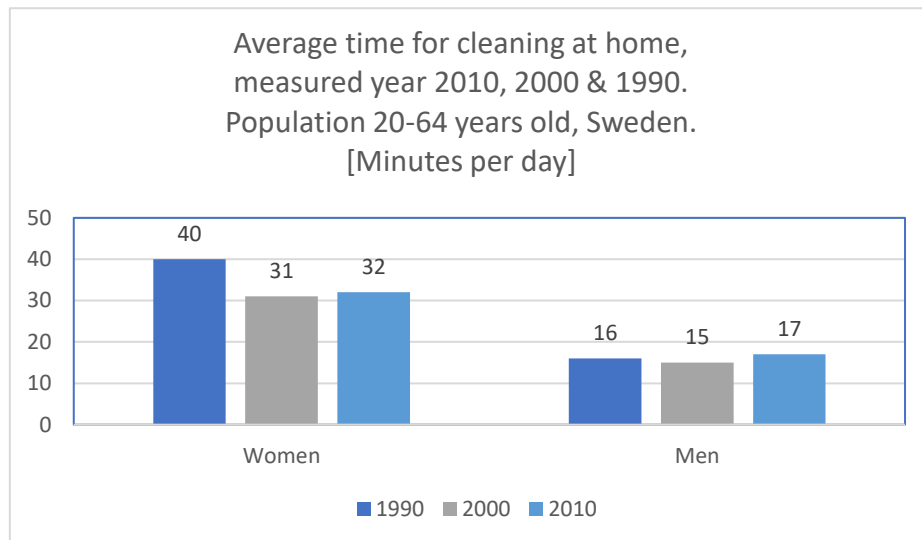


Figure 5 Minutes spent cleaning on an average weekday by men and women in Sweden

How much people clean also depends on their age, living status whether they live alone or cohabiting with a partner, if they have children living at home. Figure 6 below represents statistics from 2010/2011 for a variety of different families in Sweden (Statistiska centralbyrån, 2011). This chart does not have enough data about single male parents cleaning habits, thus left blank.

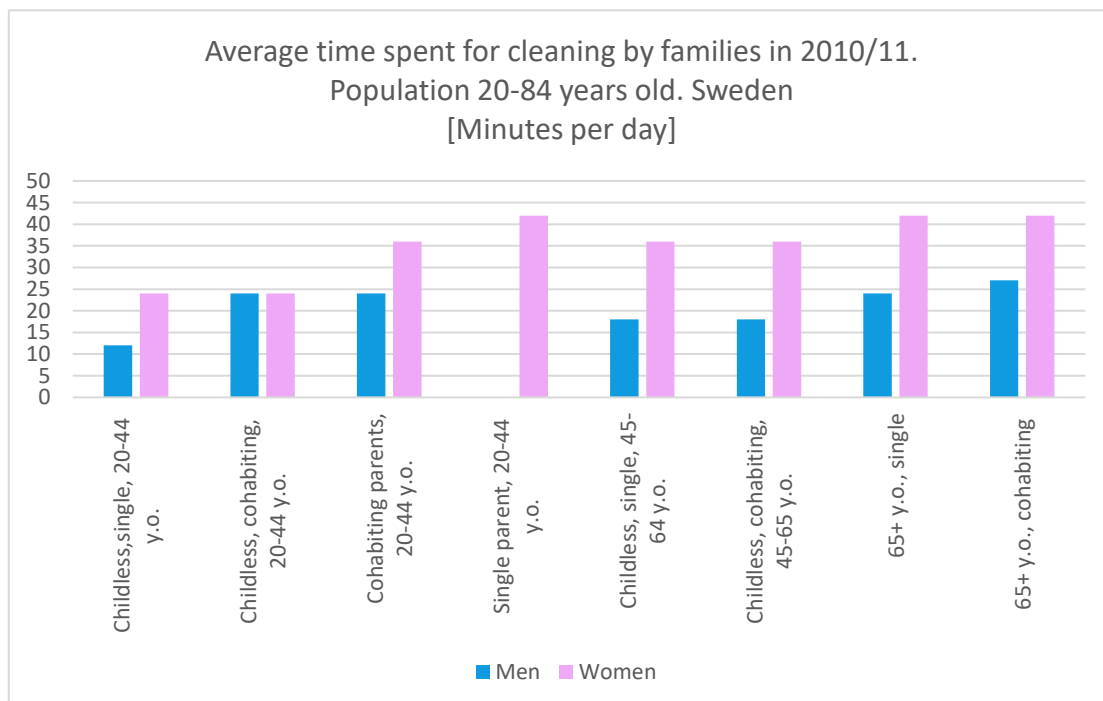


Figure 6 Minutes spent cleaning on an average day (all days of the week) by men and women of different age groups and different family set ups in Sweden

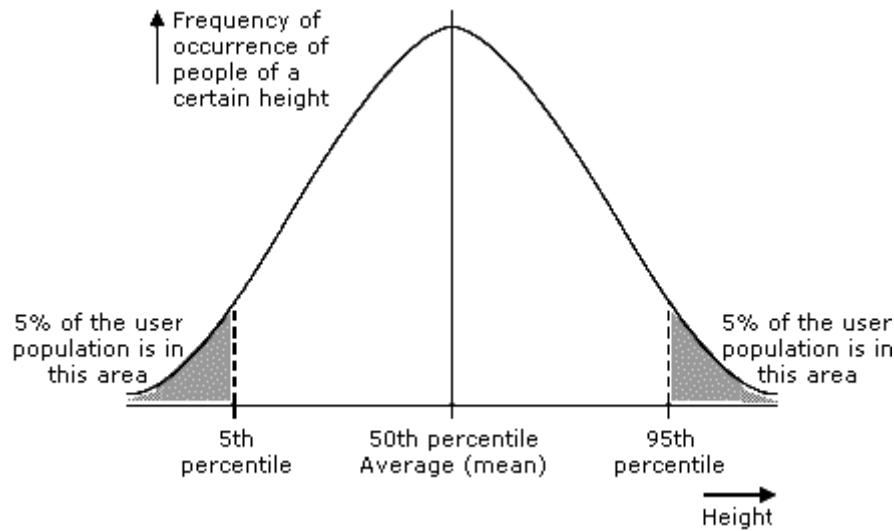


Figure 8 Percentile graph over populations height (Worthy, u.d.)

When applying anthropometry, certain conditions should be met. When designing for a better movement space, accounting for the largest 95th percentile is often used to accommodate for individuals that are larger than average as the largest individuals have more demand for movement space and dimensions. Similarly, when designing for better reach options, the shortest individuals should be prioritized, taking a minimum reach distance into account where it also is advisable to use the 5th percentile so that 95 percent of the population will be able to reach a certain point.

The target user population's measurements are often unknown including both women and men with a large variation in measurements. The large variation increases the need for adjustability of the design with target percentiles of the 5th to the 95th percentile. Note that this would, for example, exclude 10 percent of the population, who would not fit in. However, during certain situations requiring various adaptations to fit a certain population group as well as with certain technical or economic conditions the target percentiles may have to be adjusted to higher or lower levels (Abrahamsson et al., 2015).

2.3.2 Age and Gender's Effect on Grip Strength

The strength of a grip, as well as the strength of other parts of human body, is affected by the age and gender of the user. Grip strength increases during childhood and young adulthood until reaching a maximum level at about 25 to 35 years old individuals. The strength level is relatively stable until about 50 years of age where it begins to decline at an exponential pace. Because of this decline, 60 to 80-year-old individuals are about as strong as 11 to 15-year-old children, and 80-90-year-old individuals are about as strong 6 to 10-year-old children (Kumar et al., 2008). Because of the loss of hydration, older peoples' skin is generally smoother on the hands, and elderly population tends to apply greater gripping force to prevent objects from slipping to compensate for the loss of friction in their hands (Kumar et al., 2008).

Gender also plays a role in grip strength. The differences are small in children but are accentuated in adulthood. Generally, females possess about 50 to 67 percent of the strength of males (Konz, 1990) or even 50 to 80 percent of muscle strength, with the biggest difference in the upper extremities, such as the strength of a handgrip (Abrahamsson et al., 2015). This gender difference seems to be mainly because of differences in hand size and musculature. Women have smaller body size than men. Average for different body parts measurements do not differ by percentage since women have another body shape than men. For example, the percentage difference for the hand width is greater than a difference in hand length (Abrahamsson et al., 2015).

Differences in muscle strength for different age and gender individuals can be presented as in Figure 9:

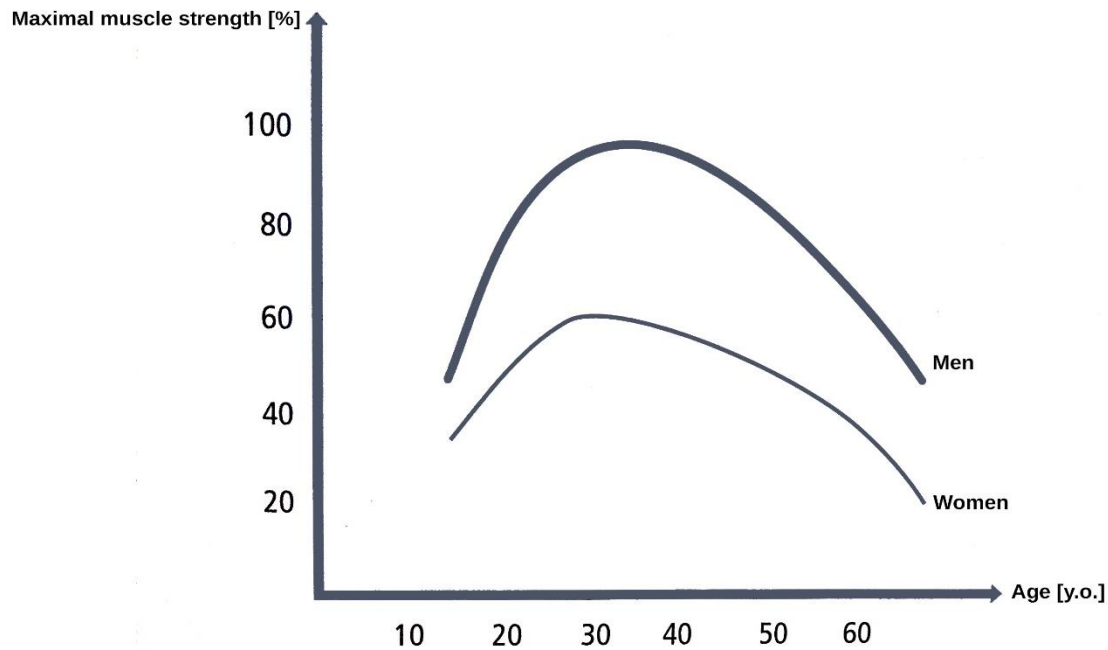


Figure 9 Muscle strength depending on age and gender (Grandjean, 1988)

2.3.3 Wrist and Forearm Positions

Movement of the hand and forearm can be described with following anatomic terms, see also Figure 10, (Abrahamsson et al., 2015):

- **Flexion** is a joint bend towards the body
- **Extension** is a stretch of the joint out from the body
- **Supination** is rotational movement outwards
- **Pronation** is rotational movement inwards
- **Radial deviation** is a lateral rotation towards the thumb
- **Ulnar deviation** is a lateral rotation towards the little finger

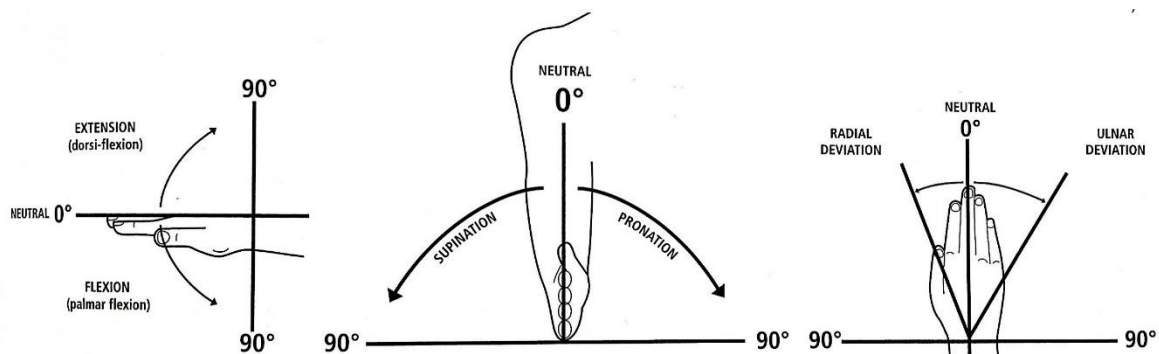


Figure 10 Terms for the hand and forearm movement (Abrahamsson et al., 2015)

The range of flexion for the wrist joint is greater than the range for an extension. The recommended wrist orientation is where the wrist position is slightly leaning forward, and the forearm is close to its neutral position with no supination or pronation. The optimal wrist position can be described as a straight orientation such as in a handshake (Kumar et al., 2008), as shown in Figure 11. If

bending is required for the use of the tool, then it is the tool rather than the wrist that should bend (Tichauer & Gage, 1977).

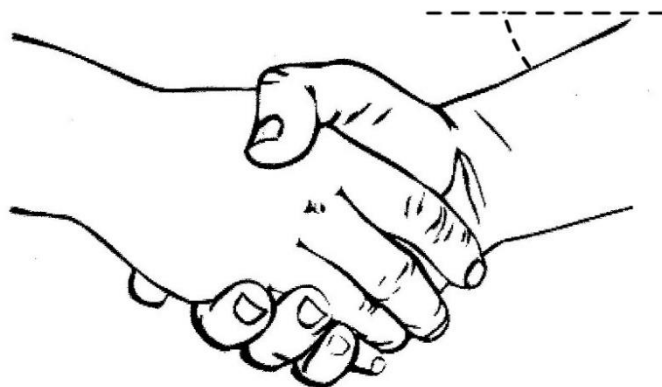


Figure 11 Wrist position in a handshake has the optimal orientation

According to (C. Pryce, 1980) (Hazelton, et al., 1975) (P.Kattel, et al., 1996) (Kumar et al., 2008), the wrist and forearm postures influence the grip strength of the hand. The majority of them sort the position from strongest to weakest in following order: neutral, ulnar and radial deviation, extension (dorsiflexion) and flexion (palmar flexion). For the extension of the wrist to make an impact on the strength the angle should be noticeable: greater than 30 degrees, as a result of the wrist resting position occurs when the wrist is approximately 35 degrees in the extension (Taylor & Schwartz, 1955).

The forearms pronated or supinated positions were not found to make an appreciable impact on the grip strength (Kumar et al., 2008). However, the deviation of the wrist still is one of the major factors that affect a decrease in grip strength.

2.4 Hand Tool Ergonomics

Hand tools can be shaped and utilized with several dimensions and grips. This section presents the main ways we as humans use hand tools and describes how they can be made with desirable characteristics in mind.

2.4.1 Power Grip and Precision Grip

Grasping of objects can be described by covering the variation of two grip types for a human hand activity: power grip and precision grip. The power grip involves a grasp with the palm of the hand and force from the thumb countered by force of the other fingers. The precision grip is a grip between the thumb and one or two other fingers of the palm (Napier, 1956). Figures 12 and 13 show a selection of different phases for both grips.

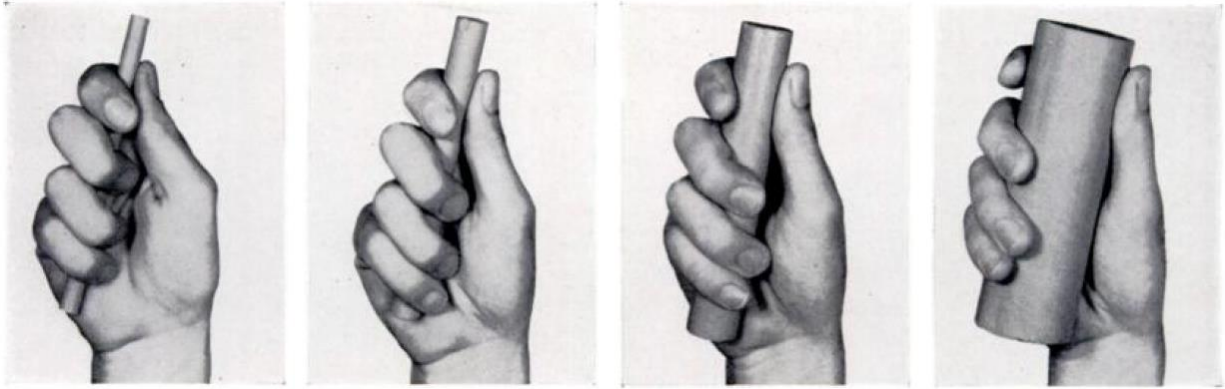


Figure 12 "An arbitrarily chosen series of postures illustrating some of the phases of the power grip complex." (Napier, 1956)

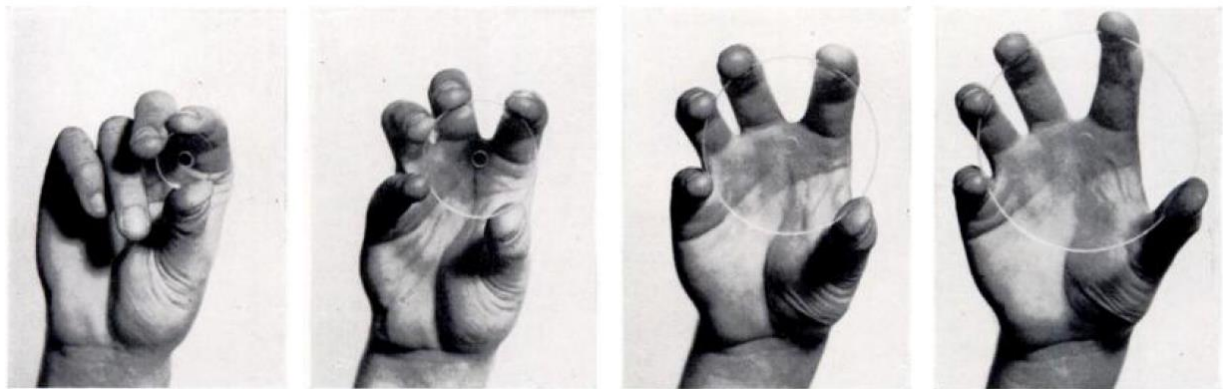


Figure 13 "An arbitrarily chosen series of postures illustrating some of the phases of the precision grip complex." (Napier, 1956)

Power grip is always to be preferred to a precision grip when a larger muscular force must be applied to hold the object (Kumar et al., 2008).

Among the most important factors that can influence the force required for the power grip are the intended activity and object itself: its size, weight, and shape. There is a classification of the power grips, where the power grip can be described as (Kumar et al., 2008):

- i. Spherical grasp used on spherical, boll shaped objects
- ii. Cylindrical grasp around an objects circumference, for example, screwdriver handle
- iii. Disc grasp, for example, jar lid
- iv. Hook grasp where the handle is hooked by index, middle, ring and little fingers but not opposed to the force from the thumb

The precision of the power grip relies on the position of the thumb. Where there is little or none need for precision, the thumb wraps around the digits to help contribute to the grip force of the rest of the fingers, see Figure 14.



Figure 14 An example of a power grip posture, where precision is not required or demand for precision is insufficient (Napier, 1956).

If there is a demand for precision for an object held in a power grip, the thumb changes its posture to control the direction of the force applied. Figure 15 illustrates an example with a power grip, where precision plays an important part: the thumb is no longer in position over the digits but instead applies its force to the tool.

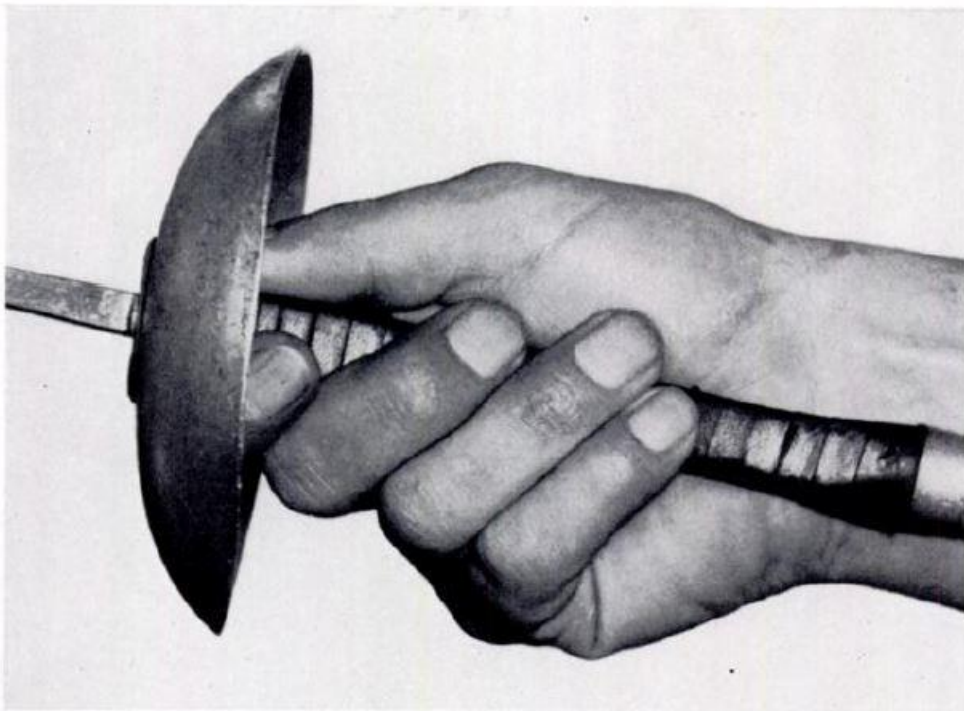


Figure 15 An example of a power grip where precision is important (Napier, 1956)

A general conclusion in (Napier, 1956) is if a higher force is required of the whole hand to hold an object in a power grip, the more thumb enforced to act as a reinforcement for the grip itself and is less capable of helping to achieve the precision required.

2.4.2 Dimensions for Handles

When it comes to the size of the grip, there is no coherent conclusion in the published studies. The reason for it is that variety of test procedures, sample, and method, are too diverse to be summarized to an optimum grip span (Kumar et al., 2008).

Atlas Copco recommends in their book *Verktygsergonomi* the optimum range for the length of a handle for their tools as (Lindqvist, 1998):

For women: Approximately from 90 to 110 mm, but not less than 80 mm.

For men: Approximately from 100 to 130 mm, but not less than 90 mm.

The diameter of a handle is one of the key parameters that affect user's ability to apply force. For a cylinder, shaped handles the recommendations are following (Lindqvist, 1998):

Power grip:

For women: 34 mm

For men: 38 mm

Acceptable range: 34 to 45 mm

For precision grip, it is 12 mm, but a range between 8 and 16 mm is acceptable. Another study suggests a range of 30-50 mm as the optimal diameter for cylinder shaped handles hold with a power grasp (Pheasant & O'Neill, 1975). The same study showed that when gripping a handle with a very large diameter causes a decline in torque ability.

Grip surface is another factor that affects the grips comfort and perception of hand fatigue. Foam rubber has been proved to show a decrease the hand's fatigue when used on hand tools handles (Fellows & Freivalds, 1991).

Overall the hand size should regulate the dimensions of the handle, and extra attention should be paid to the hand measurements depending on the population that will be using the tool and their anthropometric data.

3. METHODOLOGY

This chapter starts by presenting existing products that are currently on the market, including a product autopsy on such a product to give a better understanding of the product. This is followed by the gathering of population- and anthropometric data to get an understanding the physical characteristics of a typical user. To examine the load on the human wrist when using a handheld vacuum cleaner, calculations on the torque load on the wrist during usage were conducted.

3.1 Existing Product

The complete range of the current Electrolux' cordless vacuum products was tested briefly in an Electrolux Home store. Two models Rapido and Ergorapido were chosen to buy to be used by the author during the 20 weeks given for this master thesis project to make self-observations and potentially find problem areas thesis before moving forward to user studies.

Modern vacuum cleaners no longer measure its effectiveness in Watt as they were before, but nowadays it is the battery power that matters for the cordless vacuum cleaners, measured in Volt. The amount of Volt has an impact on how powerful the tool is and how long it lasts. The ultimate goal is to have a high-performance product, that can work for a long time without needing to recharge.

Rapido vacuum cleaners are sold with a variety of battery capacities with different performance levels of the Rapido-model from 4.8 volts to 14.4 volts and the latest and most powerful (also most heavy) model Rapido ZB6114BO was bought. For the Ergorapido model, the latest and most powerful available model was bought as well Ergorapido ZB3225POW with 19 V battery power.

Even though both products were tested, this thesis's case is built on Ergorapido hand-unit do to the company's bigger interest in further development of the Ergorapido model.

3.1.1 Product autopsy – Ergorapido Handheld Unit

Product autopsy is a method that gives a better understanding of the product, its components, materials used, how it was manufactured and how the technique and manufacturing requirements have affected the design of the shape and form of the product. Product autopsy can also provide knowledge about how well a product has functioned, how it has aged and if the product fulfills its initiate purpose it was designed for (Milton & Rodgers, 2013).

The Rapido model consists of two main parts, see Figure 16 and 17: a forepart container and rear part with motor, fan, batteries, and electronics (User manual, Electrolux, 2017).

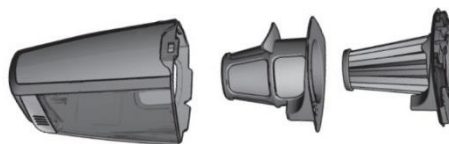


Figure 16 The forepart with the filters and dust container for Ergorapido

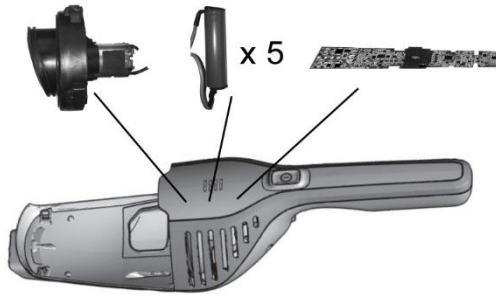


Figure 17 The bottom part with motor, fan, batteries, and electronics.

List of components was simplified to larger parts only to facilitate the biomechanical calculations further on. In Table 1 the main components, their weight, and approximate distance from their centre of mass to the end of the handle furthest out. Besides the components shown in Figure 16 and 17, the Ergorapido hand-unit sells with one of two nozzles: Bed Pro UV nozzle and Pro nozzle, see Figure 18. Calculations were made for the Bed Pro UV nozzle as the newest nozzle model for this product.



Figure 18 To the left: Pro nozzle, to the right: Bed Pro UV nozzle (Electrolux. 2017)

Table 1 Main components of the Ergorapido

Number	Component	Quantity	Total weight [g]	CM distance [cm]
1.	Forepart with filters	1	$m_1 = 230 \text{ g}$	$r_1 = 34 \text{ cm}$
2.	Motor and fan	1	$m_2 = 300 \text{ g}$	$r_2 = 27 \text{ cm}$
3.	Batteries in the core part	3	$m_3 = 180 \text{ g}$	$r_3 = 24 \text{ cm}$
4.	Batteries in the handle	2	$m_4 = 120 \text{ g}$	$r_4 = 5 \text{ cm}$
5.	Bottom part inclusive electronics	1	$m_5 = 310 \text{ g}$	$r_5 = 22 \text{ cm}$
6.	Bed Pro nozzle	1	$m_6 = 360 \text{ g}$	$r_6 = 51 \text{ cm}$
Total without nozzle			1140g = 1.14 kg	24 cm = 0.24 m
Total with a nozzle			1500g = 1.5 kg	31 cm = 0.31 m

Centre of mass for the Ergorapido hand unit was calculated with the formula:

$$R_{CM} = \frac{m_1 r_1 + m_2 r_2 + m_3 r_3 + m_4 r_4 + m_5 r_5}{m_1 + m_2 + m_3 + m_4 + m_5}$$

First, a centre of mass for the Ergorapido hand unit was calculated without the nozzle or any other accessories according to the formula above to 0.24 m.

The centre of mass for the Ergorapido hand unit with a Bed Pro UV nozzle was calculated using the same formula with added weight and distance for the Bed Pro UV Nozzle to 0.31m.

The distance to the centre of mass after first observations and calculations appear to be too far out from the handle, See Figure 19 and 20, and its impact on the human body will be further investigated in the next chapter. In the same way, the centre of mass for the bottom part inclusive electronics, batteries, motor, and the fan was calculated to 0.22 m, as it might be of use for the biomechanical calculations.

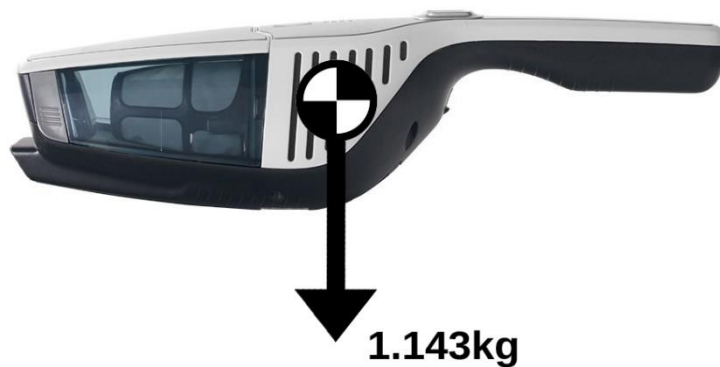


Figure 19 Illustration for the centre of mass position

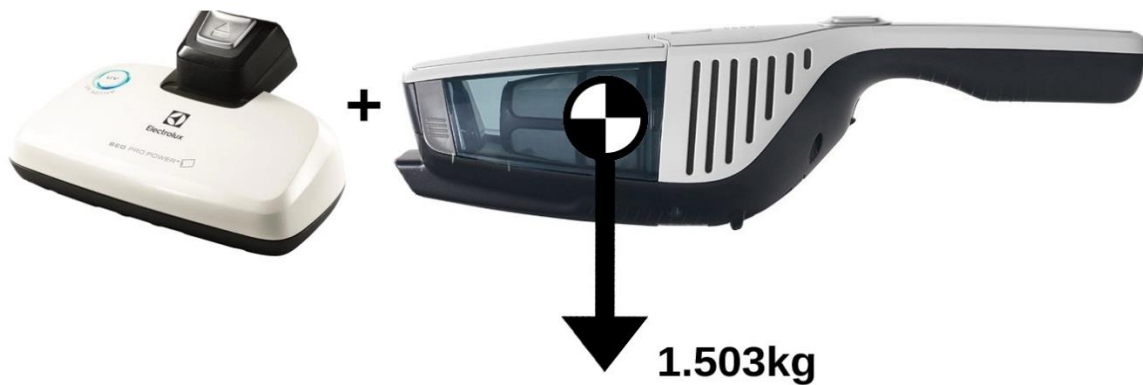


Figure 20 Centre of mass position with the nozzle attached

3.2 Population and Anthropometric Data

Ergorapido is a product that is sold worldwide to different populations that have contrasting anthropometric data. For this case study, two populations were chosen to be compared Sweden, and Hong Kong, China to represents both the European and Asian users' needs and body data. However, to design a perfect product, its dimensions should be adapted to each population group that the product is sold to.

For the biomechanical calculations, an average user was assumed to be from Hong Kong, China so that the later developed guidelines first and foremost would fit for smaller and shorter users with smaller hands and less muscular force. The goal is to calculate what impact does the product on the human body with its given dimensions and to investigate which dimensions and changes can lead to less fatigue for the end user and higher experience of comfort after using the Ergorapido handheld vacuum cleaner.

The data output from ALBA-programme that was developed at School of Technology and Health at KTH is presented in Figure 21:

Adults body mass [kg]	men				women			
	5%	50%	95%	sd	5%	50%	95%	sd
1. Sverige					48,3	59,3	70,2	6,7
2. England	55,3	74,5	93,7	11,7	44,1	62,5	80,9	11,2
3. USA	55,2	78,4	101,6	14,1	40,5	64,7	88,9	14,7
4. Frankrike	58,2	73,2	94,6	11,0	46,5	58,0	78,0	10,0
5. Tyskland	59,4	76,2	95,7	11,7				
6. Japan	46,1	60,2	74,3	8,6	39,8	51,3	62,8	7,0
7. Indien		49,2				43,5		
8. Hongkong (kineser)	46,6	59,9	75,3	8,6	38,5	47,1	61,8	7,2

Figure 21 Anthropometric data from ALBA database for body mass weights for adults from different countries

3.3 Calculations for the Torque Load on the Wrist

Biomechanical calculations presented below was conducted to examine the load on the human wrist when using a handheld vacuum cleaner. As a base for these calculations data from section 3.1 and population from section 3.2 was taken, presented in Table 1. Wrist position was set to be 7 cm from the end of the handle as the most suitable place to hold; it is marked with a cross in Figure 22.

The weight of the hand and forearm was calculated based on weight for 50 percentile Chinese women from Hong Kong which is equivalent to the average value for this population. The data was taken from ALBA database and cross-referenced with data on anthropometric estimates for Hong Kong Chinese industrial workers (Pheasant, 2003) and set to 47.1 kg.

According to (Plagenhoef, et al., 1983) the weight for different parts of the body is presented as a percentage of the total body weight for males and females in Table 2 and Table 3 presents percentages of segment length from the corresponding segments proximal ends.

Table 2 Data on the percentage of total body weight (Plagenhoef, et al., 1983)

Percentages of Total Body Weight			
Segment	Males	Females	Average
Head	8.26	8.2	8.23
Whole Trunk	55.1	53.2	54.15
Thorax	20.1	17.02	18.56
Abdomen	13.06	12.24	12.65
Pelvis	13.66	15.96	14.81
Total Arm	5.7	4.97	5.335
Upper Arm	3.25	2.9	3.075
Forearm	1.87	1.57	1.72
Hand	0.65	0.5	0.575
Forearm & Hand	2.52	2.07	2.295
Total Leg	16.68	18.43	17.555
Thigh	10.5	11.75	11.125
Leg	4.75	5.35	5.05
Foot	1.43	1.33	1.38
Leg & Foot	6.18	6.68	6.43

Table 3 Percentages of Segment Length (Plagenhoef, et al., 1983)

Percentages of Segment Length from proximal ends			
Segment	Males	Females	Average
Head and Neck	55	55	55
Trunk	63	56.9	59.95
Thorax	56.7	56.3	56.5
Abdomen	46	46	46
Pelvis	5	5	5
Upper Arm	43.6	45.8	44.7
Forearm	43	43.4	43.2
Hand	46.8	46.8	46.8
Thigh	43.3	42.8	43.05
Leg	43.4	41.9	42.65
Foot	50	50	50
Abdomen & Pelvis	44.5	39	41.75

Data from Table 3 were combined with anthropometric data from (Pheasant, 2003) for anthropometric estimates for Hong Kong Chinese industrial workers to calculate the position of the centre of mass of the hand and forearm for the 50-percentile female. The positions were estimated to be 80 mm from the wrist joint's position for the hand and 130 mm from the wrist for the forearm, but in the opposite direction than the applied weight of the hand and the handheld vacuum cleaner parts.

With data from Table 2 mass of the hand and forearm were calculated for an average Chinese woman from Hong Kong and presented in Table 4. Vertical forces that apply to the components of the system were calculated with the formula:

$$F = mg$$

Where g stands for gravitational acceleration and is equal to 9.82 in Sweden, where this thesis is written.

Table 4 Data for biomechanical calculations

Title	Mass [g]	Position [cm]	Vertical force [N]
Hand	$m_{hand} = 235$ g	8 cm	$F_{hand} = 2.31$ N
Forearm	$m_{forearm} = 739$ g	13 cm	$F_{forearm} = 7.26$ N
Ergorapido bottom part	$m_{bottom} = 910$ g	22 cm	$F_{bottom} = 8.94$ N
Ergorapido top forepart with the dust container	$m_{top} = 233$ g	34 cm	$F_{top} = 2.29$ N
Bed Pro UV nozzle	$m_{nozzle} = 360$ g	51cm	$F_{nozzle} = 3.54$ N

Some assumptions and simplifications were applied according to (Abrahamsson et al., 2015):

- Body segments are regarded as rigid bodies
- The joints are frictionless, friction coefficient in a normal joint is 0.005
- Mechanical equilibrium prevails
- The importance of support forces is simplified

The data from Table 4 and arguments the from above about the different components' position and acting forces in relation to the wrist can be represented by the model in Figure 22.

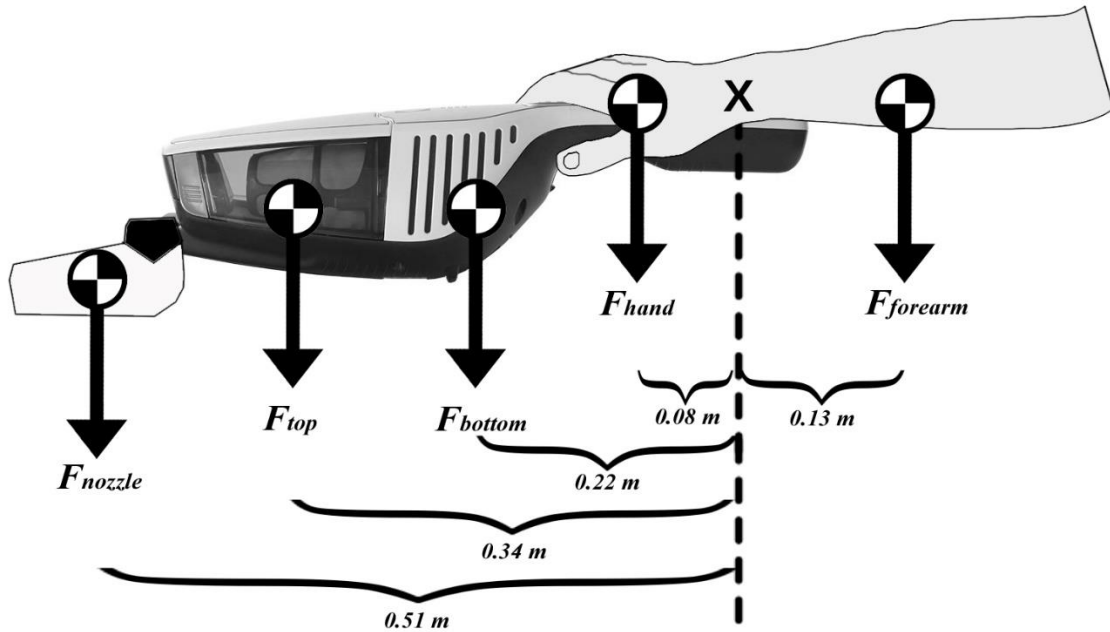


Figure 22 Forces applied on the wrist during the use of Ergorapido hand unit with a Bed Pro nozzle on

The corresponding equation that describes this model, if mechanical equilibrium is assumed, can be formulated as follows:

$$F_{nozzle} \times 0.51 + F_{top} \times 0.34 + F_{bottom} \times 0.22 + F_{hand} \times 0.08 - F_{forearm} \times 0.13 = T_{wrist}$$

The theoretical torque in the wrist joint based on anthropometric data was therefore calculated to be $T_{wrist} = \underline{\underline{3.8 \text{ Nm}}}$.

4. USER STUDIES

To archive an understanding of users' needs and issues for the given product this user study was carried out with interviews with a focus group and a survey.

For all user studies in this thesis at least 6 participants have been asked to engage in the studies to discover all of the high priority problems. A study in the Human factors field has previously investigated how many subjects is enough for revealing high and low priority problems in a usability evaluation: with groups of 5 participants all the high priority problems were discovered by the participants, and about 55 percent of low priority problems were discovered (Virzi, 1992). A quantitative study in the form of a survey was also conducted to prove that all major and most of the minor issues were discovered in the contextual interviews and reflected a typical user experience using a handheld vacuum cleaner.

4.1 Contextual Interviews

For contextual interviews home visits were made to each of the participants. Six participants engaged: four females and two males, age 20-63 y.o., all of them living in the suburban areas of Stockholm with their families, as presented in Figure 23. First, a participant was asked semi-structured questions about themselves, their home and their cleaning habits.



Figure 23 Participants for contextual interview: their age, gender, living area and cleaning habits

A typical use of a handheld vacuum cleaner for the interviewed group was:

- 1-10 minutes every day
- 10-15 minutes at major cleaning
- 20 minutes or until the battery dies during car cleaning and similar

After, interviewees were asked to demonstrate how they use their handheld units in everyday life and perform all the tasks that they are usually doing when cleaning with the hand unit. Some of the most common tasks are shown below. In Figure 24, Björn is showing how he usually cleans the tablecloth after meals. He uses his handheld vacuum cleaner very rapidly and mostly only for short intervals. He has never experienced any fatigue from its weight or the handle.



Figure 24 Björn is showing one of his few cleaning habits

In Figure 25, Inga is showing how she uses her Ergorapido to clean up crumbs in the kitchen. Her right upper arm and shoulder were forced into an unnatural posture due to her short height and the tool's straight, unbent handle. Her hand is too small to hold the handle in, and she applies a lot of force to grip the hand unit.



Figure 25 Inga is performing a typical cleaning in her kitchen

Eva is using her handheld vacuum cleaner a lot, among other tasks to reach dust and spill between kitchen cabinets and the floor, see Figure 26.



Figure 26 Eva is using her Rapido to access the space between the floor and the kitchen cabinets

After performing the standard tasks, participants were asked to answer questions about their user experience, to reflect on the hand unit's weight, size, storage, emptying container and battery lifetime. In a separate series of questions areas of comfort, discomfort and soreness in the hand, wrist joint, and arm. All of the interview questions are reported in Appendix B. Findings from both interviews, and the questionnaire was later compiled into different problem areas and are presented in the section 4.3 Clustering and Customer Journey Map.

The participating users had several opportunities to give feedback on any issues they have with their models both prior to usage and after the demonstration. The feedback after demonstration was more insightful and all the participants experienced that the product was not as comfortable as they recalled from memory earlier.

4.2 Survey

A survey is a simple but effective method of gathering quantitative information. However, this method has a disadvantage in its inability to get explore all aspects of responses, since 90 percent of all communication between people is visual and gestures and visual indications presumably lost (Milton & Rodgers, 2013). For this reason, the survey was performed after the contextual interviews, where it was possible to get access to all forms of responses and ask follow-up questions. This survey was primarily used to confirm the problem areas discovered in the contextual interviews and investigate whether or not there were any issues that were not noted yet.

The survey with a total of 17 questions, including both fixed response and open-ended questions. It was posted in different online communities about cleaning in Swedish with a goal of reaching out to consumers who first and foremost uses Electrolux handheld vacuum cleaners. Participants who owned other models were also allowed to submit answers about their cleaning habits and how they experience the product, see Figure 27 for distribution between the different brands. A full list of groups used and questions asked can be found in Appendix C.

WHAT BRAND OR MODEL IS YOUR HANDHELD VACUUM CLEANER?

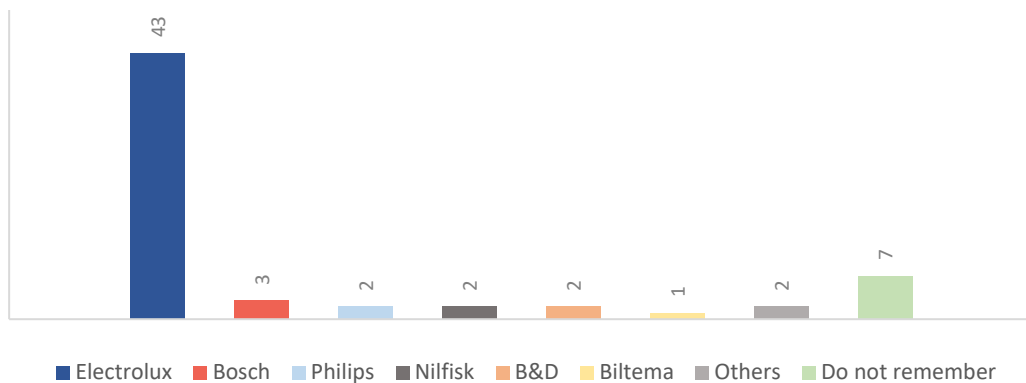


Figure 27 Distribution for different brands owned by the responders

In total 62 users of handheld vacuum cleaners answered the survey, Figure 28 and 29 represents distribution between age and gender of the participants.

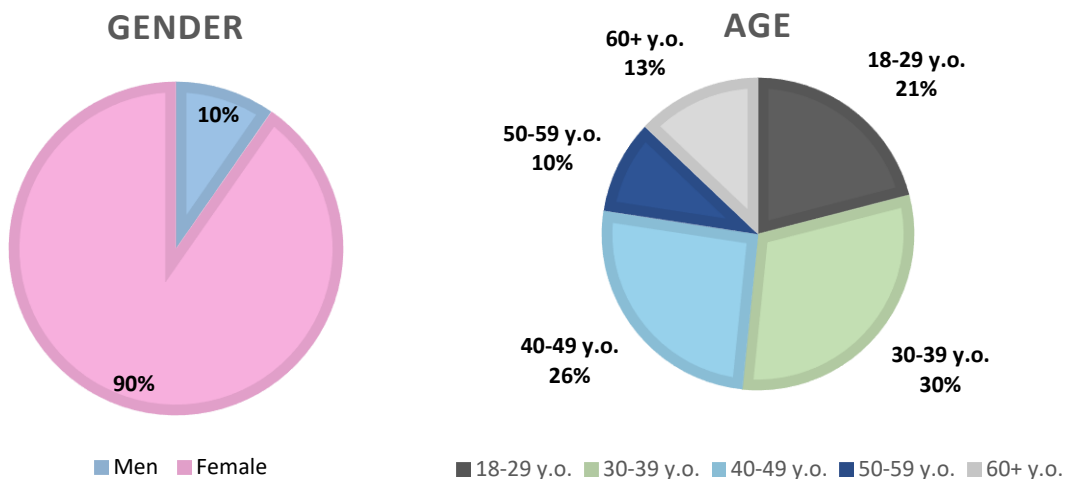


Figure 28 Gender of the survey participants

Figure 29 Age of the survey's participants

Survey responses confirmed the pattern for cleaning habits and typical use for handheld vacuum cleaners, see Figure 30 and 31. Majority of the users, 68 percent, are using their hand units at least once a week. The time spent using a handheld vacuum cleaner depends on cleaning habits of the user, whether he or she is used to put the product to use mostly while cleaning up some minor spills or if it is an irreplaceable part of the weekly cleaning.

Only 5 percent of the respondent participants in the survey stated that handheld vacuum cleaners weight is perceived as light, and for 47 percent their tool was heavy to hold, see Figure 32.

HOW OFTEN DO YOU USE YOUR HANDHELD VACUUM CLEANER?

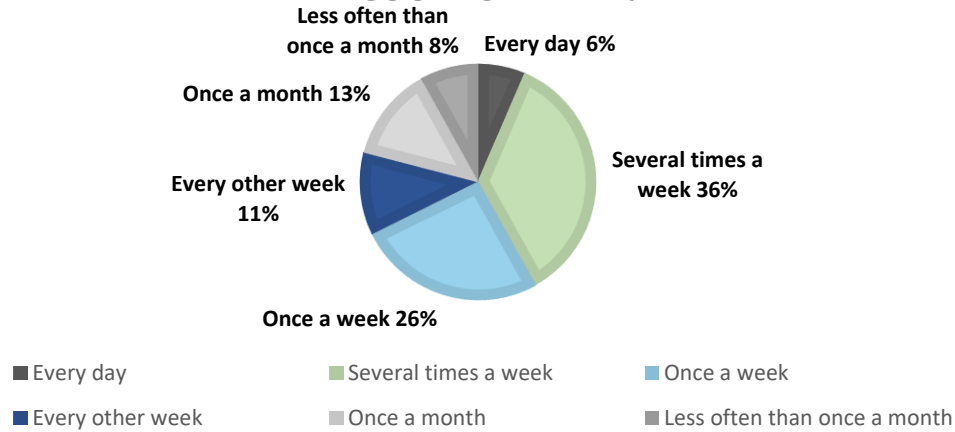


Figure 30 Survey responses for frequency for using handheld vacuum cleaners

HOW LONG DO YOU USE YOUR HANDHELD VACUUM CLEANER AT A TIME? PER TYPICAL USE

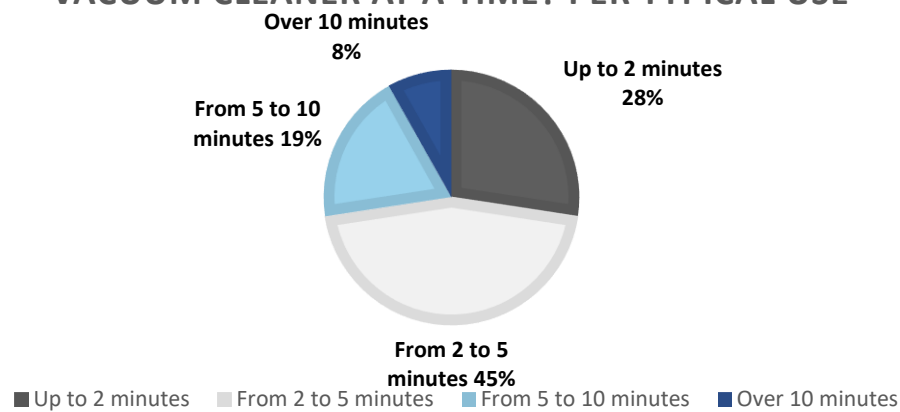


Figure 31 Survey responses for time per typical use

WHAT DO YOU THINK ABOUT THE WEIGHT OF YOUR HANDHELD VACUUM CLEANER?

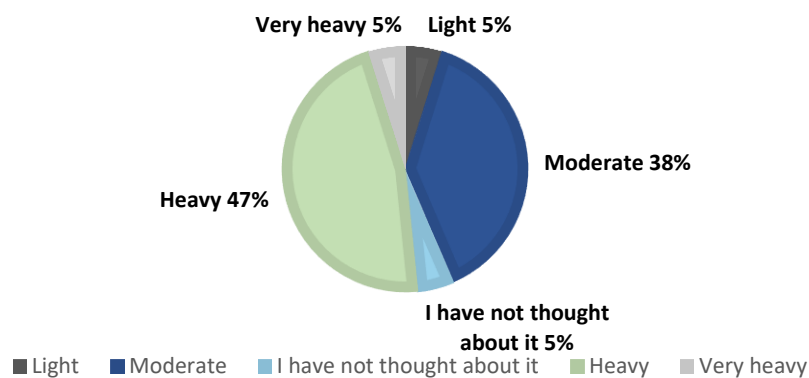


Figure 32 Experience of the products weight

However, the product is mostly beloved and favored by its users, see Figure 33. A complete list of survey results and responses to open-ended questions can be found in Appendix C.

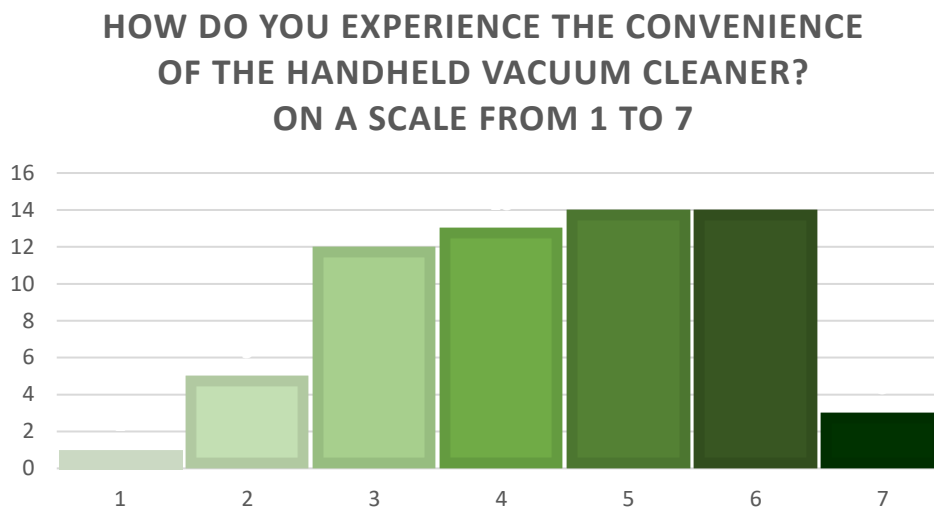


Figure 33 Overall feeling of the convenience of the handheld vacuum cleaner as a product

Gained insights from the survey confirmed the insights from the contextual interviews and did not discover any new severe issues that users were experiencing with their handheld vacuum cleaners.

4.3 Clustering and a Customer Journey Map Scenario

All main insight gathered during contextual interviews and survey were compiled into different clusters with each cluster representing a certain type of information or a specific problem area, see Figure 34.



Figure 34 Different insight sorted into clusters

All the insights were divided into different clusters:

- Demographics
- Residence conditions
- Use: times per week, minutes per use, most common situations
- Discomfort and ache
- Handle and weight issues

- Positive comments
- Negative comments
- Requests and ideas for future products

All high priority issues that were discovered during this user study were organized into a customer journey map, which visualizes different interaction points between the user and the product and describes the reactions and feelings that users experience (Marc Stickdorn, 2011). This customer journey map was made based on the Ergorapido model, as the one more widely used. Figure 35 shows different interaction points: taking the hand unit out from the stick, use for cleaning surfaces at table height, use for cleaning up dirt on the floor and dust from baseboards, use for cleaning up spills from the seats, emptying the dust container and putting the hand unit back in the stick for charge.

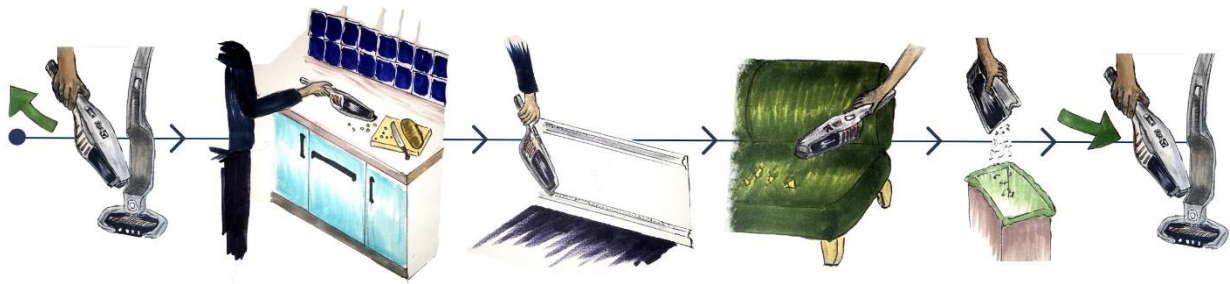


Figure 35 Customer journey map for the use of a handheld vacuum cleaner

Below, each key point of this scenario with quotes from user study will be presented separately in Figures 36 to 41.

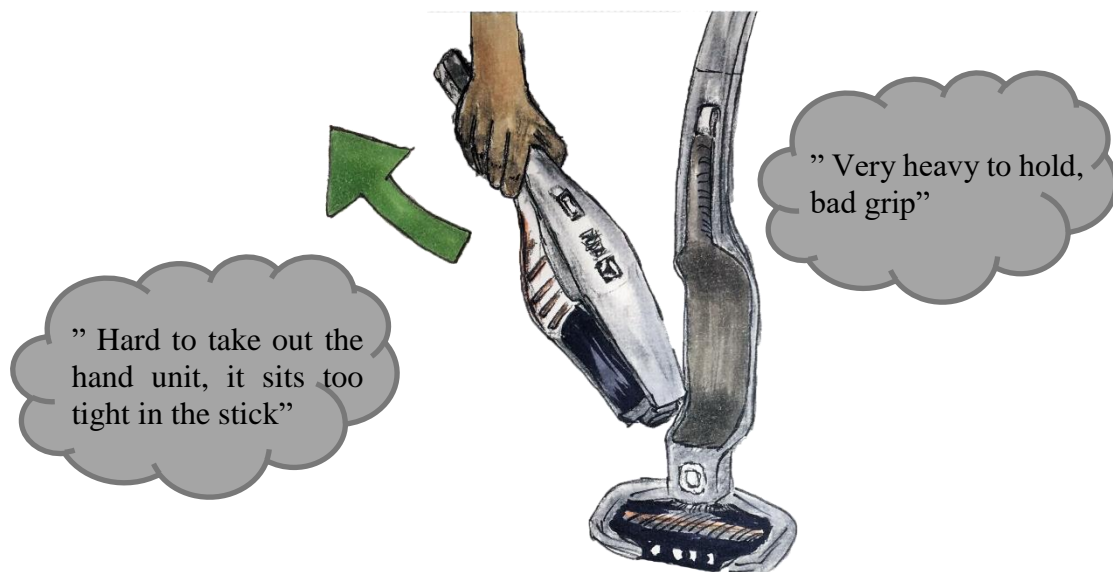


Figure 36 Taking the hand unit out from the stick

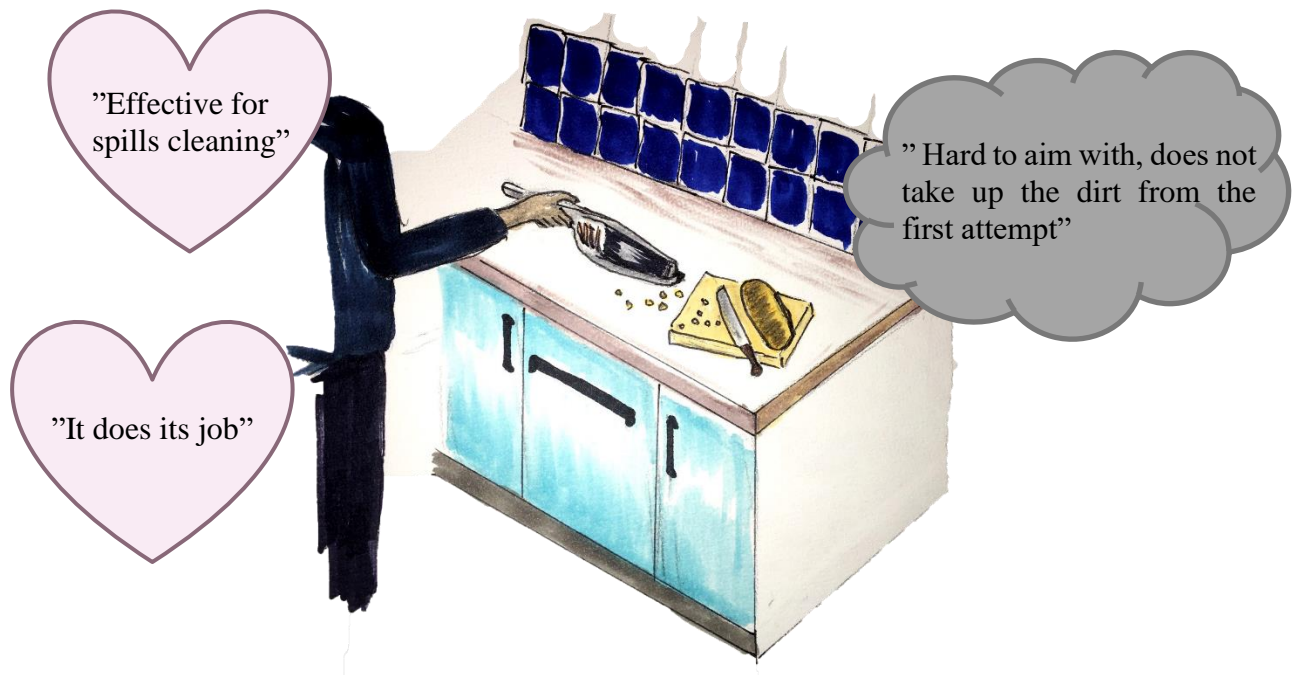


Figure 37 Cleaning surfaces at table height

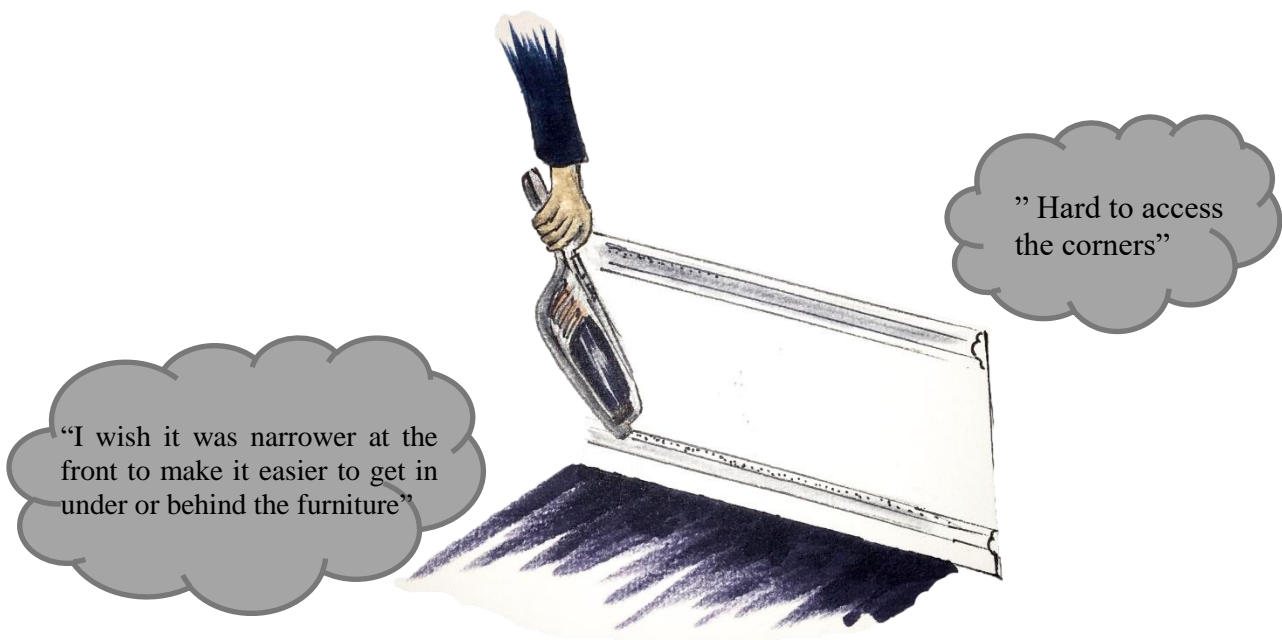


Figure 38 Cleaning up dirt on the floor and dust from baseboards



Figure 39 Cleaning up spills from the seats



Figure 40 Emptying the dust container



Figure 41 Putting the hand unit back in the stick for charge

Extra attention should be paid to the Discomfort and Handle, and weight issues reported by users, main insights on these subjects are presented below in Figure 42 and 43.



Figure 42 Handle and weight issues



Figure 43 Users answers about experienced discomfort

4.4 MAXIMAL VOLUNTARY CONTRACTION

After the interaction with the interview group and the survey results, many concerns were raised about the weight of the hand unit and the fatigue that users experienced in hand and the wrist. To gain a better understanding of what is “heavy” and what is the limit for what is an acceptable weight and fatigue and what is not, a measurement study was developed to measure the maximal voluntary contraction (MVC). It's hard to measure a grip strength or a maximal possible load on the wrist. Therefore MVC is a standard method for measuring the maximal voluntary muscle load that a test participant is willing to apply. Since the muscle contraction is voluntary, MVC shows a lower level than an actual maximal possible load level as a result of safety factor that protects muscles, tendons, and skeleton from overload. The exact value of this safety factor is unknown, but may be up to 30 percent (Lindqvist, 1998). As a reference, a load that corresponds to 5 percent of the MVC can be held by the tested in one hour (Sjøgaard, et al., 1986). Even though an exact ratio between MVC and actual maximal contraction is not known, MVC serves as a good indicator for a limit that should not be exceeded.

For the participation in the study, a group of Asian women was chosen. All six women were from Mongolia, in the ages of 37-46 years old and suitable for the user profile that Electrolux have: women, have families, living in the suburbs. The participants were chosen to be the same age and ethnic group to avoid the variabilities in muscle strength caused by aging or different ethnic background.

The measurements were taken as a cross-sectional survey: at one point in time (Roebuck, 1995) during a series of attempts all carried out on the same occasion. The participants first received general information about this master thesis project and the goal of the measurement: to measure the maximal voluntary contraction. It was explained, MVC corresponds to the limit of force a person is willing to develop in order to be able to hold an object, in this case. This should not be a limit where a participant should hold the prototype against their will and not to a limit where actual damage to the wrist, forearm and flexor muscles can occur.

Typical MVC measurements are made on standard handgrip dynamometers with two straight or slightly curved handles, that often differs from shapes used for commercial products (Kumar et al., 2008). For that reason, a prototype was developed from an emptied Ergorapido hand unit where different weights were attached for testing, see Figure 44. The weight of the hand unit without extra additional weight was 0.285 kg.



Figure 44 The prototype with attached weights

The holding area was defined by two red lines, and a ruler piece was attached for further reference as an established dimension, as shown in Figure 45.

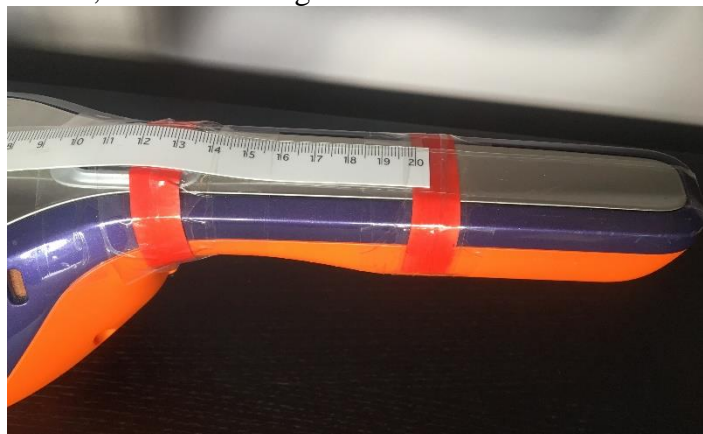


Figure 45 The holding area is defined by two red lines

First, participants were given a form to fill in where they were asked to state their age and height. A measurement from the centre point of the prototype to the wrist joint, while holding within the marked area, was made. Because of the difference in hand sizes and lengths to the wrist, each participant was measured individually, and an individual maximal torque was later calculated for each user depending on the distance to the CG. The measurements started with 1.0 kg attached weight, and 100g weights were further attached for each try during the test. The centre of gravity of the prototype measurements with attached weights was set to 2.5 cm to the left from the attached scale. A ruler was used to note the distance to the centre of the attached weight for every attempt, as shown in Figure 46.



Figure 46 Measuring distance to the attached weight

All the participants were instructed:

- To hold the prototype only between the marked red lines
- To hold the prototype with a 90-degree arm angle
- To hold the prototype no more than 2-3 seconds at the time of each try
- To after each measurement evaluate if the current weight of the prototype was the absolute maximum they voluntarily would hold. If not, how they experienced the load: *light*, *tolerable*, *heavy*, *very heavy* and eventually *too heavy to hold* when the maximal limit would be met

- After each measurement, each participant should rest for 10 minutes before the next attempt to be able to recover from the fatigue of the previous attempt in a way so that future measurements should not be affected by the fatigue applied earlier and exhaustion

Figure 47 is showing one of the participants holding the prototype according to the protocol above.



Figure 47 One of the test participants during the test

After the MVC point was found the participants were asked to rest for 30 minutes and perform the measurements for the second time to see if the results were the same or acceptably close. For the second round of measuring the participants were asked to try the weight preceding the maximal weight from prior results and to try the same weight as the one, they indicated as maximal/critical. Examples of this procedure are as follows:

Ex.1

Participant #5 in the first round of measurements with steps: 1.0 kg, 1.1 kg, 1.2 kg, 1.3 kg 1.4 kg, 1.5 kg, 1.6 kg, 1.7 kg, 1.8 kg, 1.9 kg, 2.0 kg, 2.1kg and 2.2 kg; indicated 2.2 kg attached weight as the critical weight that she could hold and was not given any heavier weights to try out after that mark. After 30 minutes from the last attempt, she was given the preceding weight of 2.1 kg without informing of what weight was her maximum and what weight was the current attempt of second-round measurements. She indicated it is “very heavy, but not critical” and after 10 minutes was given 2.2 kg weight to evaluate and indicated it as critical. In this case with the same result as from the first round of measurements.

Ex. 2

Participant #1 indicated 2.4 kg as a critical weight in the first round of measurements and in the second round tried 2.3 kg with a “very heavy, but not critical” response. Then her critical weight of 2.4 with the response “very heavy, but not critical” and therefore was given an additional 0.1kg increase and indicated 2.5 kg as her critical load.

It should be mentioned that 5 out of 6 got the same results in both the first and second round of measurements. All the test results can be found in Appendix D.

5. RESULT

In this chapter, the main improvement areas for the handheld vacuum cleaners are presented along with the results from biomechanical calculations for the wrist load under different conditions and finally ergonomic guidelines for designing handheld vacuum cleaners.

Results from the maximal voluntary contraction measurements were used to calculate maximal torque the participants were managed to handle, the torque which corresponds to fatigue levels marked by participants as “Heavy” and “Very heavy” and a torque representing existing product Ergorapido hand unit used by an average Chinese woman. The calculations for the maximal torque for all 6 participants can be found in Appendix E. Appendix F, and G include calculations for the “Heavy” and “Very heavy” responses.

The calculated data can be presented in the following chart, see Figure 48:

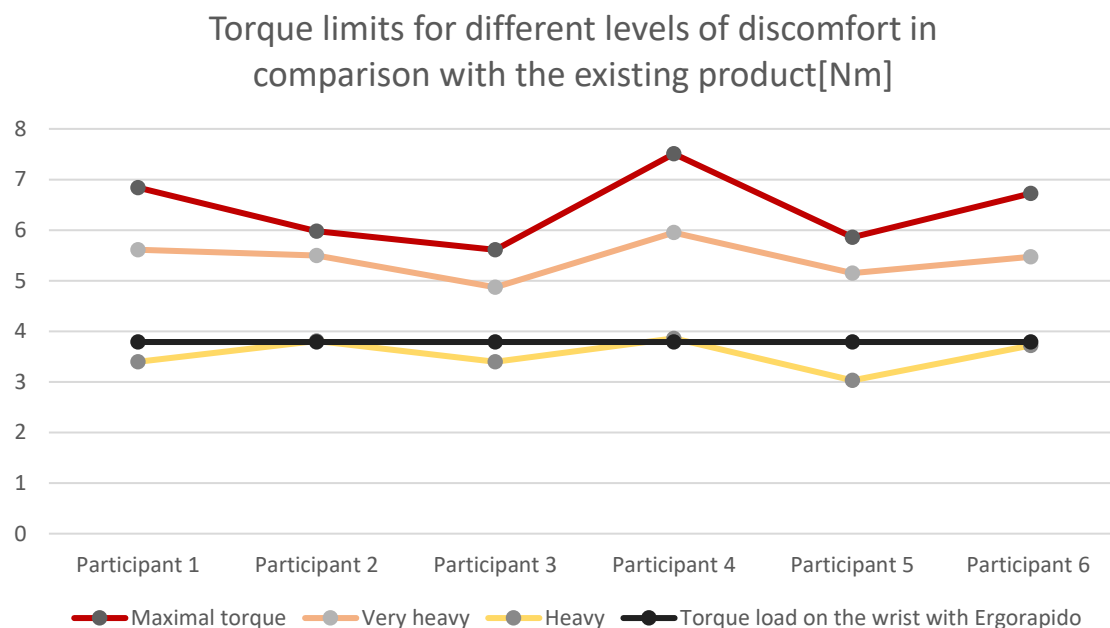


Figure 48 Torque limits: red, orange and yellow for the tested Mongolian users and black for the reference to the existing product, based on anthropometric data for the population from Hong Kong

The black line in Figure 48 presents the torque load calculated in section 3.3 equal to **3.8 Nm** and represents the theoretical torque load on the wrist that Ergorapido contributes with while in use. It corresponds with the test participants definition of “Heavy” to hold for even 2-3 seconds thus using the product in its current shape and weight for a longer period of time would cause fatigue on the wrist for Asian women.

Current trends for cordless products for home appliances are to make focused on making the products more powerful through adding more batteries and batteries to last longer. Even though development of the technology for batteries is progressing forward, batteries still weight a lot. More batteries and their placement in the product without considering the ergonomic guidelines will result in increased fatigue for Asian female users and if using the product constantly in possible damage to the wrist.

5.1 Ergonomic design guidelines and recommendations

Insights gathered from user studies, biomechanical calculations, the frame of reference and methodology chapters led to following conclusions for the researched product:

- The **centre of mass** position in relation to the wrist position should be **adjusted**. Shorter distance between the centre of mass and the wrist joint would increase the feeling of comfort for users and decrease the load on the wrist.
- The **handle's position** should be **changed**. The **adjustable handle** is recommended, and the data for optimal wrist position from chapter 2.3.3 should be applied when developing a new handle. **"The handshake rule"** for optimal wrist position should always be applied when possible.
- The **diameter** of the handle should be **changed** to fit the Electrolux Brand Consumer Profile: women, ages 25-50. The diameter for optimal grip will vary for different populations, and a smaller diameter should be considered for the Asian market. According to chapter 2.4.2, the optimal handle diameter for Swedish/European population should be **34 mm for women**.
- The **length** of the handle where women supposed to hold the product should be **adjusted to palm's size**. According to data from 2.4.2, the optimal handle length for women should be **90 to 110 mm**, see Figure 49.



Figure 49 Part of the handle where women with smaller hands are supposed to hold the product

- **Lower product weight** should be prioritised when it is possible.
- The **torque load on the wrist** should **not exceed the limit** for what was **"Tolerable"** while testing for MVC in chapter 4.4. In Figure 50, green colour illustrates the **"Tolerable"** level of discomfort and black colour stands for the load applied on the wrist of an average Asian woman by the product as it is designed today (2017-year model).

- The chart in Figure 50 presents responses of the users after holding the product for only 2-3 seconds. Using the product during longer period of time will result in a higher feeling of discomfort. Thus **as low torque load as possible** should be sought at all times.

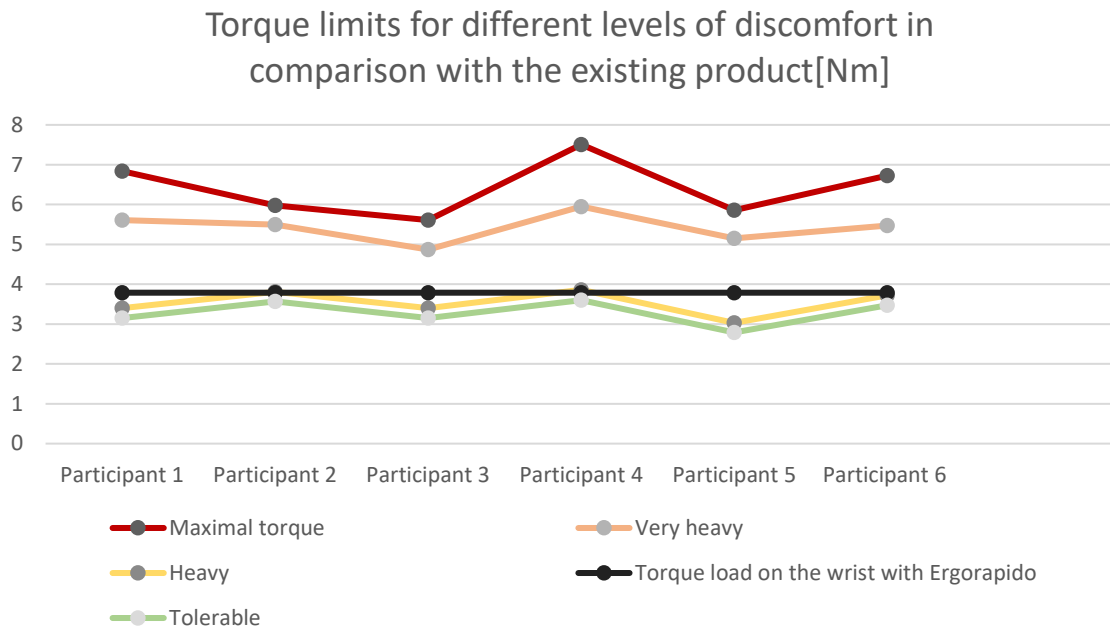


Figure 50 Product's current load on the wrist corresponds with a description for "Heavy" by the users. Lower wrist load and higher comfort feeling should be prioritised.

5.2 Implementation folder

To facilitate the implementation of the guidelines earlier mentioned in this thesis, a folder with the central insights and recommendations was developed on the authors initiative, Figure 51.



Figure 51 The folder with main insights and recommendations.

The data compiled in Frame of reference and Methodology chapters were presented in the folder together with a suggestion of applicable evaluation methods and tools that were created to evaluate work environment, but can be applied to evaluate consumer products, see Figure 52. The folder is fully presented in Appendix I.

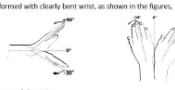
Applicable evaluation methods and other tools

Most of the ergonomic methods that are being developed by universities are made to evaluate human work, often in an industrial environment. This leaves a gap for evaluation of commercial products used in everyday life for less than 8 hours per day. However, these methods can give an insight into what body postures are to be avoided to design for users increased convenience.

RAMP tool


RAMP is a risk management tool for manual handling. RAMP I provides a simple checklist of ergonomic risk factors, and RAMP II offers an in-depth analysis. The tool is available for free at <https://www.ramp.proj.kth.se/>.

1.7 Wrist posture
Is work performed with clearly bent wrist, as shown in the figures, or more?



	Left	Right
4 hours or more	5	5
3 to < 4 hours	4	4
2 to < 3 hours	3	3
1 to < 2 hours	2	2
30 minutes to < 1 hour	1	1
15 to < 30 minutes	0	0
< 15 minutes	0	0

2.2 Movements of the wrist
Do similar movements of the wrist occur?



	Left	Right
More than 10 times per minute	5	5
11 - 20 times per minute	4	4
21 - 30 times per minute	3	3
Up to 30 times per minute	0	0

Example for evaluation of body postures, RAMP II

ErgoArmMeter app

ErgoArmMeter is an inclinometer tool available as an app for iPhone. It is developed in a collaboration between KI and KTH it measures arm elevation when performing different tasks.

The application is free, simple to use and shows the results in an accessible and comprehensible way. The user manual and more detailed information is available at <http://ki.se/en/imm/ergoarmmeter>.




Figure 52 Example of methods used for evaluating workplaces and job tasks that could be used for understanding the fatigue users endure while using a consumer product repeatedly or under a long period (at least 30 minutes).

6. DISCUSSION AND CONCLUSIONS

In this chapter used methods and results are discussed. Finally, suggestions are given on how the ergonomic guidelines can be further developed and how to improve a similar project in the future.

6.1 Discussion

One of the biggest challenges for this master thesis was finding the right audience for the user studies. For the contextual interviews only four out of six participants were found who would match Electrolux user target group for handheld vacuum cleaners: women, living with their families with children and possibly pets. For this master thesis was also crucial to find participants who were using exactly Electrolux models for a longer time and who could share many insights about their products and willing to contribute with a contextual interview in their home— a task proven to be difficult. Yet, the survey has confirmed that all the main issues were discovered during the contextual interview stage, despite the number of participants.

Partly, the research carried out in this master thesis was focused on Asian users, that potentially have smaller hands and less muscle strength. Due to resource constraints and intentions to keep the test group for MVC measurements as homogeneous as possible in population terms, the choice was limited to study six Mongolian women. This caused some complications to compare the theoretical data from anthropometry databases with the test results since Chinese population is the one that is well researched regarding anthropometry and no directly comparing studies between this two populations were found in the literature.

Further, Atlas Copco's material (Lindqvist, 1998), provided a lot of useful information for hand tool designing for choosing tool dimensions. However, the book does not state what population those dimensions are developed for and leaves to the reader to assume, that it was developed with a Swedish or at least Western population in mind. The dimensions stated in this source corresponded well with dimensions recommended by several sources in (Kumar et al., 2008), but none of the referenced authors gave any guidelines on having those dimensions should be used when applying to a population with smaller body size, like for example Chinese people.

The prototype for the MVC measurements was made based on the existing product and measures MVC for this shape of the product only. A different prototype with more ergonomic shape could have given higher tolerance levels for users' discomfort during the tests. Thus, the calculated MVC data is bound to research on this type of hand-held vacuum cleaners only and cannot be used as a general MVC recommendation for wrist load of Mongolian female users.

6.2 Future Work

Suggestion for future work is to implement similar user studies in China including contextual interviews, survey, and MVC tests and compare the results with this thesis user studies. Such a comparison might share new insights because of possibly different cleaning habits between Sweden and China, as well as a contrasting way of living and accommodation, anthropometrics, mentality and social norms.

My hope is for Electrolux to implement the insight from this report in their design process and make ergonomics an important part of user experience evaluation of existing and future products.

REFERENCES

- Abrahamsson et al., 2015. *Arbete och teknik på människans villkor*. 3:1 red. u.o.:Prevent.
- C. Pryce, J., 1980. The wrist position between neutral and ulnar deviation that facilitates the maximum power grip strength. *Journal of Biomechanics*, 13(6), pp. 505-511.
- Electrolux, 2017. *History 2000-2009*. [Online]
Available at: <http://www.electroluxgroup.com/en/history-2000-2009-770/>
[Använd 15 May 2017].
- Electrolux, 2017. *Product overview*. [Online]
Available at: <http://www.electroluxgroup.com/en/product-overview-16654/>
[Använd 15 May 2017].
- Fellows, G. & Freivalds, A., 1991. Ergonomics evaluation of a foam rubber grip for tool handles. *Applied ergonomics*, Volym 22, pp. 225-230.
- Galer, 1987. *Applied ergonomics handbook*. u.o.:Butterworth.
- Gantz, C., 2012. *The vacuum cleaner, a history*. North Carolina: McFarland & Company.
- Grandjean, E., 1988. *Fitting the task to the Man*. London: Taylor&Francis .
- Hazelton, F. T., Smidt, G. L., Flatt, A. E. & Stephens, R. I., 1975. The influence of wrist position on the force produced by the finger flexors. *Journal of Biomechanics*, 8(5), pp. 301-306.
- Illustrerad vetenskap, 2017. *Vad består damm egentligen av?*. [Online]
Available at: <http://illvet.se/naturen/vad-bestar-damm-egentligen-av>
[Använd 22 April 2017].
- International Ergonomics Association, 2017. *Definition and domains of ergonomics*. [Online]
Available at: <http://www.iea.cc/whats/index.html>
[Använd 26 May 2017].
- Konz, S., 1990. *Work design: Industrial Ergonomics*. 3 red. Washington, OH: Publishing Horizons.
- Kumar et al., 2008. *Biomechanics in ergonomics*. 2 red. u.o.:Taylor&Francis group.
- Lindqvist, B., 1998. *Verktygsergonomi - utvärdering av industriverktyg*. Helsingborg: Atlas Copco via ABE Tryck.
- Marc Stickdorn, J. S., 2011. *This is service design thinking*. Hoboken, New Jersey: John Wiley & Sons, Inc. .
- Milton & Rodgers, 2013. *Research methods for product design*. London: Laurence King Publishing Ltd.
- Napier, J., 1956. THE PREHENSILE MOVEMENTS OF THE HUMAN HAND. *Journal of Bone and Joint Surgery*, Volym 38-B, pp. 902-913.
- P.Kattel, B., K.Fredericks, T., E.Fernandez, J. & C.Lee, D., 1996. The effect of upper-extremity posture on maximum grip strength. *International Journal of Industrial Ergonomics*, 18(5-6), pp. 423-430.
- Pheasant, S., 2003. *Bodyspace. Anthropometry, Ergonomics and Design of Work*. 2 red. London: Taylor & Francis.
- Pheasant, S. & O'Neill, D., 1975. Performance in gripping and turning: A study in hand/handle effectiveness. *Applied Ergonomics*, Issue 6, pp. 205-208.
- Plagenhoef, S., Evans, F. & Abdelnour, T., 1983. Anatomical data for analyzing human motion. *Research Quarterly in Exercise and Sport* , Volym 54, pp. 169-178.
- Roebuck, J. A. J., 1995. *Anthropometric methods: Designing to Fit the Human Body*. Santa Monica, California: Human Factors and Ergonomics Society.
- Sjøgaard, G., Kiens, B., Jørgensen, K. & Saltin, B., 1986. Intramuscular pressure, EMG and blood flow during low-level prolonged static contraction in man. *Acta Physiologica Scandinavica*, 128(3), pp. 475-484.
- Statistiska centralbyrån, 2010. *Genomsnittlig tid för olika hemarbetsaktiviteter 2010, 2000 & 1990. Befolkningen 20–64 år. Alla veckodagar*. [Online]
Available at: <http://www.sverigeisiffror.scb.se/hitta-statistik/statistik-efter->

amne/levnadsforhallanden/levnadsforhallanden/tidsanvandningsundersokningen/pong/tabell-och-diagram/

[Använd 27 Aug 2017].

Statistiska centralbyrån, 2011. *Genomsnittlig tid för hemarbetsaktiviteter efter familjecykel år 2010/11. Befolkningen 20–84 år. Alla dagar.* [Online]

Available at: <http://www.sverigeisiffror.scb.se/hitta-statistik/statistik-efter-amne/levnadsforhallanden/levnadsforhallanden/tidsanvandningsundersokningen/pong/tabell-och-diagram/genomsnittlig-tid-for-hemarbetsaktiviteter-efter-familjecykel-ar-201011.-befolkningen-2084>

[Använd 27 Aug 2017].

Stockholm vatten och avfall, 2015. *Så undviker du kemikalier i din vardag - riktlinjer för tvätt och städ.* [Online]

Available at: http://www.stockholmvattenochavfall.se/tips-och-riktlinjer/miljotips/sa-undviker-du-kemikalier-i-din-vardag/#!/tvatt-och-stad?list=vad-ar-ett-hamtforhallande_5400

[Använd 22 Apr 2017].

Taylor, C. L. & Schwartz, R. J., 1955. The Anatomy and Mechanics of the Human Hand. *Artificial Limbs*, 2(2), pp. 22-35.

Tichauer, E. & Gage, H., 1977. Ergonomic principles basic to hand tool design. *American Industrial Hygiene Association Journal*, Volym 38, pp. 622-634.

User manual, Electrolux, 2017. *Electrolux. Ergorapido Skaftdammsugare.* [Online]

Available at: <http://www.electrolux.se/homecare/vacuum-cleaners/stick-vacuum-cleaners/cordless-sticks/zb3214g/>

[Använd 29 Aug 2017].

Virzi, R. A., 1992. *Refining the Test Phase of Usability Evaluation: How Many Subjects Is Enough?*, GTE Laboratories Inc., Waltham, Massachusetts: The Human Factors Society, Inc..

Worthy, T., u.d. *Ergonomics for schools. Antropometry.* [Online]

Available at: <http://www.ergonomics4schools.com/lzone/anthropometry.htm>

[Använd 22 May 2017].

APPENDIX A: INTERVIEW WITH CAJSA WAHLBERG

Interview with Cajsa Wahlberg, environmental chemist at Stockholm Vatten och Avfall (Water and Waste) 23 March 2017

After a short introduction to the master thesis subject, Cajsa was asked a series of questions. The shortened transcription is found below:

Lesya: *I have seen an advertisement from waste treatment plants about the importance of the dry collection of the dust.*

Cajsa: Yes, it was Käppala treatment plant which was advertising about these issues, but all the waste management companies and authorities in Sweden are working to increase the dry collection of the dust.

L.: *What is the main issue for the wet dust collecting and rinsing off the dust to the wastewater? Why is it important?*

C.: The dust takes up organic compounds from flame retardants and softening perfluorinated compound. Compounds that are present in electronics, textiles, construction materials, the floor, etc. Those particles are present everywhere: in every home, kinder garden and office. When collected dry, the dust and the particles in it, are incinerated with the rest of the household waste. With wet cleaning, all the particles from the dust end up in the wastewater.

L.: *What particles are hard to purify the water from for the treatment plant?*

C.: All the particles are retrieved by the treatment plants today.

L.: *How are they being collected today?*

C.: As usual, all the particles end up in the sludge. We want to sell the sludge as fertilizer for the farmland, but only if the organic compounds and heavy metal levels are low enough. The reason for this is that heavy metals are not degradable.

L.: *Do all the farms buy the sludge as fertilizer? Do organic farms buy it too?*

C.: No, organic farms do not use the sludge as fertilizer.

L.: *Are there any health risks associated with the use of sludge in agriculture?*

C.: There are no studies that find a direct correlation what I know of, but there are data about the measurement values of the substances in the dust. There is also a study about how dust affect the cats' health negatively that might be interesting to investigate further.

L.: *Do the plants take up chemicals? And are the chemicals later present in the food and eatables?*

C.: No, there is no absorption in the plants generally. However, there are chemicals such as cadmium that crops can take up and that has effects on osteoporosis (bone fragility) for humans. But the presence of cadmium has decreased by 99 percent over a few past decades. Prohibitions of dangerous substances and constantly ongoing work with the EU-legislation helps to decrease the levels.

L.: *Are there any other applications for the sludge besides the agriculture?*

C.: Yes, sometimes we sell it to mining companies for the land restoration in the mining areas.

L.: *What plans of action do the state, and municipal authorities have for future work?*

C.: We are trying to lobby the ban of the most dangerous substances. We also make chemistry inspections. But new chemicals and chemical treatment methods are being developed all the time, and it takes a while to evaluate them and to ban them. So, this is an always ongoing work.

L.: *Do you have anything you want to add?*

C.: When I am vacuum cleaning myself I often think that the brush for furniture is too small, I wish those were larger.

APPENDIX B: INTERVIEW PROTOCOL

Fakta

Kön:

Ålder:

Yrke:

Kroppsvikt:

Längd:

Handmått:

Hur stort är ditt boende? [kvm] [antal rum?]

Hur länge har du haft en handdammsugare?

Modell på din nuvarande HD:

Användning

Hur ofta storstädar du hemma?

☐ Varje dag ☐ flera ggr/vecka ☐ 1 gång/vecka ☐ varannan vecka ☐ 1 gång/månad

Hur ofta använder du din handdammsugare?

☐ Flera ggr/dag ☐ 1gång/dag ☐ flera ggr/vecka ☐ 1 gång/vecka ☐ varannan vecka ☐ 1 gång/månad

Hur länge använder du din handdammsugare åt gången? [minuter per typisk användning]

I vilka situationer plockar du fram HD?

Vid spill?

När du städar hela lägenheten?

Övrigt:

I vilka situationer uppskattar du mest HD?

Hur rengör du din HD?

Hur svårt eller enkelt är det att rengöra din HD?

Hur förvarar du din HD?

Står HD framme på en laddningsstation? Är den fast i väggen? I förvaringsutrymmet? Hur ofta laddar du din HD?

Sitter handtaget på rätt ställe?

Vad tycker du om storleken och vikten på HD?

Beskriv (och gärna visa) en vanlig rutin vid användning av HD [här anteckna på separat blad alla moment som utförs och användarens kommentarer]

Upplever du några problem med din HD?

Har du några förslag på förbättringar?

Upplevelse

Vad tycker du om din HD? Försök att beskriva känslan du får vid användningen

Hur upplever du styrka hos din HD?

Hur upplever du batteritiden?

Upplever du påtagliga vibrationer vid användning?

Vad är din helhetsupplevelse av HD i stort?

Vill du komplettera med något?

Komfort/obehag

Upplever du en känsla av obehag eller fysisk ansträngning i handleden vid användning av HD?
Om ja, efter hur lång tid?

Upplever du diskomfort i andra kroppsdelar vid användning?

Hur upplever du handtagets position? Storlek? Form?

Vill du komplettera med något angående din upplevelse av HD?

Övriga synpunkter

Är det någonting mer du skulle vilja tilläga?

Uppföljning

Har du känt av smärta eller obehag i handleden senare samma dag som intervjun?

Har du känt av smärta eller obehag i axeln senare samma dag som intervjun?

Har du känt av smärta eller obehag i axeln dagen efter intervjun?

Har du känt av smärta eller obehag i handleden dagen efter intervjun?

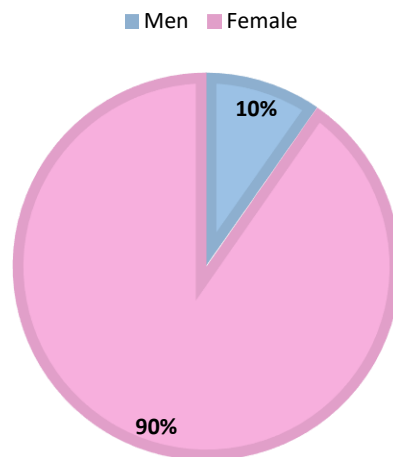
Har du i efterhand känt av obehag i några andra kroppsdelar som kan vara relaterade till arbetsuppgiften?

Finns det något du skulle vilja tilläga?

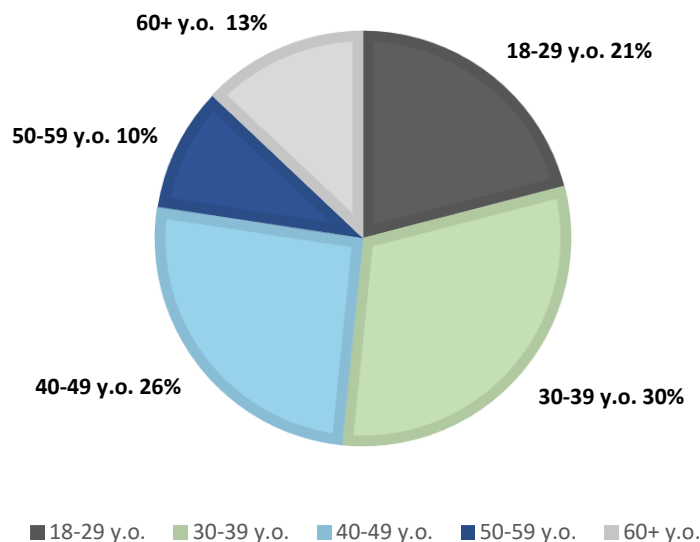
APPENDIX C: SURVEY DATA

Appendix C presents the data gathered through the survey posted in different Facebook groups on Internet, with cleaning as common subject of interest. The survey was posted in Swedish and some of the submitted answers below on optional questions can be found in Swedish, however all the statistic results were translated to English. 62 responders in total took the survey. A full list of groups used: "Rensa hemma", "Husmorstips, gamla som nya", "Husmorstips!", "Städtips för enklare städning", "Städa rent och ta bort fläckar miljövänligt", "Städning tips O trix", "Inredning, inspiration, renovering", "Rensa i röran på riktigt!".

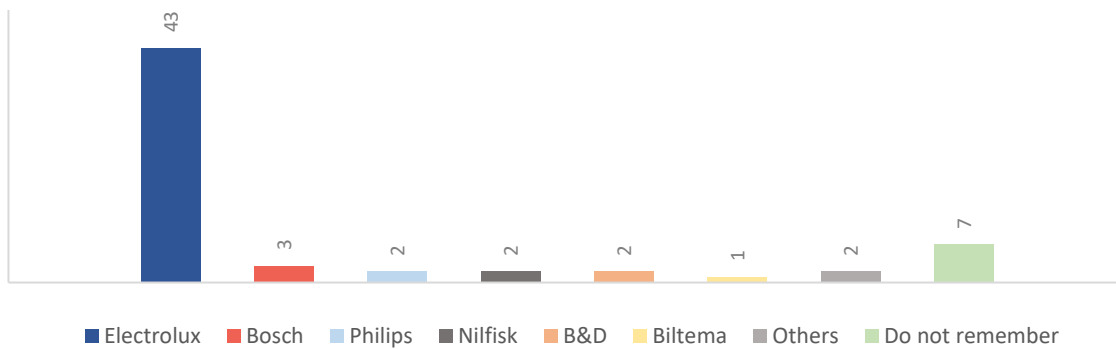
GENDER



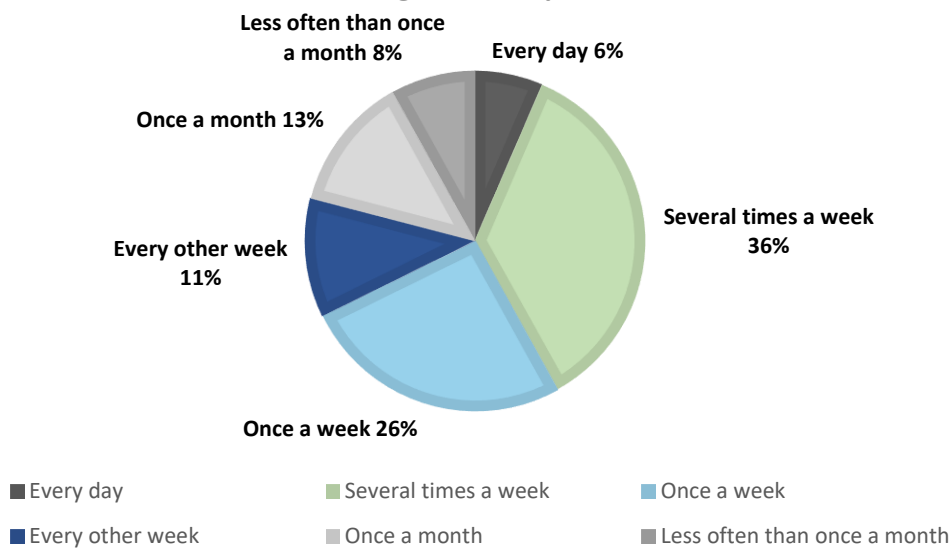
AGE



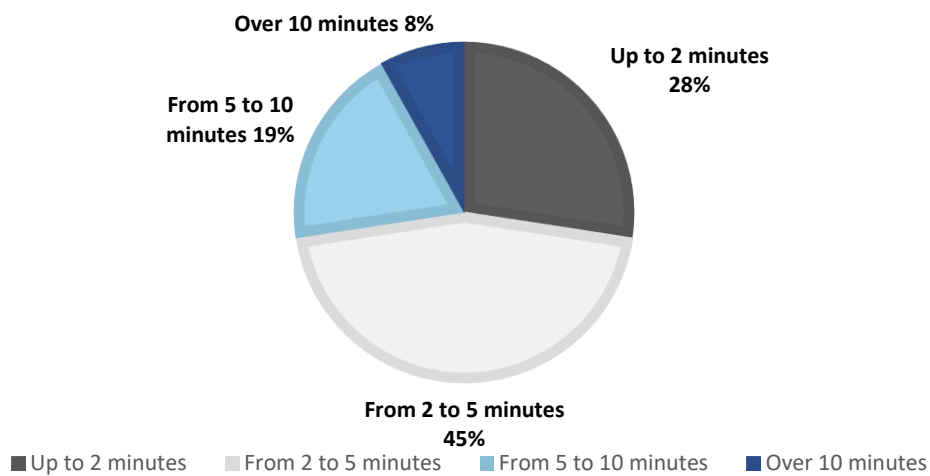
WHAT BRAND OR MODEL IS YOUR HANDHELD VACUUM CLEANER?



HOW OFTEN DO YOU USE YOUR HANDHELD VACUUM CLEANER?



HOW LONG DO YOU USE YOUR HANDHELD VACUUM CLEANER AT A TIME? PER TYPICAL USE



In what situations do you most appreciate your hand vacuum cleaner?

Att snabbt kunna dammsuga upp smulor etc på/under matbordet, på kökssoffan och i köket.

När barnen ätit och det är smulor på golvet.

Bord, platser som är svåra att komma åt, spill, smulor. Det är smidigt och snabbt.

När jag tappat eller spillt något

När man snabbt ska dammsuga en liten yta och för att dammsuga möbler

Vid akutstädning, orkar inte ta fram stora dammsugaren

Dammsuga bilen

Smulor och spill i köket

Avlägsna smulor, skräp vid blomkrukor, badrummet, spisen, soffan

Smulor på bordet

När Lego staden ska dammsugas!

I bilen

Hyllor och bord

Vid snabbstäd efter måltider

Snabba städningar

städa i fågelburen

När barnen spiller på golvet eller man spiller när man lagat mat

Inga

När det har smulats med kex

Köksbordet (och arbetsytornas) smulor

Småsmulor på golvet och annat småskräp

Ett par ggr. Onödig apparat.

Inte längre

Snabb städning efter att barnen ätit

För att suga upp kattsand

Vid matbordet

Jag gillade den inte så mkt.

Kattsanden

Smulor og store damm-rotter

När jag spiller vid bakning samt vid användning av vedspis i köket

Vid gäster så lätt

Smulor på bordet

När sonen drar in grus och sand i hallen

Få bort kattsanden från badrummet, jord när katten varit i blommorna och att snabbt kunna ta upp på ytor som är svåra att torka av.

När det ska gå snabbt och jag är för lat att ta fram den vanliga dammsugaren

Smulor i sängen t ex

I svåråtkomliga platser, i sängen

Dammsuger runt fågelbur

När man har bråttom eller för enkel städning

När det är smuligt eller jag måste snabbstäda några dammråttor, eller städa ur lådor och skåp.

Snabbstäda trappan

Vid små akuta saker

Ta upp smulor på bord och golv utan att behöva ta ut den stora dammsugaren

Vid storstädning - dammsuga sängen, soffor, svåråtkomliga skyllor

När jag tar upp smulor under matbord och när man har tappat något, exv blomjord.

till mattor och i köket

Skräp under bord

När det inte är så mycket.

För att dammsuga i bilen.

I köket

Vid bakning och barnbarnspyssel

Smulor i soffor, grus i sängen etc

Att slippa ta fram stora dammsugaren för att ta bort smulor på stolsdynorna.

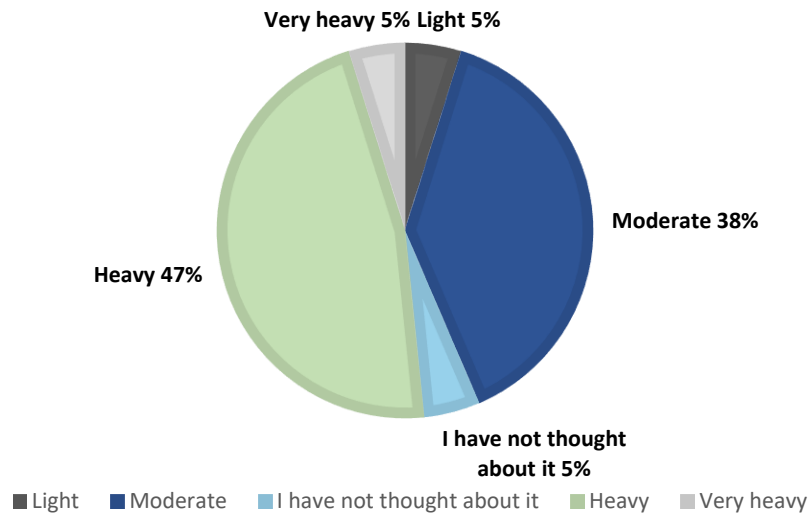
Snabbstädning, ta bort smulor på bordet.

Smulor

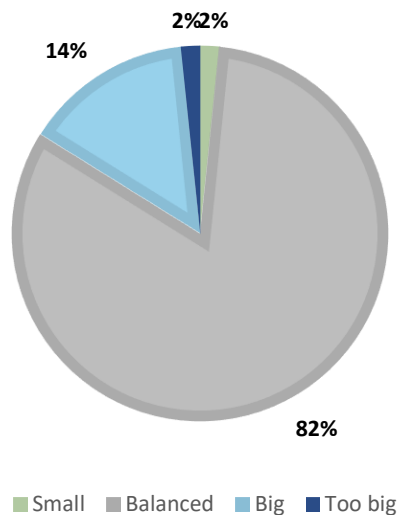
Ta bort smulor, djurhår och glaskross

Experience of the Unit's Weight, Size, and Handle

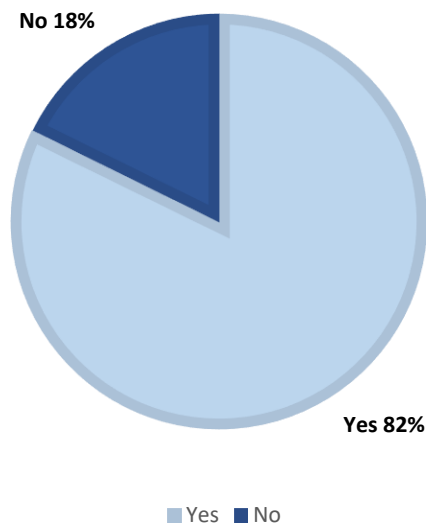
WHAT DO YOU THINK ABOUT THE WEIGHT OF YOUR HANDHELD VACUUM CLEANER?



WHAT DO YOU THINK ABOUT THE SIZE OF YOUR HANDHELD VACUUM CLEANER?



WOULD YOU SAY THE HANDLE IS IN THE RIGHT PLACE?



Do you have any suggestions for improvements for hand vacuum cleaners?

Det viktigaste tycker jag är hur munstycket är utformat för att komma åt så bra som möjligt överallt. Och att "kroppen" inte är för tjock och klumpig så att man inte kommer åt.

Den jag hade var jättedålig och sög inte alls upp det jag ville. Gick sönder ganska fort

Tyngpunkten skulle kunna vara närmare handen för lägre moment

Kraftigare motor.

Smalare vid insugningsstället så man inte behöver använda det extra munstycket mer än ibland.

Olika munstycken för ex tyg

Den blir framtung och då behövs ett tvåvägshandtag som motverkar känslan av att den är framtung.

Nått längre bak på handtaget som handen kan vila mot.

Sug för dåligt

minska vikten genom att minska dammupsamlingskammaren. öka kraften i suget

Sugförmågan är usel!!!!

Det allra viktigaste är att den är lätt att tömma

Bättre luftfilter

Viktfördelning. Dammsugaren tippas framåt och man behöver hålla emot.

Den låter för mkt.

Formen i fram

Lägre ljud

Lättare

Starkare sug

Någon form av låsning av det lilla utdragbara munstycket längst fram så det inte åker in så lätt.

Kapaciteten av sugning

Förra modellen hade ett utdragbart munstycke som var jättebra så att man kom åt i hörn och kanter - det saknar jag. Skulle vilja ha munstycken man kan byta ut, exempelvis ett man kan använda vid dammning.

Bättre sugförmåga och ett annat uppsamlings sätt som är lättare och fräschare att tömma

Den är för tung, tippas framåt hela tiden

Lättare vikt, mindre vikt framme, större synligare luftintag framme - svårt att se/sikta

lite mer böjt handtag

Skulle behöva ha lite "starkare" sugförmåga. Och man måste tömma den/göra rent filtret väldigt ofta.

Lägre vikt. Har man minsta ont i händer och/eller armar och/eller är svag så är handdammsugare tunga att hantera.

Bättre munstycke så smulor inte ramlar ut igen.

Do you have any suggestions for improvements for the handle?

Byt plats för handtaget

Lite smalare så att man når runt med handen och får ett bra grepp.

Man skulle kunna ändra det så att handen inte behöver vinklas lika mycket

Man håller handtaget som "kniv". Handleden böjs framåt hela tiden. Handtaget ska inte vara rakt.

Handtag över tyngdpunkt

Mer greppvänligt

Bättre sug

Ergonomiskt

Inget speciellt

Gummerat.

Hålet är för stort, handtaget ger dåligt grepp

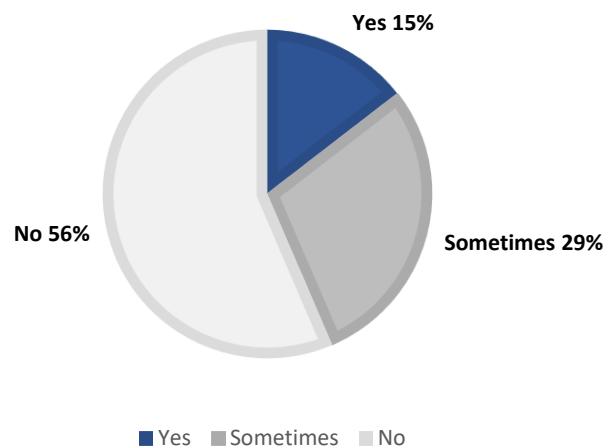
Smalare, annan placering

lättare att rengöra och tömma på dam o.d...!

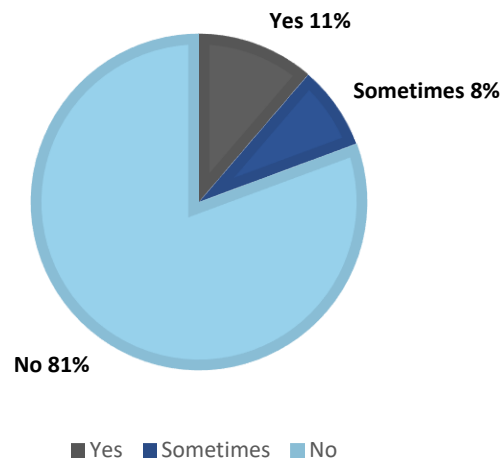
Gummerat och mer ergonomiskt handtag.

Discomfort, Fatigue and Anthropometry

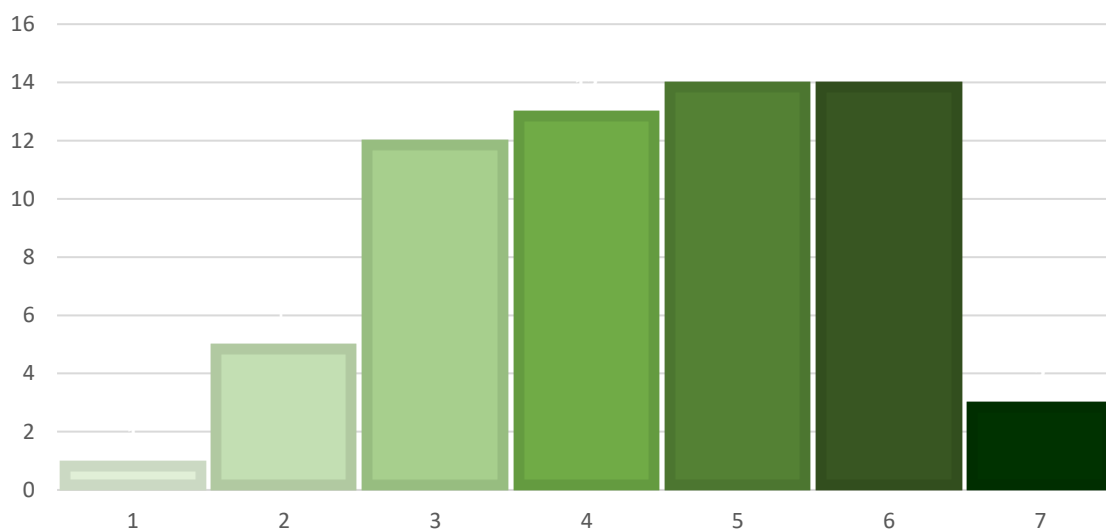
DO YOU EXPERIENCE A FEELING OF DISCOMFORT OR PHYSICAL EXERTION IN THE WRIST WHEN USING A HAND VACUUM CLEANER?



DO YOU EXPERIENCE THE FEELING OF DISCOMFORT OR PHYSICAL EXERTION IN THE ARM OR SHOULDER WHEN USING A HAND VACUUM CLEANER?



HOW DO YOU EXPERIENCE THE CONVENIENCE OF THE HAND VACUUM CLEANER? ON A SCALE FROM 1 TO 7



Do you want to add something about your experience of hand vacuum cleaners?

Eftersom den är ganska tung så används den inte långa stunder utan bara korta.
Denna handdammsugare passar ej riktigt för bilar :)

Bra med hjul!

Tyckte den var oerhört onödig men minns inte att apparaten var oskön att använda.

Batteriet tar slut snabbt.

Jeg har ergorapido og bruker den mest fordi den også kan brukes som "vanlig" dammsugare uten sladd.

Ganska onödig pryl för mig och eftersom jag endast använde den korta stunder så spelade tyngden inte så stor roll.

Hög ljudstyrka

APPENDIX D: TEST PROTOCOL, MVC

Text

Participant № *1*

Name: *Baasansuren*

Age: *38 y.o.*

Height: *152 cm*

Measured distance to the wrist (from 0 on the attached scale): *22.5 cm*

Test #	Weight attached [kg]	Comment
1	1.0	<i>tolerable</i>
2	1.1	<i>heavy</i>
3	1.2	<i>heavy</i>
4	1.3	<i>heavy</i>
5	1.4	<i>heavy</i>
6	1.5	<i>heavy</i>
7	1.6	<i>heavy</i>
8	1.7	<i>heavy</i>
9	1.8	<i>heavy</i>
10	1.9	<i>heavy</i>
11	2.0	<i>very heavy</i>
12	2.1	<i>very heavy</i>
13	2.2	<i>very heavy</i>
14	2.3	<i>very heavy</i>
15	2.4	<i>too heavy to hold</i>

Second round control test: *2.4 kg indicated as “very heavy.”*

Was an adjustment of the weight needed? *Yes.*

If yes, how much and how many more tests were run: *one more test with 2.5 kg which was indicated as “too heavy to hold.”*

Participant № 2

Name: *Ariuntungalag*

Age: **46 y.o.**

Height: **156 cm**

Measured distance to the wrist (from 0 on the attached scale): **22 cm**

Test #	Weight attached [kg]	Comment
1	1.0	<i>tolerable</i>
2	1.1	<i>tolerable</i>
3	1.2	<i>tolerable</i>
4	1.3	<i>heavy</i>
5	1.4	<i>heavy</i>
6	1.5	<i>heavy</i>
7	1.6	<i>heavy</i>
8	1.7	<i>heavy</i>
9	1.8	<i>heavy</i>
10	1.9	<i>heavy</i>
11	2.0	<i>very heavy</i>
12	2.1	<i>very heavy</i>
13	2.2	<i>too heavy to hold</i>

Second round control test: **2.2 kg confirmed as “too heavy to hold.”**

Was an adjustment of the weight needed? *No*

If yes, how much and how many more tests were run: -

Participant № 3

Name: *Lyankluatsetseg*

Age: *44 y.o.*

Height: *167 cm*

Measured distance to the wrist (from 0 on the attached scale): *22.5 cm*

Test #	Weight attached [kg]	Comment
1	1.0	<i>tolerable</i>
2	1.1	<i>heavy</i>
3	1.2	<i>heavy</i>
4	1.3	<i>heavy</i>
5	1.4	<i>heavy</i>
6	1.5	<i>heavy</i>
7	1.6	<i>heavy</i>
8	1.7	<i>very heavy</i>
9	1.8	<i>very heavy</i>
10	1.9	<i>very heavy</i>
11	2.0	<i>too heavy to hold</i>

Second round control test: *2.0 kg confirmed as “too heavy to hold.”*

Was an adjustment of the weight needed? *No*

If yes, how much and how many more tests were run: -

Participant № 4

Name: *Delgertsetseg*

Age: *37 y.o.*

Height: *161 cm*

Measured distance to the wrist (from 0 on the attached scale): *24 cm*

Test #	Weight attached [kg]	Comment
1	1.0	<i>tolerable</i>
2	1.1	<i>tolerable</i>
3	1.2	<i>heavy</i>
4	1.3	<i>heavy</i>
5	1.4	<i>heavy</i>
6	1.5	<i>heavy</i>
7	1.6	<i>heavy</i>
8	1.7	<i>heavy</i>
9	1.8	<i>heavy</i>
10	1.9	<i>heavy</i>
11	2.0	<i>very heavy</i>
12	2.1	<i>very heavy</i>
13	2.2	<i>very heavy</i>
14	2.3	<i>very heavy</i>
15	2.4	<i>very heavy</i>
16	2.5	<i>very heavy</i>
17	2.6	<i>too heavy to hold</i>

Second round control test: *2.6 kg confirmed as “too heavy to hold.”*

Was an adjustment of the weight needed? *No*

If yes, how much and how many more tests were run: -

Participant № 5

Name: *Gereltuya*

Age: *40 y.o.*

Height: *165 cm*

Measured distance to the wrist (from 0 on the attached scale): *21.5 cm*

Test #	Weight attached [kg]	Comment
1	1.0	<i>heavy</i>
2	1.1	<i>heavy</i>
3	1.2	<i>heavy</i>
4	1.3	<i>heavy</i>
5	1.4	<i>heavy</i>
6	1.5	<i>heavy</i>
7	1.6	<i>heavy</i>
8	1.7	<i>heavy</i>
9	1.8	<i>heavy</i>
10	1.9	<i>very heavy</i>
11	2.0	<i>very heavy</i>
12	2.1	<i>very heavy</i>
13	2.2	<i>too heavy to hold</i>

Second round control test: *2.2 kg confirmed as “too heavy to hold.”*

Was an adjustment of the weight needed? *No*

If yes, how much and how many more tests were run: -

Participant № 6

Name: *Urantsatsral*

Age: *38 y.o.*

Height: *172 cm*

Measured distance to the wrist (from 0 on the attached scale): *23 cm*

Test #	Weight attached [kg]	Comment
1	1.0	<i>tolerable</i>
2	1.1	<i>tolerable</i>
3	1.2	<i>heavy</i>
4	1.3	<i>heavy</i>
5	1.4	<i>heavy</i>
6	1.5	<i>heavy</i>
7	1.6	<i>heavy</i>
8	1.7	<i>heavy</i>
9	1.8	<i>heavy</i>
10	1.9	<i>very heavy</i>
11	2.0	<i>very heavy</i>
12	2.1	<i>very heavy</i>
13	2.2	<i>very heavy</i>
14	2.3	<i>very heavy</i>
15	2.4	<i>too heavy to hold</i>

Second round control test: *2.4 kg confirmed as “too heavy to hold.”*

Was an adjustment of the weight needed? *No*

If yes, how much and how many more tests were run: -

APPENDIX E: MAXIMAL TORQUE CALCULATIONS

Calculations for the maximal torque applied to the wrist joint based on the gathered data from MVC user study.

Participant #1

Distance from the prototype's CG to the wrist joint: $0.025\text{m} + 0.225\text{ m} = 0.25\text{ m}$

Total weight $0.285\text{ kg} + 2.5\text{ kg} = 2.785\text{ kg}$

Vertical force $2.785 \times 9.82 = 27.3487\text{ N}$

Max torque $27.3487 \times 0.25 = \underline{\underline{6.837175\text{ Nm}}}$

Participant #2

Distance from the prototype's CG to the wrist joint: $0.025\text{m} + 0.22\text{ m} = 0.245\text{ m}$

Total weight $0.285\text{ kg} + 2.2\text{ kg} = 2.485\text{ kg}$

Vertical force $2.485 \times 9.82 = 24.4027\text{ N}$

Max torque $24.4027 \times 0.245 = \underline{\underline{5.9786615\text{ Nm} \approx 5.98\text{ Nm}}}$

Participant #3

Distance from the prototype's CG to the wrist joint: $0.025\text{m} + 0.225\text{ m} = 0.25\text{ m}$

Total weight $0.285\text{ kg} + 2.0\text{ kg} = 2.285\text{ kg}$

Vertical force $2.285 \times 9.82 = 22.4387\text{ N}$

Max torque $22.4387 \times 0.25 = \underline{\underline{5.609675\text{ Nm} \approx 5.61\text{ Nm}}}$

Participant #4

Distance from the prototype's CG to the wrist joint: $0.025\text{m} + 0.24\text{ m} = 0.265\text{ m}$

Total weight $0.285\text{ kg} + 2.6\text{ kg} = 2.885\text{ kg}$

Vertical force $2.885 \times 9.82 = 28.3307\text{ N}$

Max torque $28.3307 \times 0.265 = \underline{\underline{7.5076355\text{ Nm} \approx 7.51\text{ Nm}}}$

Participant #5

Distance from the prototype's CG to the wrist joint: $0.025\text{m} + 0.215\text{ m} = 0.24\text{ m}$

Total weight $0.285\text{ kg} + 2.2\text{ kg} = 2.485\text{ kg}$

Vertical force $2.485 \times 9.82 = 24.4027\text{ N}$

Max torque $24.4027 \times 0.24 = \underline{\underline{5.856648\text{ Nm} \approx 5.86\text{ Nm}}}$

Participant #6

Distance from the prototype's CG to the wrist joint: $0.025\text{m} + 0.23\text{ m} = 0.255\text{ m}$

Total weight $0.285\text{ kg} + 2.4\text{ kg} = 2.685\text{ kg}$

Vertical force $2.685 \times 9.82 = 26.3667\text{ N}$

Max torque $26.3667 \times 0.255 = \underline{\underline{6.7235085\text{ Nm} \approx 6.72\text{ Nm}}}$

APPENDIX F: TORQUE CALCULATIONS FOR THE “HEAVY” RESPONSE

Calculations for the torque applied to the wrist joint that participants started to indicate as “heavy”, based on the gathered data from MVC user study.

Participant #1

Distance from the prototype’s CG to the wrist joint: $0.025\text{m} + 0.225\text{ m} = 0.25\text{ m}$
Total weight $0.285\text{ kg} + 1.1\text{ kg} = 1.385\text{ kg}$
Vertical force $1.385 \times 9.82 = 13.6007\text{ N}$
Max torque $13.6007 \times 0.25 = \underline{\underline{3.400175\text{ Nm} \approx 3.4\text{ Nm}}}$

Participant #2

Distance from the prototype’s CG to the wrist joint: $0.025\text{m} + 0.22\text{ m} = 0.245\text{ m}$
Total weight $0.285\text{ kg} + 1.3\text{ kg} = 1.585\text{ kg}$
Vertical force $1.585 \times 9.82 = 15.5647\text{ N}$
Max torque $15.5647 \times 0.245 = \underline{\underline{3.8133515\text{ Nm} \approx 3.81\text{ Nm}}}$

Participant #3

Distance from the prototype’s CG to the wrist joint: $0.025\text{m} + 0.225\text{ m} = 0.25\text{ m}$
Total weight $0.285\text{ kg} + 1.1\text{ kg} = 1.385\text{ kg}$
Vertical force $1.385 \times 9.82 = 13.6007\text{ N}$
Max torque $13.6007 \times 0.25 = \underline{\underline{3.400175\text{ Nm} \approx 3.4\text{ Nm}}}$

Participant #4

Distance from the prototype’s CG to the wrist joint: $0.025\text{m} + 0.24\text{ m} = 0.265\text{ m}$
Total weight $0.285\text{ kg} + 1.2\text{ kg} = 1.485\text{ kg}$
Vertical force $1.485 \times 9.82 = 14.5827\text{ N}$
Max torque $14.5827 \times 0.265 = \underline{\underline{3.8644155\text{ Nm} \approx 3.86\text{ Nm}}}$

Participant #5

Distance from the prototype’s CG to the wrist joint: $0.025\text{m} + 0.215\text{ m} = 0.24\text{ m}$
Total weight $0.285\text{ kg} + 1.0\text{ kg} = 1.285\text{ kg}$
Vertical force $1.285 \times 9.82 = 12.6187\text{ N}$
Max torque $12.6187 \times 0.24 = \underline{\underline{3.028488\text{ Nm} \approx 3.03\text{ Nm}}}$

Participant #6

Distance from the prototype’s CG to the wrist joint: $0.025\text{m} + 0.23\text{ m} = 0.255\text{ m}$
Total weight $0.285\text{ kg} + 1.2\text{ kg} = 1.485\text{ kg}$
Vertical force $1.485 \times 9.82 = 14.5827\text{ N}$
Max torque $14.5827 \times 0.255 = \underline{\underline{3.7185885\text{ Nm} \approx 3.72\text{ Nm}}}$

APPENDIX G: TORQUE CALCULATIONS FOR THE “VERY HEAVY” RESPONSE

Calculations for the torque applied to the wrist joint that participants started to indicate as “very heavy”, based on the gathered data from MVC user study.

Participant #1

Distance from the prototype’s CG to the wrist joint: $0.025\text{m} + 0.225\text{ m} = 0.25\text{ m}$
Total weight $0.285\text{ kg} + 2.0\text{ kg} = 2.285\text{ kg}$
Vertical force $2.285 \times 9.82 = 22.4387\text{ N}$
Max torque $22.4387 \times 0.25 = \underline{\underline{5.609675\text{ Nm} \approx 5.61\text{ Nm}}}$

Participant #2

Distance from the prototype’s CG to the wrist joint: $0.025\text{m} + 0.22\text{ m} = 0.245\text{ m}$
Total weight $0.285\text{ kg} + 2.0\text{ kg} = 2.285\text{ kg}$
Vertical force $2.285 \times 9.82 = 22.4387\text{ N}$
Max torque $22.4387 \times 0.245 = \underline{\underline{5.4974815\text{ Nm} \approx 5.5\text{ Nm}}}$

Participant #3

Distance from the prototype’s CG to the wrist joint: $0.025\text{m} + 0.225\text{ m} = 0.25\text{ m}$
Total weight $0.285\text{ kg} + 1.7\text{ kg} = 1.985\text{ kg}$
Vertical force $1.985 \times 9.82 = 19.4927\text{ N}$
Max torque $19.4927 \times 0.25 = \underline{\underline{4.873175\text{ Nm} \approx 4.87\text{ Nm}}}$

Participant #4

Distance from the prototype’s CG to the wrist joint: $0.025\text{m} + 0.24\text{ m} = 0.265\text{ m}$
Total weight $0.285\text{ kg} + 2.0\text{ kg} = 2.285\text{ kg}$
Vertical force $2.285 \times 9.82 = 22.4387\text{ N}$
Max torque $22.4387 \times 0.265 = \underline{\underline{5.9462555\text{ Nm} \approx 5.95\text{ Nm}}}$

Participant #5

Distance from the prototype’s CG to the wrist joint: $0.025\text{m} + 0.215\text{ m} = 0.24\text{ m}$
Total weight $0.285\text{ kg} + 1.9\text{ kg} = 2.185\text{ kg}$
Vertical force $2.185 \times 9.82 = 21.4567\text{ N}$
Max torque $21.4567 \times 0.24 = \underline{\underline{5.149608\text{ Nm} \approx 5.15\text{ Nm}}}$

Participant #6

Distance from the prototype’s CG to the wrist joint: $0.025\text{m} + 0.23\text{ m} = 0.255\text{ m}$
Total weight $0.285\text{ kg} + 1.9\text{ kg} = 2.185\text{ kg}$
Vertical force $2.185 \times 9.82 = 21.4567\text{ N}$
Max torque $21.4567 \times 0.255 = \underline{\underline{5.4714585\text{ Nm} \approx 5.47\text{ Nm}}}$

APPENDIX H: TORQUE CALCULATIONS FOR THE “TOLERABLE” RESPONSE

Calculations for the torque applied to the wrist joint that participants started to indicate as “very heavy”, based on the gathered data from MVC user study.

Participant #1

Distance from the prototype’s CG to the wrist joint: $0.025\text{m} + 0.225\text{ m} = 0.25\text{ m}$
Total weight $0.285\text{ kg} + 1.0\text{ kg} = 1.285\text{ kg}$
Vertical force $1.285 \times 9.82 = 12.6187\text{ N}$
Max torque $12.6187 \times 0.25 = \underline{\underline{3.154675\text{ Nm} \approx 3.15\text{ Nm}}}$

Participant #2

Distance from the prototype’s CG to the wrist joint: $0.025\text{m} + 0.22\text{ m} = 0.245\text{ m}$
Total weight $0.285\text{ kg} + 1.2\text{ kg} = 1.485\text{ kg}$
Vertical force $1.485 \times 9.82 = 14.5827\text{ N}$
Max torque $14.5827 \times 0.245 = \underline{\underline{3.572761\text{ Nm} \approx 3.57\text{ Nm}}}$

Participant #3

Distance from the prototype’s CG to the wrist joint: $0.025\text{m} + 0.225\text{ m} = 0.25\text{ m}$
Total weight $0.285\text{ kg} + 1.0\text{ kg} = 1.285\text{ kg}$
Vertical force $1.285 \times 9.82 = 12.6187\text{ N}$
Max torque $12.6187 \times 0.25 = \underline{\underline{3.154675\text{ Nm} \approx 3.15\text{ Nm}}}$

Participant #4

Distance from the prototype’s CG to the wrist joint: $0.025\text{m} + 0.24\text{ m} = 0.265\text{ m}$
Total weight $0.285\text{ kg} + 1.1\text{ kg} = 1.385\text{ kg}$
Vertical force $1.385 \times 9.82 = 13.6007\text{ N}$
Max torque $13.6007 \times 0.265 = \underline{\underline{3.604186\text{ Nm} \approx 3.6\text{ Nm}}}$

Participant #5

Distance from the prototype’s CG to the wrist joint: $0.025\text{m} + 0.215\text{ m} = 0.24\text{ m}$
Total weight $0.285\text{ kg} + 0.9\text{ kg} = 1.185\text{ kg}$
Vertical force $1.185 \times 9.82 = 11.6367\text{ N}$
Max torque $11.6367 \times 0.24 = \underline{\underline{2.792808\text{ Nm} \approx 2.79\text{ Nm}}}$

Participant #6

Distance from the prototype’s CG to the wrist joint: $0.025\text{m} + 0.23\text{ m} = 0.255\text{ m}$
Total weight $0.285\text{ kg} + 1.1\text{ kg} = 1.385\text{ kg}$
Vertical force $1.385 \times 9.82 = 13.6007\text{ N}$
Max torque $13.6007 \times 0.255 = \underline{\underline{3.468178\text{ Nm} \approx 3.47\text{ Nm}}}$

APPENDIX I: IMPLEMENTATION FOLDER

The folder “Ergonomic guidelines for designing handheld products“ with the central insights and recommendations from this report.

Ergonomic guidelines for designing handheld products



The purpose of this master thesis was to summarize and develop design guidelines as well as improvements for the design of small handheld products with ergonomics in focus based on a study of handheld vacuum cleaners. The guidelines are meant to be useful for designing other similar products for domestic use as well, where ergonomics can improve the comfort feeling of the end user and contribute to less heavily loaded positions of the wrist and forearm.

The guidelines presented in this booklet give recommendations for dimensions and design of handheld products in general. This guide also provides examples on how to calculate the torque load applied on the wrist and presents various existing ergonomic methods for workload assessment and explains how they can be applied to product design.

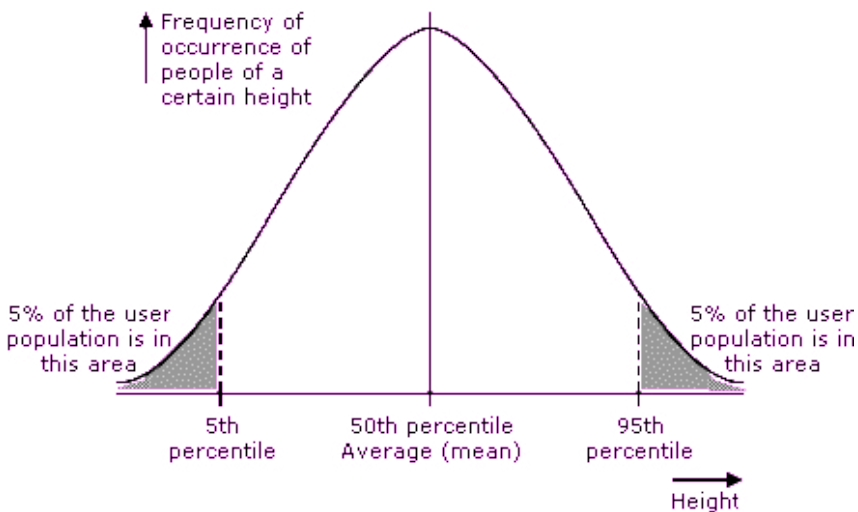
Content

Percentiles	4
Age and gender	7
Power grip	8
Precision grip	10
Recommended dimensions	11
Wrist and forearm positions	12
Applicable evaluation methods and other tools	14
How to calculate the torque load on the wrist	17
References	19

Percentiles

What is it and how to use it?

A population can be illustrated by a symmetrical bell curve where it can be shown that for example 50 percent of the population is taller than average and 50 percent of the population is shorter than average. The mean is therefore equal to the 50th percentile. In a similar way, arbitrary points can be used on either side of the curve; for example, the 5th percentile on the left; where it is possible to conclude that 5 percent of people are shorter than that point. 90 percent of the population is therefore between the 5th and 95th percentile in length. However, it is important to note that percentiles are specific to the populations they describe, for example, the 95th percentile of the general public could represent the 70th percentile of a particular occupational group such as professional chefs.



How to use it?

When designing for a better movement space, accounting for the largest 95th percentile is often used to accommodate for individuals that are larger than average as the largest individuals have more demand for movement space and dimensions.

When designing for better reach options, the shortest individuals should be prioritized, taking a minimum reach distance into account where it also is advisable to use the 5th percentile so that 95 percent of the population will be able to reach a certain point.

The target user population's measurements are often unknown including both women and men with a significant variation in measuring sizes. The large variation increases the need for adjustability of the design with target percentiles of the 5th to the 95th percentile. Note that this would, for example, exclude 10 percent of the population, who would not fit in. However, during certain situations requiring various adaptations to fit a certain population group as well as with certain technical or economic conditions the target percentiles may have to be adjusted to higher or lower levels.

Where to find it?

There are several online databases; some focus on a specific population, other provide data from research for different populations:

DINED, Anthropometric database

Open Design Lab

Open Ergonomics

antropometri.se also provides a simple tool for anthropometric measurements for Swedish adults.

The book "Bodyspace" by S. Pheasant and C.M. Haslegrave combines data from several sources and presents anthropometrics estimates for British, Swedish, Dutch, French, Polish, American, Brazilian, Sri Lankan, Indian, Chinese and Japanese adults. It also provides data for deviation in age, and the book is highly recommended to use.

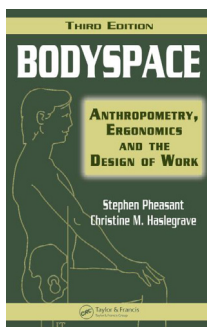


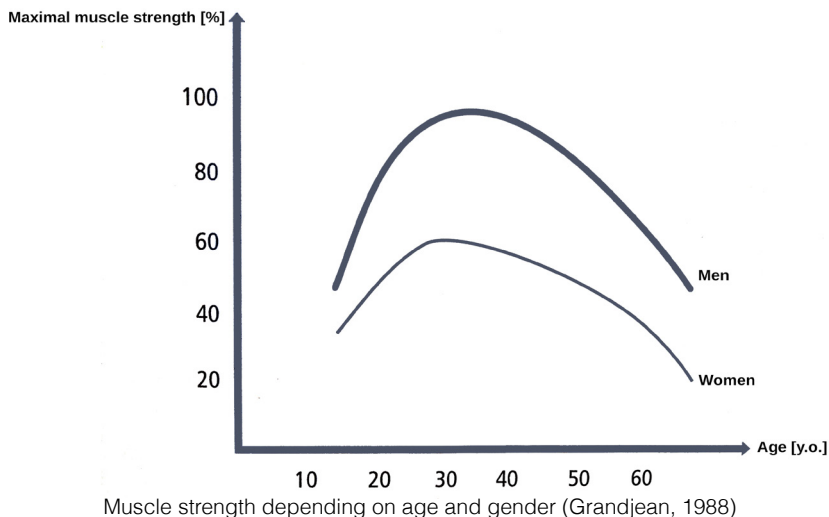
Table 10.15 Anthropometric estimates for Hong Kong Chinese industrial workers (all dimensions in mm, except for bodyweight, given in kg).

Dimension	Men				Women			
	5th %ile	50th %ile	95th %ile	SD	5th %ile	50th %ile	95th %ile	SD
1. Stature	1585	1680	1775	58	1455	1555	1655	60*
2. Eye height	1470	1555	1640	52	1330	1425	1520	57*
3. Shoulder height	1300	1380	1460	50	1180	1265	1350	51*
4. Elbow height	950	1015	1080	39	870	935	1000	41*
5. Hip height	790	855	920	41	715	785	855	42
6. Knuckle height	685	750	815	40	650	715	780	41
7. Fingertip height	575	640	705	38	540	610	680	44
8. Sitting height	845	900	955	34	780	840	900	37*
9. Sitting eye height	720	780	840	35	660	720	780	35*
10. Sitting shoulder height	555	605	655	31	510	560	610	29*
11. Sitting elbow height	190	240	290	31	165	230	295	38*
12. Thigh thickness	110	135	160	14	105	130	155	14
13. Buttock-knee length	505	550	595	26	470	520	570	30*
14. Buttock-popliteal length	405	450	495	26	385	435	485	29*

Age and gender

The strength of a grip, as well as the strength of other parts of human body, is affected by the age and gender of the user. Grip strength increases during childhood and young adulthood until reaching a maximum level at about 25 to 35 years old individuals. The strength level is relatively stable until about 50 years of age where it begins to decline at an exponential pace.

Gender also plays a role in grip strength. Generally, females possess about 50 to 80 percent of the strength of male's muscle strength, with the biggest difference in the upper extremities, such as the strength of a handgrip. This gender difference seems to be mainly because of differences in hand size and musculature. Women have smaller body size than men. Average for different body parts measurements do not differ by percentage since women have another body shape than men. For example, the percentage difference for the hand width is greater than a difference for hand length.



Power grip

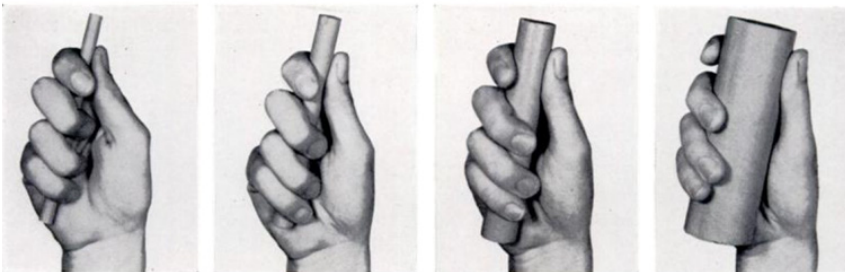
The power grip involves a grasp with the palm of the hand and force from the thumb countered by force of the other fingers.

Power grip is always to be preferred to a precision grip when a larger muscular force must be applied to hold the object. Among the most important factors that can influence the force required for the power grip are the intended activity and object itself: its size, weight, and shape.

There is a classification of the power grips, where the power grip can be described as:

- i. Spherical grasp used on spherical, ball-shaped objects
- ii. Cylindrical grasp around an objects circumference, for example, screwdriver handle
- iii. Disc grasp, for example, jar lid
- iv. Hook grasp where the handle is hooked by index, middle, ring and little fingers but not opposed to the force from the thumb.

The most usual type of power grip is a cylindrical grasp, where the diameter of the handle affects the strength of the grip and comfort of the hand.

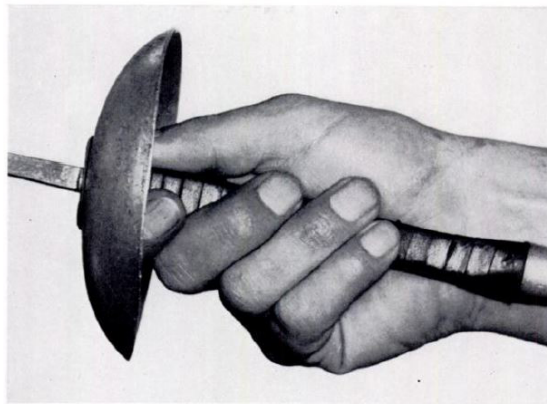


"An arbitrarily chosen series of postures illustrating some of the phases of the power grip complex." (Napier, 1956)



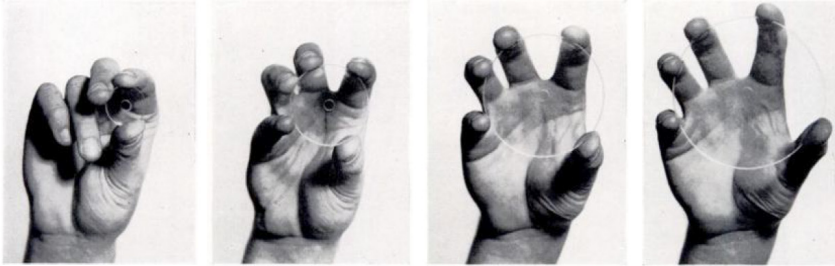
The precision of the power grip relies on the position of the thumb. Where there is little or no need for precision, the thumb wraps around the digits in order to help contribute to the grip force of the rest of the fingers, as in the image to the left. If there is a demand for precision for an object held in a power grip, the thumb changes its posture to control the direction of the force applied.

The image below illustrates an example with a power grip, where precision plays an important part: the thumb is no longer in position over the digits but applies its force to the tool instead.



A general conclusion is that the higher force is required of the whole hand to hold an object in a power grip, the more the thumb is enforced to act as a reinforcement for the grip itself and is less capable of helping to achieve the precision required.

Precision grip



"An arbitrarily chosen series of postures illustrating some of the phases of the precision grip complex." (Napier, 1956)

Grasping of objects can be described by covering the variation of two grip types for a human hand activity: power grip, described in the previous section, and precision grip. In the precision grip, the object is held between the thumb and fingers.

The precision grip is not to recommend for holding heavy objects, and hence might not be used for a product's primary type of holding hand posture. Still, this grip can be applied for holding products' smaller parts, for example, the mechanism for filter cleaning in the dust container or any types of knobs.

Grip surface is another factor that affects the grips comfort and perception of hand fatigue. Foam rubber has been proved to show a decrease the hand's fatigue when used on hand tools handles.

Recommended dimensions

When it comes to the size of the grip, there is no coherent conclusion in the published studies. The reason for this is that the variety of test procedures, sample, and method, are too diverse to be summarized to an optimum grip span. Dimensions presented below are suited for Swedish or any other typical western population. Overall the hand size should regulate the dimensions of the handle, and extra attention should be paid to the hand measurements depending on the population that will be using the tool and their anthropometric data.

The diameter of a handle is one of the key parameters that affect user's ability to apply force. For a cylinder-shaped handles the recommendations are following:

Handle length

For **women**: from **90** to **110 mm**, but not less than **80 mm**.

For **men**: from **100** to **130 mm**, but not less than **90 mm**.

Power grip

For **women**, cylindrical grip: **34 mm**

For **men**, cylindrical grip: **38 mm**

Acceptable range: **30** to **45 mm**

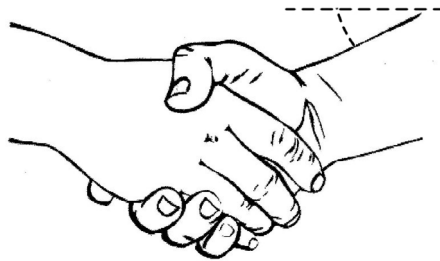
Gripping a handle with a very large diameter causes a decline in torque ability.

Precision grip

For the precision grip, it is **12 mm** regardless of gender, but a range between **8** and **16 mm** is acceptable.

Wrist and forearm positions

The recommended wrist orientation is where the wrist's position is slightly leaning forward, and the forearm is close to its neutral position with no supination or pronation. The optimal wrist position can be described as a straight orientation such as in a handshake. If bending is required for the use of the tool, then ***it is the tool rather than the wrist that should bend.***

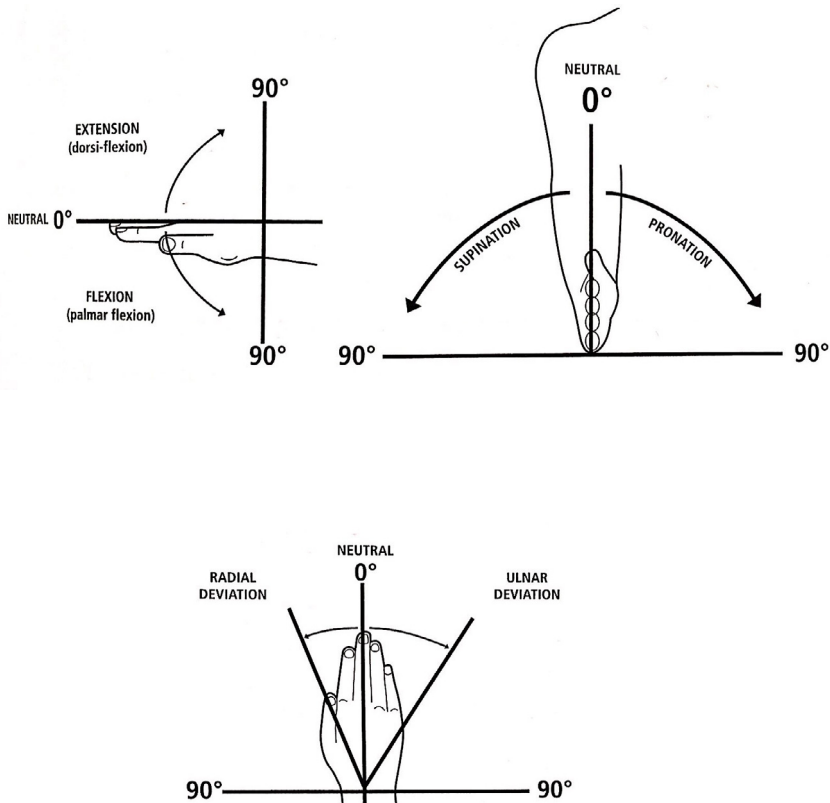


The wrist and forearm postures influence the grip strength of the hand. The wrist positions from strongest to weakest in the following order: neutral, ulnar and radial deviation, extension (dorsiflexion) and flexion (palmar flexion). For the extension of the wrist to make an impact on the strength, the angle should be noticeable: greater than 30 degrees, as a result of the wrist resting position occurs when the wrist is approximately 35 degrees in the extension.

The forearms' pronated or supinated positions were not found to make an appreciable impact on the grip strength. However, the deviation of the wrist is still one of the major factors that affect a decrease in grip strength.

Movement of the hand and forearm can be described with the following anatomic terms, that are widely used in ergonomics:

- **Flexion** is a joint bend towards the body
- **Extension** is a stretch of the joint out from the body
- **Supination** is rotational movement outwards
- **Pronation** is rotational movement inwards
- **Radial deviation** is a lateral rotation towards the thumb
- **Ulnar deviation** is a lateral rotation towards little finger



Terms of the hand and forearm movement (Abrahamsson et al., 2015)

Applicable evaluation methods and other tools

Most of the ergonomic methods that are being developed by universities are made to evaluate human work, often in an industrial environment. This leaves a gap for evaluation of commercial products used in everyday life for less than 8 hours per day. However, these methods can give an insight into what body postures are to be avoided to design for users increased convenience.

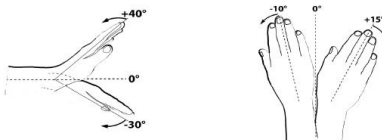
RAMP tool

RAMP is a risk management tool for manual handling. RAMP I provides a simple checklist of ergonomic risk factors, and RAMP II offers an in-depth analysis.

The tool is available for free at <https://www.ramp.proj.kth.se/>.

1.7 Wrist posture

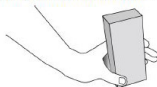
Is work performed with clearly bent wrist, as shown in the figures, or more?



	Left	Right
4 hours or more	7	7
3 to < 4 hours	5	5
2 to < 3 hours	3	3
1 to < 2 hours	2	2
30 minutes to < 1 hour	1	1
5 to < 30 minutes	0	0
< 5 minutes	0	0

2.2 Movements of the wrist

Do similar movements of the wrist occur?



	Left	Right
More than 20 times per minute	5	5
11 - 20 times per minute	3	3
6 - 10 times per minute	1	1
Up to 5 times per minute	0	0

Example for evaluation of body postures, RAMP II

As mentioned earlier, the time for different activities for commercial products makes it hard to use tools similar to RAMP, but the tool still provides good insights on risk zones and body postures that should be avoided.

Rapid Upper Limb Assessment (RULA) tool

RULA Employee Assessment Worksheet was developed at Cornell University and offers a step-by-step evaluation of upper extremity risk factors. In different evaluation steps, it presents a ranking point system for biomechanical and postural loads. This tool's final score cannot be used as a guideline for commercial products for domestic use, but the ranking points provide a useful overview for what it is considered to be ergonomic risk factors.

The sheet is available for download at <http://ergo.human.cornell.edu/pub/ahquest/curula.pdf>.

A. Arm & Wrist Analysis

Step 1: Locate Upper Arm Position

+1 +2 +2 +3 +4

-15° to 15° -15° +15° to 45° +45° to 90° 90°+

Step 1a: Adjust...

If shoulder is raised: +1;
If upper arm is abducted: +1;
If arm is supported or person is leaning: -1

Final Upper Arm Score =

Step 2: Locate Lower Arm Position

+1 +2 +1

0° to 90° 90°+ 90°+

Step 2a: Adjust...

If arm is working across midline of the body: +1;
If arm out to side of body: +1

Final Lower Arm Score =

Step 3: Locate Wrist Position

+1 +3 +2

0° to 15° 15°+ 15°+

Step 3a: Adjust...

If wrist is bent from the midline: +1

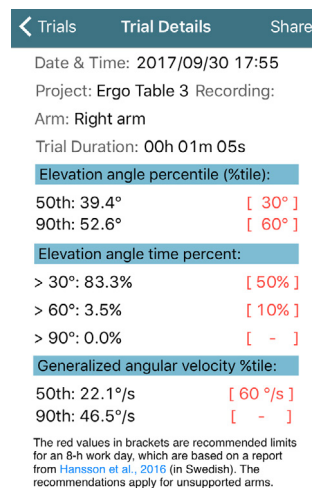
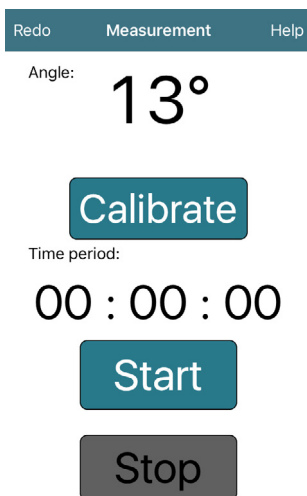
Final Wrist Score =

Step 1, 2 and 3 from the worksheet, RULA

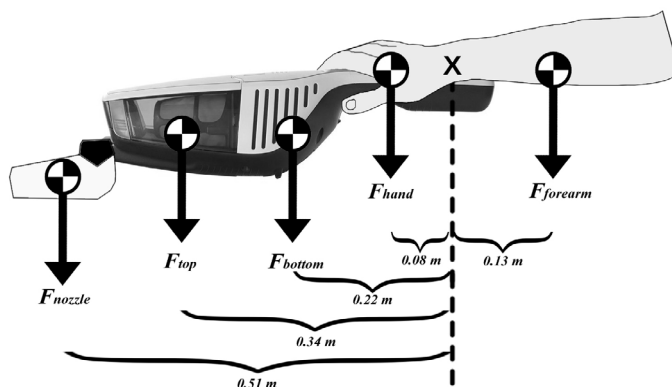
ErgoArmMeter app

ErgoArmMeter is an inclinometer tool available as an app for iPhone. It is developed in a collaboration between KI and KTH it measures arm elevation when performing different tasks.

The application is free, simple to use and shows the results in an accessible and comprehensible way. The user manual and more detailed information is available at <http://ki.se/en/imm/ergoarmmeter>.



How to calculate the torque load on the wrist



Forces applied on the wrist during the use of Ergorapido hand unit with a Bed Pro nozzle

Vertical forces that apply to the components of the system were calculated with the formula:

$$F=m \times g$$

where ***m*** represents mass for different components and ***g*** stands for gravitational acceleration and is equal to 9.82 in Sweden.

Some assumptions and simplifications applied in simpler biomechanical calculations:

- Body segments are regarded as rigid bodies
- The joints are frictionless, friction coefficient in a normal joint is 0.005
- Mechanical equilibrium prevails
- The importance of support forces is simplified

The general equation for torque, where ***F*** is the force applied, and ***r*** is the distance to the fixed suspension point, which in this case is the wrist:

$$\text{Torque} = F \times r$$

The corresponding equation that describes this model in the image on the previous page, if mechanical equilibrium is assumed, can be formulated as follows:

$F_{nozzle} \times 0.51 + F_{top} \times 0.34 + F_{bottom} \times 0.22 + F_{hand} \times 0.08 - F_{forearm} \times 0.13 = \text{Wrist Torque}$

where each force is multiplied by the distance to the wrist. The sum of the torque contributions, both positive and negative, is the **Wrist Torque** that the wrist will be exposed to in order to keep holding the object.

Weights of body parts and their centre of mass location

The weight of different parts of the body, that might be useful for biomechanical calculations is presented as a percentage of the total body weight for males and females in the top table to the right. The bottom table shows the segmental centre of gravity locations as percentages of segment length from the corresponding segments proximal ends (Plagenhoef, et al., 1983).

Percentages of Total Body Weight			
Segment	Males	Females	Average
Head	8.26	8.2	8.23
Whole Trunk	55.1	53.2	54.15
Thorax	20.1	17.02	18.56
Abdomen	13.06	12.24	12.65
Pelvis	13.66	15.96	14.81
Total Arm	5.7	4.97	5.335
Upper Arm	3.25	2.9	3.075
Forearm	1.87	1.57	1.72
Hand	0.65	0.5	0.575
Forearm & Hand	2.52	2.07	2.295
Total Leg	16.68	18.43	17.555
Thigh	10.5	11.75	11.125
Leg	4.75	5.35	5.05
Foot	1.43	1.33	1.38
Leg & Foot	6.18	6.68	6.43

Percentages of Segment Length from proximal ends			
Segment	Males	Females	Average
Head and Neck	55	55	55
Trunk	63	56.9	59.95
Thorax	56.7	56.3	56.5
Abdomen	46	46	46
Pelvis	5	5	5
Upper Arm	43.6	45.8	44.7
Forearm	43	43.4	43.2
Hand	46.8	46.8	46.8
Thigh	43.3	42.8	43.05
Leg	43.4	41.9	42.65
Foot	50	50	50
Abdomen & Pelvis	44.5	39	41.75

References

- Abrahamsson et al., 2015. Arbete och teknik på människans villkor. 3:1 red. u.o.:Prevent.
- C. Pryce, J., 1980. The wrist position between neutral and ulnar deviation that facilitates the maximum power grip strength. *Journal of Biomechanics*, 13(6), pp. 505-511.
- Fellows, G. & Freivalds, A., 1991. Ergonomics evaluation of a foam rubber grip for tool handles. *Applied ergonomics*, Volym 22, pp. 225-230.
- Galer, 1987. *Applied ergonomics handbook*. u.o.:Butterworth.
- Grandjean, E., 1988. *Fitting the task to the Man*. London: Taylor&Francis .
- Hazelton, F. T., Smidt, G. L., Flatt, A. E. & Stephens, R. I., 1975. The influence of wrist position on the force produced by the finger flexors. *Journal of Biomechanics*, 8(5), pp. 301-306.
- Konz, S., 1990. *Work design: Industrial Ergonomics*. 3 red. Washington, OH: Publishing Horizons.
- Kumar et al., 2008. *Biomechanics in ergonomics*. 2 red. u.o.:Taylor&Francis group.
- Lindqvist, B., 1998. *Verktygsergonomi - utvärdering av industriverktyg*. Helsingborg: Atlas Copco via ABE Tryck.
- Napier, J., 1956. The Prehensile Movements of the Human Hand. *Journal of Bone and Joint Surgery*, Volym 38-B, pp. 902-913.
- P.Kattel, B., K.Fredericks, T., E.Fernandez, J. & C.Lee, D., 1996. The effect of upper-extremity posture on maximum grip strength. *International Journal of Industrial Ergonomics*, 18(5-6), pp. 423-430.
- Pheasant, S., 2003. *Bodyspace. Anthropometry, Ergonomics and Design of Work*. 2 red. London: Taylor & Francis.
- Pheasant, S. & O'Neill, D., 1975. Performance in gripping and turning: A study in hand/handle effectiveness. *Applied Ergonomics*, Issue 6, pp. 205-208.
- Plagenhoef, S., Evans, F. & Abdelnour, T., 1983. Anatomical data for analyzing human motion. *Research Quarterly in Exercise and Sport* , Volym 54, pp. 169-178.
- Roebuck, J. A. J., 1995. *Anthropometric methods: Designing to Fit the Human Body*. Santa Monica, California: Human Factors and Ergonomics Society.
- Taylor, C. L. & Schwartz, R. J., 1955. The Anatomy and Mechanics of the Human Hand. *Artificial Limbs*, 2(2), pp. 22-35.
- Tichauer, E. & Gage, H., 1977. Ergonomic principles basic to hand tool design. *American Industrial Hygiene Association Journal*, Volym 38, pp. 622-634.
- Worthy, T., u.d. *Ergonomics for schools. Antropometry*. [Online] Available at: <http://www.ergonomics4schools.com/lzone/anthropometry.htm>

Master thesis project by Lesya Elam
KTH Machine design
Stockholm, Sweden. 2017.

Contact:
lesya.elam@outlook.com
+46 70 862 00 38

