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Exoskeletons and Ergonomic Safety within the Construction Industry

An exploratory study of the usage of heavy handheld machines

ALEXANDRA ROSÉN & ISABELLA ROSENQUIST

Master's Thesis in Industrial Design Engineering

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
Division Design & Human Factors

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Master of Science Thesis (IMSX30)

Exoskeletons and Ergonomic Safety within the Construction Industry
An exploratory study of the usage of heavy handheld machines

Supervisor & Examiner: Anna-Lisa Osvalder, Professor in Human-Machine Systems at the Division of Design & Human Factors and Senior Lecturer in Ergonomics

Department of Industrial and Materials Science
Division of Design & Human Factors
Chalmers University of Technology
SE-412 96 Gothenburg

Cover: A visualization of the user context for construction workers using heavy handheld machines
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Abstract

The construction industry is characterized by the usage of heavy machines and challenging physical work. With an increasing awareness about workplace ergonomics, the demand for safe and user-friendly equipment is growing. Husqvarna Construction is a company offering machines for the construction industry and is currently investigating how they could contribute to a more ergonomic usage of two of their heavy handheld machines, the core drilling machine and the power cutter.

This thesis explores how ergonomic aids and exoskeletons could be designed to contribute to a more ergonomic work situation for construction workers. Further, the project aims at investigating what attitudes construction workers have toward ergonomic aids and exoskeletons. To achieve this, user studies with the intended user group as well as literature study of work-related musculoskeletal disorders within the construction industry have been conducted. This resulted in an analysis of user needs and a compilation of guidelines for the future development of an ergonomic aid.

In this thesis, it could be concluded that a construction worker's user needs are complex. There is a clear need for an ergonomic aid but the attitudes towards these devices within this user group are challenging. The results also showed that an ergonomic product for the lower back could benefit this user group the most and that a back-supporting exoskeleton could reach a high user acceptance if it is customized to this specific target group. However, further investigation of the long-term usage of an exoskeleton in an actual industry setting is needed before concluding on whether an exoskeleton could provide an increased ergonomic safety or not for users of heavy handheld machines.

Keywords: Exoskeletons, ergonomic safety, heavy handheld machines, construction industry.

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Isabella Rosenquist & Alexandra Rosén
Gothenburg, 2022

Abbreviations

- EMG - Electromyography
- HTA - Hierarchical Task analysis
- PPE - Personal Protective Equipment
- REBA - Rapid Entire Body Assessment
- WRMSDs - Work-related Musculoskeletal Disorders

Contents

List of Figures

List of Tables

1

Introduction

This chapter presents background information about the project as well as the project aim, the research questions, objectives, and delimitations of the project. In the end, the user group that has been of focus during the project is presented.

1.1 Background

The development of exoskeletons has increased rapidly during the last decade and the industry for wearable robotics is expected to increase by 14% per year (Debusmann, 2021). In general terms, exoskeletons could be described as a wearable device that enables increased levels of strength, stability, and endurance by protecting and covering the user. These products can be constructed in different levels of complexity, with some being computer-operated and battery powered, incorporating sensors, hydraulics, and motors, while others mainly rely on more simple and passive designs with dampers and springs.

Many of the products that construction workers use daily cause large ergonomic discomfort (Desbrosses & Theurel, 2019). These products are often heavy and used for longer time periods, increasing the risk of causing fatigue and strain disorders. Work-related disorders are not only costly for the companies but also impact the worker's quality of life negatively. To increase the safety of the workplace, investigating how ergonomic aids could be used and developed for this industry is necessary. Further, studying whether industrial exoskeletons could have the potential of relieving the construction worker of workload and preventing work-related disorders is of interest.

Currently, Husqvarna Construction is investigating how they could contribute to a more ergonomic usage of two of their heavy handheld machines, the core drilling machine, and the power cutter. One of Husqvarna's main objectives with this project is hence to increase the knowledge about the users of their power cutters and core drilling machines to create a foundation for a future product development process of an ergonomic aid.

1.2 Aim

The aim of this project is to gain a deeper understanding of construction workers using heavy handheld machines. This includes user behavior, user needs, and attitudes towards ergonomic aids and their own work situation. Furthermore, this project aims to investigate how ergonomic aids, in particular exoskeletons, can be designed and used to increase physical ergonomics safety for construction workers.

In this report, ergonomic safety refers to safety concerning the work environment, methods, and products used by the worker that are appropriate to the worker's capabilities and job requirements (SafetyCulture, 2022).

1.3 Research Questions

To reach the aim of this study, the following research questions will be investigated:

RQ1: What are the users of heavy handheld machines' needs concerning physical ergonomics?

- What work tasks are considered the most challenging according to this user group?
- Which body parts are the most prone to pain from working in the construction industry?
- What does the literature say about work-related musculoskeletal disorders within the construction industry?

RQ2: Which aspects are important to consider when developing an ergonomic aid to increase ergonomic safety?

- Which design measures are of the highest importance to achieving high user acceptance?

RQ3: Which potential effects on physical ergonomic safety exist with the usage of exoskeletons?

- What types of exoskeletons exist on the market today?
- Could wearing an exoskeleton result in any unwanted consequences?

RQ4: What attitudes do construction workers have towards their work situation, ergonomic aids, and exoskeletons?

- Which are the main reasons for using heavy handheld machines?
- What are the reasons for choosing to use or not use ergonomic aids?

1.4 Objectives

To answer the research questions, the following objectives should be met:

- Gain deeper knowledge of the existing exoskeletons on today's market, including:
  - Why and how they are used today.
  - What different types of exoskeletons exist on the market today.
  - Which potential safety benefits and risks exist with the usage of exoskeletons.

- Gain a deeper understanding of the potential users of an exoskeleton, including:
    - Problem areas, work tasks, and context of the users of handheld core drilling machines and power cutters.
    - User behavior, the user needs, and attitudes towards the usage of an exoskeleton and other protective equipment.

- Follow the initial steps of a product development process in order to come up with design recommendations for the future development of an ergonomic aid, including:
    - Establishing a compilation of guidelines for the future product development of an ergonomic aid.
    - Identifying potential barriers and challenges with the launch of an exoskeleton in the industry of construction workers related to user acceptance.

1.5 Delimitation

This project is limited to investigating the handheld core drilling machines and power cutters found within Husqvarna Construction's assortment. Since the market size of Husqvarna's power cutters is considerably larger than the market size of the core drilling machines, the power cutter is of primary interest in this project. The project investigates different variants of usage within the industry of concrete cutters within the Swedish industry. However, limitations are made to not include construction work made on railways and to not investigate the usage of power cutters for emergency service.

This project further provides ideas and design suggestions on ergonomic aids but does not investigate any technical or economical aspects. Further, the analysis of attitudes within the construction industry does not include an analysis of macho culture or differences in work culture.

1.6 The User Group

One of the main user groups of Husqvarna's power cutters and core drilling machines is concrete cutters. This user group mainly works with concrete surfaces within the construction industry and is also the main focus group in this project.

2

Collaborator Husqvarna Construction

This master thesis is made in collaboration with Husqvarna Construction. This section provides information about the company and the machines studied within this project, the handheld power cutters and core drilling machines.

2.1 Husqvarna Construction

Husqvarna was founded in the city of Husqvarna in Sweden in the 18th century (Husqvarna Construction, n.d.-a). Since then, the company has grown gradually and production has included many different industries and products, such as sewing machines, hunting weapons, motorcycles, and household products. Within the Husqvarna Group today, there are several different brands such as Husqvarna Forest & Garden and Husqvarna Construction (Husqvarna Group, n.d). Husqvarna Construction manufactures tools and machines for industry and construction work and is represented in more than a hundred countries around the world (Husqvarna Construction, n.d.-b).

2.2 Power Cutters

Power cutters also go under the terms abrasive cut-off saws, concrete cutters and concrete saws and are often used within the construction industry. It is a power tool that has its blades tipped in diamond which could be used to cut in solid and hard materials such as concrete, asphalt and tiles (Shuanglong Machinery, 2021). These machines can be used to cut out wall openings as well as other surface jobs such as cutting stone pillars. Both handheld and smaller power cutters exist, as well as larger machines such as wall saws that are attached to walls and walk-behinds that the user operates while standing behind it. See some examples on handheld power cutters in its user context in Figure 1-2.

Figure 1-2: Two examples of power cutters
Husqvarna Construction, (n.d.-a), reprinted with permission

When using a power cutter, either wet cutting or dry cutting could be applied (Everett Industries, n.d.). For wet cutting, a water hose is attached to the machine. Wet cutting allows for maintaining cooler temperatures when cutting which results in the prevention of excessive wheel wear as well as a finer surface finish on the workpiece. The water also allows for cutting faster, further keeping the dust down (The family handyman, 2019). However, wet cutting requires high volumes of water, up to five gallons per minute or greater. In contrast, with dry cutting, there is a risk of overheating and the blade must run free every 30 to 45 seconds.

The handheld power cutters could be used for both vertical and horizontal cuts (Husqvarna Construction, n.d.-c). Depending on the purpose of the cut, different cutting techniques exist. For horizontal cuts, Husqvarna recommends making the cut from left to right. For vertical cuts, the cut is recommended to be made from the bottom up in order to better trace the cutting line. For pipes, the cut should be made from two opposite sides of the pipe. In general, the cut should always be done gradually.

Sometimes the power cutter makes a sudden upward movement called a kickback (Husqvarna Construction Products, n.d.). This happens if the blade is installed in the wrong direction, if the upper quadrant of the blade is used, or if the blade gets stuck. Further, when inserting the blade into an existing cut, there is a risk of the blade getting pinched, which would also cause a kickback. Because of this, using the power cutter above shoulder height is strictly discouraged since a kickback would cause the machine to hit the user in the head.

2.3 The Power Cutters of Husqvarna Construction

Husqvarna offers a broad assortment of powerful, handheld power cutters (Husqvarna Construction, n.d.-a). Within Husqvarna's product assortment, different variants of hydraulic and pneumatic power cutters, as well as petrol powered and electric powered ones, can be found. See an example of one of the power cutters within Husqvarna's assortment in Figure 3. See additional information about some of Husqvarna's handheld power cutters in Appendix A.1.

Figure 3: The power cutter Husqvarna K970
Husqvarna Construction, (n.d.-b), reprinted with permission

Husqvarna's power cutters can be used for a variety of different work tasks and conditions due to their compatibility with many different materials (Husqvarna Construction, n.d.-a). Some of the power cutters are designed for more extreme work conditions performed within the rescue service, where material such as aluminum, steel, plastic and rubber could be cut through. Husqvarna's assortment also includes trolleys which can be used together with the petrol powered power cutters, see Figure 4.

Figure 4: A trolley from Husqvarna to combine with a power cutter

Husqvarna Construction, (n.d.-c), reprinted with permission

2.4 Core Drilling Machines

A core drilling machine is a cylindrical and hollow drill (A-core concrete specialists, 2021). This tool is most often used when drilling holes in concrete structures (Matthews, 2017). Core drilling machines are also compatible with materials such as wood, rocks, ice, and cement (A-core concrete specialists, 2021). Additionally, drill bits exist in different variants where the main types are usually coated with carbide or diamond.

Drilling is performed by applying yielding pressures to the material, which in turn creates crack propagation, making it possible for the core drill to dig into the material (Matthews, 2017). A sample of the material, a core sample, can be extracted as a result from drilling the hole (A-core concrete specialists, 2021). See examples of core drilling machines in its user context in Figure 5-6.

Figure 5-6: Two examples of core drilling machines
Husqvarna Construction, (n.d.-d), reprinted with permission

Core drilling machines are mainly used for two different types of areas and/-or surfaces within concrete works, reinforced and non-reinforced surfaces (Matthews, 2017). Due to the differences in properties between these types of surfaces, they are drilled differently and require different amounts of force from the worker. For instance, drilling through reinforced concrete takes a longer time and requires a larger amount of pressure than drilling in non-reinforced concrete.

2.5 The Core Drilling Machines of Husqvarna Construction

Husqvarna's assortment of core drilling machines include both handheld machines and machines that could be attached to stands (Husqvarna Construction, n.d.-d). Different kinds of drill bits are also available. Husqvarna's assortment further contains equipment that help reduce dust and that provide water while drilling. See Figure 7 for an example of one of Husqvarna's core drilling machines. For additional examples, see Appendix A.2.

Figure 7: The core drilling machine Husqvarna DM 200
Husqvarna Construction, (n.d.-e), reprinted with permission

3

Theoretical Framework

This chapter starts with a description of the construction industry in Section 3.1. In Section 3.2, information about anatomy is provided followed by a description of ergonomics and design in Section 3.3. After this, information regarding work-related musculoskeletal disorders within the construction industry is presented in Section 3.4. This is followed by an introduction to anthropometry in Section 3.5. The final part of this chapter, Section 3.6, presents information regarding different types of exoskeletons and their effects on physical ergonomics.

3.1 The Construction Industry

In this section, work environment responsibilities, different ways of managing equipment, regulations and examples of protective equipment are presented.

3.1.1 Rented and Privately Owned Equipment

Within the construction industry, construction contractors are pressured with complex projects and tight timelines (Schmidt, 2021). It is therefore critical to have the right equipment available at the right time. To provide flexibility in terms of money and machine options, many business owners use both rented equipment and equipment that they own themselves. Using rented equipment is a way of getting access to a larger and more specialized assortment of updated equipment with the latest technologies.

3.1.2 Swedish Regulations at Construction Sites

Laws and regulations apply for all Swedish workplaces, which states that risks of accidents and health problems due to the work environment must be prevented and regulated (Osvalder et al., 2022). Additionally, it is required that the work environments and work tasks are organized to ensure good work conditions. Risks should primarily be avoided and prevented through organizational measures and organized techniques. Additionally, personal protective equipment should be used to prevent injuries.

3.1.3 Regulations Regarding Personal Protective Equipment

According to Occupational Safety and Health Administration (OSHA), the protection and prevention is of high importance and personal equipment should be provided and used when there exist safety risks caused by the work environment or processes (United States Department Of Labor, n.d.-a). In case of any hazard capable of causing impairment or injury through physical contact, inhalation, or absorption, personal equipment should be used. Personal Protective Equipment (PPE) are different types of products used to protect workers at work (European Commission, n.d.). According to OSHA, PPE includes protective equipment for the face, eyes, head, and extremities. It is the responsibility of the employer to require appropriate PPE when needed (United States Department Of Labor, n.d.-b).

For a more detailed explanation of various types of protective equipment such as respiratory protections, protective clothing, protective gloves, hearing protection, safety shoes helmet, eye and face protection, see Appendix B.1.

Personal Protective Equipment in Sweden

In Sweden, personal protective equipment is regulated through the Swedish Work Environment Authority, Arbetsmiljöverket (Osvalder et al., 2022). The protective equipment must be suitable for the task performed and enable adjustments to fit the user well. PPE should be chosen with concern to the available risks at the workplace as well as the risks which could be entailed by using the equipment while working. Routines for personal protective equipment should be incorporated at the workplace, including purchases, maintenance and usage. Furthermore, knowledge regarding how, when and where the equipment should be used is necessary.

3.2 Anatomy

This section presents theory about the human anatomy and how the body could be affected by work-related musculoskeletal disorders.

3.2.1 Back and Spine

The spine is the part of the body that carries the head, arms, torso, and the external loads added onto these body parts (Bohgard et al., 2009a). The spine is supported by surrounding muscle groups, where the most important is the so-called *musculus erector spinae* which helps stabilize the body by preventing the torso from falling forward. This muscle is also involved in various lifts, as it counteracts the moment that arises. Furthermore, the distance between the midpoints of the vertebrae and the *musculus erector spinae* is approximately five centimeter. As the distance to a lift is usually significantly longer than that, this entails a high load on both the spine and the disks that are there to capture these forces. Additionally, the strain is often higher in the lumbar region, which makes the risk of developing a herniated disc greatest in these regions of the back. If work is performed in working positions that are twisted or skewed, these risks are multiplied

3.2.2 Shoulders

The upper and lower arm should be able to rotate more than 180 degrees. This is made possible due to the high mobility of the shoulder joint as it is built up as a ball-and-socket joint (Humphrey Shoulder Clinic, n.d.). The head of the upper arm, the ball joint, rests in a circular concavity in the shoulder bone, which enables mobility. The joint stability is relatively small and thus needs to be stabilized by muscles and ligaments. Therefore, there are a large number of muscles around the shoulder joint to stabilize during all types of hand and arm activities.

The cavity where the shoulder joint is placed is a part of the shoulder blade, scapula, that is connected to the rest of the torso via the collarbone (Bohgard et al., 2009a). On the back, the shoulder blade is held in place by the *trapezius muscle* among other muscles. The upper part of the *trapezius muscle* is a very common area for work-related muscle pain.

3.2.3 Hands and Arms

The hand is a very flexible and complex system, which works as a gripping tool with many different functions, both in terms of power and precision (Bohgard et al., 2009a). The ability of the fingers to move is made possible with the help of two main groups of muscles, the internal and the external muscles. The internal muscles are responsible for the fine motor skills and positioning of the fingers and thumb and are located in different parts of the hand. The external muscles are responsible for force development during bending and stretching and are located in the forearm. To transmit force, there are tendons placed over the wrist. Furthermore, the bending tendons run through the narrow carpal tunnel. In general, the ability to develop power decreases as precision increases.

The stability of the forearm is created by the two bones, the *ulna* and the *radius* (Bohgard et al., 2009a). When the forearm is rotated, this causes a rotation at the elbow joint. In the forearm, there are also a large number of muscles to enable mobility and stability. In these regions, it is mainly the tendon attachments at the elbow and the wrist that risk suffering from discomfort or injuries.

3.3 Ergonomics and Design

This section provides information regarding different types of work-related musculoskeletal disorders, recommendations regarding work postures and aspects to take into consideration when designing heavy handheld tools.

3.3.1 Handheld Machines

Some aspects that should be considered when designing handheld tools are power and torque, comfort, control of the tool, the possibility of afferent feedback of the tool's exact position, and damage risk minimization (Bohgard et al., 2009a). When it comes to comfort and discomfort, the force should be distributed over as large an area as possible. This is especially important when power is to be combined with precision.

The maximum recommended weight for precision tools is 1.75 kilos and 2.3 kilos for handheld tools. Additionally, in order to give as small torque as possible on the wrist, the center of the mass should be located as close to the wrist as possible. However, an exception should be made for tools like a hammer or ax where the center of gravity should be far away from the hand due to dynamic reasons.

The design of a handheld tool will have consequences on the user's overall working position. Consideration should be taken to the shape of the shaft and the working height in order to avoid putting the user in a position with a bent and twisted back. Static positions with a lifted upper arm should also be avoided. The Swedish Work Environment Authority, Arbetsmiljöverket (n.d.-a) explains that working above shoulder level is highly unergonomic, partly due to the risk of nerves in the shoulder joints getting squeezed. In this case, just working with one's hands above shoulder level, although not carrying any heavy tools or material, is enough to cause a harmful pressure on the shoulders.

3.3.2 Ergonomic Design and Safety

In addition to the product's properties, the user group itself is a critical aspect to take into account and data such as age, anthropometry, disability, and experience are therefore crucial to have in mind when designing an ergonomic product (Bohgard et al., 2009b). Furthermore, designing the interface so that it facilitates making the right actions and reduces the risk of incorrect efforts is important. It is also of great importance to design interfaces so that making mistakes does not have serious consequences. Since it has to be possible to regret a maneuver, the design needs to be forgiving. This could mean using interlocks to prevent dangerous maneuvers from being carried out under certain conditions.

When designing an ergonomic product, five factors are important to keep in mind as they may contribute to safety hazards:

- The environment affects the functionality of the product in a way that the user does not understand.
- The product is used in a way that was not predicted.
- The product is used in a predicted way but in a way that was not designed safely.
- The usage of the product requires abilities that exceed those of the user.
- The product’s functionality is not consistent with the user’s expectations.

3.3.3 Ergonomics and Body Positions

The body position that the user takes on while working is dependent on the relationship between the body’s dimensions and the design of the workplace (Bohgard et al., 2009a). The intended working method could be ignored if it requires time-consuming detours or cumbersome protective equipment. This could result in unergonomic working positions being adopted. Therefore, a good working position should be possible to take on without any time-consuming additional steps.

Bohgard et al. (2009a) give several recommendations regarding ergonomic working positions:

- A forward-leaning position on the head and body should be avoided.
- The upper arms should be next to one’s body. Working with the hands above shoulder height should not occur for longer time periods.
- Twisted and asymmetrical postures should be avoided.
- There should exist a possibility to change the posture as much as possible.

During standing work, the person’s body position is affected by the height above the floor at which the manual work is performed. If the working height is too high and the arms must be kept in a high position, the muscles of the shoulders get an unwanted static load. Applying downward forces also becomes more difficult at too high working heights. However, if the working height is too low, the body and head must bend forward, resulting in an increased load on the muscles in the neck and back.

Bohgard et al. (2009a) give several additional recommendations on reaching a good working height:

- Heavy work should be performed 150-140mm below elbow height.
- Precision work should be performed 50-100mm above elbow height where relief for the arms is recommended.
- Light manual work should be performed 50-100mm below elbow height.
- When lifting, the work should be performed with bent knees, a stable and wide foot distance, and in a forward-facing position without the body being twisted or the back bending.

3.3.4 Different Types of Strains

In this section, information regarding different types of strains are presented.

Full Body Strain and Local Strain

Full body strain or global strain, means strain that engages large parts of the body's muscles, often requiring higher blood circulation capacity (Bohgard et al., 2009a). Local strain is strain on limited parts of the body where the total strain on the circulatory system is low. Local strain most often occurs in the upper extremities and usually only causes damage in its local area of action. In contrast, global strain can cause damage both to individual muscles and joints and to the circulatory organs.

Static and Dynamic Strain

Prolonged and continuous strain without variation in muscle length or force is called static strain (Bohgard et al., 2009a). Decreased blood circulation and fatigue as well as pain in the muscles are effects of higher static strains. Very low short-term static strains could in the long run result in problems in joints and muscles.

Dynamic loads mean that the load changes over time. However, seemingly dynamic work often involves static strain on muscles. Bohgard et al. (2009a) give the example of that working with the arms in different movements to maneuver an excavator still exposes the muscles in the shoulder to an unchanged force development.

Fatigue and Recovery

There are different types of fatigue (Bohgard et al., 2009a). Mental fatigue arises from mental strain, circulatory fatigue from heavy body work and local fatigue most often from static contraction. In case of local fatigue, lactic acid often arises due to the static muscle work. An depletion of energy reserves and storage of lactic acid reduces work capacity. Fatigue and pain are often signs of the body running out of resources. In case of fatigue, recovery is required so that the physiological systems can be relieved.

In the long run, fatigue and pain could turn into chronic ailments and diseases (Bohgard et al., 2009a). To avoid this, the work should be designed so that it provides strain variation. This means that the work should be carried out with alternating light and heavy loads and with a sufficient number of breaks that include moments of total relaxation of the muscles. One-sided repetitive work should be avoided as much as possible.

Heavy Physical Work

In Sweden, the recommendation is that physical work should not have a greater weight than that if one works continuously during a working day, one does not exceed 35% of one's maximum physical work capacity (Bohgard et al., 2009a). During an entire working day, it is not possible to apply higher load levels higher than this more than temporarily.

It has been shown that people who have worked within industries where heavy physical work is required have poorer physical capacity than the average worker. As the work often takes place during a large part of the day, there is not enough time for recovery and building muscles, which leads to decomposition of muscles taking place instead. Heavy work steps should therefore be alternated with lighter tasks.

3.4 Work-related Musculoskeletal Disorders

In this section, some examples of work-related musculoskeletal disorders are presented as well as information about how work-related disorders are reflected within the construction industry.

3.4.1 Examples of Work-related Musculoskeletal Disorders

Work-related musculoskeletal disorders (WRMSDs) are work-related injuries on supporting structures such as muscles, nerves, cartilage, ligaments, and joints (Abdel-Wahab et al., 2016). WRMSDs also goes under the names repetitive strain injuries or repetitive motion disorders and can be categorized into cumulative trauma disorder, strains and sprains (Dai et al., 2015). Strains and sprains in joints and muscles are often caused by excessive force that takes place at a single event, such as when lifting heavy objects. In contrast, cumulative trauma disorder often originates from performing repetitive work tasks with smaller workloads or from keeping the body in an unnatural position for a long period of time.

In this section, the two WRMSDs, tennis elbow and Raynaud's disease, are explained. For additional examples of WRMSDs such as herniated disc, sciatica, tendonitis and trigger fingers syndrome, see Appendix C.1.

Tennis Elbow

Tennis elbow is a common tendon attachment injury (Bohgard et al., 2009a). This injury can occur if the wrist extensors are activated repetitively and/or statically. This type of injury can also occur in work tasks where a forcing grip is used together with stabilization of the wrist. The degree of force and repetitiveness is crucial for this type of injury. In general, the combination of simultaneous force and repetitiveness has a negative effect, which multiplies the risk of hand and elbow injuries.

Raynaud's Disease

Raynaud's disease, also called White fingers, is one of the most common occupational diseases (Tekavec, 2016). Raynaud's disease is a disorder in the blood vessels that results in a chronically reduced feeling and strength in the hands, constant tingling and numbness in the fingers, and cold intolerance. One of the causes behind this disease is an extensive use of vibrating tools, causing the small vessels and nerves in the fingers to be damaged by a constant exposure of vibrations. The blood vessels narrow when being exposed to cold or stress which further causes the surface of the skin of the affected areas to turn white and blue (Johns Hopkins Medicine, n.d.). This disease is common in professions that use tools that cause vibrations, such as in the concrete industry where breaker hammers, compactor plates, reciprocating saws, and drilling machines are used.

3.4.2 WRMSDs in the Construction Industry

Since the construction industry is a labor-intensive work environment, construction workers are exposed to high risks of developing WRMSDs (Dai et al., 2015). The most common WRMSDs are sciatica, herniated discs, carpal tunnel syndrome, tennis elbow, tendonitis, trigger finger, and low back pains. These injuries normally occur at joints such as wrists, elbows, and fingers, but also in the back, shoulders and arms. Symptoms of tingling, aching, and numbness are not unusual (Antwi-Afari et al., 2021). Additionally, studies have shown that within the construction industry, experiencing lower back pain is one of the most common problems (Dai et al., 2015).

Most Prominent Physical Risk Factors in the Construction Industry

According to Abdel-Wahab et al. (2016), some of the most common ergonomic problems in the construction industry are: Working with a twisted and bent back, keeping the body in the same position for a long period of time, and managing heavy equipment. This is supported by what Antwi-Afari et al. (2021) write about keeping a twisting back as well as long work periods of manual material handling having a high correlation to WRMSDs. However, Dai et al. (2015) explain that another prominent physical risk factor is performing repetitive tasks. In contrast, Ramirent (n.d.) explains that both lifting heavy tools and performing monotonous work are the most common risk factors. These differences are explained by Antwi-Afari et al. (2021) to depend on that the type of injury is highly task-specific and what risk factor that is most common for which segment of the construction industry varies. The most prominent risk factors for construction workers within one trade can hence not be generalized to work in other trades.

Furthermore, Arbetsmiljöverket (n.d.-a) writes that material that weighs more than 25 kilos is harmful to carry since it requires a large force generation from the smaller muscles around the lumbar spine to resist the tendency of falling forwards. The distance between the object and the user is also crucial. The larger the distance between the user and the object that is to be carried, the lighter the object needs to be. Dai et al. (2015) further describe how lumbago and other urgent injuries often are a consequence of having combined carrying with bending or twisting of the body.

Dai et al. (2015) also explain that in order to decrease the risk of developing inflammation in the muscles and joints in the neck, shoulders and arms, taking breaks and having a rotation of work tasks within the staff is crucial, especially if working with repetitive tasks. If the work is strictly ruled or if the worker is bound to a certain working position or limited area, the risk for repetitive tasks increases.

Psychosocial Factors

The risk factors for developing WRMSDs can be divided into different categories, and one of them is the physical or biomechanical exposures described in the previous section (Dai et al., 2015). A second category is called psychosocial stressors, which include both social and physiological factors such as social unsafety, role ambiguity, and long work hours (Daraiseh et al., 2006). There is evidence of physical stressors increasing the risk of developing WRMSDs. For example, Daraiseh et al. (2006) explain that a study with 1800 Swedish construction workers showed a relation between stress about job insecurity and severe lower back pain. This relation is confirmed by Antwi-Afari et al. (2021) that explain that there is evidence that mental stress can cause WRMSDs.

3.4.3 Work-related Diseases in Sweden

According to the Swedish Work Environment Authority, a work-related disease refers to a disease caused by harmful effects at work that are not accidents (Arbetsmiljöverket, 2020a). Here, harmful effects refer to factors in the work environment that can adversely affect physical or mental health (AfA Försäkring, 2022). For example, through recurring one-sided movements or psychologically stressful conditions at work (Arbetsmiljöverket, 2020a).

A report carried out by the Swedish Work Environment Authority showed that ergonomic factors were the second most common reason to report a work-related disease in Sweden, organizational and social factors being the most common reason (33% compared to 40%) (Arbetsmiljöverket, n.d.-b). In addition, the percentage of work-related diseases registered due to ergonomic factors was higher among men than women, 43% compared to 27%. Physical pain as well as fatigue and aches were the most common work-related ailments. Two-thirds of workers with work-related injuries suffered from aches or physical pain while around seven out of ten had felt tired due to work during the past 12 months, 80% women and 68% men. Physical pain or aches affected about as many men as women.

Registered injury statistics found at Swedish Work Environment Authority show that the number of registered cases of work-related diseases within the construction industries varies from year to year (Arbetsmiljöverket, 2022a). The average value of registered cases between 2016 and 2019 was 574.2 cases per year.

3.5 Anthropometry

When designing, it is important to keep the differences of the population in mind in order to create an inclusive design that fits the target group (Bohgard et al., 2009a). Generally, the 5th and 95th percentiles are suitable to accommodate an inclusive design. This means that to ensure that 95% of the population can use the product, the 5th percentile of a population is appropriately selected. In this section, additional information about anthropometry is given.

3.5.1 Biological Variations

In this section, biological variations in regards to age and gender are presented.

Age

At the age of 20 to 25, the human's physical capacity is at its fullest potential (Bohgard et al., 2009a). From this age onwards, most bodily functions gradually decrease. Examples of two of these functions are muscle and skeletal strength. For example, the maximum strength has been reduced by 25% at the age of 60. This usually results in an increased risk of developing work-related illnesses. Furthermore, the maximum axial load that the vertebrae of the spine can manage without risk of injury is reduced for people over 60 years compared to those in their forties, about six kilonewton compared to three kilonewton. It is further described that the discs between the vertebrae are compressed with age.

This reduction in physical capacity can be an obstacle when working in the construction industry (Bohgard et al., 2009a). People in industries where heavy physical work is required could have to quit their job before retiring due to work-related disorders or because the work pace is too high.

Men and Women

Body measures and body shapes differ between men and women, with men having larger body measures than women (Bohgard et al., 2009a). Also the maximum muscle strength between men and women differs, mainly in the upper extremities, for example in terms of hand strength. In general, women have approximately 50-80% of muscle strength compared to men. Furthermore, if the same load is to be carried by both men and women, women have a lower muscular endurance.

3.6 Exoskeletons

Anastasi et al. (2019) describe exoskeletons as wearable devices that can enhance or assist physical activity by generating forces or torques on human joints. Furthermore, exoskeletons could be described as external frames on the user that should offer support to muscles similar to a human skeleton (Kuber & Rashedi, 2021). In this section, the results from the literature study about exoskeletons are presented.

3.6.1 Different Types of Exoskeletons

In this subchapter, descriptions of different types of exoskeletons are presented.

Passive and Active Exoskeletons

Exoskeletons are usually divided into two main categories, passive and active exoskeletons. A passive exoskeleton relies on the user providing the energy that will support motions or postures while an active exoskeleton has external sources such as batteries that introduce additional energy (Anastasi et al., 2019).

The majority of passive exoskeletons employ different types of elastic elements such as elastic bands, rotational springs, and integrated gas springs (Anastasi et al., 2019). Flexible beams such as carbon fiber beams could also be used to transfer and generate torques between one body part and another, such as between the torso and pelvis. As an example, in a back-supporting exoskeleton, when the user bends forward, the energy could be stored in the mechanical structure and then dissipated to support the user when she lifts a heavy object (Bosch et al., 2016).

Active exoskeletons compromise actuators such as electoral motors, hydraulic actuators or pneumatic actuators and a computer program based to augment the user's power (Anastasi et al., 2019). This type of exoskeleton can reduce larger physical loads compared to passive exoskeletons, especially if the number of actuators and a larger power supply is used (Bosch et al., 2016). Additionally, some active exoskeletons rely on onboard batteries which makes them more mobile but also heavier than passive devices (Anastasi et al., 2019).

Anastasi et al. (2019) propose that passive exoskeletons could be more appropriate for users that are working with lighter loads who are in the need of light to moderate assistance. When stronger assistance is needed, active exoskeletons could be more beneficial, such as when working with more demanding and dynamic tasks. However, Anastasi et al. also explain that passive exoskeletons are more common in the market due to the technical complexity of active ones.

Control Strategies for Active Exoskeletons

Anastasi et al. (2019) suggest two different control strategies for active exoskeletons, indirect and direct control. Measurements from the user environment and device would result in an indirect control while for example biosignals through electromyography EMG would result in direct control. Additionally, the sensor information acquired from these systems could potentially be used to recognize different activities and then apply different strategies to adjust to this. For example, some exoskeletons can distinguish between the user walking and lifting heavy objects (Anastasi et al., 2019).

Anastasi et al. further explain that one main challenge for active exoskeletons is to acquire useful information about the user's intention to follow the user's intent and provide the right timing and frequency of support. This is also supported by what Bosch et al. (2016) write about detecting human intentions where it is stated that this is crucial for enabling smooth movements of the user. Additionally, distinguishing between unintended movements and intended movements is challenging and could require systems of complex sensors and signal processing (Bosch et al., 2016). To detect the intentions of the user to allow for as smooth movements as possible could require a number of sensors that could possibly decrease the freedom of movement of the user.

Back-supporting and Upper Limb Exoskeletons

Categorizations of exoskeleton can also be made according to which body part it is designed to assist, such as full body, upper body or lower body support (Anastasi et al., 2019). Back-supporting exoskeletons and upper limb exoskeletons are the most common ones and are designed to reduce lower back pain and shoulder pain. For the upper limb exoskeletons, the shoulder muscles are supported when lifting the arms. In the back-supporting exoskeletons, forces and torques are often applied between the user's torso and thighs in order to assist the back muscles.

Rigid and Soft Exoskeletons

Exoskeletons can further be divided into soft and rigid exoskeletons. However, there exist exoskeletons that combine soft and rigid structures (Anastasi et al., 2019). Soft exoskeletons, also termed as exosuits, use garments as interfaces and cables or straps to provide assistance to the user. An exosuits is often lightweight and flexible with a higher freedom in movement than a rigid one (Kuber & Rashedi, 2021). It also has the advantage of enabling the user to wear it underneath work clothes and safety protection (Anastasi et al., 2019).

In rigid exoskeletons, the garments are made of connected actuators with hard structures that often run in parallel to the body (Anastasi et al., 2019). These rigid structures could be applying forces in perpendicular to the body segments, such as applying force on the chest in order to create a back-extension moment. Additionally, in order to create a hip extension, forces could be applied by pulling from the back of the leg or pushing the front of the thighs.

Anthropomorphic Exoskeletons

Another category of exoskeletons is called anthropomorphic exoskeletons which are devices that resemble the human body (Bosch et al., 2016). For this type of exoskeleton, the joints and rotational axes are aligned with the human joints and its rotational movements. Exoskeletons that are completely anthropomorphic follow the motions of the user and offer a large degree of freedom. However, this type of system has to ensure a close fit to the user in order to accommodate the movement, introducing major design challenges. For example, the shoulder comprises several different rotational movements which makes it a complex joint to incorporate in an exoskeleton. Therefore, non-anthropomorphic devices that are of a less complex structure are more common and designed to improve performance at specific tasks.

3.6.2 The Efficacy of Exoskeletons

In this section, the efficacy of upper limb and back-supporting exoskeletons according to the reviewed literature is presented. These two types of exoskeletons are the ones the majority of the reviewed literature studied in this project has covered.

Back-supporting Exoskeletons

A method that is commonly used to evaluate the efficacy of exoskeletons is using electromyography (EMG) to measure change in muscular activity (Milosavljevic et al., 2020). A study of a back-supporting exoskeleton showed a decrease in muscle activity of 16% in the lower back region when performing a five-minute repetitive lifting task in a laboratory (Kuber & Rashedi, 2021). Another study of an active back-supporting exoskeleton showed a decrease in muscle activity of 40% to 80% when performing repetitive lifting tasks. This resulted in the user being able to work for a longer time period. Furthermore, in another laboratory-based study, a reduction in hip extensor muscle activity (24%) and neck muscle activity (50%) were observed for static bending tasks when using a passive exoskeleton (Desbrosses & Theurel, 2019).

These studies are consistent with what Kermavnar et al. (2021) found when conducting a review of papers about industrial back-supporting exoskeletons tested during various bending and lifting tasks. Kermavnar et al. state that there are often decreases in back-muscle activity during lifting and static bending when using exoskeletons, enabling user endurance to be improved. This performance is however lower during tasks requiring a higher agility. Additionally, several side effects are often observed, such as alterations in joint angles and increased lower limb and abdominal muscle activity.

Upper Limb Exoskeletons

In a study performed by De Bock et al., (2021), the effectiveness of two passive exoskeletons for shoulders was evaluated both in-field and in a laboratory setting with four industrial workers. It was found that the exoskeletons had a positive effect on isolated tasks with a decreased heart rate and muscle activity. However, the muscle activity decreased less during the in-field testing. When users performed manual precision tasks with objects of between 13.1 kilos and 17 kilos, the muscle activity in the shoulder decreased by up to 26% compared to up to 46% in the lab. However, the study also showed increased feelings of discomfort and frustration among the users that wore the exoskeletons.

Another study conducted in the automotive industry showed an increase in productivity in overhead tasks when wearing a passive upper limb exoskeleton (Kuber & Rashedi, 2021). However, although there is some evidence of passive upper limb exoskeletons reducing muscular demand, Fischer & McFarland (2019) emphasize that there is too little evidence to support the usage of active exoskeletons for the prevention of WRMSDs. They further state that their literature review of existing papers on active and passive upper limb exoskeletons indicates that there is insufficient evidence of exoskeletons having a positive impact on kinematics and fatigue.

Additionally, De Bock et al. (2021) explain that the effects of exoskeletons are task-specific and that the majority of evaluations of exoskeletons for overhead work have been done in laboratories. There is hence little evidence of their effectiveness outside the lab and they recommend being careful with using laboratory-based evaluations for the development of exoskeletons.

3.6.3 Potential Side Effects of Using Exoskeletons

In this section, the potential side effects of using an exoskeleton according to the literature are presented.

Altered Postural Control and Muscle Compensation

Although it has been found that both active and passive exoskeletons have the potential to limit local muscular demand, Desbrosses & Theurel (2019) explain that a side effect of using exoskeletons that has been observed is a changed postural control. They further suggest that attention should be given to how passive exoskeletons could affect spinal imbalance. For example, Desbrosses & Theurel mention that exoskeletons for back-support can result in disturbed balance and movement efficiency due to the postural adjustments that are needed.

Furthermore, the coordination between antagonist and agonist muscles could be negatively affected (Desbrosses & Theurel, 2019). This is also supported by what Bosch et al. (2016) write about that the lifting technique will be altered due to a decreased activity in certain muscles being accompanied by increased activity in other muscles. They explain that it has been observed that passive exoskeletons for the back have resulted in an increase in leg muscle activity due to the device having to be counteracted to retain balance. Additionally, apart from muscle compensation, Kuber & Rashedi (2021) found that the decreased physical demand on some joints could add an increased load on other joints. Hence, Kuber & Rashedi emphasize that this type of counterproductivity of exoskeletons is an aspect that should be considered when developing exoskeletons.

Contact Areas and Limited Motion

Other aspects that have been discussed in literature about exoskeletons are how these devices need to apply pressure on the wearer in order to function (Bosch et al., 2016). These contact areas can cause discomfort and lead to a reluctance to use the exoskeletons by the user. Additionally, Kuber & Rashedi (2021) write that the structures and joints of most of today's exoskeletons are rigid, creating a bulky structure that limits the user's range of motion. They explain that this could risk decreasing the overall productivity of the worker, especially if the user has to work in smaller spaces where a wider range of motion is of importance.

3.6.4 Predicting User Acceptance

In order to incorporate exoskeletons in the work activities of industrial workers, it is necessary to understand what factors affect the user acceptance and the user's intentions towards using exoskeletons (Elprama et al., 2020). Therefore, in this section, aspects regarding user acceptance and perceived usability are presented.

Crucial Aspects for User Acceptance

In a study about workers' attitudes towards exoskeletons at their workplace, 124 industrial workers participated in a survey that resulted in the findings of which factors are the most crucial when it comes to predicting the intention to use exoskeletons (Elprama et al., 2020). It was found that what was described as effort expectancy*,* so to say how much effort that is needed compared to the amount of perceived benefit, plays an important role. The aspect of social influence, such as whether the user thought other workers would use the devices or not, also matters.

Additionally, Kuber & Rashedi (2021) explain that the perceived usability could decrease if there are multiple attachments with high attaching times, further adding that the visually complex exoskeletons could reduce the acceptance among users. Needing help from someone else to put on the device or having to spend time on putting it on and off could also discourage people from using it (Anastasi et al., 2019). Furthermore, exoskeletons aimed at a wide variation of tasks could potentially be less effective than exoskeletons aimed at specific industry tasks. There is a trade-off between assisting the user in many work tasks but with lower efficiency and helping the user with only a several tasks but with a higher effect that needs to be considered when designing exoskeletons.

Active Exoskeletons and Usability

Anastasi et al. (2019) suggest being mindful of the delays in responses from the active exoskeleton that are caused by the signal processing. These aspects, as well as the risk of causing cognitive overload due to too heavy amounts of signals, are crucial for user acceptance. A smooth and intuitive way of controlling and adjusting the device is also of high importance and could be done from an ad-hoc device such as a smartphone app or additional control device. Since the user preference varies between each individual user, Anastasi et al. further suggest that parameters such as the maximum amount of assistance that is given should be possible for the user to adjust.

Additionally, for active exoskeletons, (Anastasi et al.) recommend keeping in mind that more powerful actuators will be heavier and therefore also risk negatively affecting the user experience. It is also suggested to rely on batteries that are less heavy but that need to be swapped more often, since too heavy batteries would compromise the comfort and effectiveness of the exoskeletons.

4

Methodology

This chapter presents theory regarding the methods used during this project. The different methods are divided into Data collection methods, Analysis methods and Ideation methods.

4.1 Data Collection Methods

Different methods for collecting data are presented in this subchapter.

4.1.1 Literature Study

A literature review is a method where previous research is analyzed and synthesized in a systematic way to map and assess the area of research (Snyder, 2019). Furthermore, this method can be used to motivate the hypothesis and research questions set up for the study as well as motivating the aim of the study.

4.1.2 Benchmark

Benchmark is a method that could be used for gaining insights about similar products or services on the market (AFHS, n.d). Analyzing how similar products perform, what the key success factors are and how attractive they are among the consumers can result in an increased awareness of how one's own product portfolio could be improved and in which market segments a product could have the most potential. Furthermore, this method could be used to gain insights about current challenges and possibilities within the industry, how the market has developed and which future trends that are emerging.

4.1.3 Observation

Observations can be used as a method to investigate and identify user needs, behaviors and attitudes in specific situations and context, or as a method of identifying unnoticed areas which are in need of development and change (Ericson et al., 2016a). Furthermore, observations give the observer the opportunity to understand important links and relations to the performance of the task. The duration of an observation can vary in time, from shorter sessions to a full day.

Participant Observation

Participant observations is a qualitative method where the researcher participates in the activities of the studied group (QuestionPro, n.d.). This allows the researcher to collect information and possibly gain a better understanding of the study group. However, the collected data from this type of methodology is affected by the subjective view of the researcher's own experience of the participation.

4.1.4 Interview

Performing interviews with users in the product development process is a method used to gather information about the user's opinions, motivations, attitudes, experiences, and behaviors regarding the usage of a service or product (Ericson et al., 2016b). The method can be used at different stages of the design process with different intentions. At an early stage of a project, interviews can be used as a method of gaining a better understanding of the users' thoughts regarding an existing product while interviews during a later stage of a project could be a way to gain feedback on a design concept.

There are different types of interviews; Structured, semi-structured and unstructured interviews, which all differ in level of flexibility and performance (Ericson et al., 2016b). Structured interviews are carried out with a predefined interview template where the interview questions to the interviewee are prepared in advance. Semi-structured interviews are more flexible where some predefined topics are discussed with less specific questions. Unstructured interviews could be compared with an ordinary conversation, where the user gets the chance to talk about a certain topic in a more natural way. This type of interview gives room for high flexibility. Additionally, a pilot interview can be performed in advance to make sure that the interview template is properly prepared and the time frame is appropriate.

When performing the interview, it is important that the interviewee feels relaxed (Ericson et al., 2016b). Therefore the interview should be held in a relaxed and calm environment, and the interview should start with a presentation of the purpose of the interview and the present project members. Information regarding the collection and processing of the gathered information should be communicated clearly. If video or pictures are taken, permission should be asked in advance. The user should also have the opportunity to be anonymous and stop the interview whenever she pleases.

4.1.5 Survey

A survey is a method of collecting information from a large number of people, making it a method of statistical power (Baxter et al., 2013). To enable analysis of the results of the survey, proper planning and a good survey design is vital. Within the questionnaire, each question should be unbiased, clear and concise. Open questions should be avoided, and the language used should be adapted so that everyone within the target group can understand it. Depending on the question, either an open or a closed response will be received. Open responses require more effort in terms of analysis compared to closed answers but also gives more freedom to the respondent.

In self-administered surveys, the order of the questions and the aesthetics of the survey are crucial in order to obtain a good result (Baxter et al., 2013). Easy questions should be placed at the beginning of the survey and more difficult questions presented later. Overall, the questions should be placed in a logical order depending on themes and topic. An introduction and summary can also be appropriate. Furthermore, a pilot study is a good way to ensure that the survey is conducted and planned properly.

4.2 Analysis Methods

In this section, theory regarding the analysis methods used during the project is presented.

4.2.1 Hierarchical Task Analysis

Hierarchical task analysis, HTA is a method used to understand and structure a certain task (Bohgard et al., 2009c). Furthermore, a HTA is used to show which steps are necessary to perform in order to reach a certain goal. Input for the HTA can be found through interviews, observations and instruction manuals. The highest step in the HTA is the main goal, which thereafter is divided into sub-goals. How many sub-goals and the level of detail provided in the HTA depends on the intended usage of the analysis. The sub-goals on the lowest level in the HTA are called operations. The operations provide clarifying information of how to carry out the actions to reach the main goal.

4.2.2 Ergonomic Analysis

Rapid Entire Body Assessment, REBA is a method for analyzing the ergonomic aspects of different work positions and physical load on the body (Hignett & McAtamney, 2000). REBA was developed to include aspects such as how well the user's grip is of the load and whether large dynamic changes occur or not. The analysis is often done by following a predetermined structure and template. The result from this analysis gives an indication on an action category ladder that informs about how critical the body position is and whether improvement measures need to be taken or not. The results further indicate whether the work position poses a high risk of injury or not.

4.2.3 Affinity Diagram

An affinity diagram is a methodology for organizing a large amount of data by dividing it into categories based on their relationships (Dam & Siang, 2022). This could be done after a research phase or a brainstorming session and provides an overview of the collected data. An affinity diagram could further help creating a better understanding of the data and help the user see solutions after having synthesized the data.

4.2.4 User Persona

A user persona is a fictional character which is created to reflect a relevant view of the target group (Ericson et al., 2016Ac). The method can be used by designers to create a foundation of empathy and understanding of the users and their needs and could be used throughout the design process. The persona should be based on relevant information found from interviews, observations, statistics and analysis of the context.

4.2.5 User Scenario

A user scenario is a fictional story describing a situation with the user group and user context (Interaction Design foundation, n.d.). A scenario is a method which can be used to show how the user would act in a specific environment or how the user would use a certain product. Furthermore, scenarios can help designers understand the users needs, motivations and challenges. This method can also be used as a tool for ideation and testing solutions.

4.3 Ideation Methods

Different methods for ideation are presented in this subchapter.

4.3.1 Brainstorming

Brainstorming is a method used to ideate and gather new ideas (Stiftelsen Svensk Industridesign [SVID], n.d). To keep to the scope, a defined area should be presented before the brainstorming session. Each brainstorming session is recommended to be kept at maximum forty minutes. Additionally, during a brainstorming session, it is recommended that no ideas are judged until the session is over.

Brainwriting

Brainwriting is a type of brainstorming method (SVID, n.d). The method is carried out in smaller groups where ideas are individually written down on a paper which thereafter is sent to the next person in the group. A specific example of a brainwriting method is Brainwriting

6-3-5. For this method, three different ideas are written down on paper during five minutes. After five minutes, the papers are passed onto the next person in the group which can develop the ideas further during another five minutes (Ericson et al., 2016d). The method is repeated six times. Each session is made in silence in order to not affect someone else's ideating process until all ideas are presented within the group.

Braindrawing

Braindrawing follows the same technique as brainwriting except the ideas are illustrated with sketches instead of written text (Ericson et al., 2016e).

4.3.2 Workshop

A workshop is a method where relevant people from the user group, experts or non-experts, are gathered to creatively investigate and work with a specific topic (Ericson et al., 2016f). The aim of a workshop could be to utilize the ideas developed within the workshop group in regard to problem areas or solutions. A workshop can be conducted in many different ways where the content, activities, and structure vary depending on the purpose of the workshop.

5

Process

This chapter presents the project processes and the methods used. The project was divided into four phases as shown in Figure 8. The first phase, the Pre-study phase, is described in Section 5.1. The second phase, the Problem identification phase is presented in Section 5.2. The last two phases, the Ideation phase and Concept evaluation phase, are described in Section 5.3 and Section 5.4.

The aim with the Pre-study phase was primarily to investigate both exoskeletons and ergonomic safety within the construction industry. During the Problem identification phase, the goal was to explore and identify user needs, user behavior and what challenges the user group faces in their work. During the Ideation and Concept evaluation phase, the aim was to investigate different solutions on ergonomic aids for the target group.

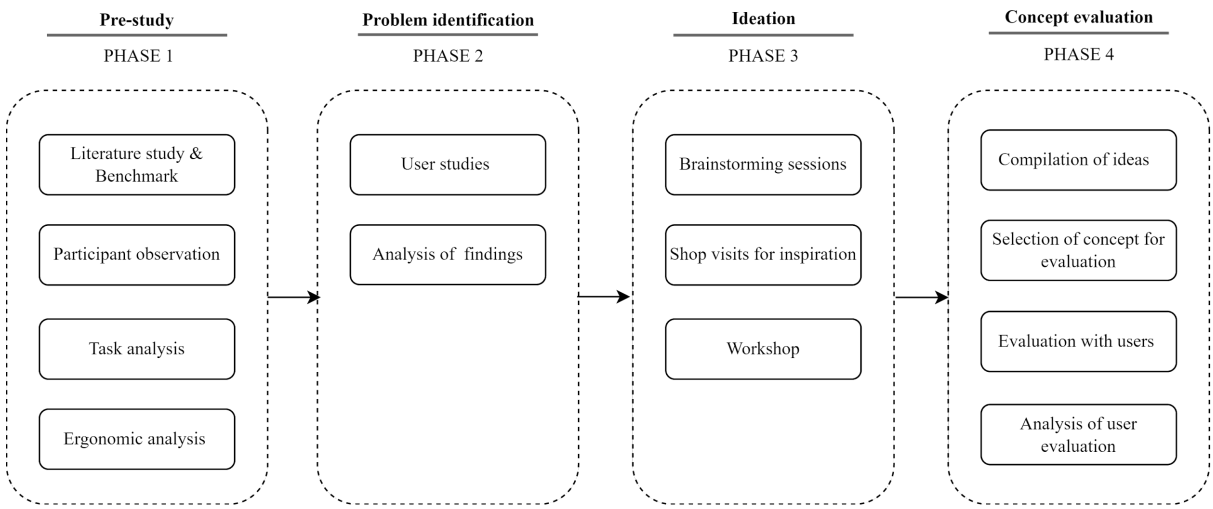

Figure 8: An overview of the project process and its four phases

5.1 Pre-study Phase

In this section, the Pre-study phase is presented. See an overview of the methods used in this phase in Figure 9.

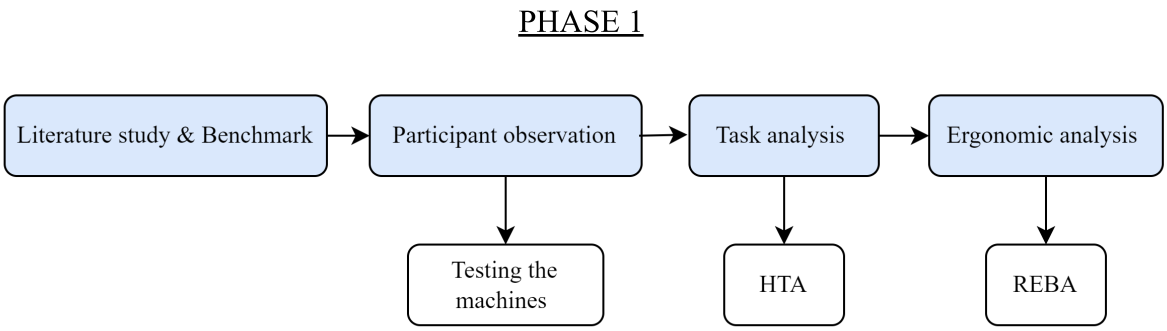

Figure 9: An overview of the Pre-study phase

5.1.1 Literature Study

A literature study was performed to explore what previous research says about the potential benefits and risks of using an exoskeleton. Additionally, the project group aimed at investigating what work-related musculoskeletal disorders that are common among construction workers and what theory regarding physical ergonomics says about work-related musculoskeletal disorders.

The study was performed by analyzing existing literature on the research topics. The papers analyzed were derived from digital sources such as Google Scholar and Chalmers Library's digital database. Some keywords used while searching were *Exoskeleton*, *Construction industry*, *Ergonomics and Musculoskeletal disorders*, and *Biomechanics*. To assure higher credibility, all the articles chosen for review had been peer-reviewed.

To synthesize the data, the sampling techniques used were based on dividing the data into categories that emerged while collecting the data, such as *Risks with Exoskeleton, Other types of ergonomic aids* and *Examples of back-related injuries*. A regrouping of data could then be made during a further analysis, where new sections emerged based on similarities and dissimilarities between the data.

5.1.2 Benchmark

A benchmark was performed to gain knowledge about the exoskeletons that exist on today's market. Some aspects that were taken into consideration when looking at the different products on the market were:

- Different sizes of exoskeletons
- Application areas
- Rigidity and structure
- Different technologies
- Price

The exoskeletons were then divided into four categories: Exoskeletons for hands and lower arms, exoskeletons for upper-body and arms, back-supporting exoskeletons, and exoskeletons attached to machines. Images of some of the most relevant exoskeletons within each category were collected in a PowerPoint and updated continuously during the project when new relevant products were encountered.

5.1.3 Hierarchical Task Analysis

A hierarchical task analysis, HTA was performed to understand the structure and usage of the machines. The HTA was then continuously updated throughout the project. The usage of the power cutter was divided into three different task areas; (A) Preparing the power cutter, (B) Starting the power cutter, and (C) Cutting correctly. Two different types of power cutters were analyzed, one battery driven and one petrol driven. Clarifications have therefore been given in the HTA to direct the user to the right sections. The usage of the core drilling machine was analyzed for one task: (D) Using the core drilling machine.

5.1.4 Ergonomic Analysis

An ergonomic analysis, a REBA, was conducted by first identifying which working positions were deemed to be the most critical. The total work cycles for two different work tasks with the cutting machine; Cutting in floor and cutting vertically in a wall, were observed during two separate observations and with two different workers. The work cycles were recorded so that pictures of the body positions could be analyzed afterwards.

Three body positions that were described by the workers to be some of the most tiring during the observed work cycles were analyzed according to Hignett & McAtamney's REBA template (2000), see Appendix D.1. See the three selected body positions for analysis in Figure 10-12; Cutting vertically at knee level, Cutting vertically above shoulder height, and Cutting in floor. Each body position was analyzed by the same person in the project group in order to assure that each analysis was conducted similarly.

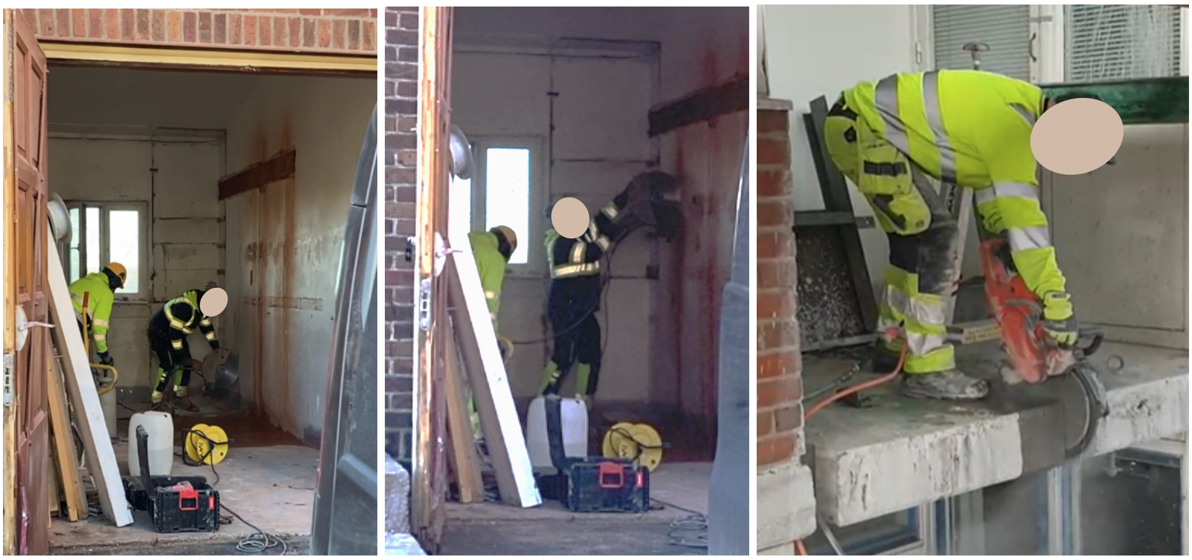

Figure 10-12: The three analyzed body positions for the power cutter

For the drilling machine, three of the most common working positions described by the users were chosen for analysis; Drilling above shoulder height, Drilling below waist height, and Drilling vertically. These positions were analyzed by observing a user of a drilling machine in these different working positions. See Figure 13-15.

Figure 13-15: The three analyzed body positions for the core drilling machine

5.1.5 Participant Observation

In order to experience using the machines studied in this project, the project group used the power cutters and core drilling machines on two different occasions at Husqvarna's office. Both petrol powered and battery driven machines were tested for some common work tasks. The sessions were held in an outside environment where wet cutting and drilling could be performed.

The supervisor of the project and an employee at Husqvarna Construction were present during the two occasions. This made it possible to ask questions about the machines and discuss ergonomic aspects while testing different working positions. Before using the machines, the supervisor also demonstrated the procedure of how to start the machine, cut/drill, and turn the machine off. During the observations, recordings were taken for later analysis of different postures.

First Occasion: Testing the Power Cutters

Two different models of power cutters were tested, one petrol powered and one battery-driven. Different cutting positions and tasks were tested to gain an understanding of how to use the machines. Examples of tasks that were performed include making smaller cuts in a concrete block laying approximately at ground level and vertical cuts in a concrete wall at approximately chest level. Horizontal cuts in a vertical surface were analyzed with the machine turned off due to safety reasons. See Figure 16.

Figure 16: Trying the power cutter

Second Occasion: Testing the Core Drilling Machines

The second observation was carried out with the core drilling machine. During this occasion, the project group both tried drilling a hole in a horizontal concrete block laying approximately at ground level and drilling a hole in a concrete wall approximately at chest level. Similar to the first occasion, different ways of supporting the core drill against the body were tested. See Figure 17.

Figure 17: Trying the core drilling machine

5.2 Problem Identification Phase

This section presents the Problem identification phase and explains how the empirical studies with users were conducted. See an overview of the methods used in this phase in Figure 18.

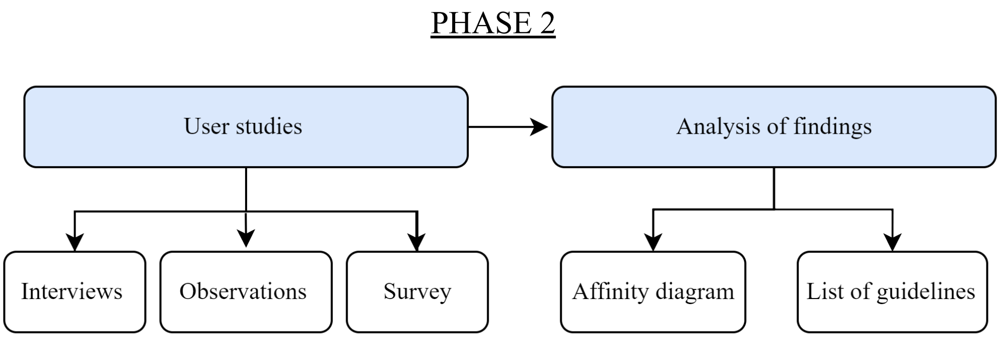

Figure 18: An overview of the Problem identification phase

5.2.1 Participants

To ensure that the majority of the target group was represented in the user studies, participants with different work responsibilities and work experiences have been included. Interviews have been conducted both with workers who actively use the machines and with project managers that have an overview of the project and the project teams. Personnel in charge of the work environment and safety have also been interviewed. The majority of the participants have worked in the industry for between 20 to 40 years and a few participants have worked within the industry for a maximum of a couple years.

During the studies, workers from different sizes of companies have been included. The majority of the companies were of a smaller size with five to ten employees and some of middle size with between 30 to 100 employees. There were also interviewees from a larger company with several hundred employees.

For an overview of all participants included in the user studies, see Table 1. In this table, concrete cutters refers to the users managing power cutters and core drilling machines in their work. Project managers refers to the interviewees which are in charge of work teams or supervising work sites. Safety representative refers to participants whose primary role is to ensure that the safety is followed at the work site. Work environment representative refers to participants whose primary role is to ensure that the work environment is pleasant for all employees. Shop accountant refers to people working at one Husqvarn's stores that sells the machines.

Table 1: An overview of the participants included in the user studies

Participant	**Profession of participant**	**Gender**	**Interview structure**
P1	Project manager	Male	Semi-structured interview
P2	Work environment representative	Male	Semi-structured interview
P3	Shop accountant	Male	Unstructured interview
P4	Shop accountant	Male	Unstructured interview
P5	Concrete cutter	Male	Semi-structured interview
P6	Safety representative	Male	Unstructured interview
P7	Safety representative	Female	Unstructured interview
P8	Safety representative	Female	Unstructured interview
P9	Concrete cutter	Male	Unstructured interview
P10	Concrete cutter	Male	Unstructured interview
P11	Project manager	Male	Semi-structured interview
P12	Concrete cutter	Male	Semi-structured phone interview
P13	Concrete cutter	Male	Unstructured interview
P14	Concrete cutter	Male	Unstructured interview
P15	Concrete cutter	Male	Semi-structured interview Videocall

P16	Concrete cutter	Male	Semi-structured digital interview
P17	Concrete cutter	Male	Semi-structured phone interview
P18	Project manager	Female	Unstructured interview
P19	Concrete cutter	Male	Semi-structured interview

5.2.2 Interviews

During the Problem identification phase, nine in-depth interviews were conducted to gain a deeper understanding of the user group. These were carried out with a semi-structured approach where an interview template was used. Out of these nine interviews, two were telephone interviews and one was a video call.

Place and Duration
The majority of the in-depth interviews were carried out at the construction workers' offices to entail a relaxed environment. These locations also made it possible to observe the investigated machines during the visits. The duration of the interviews varied from 20 minutes to one hour and 45 minutes, the majority of interviews lasted for about 60 minutes.

Interview Template
The interview template consisted of an introduction and four additional sections focusing on different areas. The introduction contained information about the aim of the project and the setup of the interview, including permission to record the interview.

The first part of the interview consisted of questions regarding the working environment and the usage of the machines. The second part of the interview included questions regarding sore muscles and work-related pain. The aim with this section was to understand which type of work tasks are the most tiring, both when using handheld tools as well as generally during the work day. During the third part of the interview, attitudes towards ergonomic aids in general and exoskeletons were investigated. To ensure that all participants had a similar interpretation of what an exoskeleton is, a short description of an exoskeleton was presented.

The final part of the interview included open questions regarding ideas of improvements on the machines and exoskeletons. Probing was being used frequently during the interviews to deepen the conversation. For a full interview template, see Appendix E.1.

Evaluation of Most Affected Body Parts
To find which parts of the body that are most affected by the work performed according to the users, an illustration of a human body was used during the interviews for the interviewees to draw on. The interviewees were asked to mark where on the body they consider to experience the most physical pain from their work. During this task, the interviewees were asked to think out loud while placing the marks. Figure 19 shows the illustrations used.

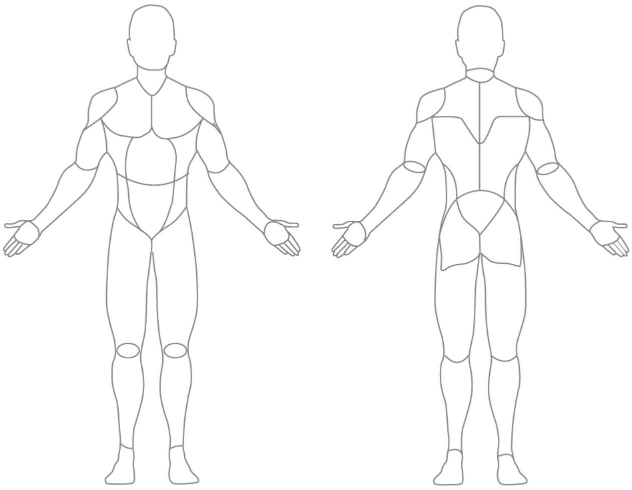

Figure 19: The illustrations used during the interviews

Evaluation of Existing Exoskeletons

To gain a better understanding of how the target group perceive the exoskeletons on today's market, pictures of five different exoskeletons were shown to the interviewees. While looking at the pictures, the interviewee was asked to openly share his or her thoughts. The pictures included three exoskeletons facilitating work above the shoulders and two back-supporting exoskeletons. Some of the pictures were taken in a warehouse environment and others had a simple white background. The selection of exoskeletons was chosen to show a range of different sizes and models. Further explanations of the different exoskeletons can be found in Appendix E.2.

Pilot Interview

To ensure that all questions were relevant and placed in a logical order, a pilot interview was made with one employee at Husqvarna Construction. The interviewee could give feedback to each question in terms of understanding and relevance. The interview template was changed after the pilot interview in accordance with the feedback received.

Changes Made During the Interviews

The interview template was changed at three different times during the user studies to ensure that the most relevant questions were asked during each of the interviews. These changes were based on new insights that were gained throughout the interviews and resulted in some questions being added and some questions being removed. For an explanation of changes applied to the interview template, see Appendix E.3.

5.2.3 Observations

Observations have been performed at three different occasions to better understand the work situation of the concrete cutters. To make sure no relevant aspects were overseen, an observation template was used. This template included relevant aspects to keep in mind while performing the observations, such as investigating different working positions and where and how the machines are stored. For a detailed overview of the observation template, see Appendix E.4.

The first observation was carried out at a large construction site in Gothenburg at a company with several hundreds of employees. The duration of this site visit was two hours and 30 minutes. The visit included a presentation of the ongoing construction project and construction site as well as a safety briefing before a guided tour. The guided tour of the construction site was carried out by the person responsible for work environment and safety. Three other visitors controlling the safety were also present, which made a total group of six visitors including the members of the project group. This site visit was made in order to gain a deeper understanding of the overall structure and context of a large construction site.

Two additional observations were carried out at two smaller project sites with the goal of observing the workers while using the machines. The duration of the visits were approximately one hour each. During this time, the power cutters were actively used for a couple of minutes. Additionally, other relevant tasks such as preparation of the work site was observed.

At one of the visits, observations were made of two concrete cutters cutting out an opening in a wall. Both horizontal and vertical cutting with a handheld power cutter was observed. Another observation showed two concrete cutters cutting out concrete blocks from a balcony. Here, cutting in the floor could be observed.

Informal conversations were held during the observations and notes were taken continuously by one of the project members. Permission to take photos and videos were given and several of the observed work tasks could be recorded. See a picture from one of the observations in Figure 20.

Figure 20: During one of the observations, walking on the scaffoldings

5.2.4 Survey

As a method to collect quantitative data from the target group, a survey was developed and distributed. The survey was structured to allow collection of data both from users of specific handheld tools, such as power cutters and core drilling machines, and from users of other heavy handheld machines. This structure was used to facilitate later analysis, where the answers from the different user groups could be analyzed separately and the more general questions could be analyzed together. For the full survey, see Appendix E.5.

The survey was divided into six different sections:

1. Description of the project.
2. General questions about age and gender.
3. Specific questions for users of handheld core drilling machines and power cutters about work-related pain and work tasks.
4. Specific questions for users of other types of heavy handheld machines about work-related pain and work tasks.
5. Questions about ergonomic aspects, the usage of external aids and protective equipment.
6. Questions about the attitudes towards exoskeletons.

Survey distribution
The survey was evaluated with one employee at Husqvarna Construction before it was distributed to the target group to ensure that the survey was understandable. The survey was then distributed within the Swedish Facebook group "Håltagare", an online community for concrete cutters with approximately 3700 members. The survey was also sent to different companies in Sweden working with core drilling machines and power cutters. The results from the Facebook group and the companies were collected separately. The results of both surveys were then analyzed together with one professional working within the concrete business to ensure that the answers from both of the surveys could be seen as representative before merging the surveys for collective analysis.

In total, 110 responses were collected. Some of the questions were answered by all participants and some of the questions were answered by the majority. Of the participants, there were 109 male participants and one female.

5.2.5 Persona

Two different user personas were created after the interviews and observations had been made. This was done to establish a representation of certain user profiles that could be used during later ideation and analysis. Some background information about each persona as well as a description of the person's attitudes towards the work conditions and environment were included.

5.2.6 Scenario

A scenario was developed to exemplify what the concrete worker's environment could look like. This was then used to communicate the user context to external parties and to show what challenges the user faces in his or her work.

5.2.7 List of Guidelines

A list of guidelines was created to create an overview of what a future ergonomic product for construction workers should obtain to achieve higher user satisfaction and safety. This list was done as a result of both empirical studies and theoretical studies and was evaluated several times throughout the project in order to obtain a representative list for the user group and its context. Additionally, the guidelines were divided into two separate lists; One general list with overall guidelines and one list specifically for an aid that would be used on the body. Comments were also added next to several of the guidelines in order to provide a better understanding for the reader.

In this list, all the guidelines were ranked on how vital it is that they are met. Thus, each guideline got a number between one to three:

(1) Crucial: If this guideline is not met, the product will not function properly and not meet the user's main requirements.
(2) Essential: If this guideline is not met, the user will most likely not use the product.
(3) Desirable: Guidelines that are not mandatory to be met but that would create added value for the user and increase user satisfaction.

By doing this ranking, it was possible to evaluate the concepts from the ideation phase and gain a better picture of which guidelines should be prioritized for the development of an ergonomic product.

5.2.8 Affinity Diagram

An affinity diagram of the data from the interviews and observations was performed continuously throughout the Problem identification phase shown in Figure 18. This was done in order to gain a shared overview of the collected data and identify patterns between relations within the collected data. The affinity diagram was analyzed in multiple sets, the first one after completing two interviews, the second one after the fourth interview and the last one after all interviews were completed. By doing this throughout the user studies, it was possible to see within which areas a saturation in interviewee answers was reached and within which areas more investigation was needed. Hence, the interview template could be altered throughout the data collection phase. Some questions were removed and new questions added according to which areas that the project group deemed necessary to explore further.

The analysis was carried out by both project members by reading through the notes from one interview after another. The project group discussed each paragraph and then summarized them before moving each summary to a digital programme, *Diagrams* in Google Docs where the affinity diagram was displayed. In this digital programme, post-it notes were used in different colors to represent different interviewees.

Since the interview template had already been divided into different sections, these became the initial categories used for categorizing the interviewees' answers. Additional categories then evolved throughout the process, both as subgroups to the initial categories and as new ones. Then, when the first round of analysis had been done, a second round of analysis was performed by dividing the categories into new subgroups. These were later summarized with text in a new document and used as a part of the basis for the ideating phase later on in the process.

5.3 Ideation Phase

This section explains how the ideation phase was conducted. The purpose of this phase was to brainstorm different solutions of exoskeletons and aids which could facilitate a more ergonomic safe work environment for the target group. See an overview of the phase and its method in Figure 21.

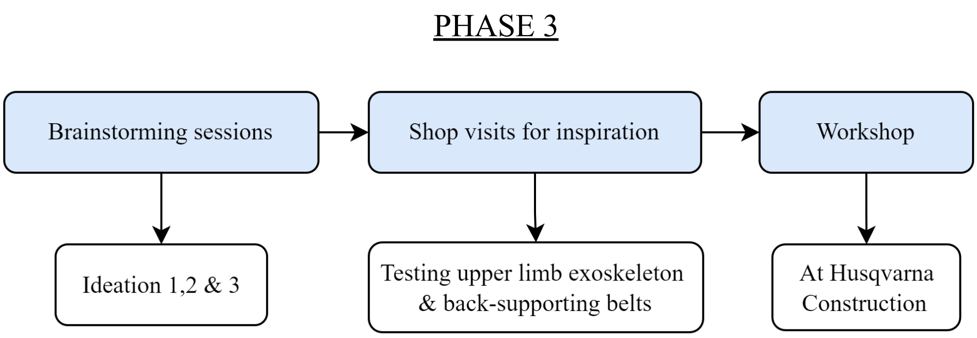

Figure 21: An overview of the Ideation phase

The ideation process was carried out in different sessions, including three main ideation sessions and a workshop. Additionally, the project group tried various solutions of ideas by visiting stores that sell similar solutions. This is described as Shop visits. Further, an inspiration board with images of products with user areas relevant for this project was continuously updated during the process. This could be used for inspiration during all stages of the ideation.

In this section, the ideation sessions and methods used are presented in a chronological order of which they were performed.

5.3.1 Ideation Session One

The first ideation session was performed with the aim of exploring different solutions within the areas identified as problematic during the user studies. To ensure that a broad variation of ideas was investigated, both exoskeletons worn on the body and other aids were included in the ideation. Both brainwriting and braindrawing were used as methods to develop a high number of ideas without specific restrictions or critical judgements.

Ideas were generated for different areas during intervals of a couple of minutes of silent ideation followed by discussion. The silent ideation method was used to gather ideas individually without affecting each other before the discussion. The different areas included in the brainstorming were:

- **Aids that can facilitate specific work tasks:** This category was used to consider how it could be possible to facilitate specific work tasks performed with the power cutters or core drilling machines. Especially tasks above the shoulders or with a bent back were investigated since these were identified as problematic during the user studies.

- **Aids that can facilitate heavy lifts:** This category was used to consider the surrounding environment and the need to carry material to and from the workplaces.

- **Ideation regarding time pressure:** This category was used to take into account the stressful environment and time pressure.

- **Ideation regarding attitudes:** This category was used to take into account the importance of the workers attitudes towards ergonomic aids and the work environment they are exposed to.

5.3.2 Ideation Session Two

The ideas from the first brainstorming were analyzed in order to find different product categories and areas to investigate further in the next ideation session. Thereafter, the second ideation session was performed similarly to the first ideation but with a focus on the product categories found during the analysis. Each of the categories were ideated for five minutes in silence, followed by a discussion and another two minutes of quiet ideation where additional thoughts could be added.

5.3.3 Shop Visits

Several stores were visited to find inspiration and to gain further insights of different kinds of supporting aids existing on the market, such as back-supporting belts and exoskeletons for overhead work. All of the shop visits were between 30 to 45 minutes each.

Sport Shop

A shop specialized in training equipment was visited with the aim of understanding what kind of support weightlifting belts could provide for construction workers. Questions regarding the usage and potential risks and benefits with back-supporting belts were prepared in advance. During the visit, the questions were answered through informal interviews with two of the employees at the shop. One of the employees had previous work experiences as a construction worker and had been using weightlifting belts when exercising. The second employee had knowledge of fitness equipment in general.

During the visit, different belts were tested, see Figure 22-23. Furthermore, the differences in support depending on rigidity and placement of the belt was discussed.

Figure 22-23: The project group trying different kinds of weightlifting belts

Ergonomic Shop

A shop that is specialized in ergonomic equipment was visited to gain further knowledge of ergonomic back supporting aids from a medical point of view. During the visit, an informal interview was held with the shop assistant who was an educated medical nurse with knowledge of the human body as well as ergonomic aids. Different models of back-supporting aids were discussed with questions regarding fit, material, purposes of different designs, and preventive and recovery purposes.

Testing of an Exoskeleton

The shop of a company that sells equipment and machines for construction workers was visited. This company sells a model of a passive exoskeleton meant to facilitate work performed above shoulder height. The project group tried the exoskeleton to gain personal experience of how it feels to wear an exoskeleton. The exoskeleton was worn while also holding a drilling machine of approximately two to three kilos above one's shoulders, see Figure 24. Each project member tried wearing it for approximately ten minutes while performing different tasks such as walking around with it, bending, putting it on and off several times and lifting the tools to various heights and towards various directions, imitating the work tasks that could be done with a drilling machine. Since the exoskeleton was only worn at the shop, it was not possible to perform any lengthy study of it.

Figure 24: The project group trying an exoskeleton for overhead work

5.3.4 Ideation Session Three

The third ideation session was carried out with the aim of implementing the new ideas and insights gained from the performed shop visits. This session was performed in a similar way as previous ideation sessions, with silent brainwriting and braindrawing methods followed by discussion. Mediating objects such as elastic bands were used to try the different ideas.

5.3.5 Workshop

A workshop was held at Husqvarna Construction to gain additional inspiration for ideation. The workshop was held with ten participants with different professional backgrounds such as product designers, head of product departments and product specialists for power cutters and core drilling machines. The duration of the workshop was one hour and 30 minutes.

An introduction of the project and insights gained from the performed user studies was presented before the workshop. The workshop was then carried out in two parts where both parts included quiet ideation sessions followed by discussion in smaller groups. The project member did not take part in the discussions but sat beside and took notes.

During the ideation and discussion, questions were presented on a PowerPoint for everyone to see. These questions could be used as an extra support to start the flow of ideas or during the group discussion to bring the discussion forward. For a full description of questions presented during the ideation and discussion and a more detailed explosion of the workshop, see Appendix E.6.

All sketches and notes from the workshop were then collected for analysis. The ideas from the workshop were compared with ideas and concepts developed from previous ideation processes with the aim of finding new possible solutions of ergonomic aids. The new ideas could then be added or combined with the ideas from previous ideation sessions.

5.4 Concept Evaluation Phase

In this section, the Concept evaluation phase is presented. This phase was conducted with the purpose of evaluating different solutions. See an overview of the phase and its methods on Figure 25.

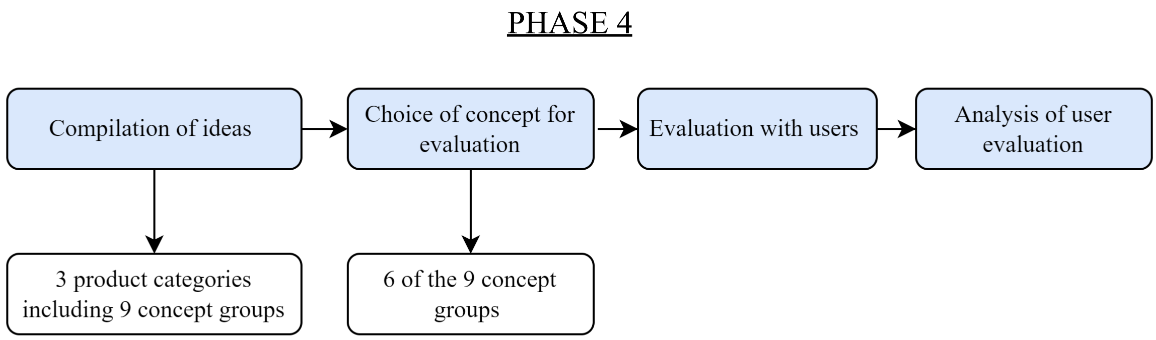

Figure 25: An overview of the Concept evaluation phase

5.4.1 Compilation of Ideas from the Ideation Phase

All sketches and notes from the ideation sessions, shop visits, and workshops were collected in one PowerPoint for a comparative analysis. All ideas were divided into three different categories depending on which kind of support they would provide for the user: Aids supporting the back, aids supporting the shoulders and arms and aids supporting both back and the upper body. When all ideas had been sorted within these three categories, they were further divided into nine concept groups depending on how similar the ideas were to each other. Each of these nine concept groups could hence consist of several alternatives of one main concept.

The nine concept groups were then analyzed separately to distinguish what strengths and weaknesses each concept group had. This analysis was based on the list of guidelines established in the Problem identification phase where the most important aspects from the list were used in the evaluation:

- Comfort
- Ease of use
- Possibility to combination with other products
- Storage, transportation and maintenance
- Durability
- Safety
- Multifunctionality
- Whether it facilitates a specific working position or not
- Whether it facilitates heavy lifts or not
- Amount of time it takes to put the device on and off
- Attitude and acceptance towards the product

The strengths and weaknesses of each of the nine concept groups were then compared to each other and six of the nine concept groups were chosen for further analysis. These six concept groups were considered to have the highest potential to provide ergonomic safety and achieve a higher user acceptance. Additionally, among these six concept groups, some concepts aimed at slightly facilitating many different tasks while others aimed at facilitating specific tasks greatly. These differences were considered interesting to evaluate with users in order to understand which requirements and product types that the users would prefer the most.

5.4.2 Visualization of Concepts

All concept groups and alternatives within each group were illustrated in Adobe Illustrator. To encourage the participants to suggest improvements with the concepts and not look at them as finished products, the illustrations were made with a low level of detail.

5.4.3 Expert Evaluation

Participants

To receive feedback from the target group, the six concept groups were evaluated with expert users. All three users have worked within the industry for over 20 years and have great experience of using both core drilling machines and power cutters. The third participant is also the owner and supervisor of a concrete cutting company.

Evaluations were performed at two different occasions. During the first evaluation, two users were present and interviewed simultaneously, whereas one participant, the owner of a concrete cutting company, was a previous study participant and the second was new to the project. During the other evaluation, a previous study participant was interviewed individually.

Evaluation Procedure

The evaluation consisted of three parts. During the first part, each of the six concept groups was presented separately one by one. The illustrations were used as a mediating tool where the user could point and draw for clarification while giving feedback and answering questions. For each of the concept groups, the experts got to both share some spontaneous thoughts and answer specific questions regarding the concepts. The users were also asked to explain which of the alternatives within each concept group they preferred and why. For a full overview of the interview questions, see Appendix F.1.

The second part of the evaluation consisted of a comparison between all of the six concept groups. The users got to rank the concepts based on areas such as which ones they believed could have the most user areas, which ones they could see themselves use and which one could be the most useful for a specific task. The users were asked to motivate their choices.

The third part of the evaluation consisted of a final discussion involving all concepts. Here the users were asked which of the concepts they would like to see in future development and why. Furthermore, attitudes and important aspects regarding implementation and advertisement were discussed to understand why similar products on the market are not used today.

5.4.4 Analysis of Expert Evaluation

The analysis of the results from the evaluations with experts were done by performing an affinity diagram. First, each concept group was analyzed separately and the notes taken during the interviews were divided into categories dependent on their relation to each other. For each concept group, categories such as *avantages*, *possible user areas*, and *challenges* were created. Afterwards, the concept groups were analyzed in regard to each other by comparing each category. Finally, the rankings about which concept the users preferred were analyzed and summarized in a table.

6

Results

This section presents the results from the theoretical and empirical studies. It starts with the results from the Pre-study phase in Section 6.1 followed by the results from the Problem identification phase in Section 6.2. A synthesis of the results can be found in Section 6.3. The final concepts chosen for evaluation with users are presented in Section 6.4. Finally, in Section 6.5, the findings from the concept evaluation with the users are presented.

6.1 Results from Pre-study Phase

In this section, findings from the Pre-study phase are presented, including results from the benchmark of existing exoskeletons, the participant observations and the task analysis HTA and ergonomic analysis REBA.

6.1.1 Benchmark

The areas investigated during the benchmark were: Exoskeletons for hands and lower arms, exoskeletons for upper body and arms, back-supporting exoskeletons, and exoskeletons attached to machines. In this subchapter, two examples of products within each of these areas are presented briefly in order to provide an overview of existing products.

Exoskeletons for Hands and Lower Arms

The performed benchmark indicates that exoskeletons for hands and lower arms are most often used for repetitive work where the users are working with tools of a maximum of a few kilos. Within these areas, both active and passive exoskeletons have been found. Two examples of exoskeletons for the hand and lower arm are:

- *Paexo Wrist* by Paexo is a passive exoskeleton worn on the wrist and hand to support the wrist when managing light-weight loads (Ottobock, n.d.-a). It is derived from a medical device used to prevent inflammation in the wrist and can be used when holding welding equipment and riveting tools and during installation jobs. See an illustration of this exoskeleton in Figure 26.

- *Ironhand* by BioServo is an active exoskeleton used to reduce fatigue in hands and arms by strengthening the grip of a user that works with repetitive and static tasks

(Bioservo, n.d.). It could be used within for example manual assembly work, logistics and warehousing. The product follows the user's actions by applying machine learning and adds force to the flexion of fingers when the user initiates a grasp. It is worn on the hand and arms with pressure sensors placed on the palm and fingers and has a connected battery that could be worn on the back or hip of the user. It is also connected to a remote control where the user can adjust parameters such as force and sensitivity. The product also collects data about the user and provides digital risk assessments where the probability of injury and additional information about the current ways of working are given.

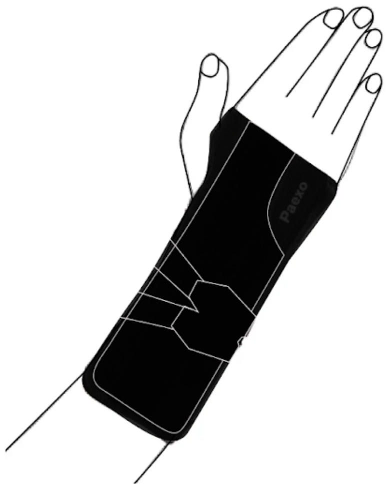

Figure 26: Illustration of the exoskeleton Paexo Wrist

Exoskeletons for Upper Body and Arms

The benchmark shows that the majority of the exoskeletons for the upper body, such as the upper arms, neck, and shoulders, aim at facilitating repetitive tasks performed above the shoulders with tools that weigh up to a few kilos. One of the main areas where these types of exoskeletons are found is in the car industry, where exoskeletons are used for repetitive work tasks performed overhead in assembly lines.

- *Paexo Shoulder* by Paexo is a supportive passive exoskeleton that can be worn throughout a work day (Ottobock, n.d.-b). It is supposed to relieve strain on upper arms and shoulder joints during work performed overhead, such as in assembly lines in logistics. It weighs two kilos, is attached around the waist, shoulder and upper arms, and takes approximately 20 seconds to put on according to the manufacturer. See an illustration of this exoskeleton in Figure 27.

- *EVO* by Ekso Bionics is a passive exoskeleton that according to the manufacturer is said to increase productivity, reduce worker fatigue and prevent workplace injuries, especially in the shoulders (Ekso Bionics, 2022a). It can be used for overhead work within for example construction, warehouse, and logistics. It is worn around the waist and upper arms and provides 2.2 to 6.9 kilos of lift assistance per arm.

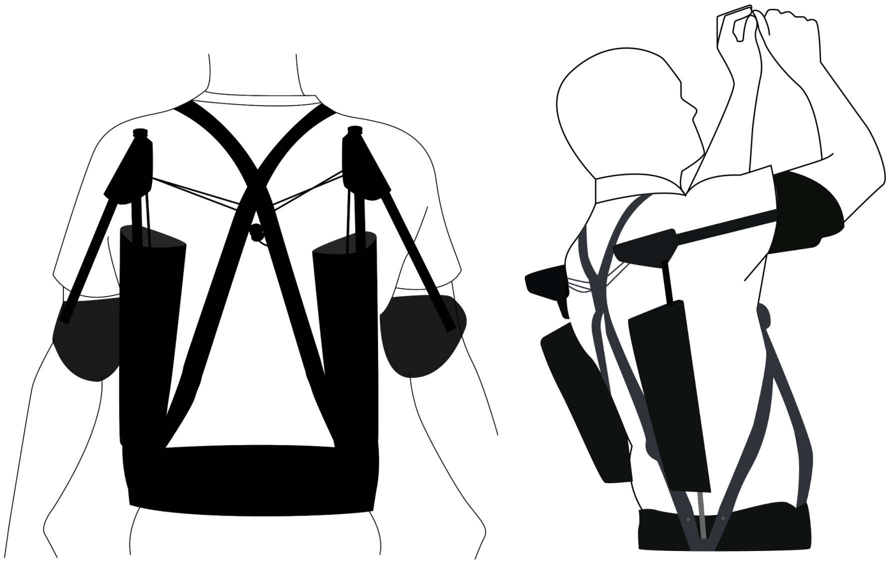

Figure 27: Illustrations of the exoskeleton Paexo Shoulder

Back-supporting Exoskeletons

The majority of back-supporting exoskeletons aim at facilitating repetitive tasks requiring heavy lifts. These models are often passive and attached around the back and legs to shift the loads from the back to the leg muscles.

- *HeroWear Apex* by Herowear is a back-supporting passive exosuit that is supposed to reduce strain on the back when performing lifts. It is worn around the shoulders and thighs, weighs 1.5 kilos, and can reduce over 75 kilos of weight (Herowear, 2022). Back-support can be turned on and off by clicking a button on the back of the exoskeleton, which is connected to the supporting strings that run along the back down to the legs.

- *Paexo Back* by Paexo is a passive and rigid back-supporting exoskeleton that can be used in warehouse and logistic industries to facilitate bending movements (Ottobock, n.d.-c). The load is reduced from the shoulders and transferred to the thighs. It can provide support up to 25 kilos, weighs four kilos, and can differentiate between bending and walking. The device switches off automatically when the user is walking. See an illustration of this exoskeleton in Figure 28.

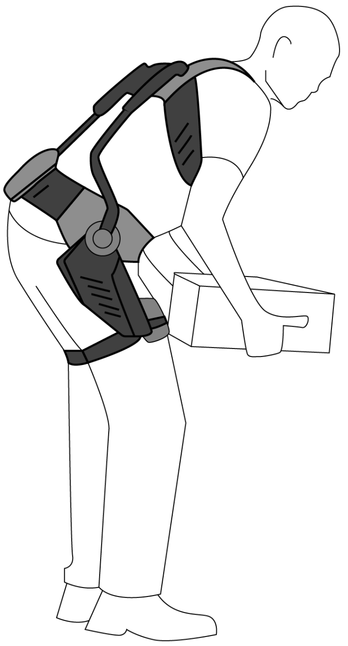

Figure 28: Illustration of the exoskeleton Paexo Back

Exoskeletons Attached to Machines

Products within this product group are often dedicated to a specific machine or type of work and are attached to either the machine or both the machine and user. These products aim at taking away most of the weight of the machine from the user and are often larger and more rigid than the products described in previous sections.

- *EksoZeroG* by Ekso Bionics is similar to a mechanical arm for the construction and demolition industry which can be used to hold heavy handheld tools such as drills, hammers, and grinders that weigh up to 19 kilos (Ekso Bionics, 2022b). This mechanical exoskeleton can be attached to the work platform or a scaffolding, where the weight of the tool is transferred to the base where the arm is attached, and onward down to the ground. The lift force provided is 16.3 kilos, which means that some tools according to the manufacturer will feel weightless when using them attached to the *EkosZeroG.* The user maneuvers the tool with his hands after it has been attached to the work platform or the scaffolding.

- *Fortis* is a passive exoskeleton for industrial work that is worn on the body and attached to heavy handheld tools (Lockheed Martin, 2022). It is said to improve productivity by reducing muscle fatigue and can support weights up to 16.3 kilos. It is worn around the waist, shoulders, shins, and feet. This exoskeleton can be worn both in a standing and kneeling position where the loads from the heavy tools are transferred down to the ground through the parts of the exoskeleton running along the legs.

Price

The benchmark shows that the price of exoskeletons varies depending on the size and structure of the exoskeleton. A supporting aid such as the wrist supporting structure, *Paexo wrist*, has an initial price of around 100 euros, while more extensive designs can reach up to a few hundred euros. Furthermore, the benchmarking shows that full-body suits, especially the active variants, are among the most expensive on the market.

6.1.2 Participant Observation

Trying the machines resulted in new insights which could be used during later stages of the project. These are described in this section.

Power Cutter

In most of the tested tasks, the power cutter was more difficult to maneuver compared to the core drilling machine due to its heavier weight. Furthermore, the petrol powered power cutter was perceived as more powerful and aggressive than the battery driven one.

Working with the power cutter was experienced as difficult since a combination of lifting and applying force was needed to perform a cut. Furthermore, a high level of precision was needed to cut straight and in the right place, which was perceived as challenging for first-time users. Furthermore, since there is a risk of kickback while using the machine, lots of attention was needed and the project members understood the importance of not letting go of the handle while cutting since there is a risk of losing control over the power cutter.

Core Drilling Machine

While performing different tasks with the core drilling machine, starting to drill the hole was the most difficult. The drill had to be tilted with an angle against the workpiece in order to grip the surface. Furthermore, the importance of water supply was noticed, since the drill got stuck in one of the work pieces due to the lack of water.

6.1.3 Hierarchical Task Analysis

The hierarchical task analysis of the power cutter was divided into three different task areas: (A) Preparing the power cutter, (B) Starting the power cutter, and (C) Cutting correctly. The HTA of the core drilling machine was analyzed for one task: (D) Using the core drilling machine. See Appendix G.1 for the HTA of the power cutter and Appendix G.2 for the HTA of the core drilling machine.

6.1.4 Ergonomic Analysis

The results from the ergonomic analysis REBA showed that the user groups work in body positions that are highly critical and that measures need to be taken to prevent injury. More specifically, for the power cutter, cutting vertically at knee level, cutting vertically above shoulder height, and cutting on the floor were all considered work positions that have a high risk of resulting in injury. For the drilling machine, cutting below waist level and cutting in the floor were considered high-risk positions. The results of the overall analysis for the power cutter could be found in Appendix G.3 and the results of the core drilling machine in Appendix G.4.

6.2 Results from Problem Identification Phase

This section presents the insights from empirical studies made during the Problem identification phase. Insights emerging from the user studies, including both interviews, observations, and surveys, are presented. First, information about aspects such as the work procedure of cutting and drilling, difficult working positions, the most affected body parts, and the worker's attitudes towards exoskeletons and ergonomic aids are presented. Next, the results from the surveys are shown. This is followed by the personas, scenario, and the list of guidelines.

6.2.1 The Work Procedure of Cutting and Drilling

The process of cutting and drilling work has several elements that are recurring regardless of the type of work. However, the context and the task itself have a major impact on what the specific process looks like. Among other things, it can take significantly longer time to work in a renovation environment than in a new building as it is of great importance that a new building does not get dirty or that the user is careful not to accidentally drop any heavy objects. Nevertheless, the process described in this section is a more general description.

In general, the preparations before making a cut or drill hole as well as the cleaning afterward, have been described to take a longer time than making the actual cutting and drilling. As an example, during an observation, the workers had to put a large beam high above the area where a door was to be cut, as there was a great risk that the wall would otherwise collapse. This took more time than cutting the actual door. Additionally, the water used for the cut was not allowed to be flushed down into an ordinary sewer but would instead be sucked up with a wet suction and then purified in a filter, which was also time-consuming.

Before and During the Cutting and Drilling

Before, for example, drilling, it is common that the customer put out markings for where they want the hole to be made. Further, the area usually gets covered in plastics and tape so that cleaning the area afterward becomes easier. If the work is to be carried out in an environment that is sensitive to dust, water, and dirt, it can become necessary to lay masonite on the floor and then cover the edges with silicone.

When performing cutting tasks, it is common to first create a small mark using a handheld power cutter and then continue the cut with a wall saw. This is sometimes done in combination with water meters. When only using handheld power cutters, some choose to cut from the bottom-up to be able to more easily follow the cut with the machine, while others prefer to cut from the top-down to be able to get help from the gravity pulling the power cutter down. In general, the concrete blocks are often divided into smaller blocks to reduce the amount of weight that is to be chopped out and then transported away. For example, a door may have to be divided into six different blocks which are then to be taken out separately.

Wet Cutting

It is most common to use wet cutting instead of dry cutting. For wet cutting, it is common to install a so-called water trap that catches the water around the cut. When drilling, one could use a type of suction pot that is connected to a vacuum cleaner and that is attached to the drill hole.

For wet cutting, a constant supply of water is required. The water is usually transported in hoses and supplied from the building that project takes place in. For example, during an observation, hoses from the floor below were used for the cutting machine on the floor above, resulting in hoses hanging in the ceiling. The interviewees explained how these hoses limit the freedom of movement and how they often become a disturbing moment since they have to go back and pull them in. However, sometimes the water is supplied from a water tank that has been filled in beforehand. During an observation, a person was pumping water from a water tank next to his colleague that was making the cut.

After Cutting and Drilling

After the cutting, what has been cut must be chopped out. The pieces can be lifted out manually with the hands, but it is also possible to attach them with a chain and stand. Sometimes the blocks are first put on car tires before they are transported away, this to spare the floor below. Thereafter, the material is usually transported by a sack cart or wheelbarrow. These are usually transported to containers where the material is unloaded. If it is to be transported downstairs, this is often done by carrying the material by hand, sometimes together with a colleague if the weight is heavy. During an observation, the workers explained that each individual piece of concrete that they chopped out weighed about 130 kilos.

The drill core, in turn, is pushed out by tapping the drill head against a harder surface. These drill cores could weigh many kilos and are transported in a similar way as the material from the cutting.

Lastly the area must be cleaned. Several interviewees have explained that these final steps can take a whole day to complete depending on the project. It is of great importance that the cleaning is carried out carefully in order to make the customer satisfied. The water may need to be sucked up with a wet suction which must then be emptied, plastic and silicone must be torn off and the area cleaned of concrete dust and water.

6.2.2 Work Tasks and the Machines

In this section, a presentation of the findings related to the overall work tasks of concrete cutters is given. Additionally, findings about how these are perceived by the concrete cutters explained as well as the where and how the machines are stored.

Daily Work Tasks

The majority of interviewees describe that their weekly work tasks often include drilling, cutting, sawing, and demolition work. However, what is done during a workday varies greatly from project to project. During certain days, the work can be monotonous and include, for example, cutting off 30 concrete pillars a day. On other days, it could be necessary to carry out several different projects a day, which means visiting several different places in one day and completing a wide range of work tasks, referred to as working on “service”.

Attitude Towards Work Tasks

Several interviewees explained that having some kind of work rotation between colleagues is preferable. However, one can not expect to not have to cut a door simply because the same person has spent the last two weeks cutting doors. This type of consideration is only taken for elderly workers or those who have injuries, otherwise the concrete worker is expected to perform all work tasks. As an example, a supervisor explained that he usually puts older staff to drive the excavators in order to avoid them having to use more physically tiring work tasks.

"If you work in a cinema, you can’t complain about sweeping popcorn!"

A concrete cutter about accepting demanding work tasks

For How Long the Machines are Used

How long each machine is used per day varies from project to project. A machine could be used for only a total of five minutes a day during some periods and sometimes for hours a day in other projects. However, some of the heaviest handheld machines are rarely used for more than a maximum of a couple of minutes in a row since several micro-breaks are usually necessary to finish a job.

The material that one works in also affects how long the overall work task takes to complete. A cut can take for a couple of minutes to make if there is a lot of reinforcement in the concrete, while it can take seconds to make a similar cut but in very porous material. When it comes to drilling, a hole can take between a few minutes to half an hour depending on the size and material.

Reasons for Using Handheld Machines

The reason why some users choose to use a handheld power cutter differs between people. Among the interviewees, those who avoid handheld machines because they find it too tiring are often above 40 years old. Many younger employees use handheld cutters more often as they believe the work is done faster with a handheld machine compared to, as an example, attaching a wall saw. Several interviewees explained that handheld power cutters are also necessary when working in small and cramped spaces. In addition, it is faster to transport the handheld machines if the stands and supplements for a wall saw or a drilling stand can be left in the work car. An interviewee explained that some workers who work on what was described as “on service”, can work at four different workplaces in one day. Hence, hours could be spent on carrying the tools and machines to the right floor and work site. This results in preferring to only use handheld machines.

Several interviewees also explained that one main reason for using handheld cutting machines is laziness. They know that attaching a power cutter to the wall instead of using it with one’s hands is safer, but still choose to use a handheld power cutter since it takes less time. They know that one should go and get a mouth guard and wear it when cutting in concrete, but still choose not to use it since it is less convenient. However, it has also been pointed out that whether someone chooses to use the handheld power cutter or not depends a lot on which company the user works for as it is more common to use handheld machines at some companies compared to others.

Supporting the Machine on the Body

The work is facilitated if the machine can be supported against the body during the drilling or cutting tasks. In general, it is preferred to work with the machine as close to the body as possible. Some common placements while cutting are to put the hand against one's thigh, press the saw to one’s stomach, or rest the elbow to the knee when cutting on the floor. While drilling in a wall, it is common to support the drill against the shoulder, chest or thigh, see Figure 29. Users also support the drill against the arm or leg. Doing this has been described to often result in the tearing of the work clothes.

Figure 29: Picture from an observation showing how the core drilling machine is being supported on the user's thigh

Where the Machines are Stored

It is common for the machines to be stored in the work car or at the company during the night and weekend. The stands are often left behind at the construction site and sometimes some machines are chained. At large construction sites, the machines are stored in containers.

Transportation of Machines and Materials

The machines are often transported with the help of a sack cart or wheelbarrow. See a picture of how a power cutter could be transported in Figure 30. However, these can not be used in stairwells. If the elevator does not work, the machines have to be carried manually. Sometimes the surface can also be difficult to access and it can be necessary to climb in order to reach the work site. It is also common to get stuck in cables and hoses which increase the risk of injury. Additionally, at larger construction sites, larger machines are sometimes transported with excavators.

Figure 30: A power cutter transported on a carriage

Materials such as concrete and brick blocks are usually transported with a cart or a wheelbarrow as well. Often, heavy material is transported by hand and although this transportation method is considered unsafe by the users, it has been explained that this is a less time-consuming method.

Work Car

The majority of concrete cutters have their own work car where they keep the tools and machines that are most often used. This includes a stand for the drill, a handheld drill and a handheld power cutter. During an observation of one of the user's work cars, it was evident that the machines need to be durable as they are usually placed on the car floor among other machines.

6.2.3 Work Context

In this section, a summary of the findings of the work environment from observations of work sites are listed.

- Temporary equipment such as stairs and scaffoldings are common at construction sites. During observations, these arrangements have been experienced as narrow with low ceiling. This increases the risk of getting stuck, falling or hitting one's head. At one site visit, it was necessary to walk sideways down the temporary stairs due to the limited space.

- When working at large construction sites, the workers may be required to move long distances by foot or by vehicle to get to another part of the construction site. Relocating may also include transportation of material.

- When cutting or drilling are carried out high up, aids such as step ladders could be used. Additional pieces of planks or other material are sometimes put under the step ladders in order to make the surface more flat.

- It is apparent that the work context varies greatly between different work sites. During one observation, the concrete cutters were standing on a balcony on the sixth floor and cutting at an open gap between the balcony and the scaffolding on 0.5 meter. See Figure 31. At another work site, the concrete cutter was standing on a step ladder with the power cutter above his head and in a cloud of brick dust.

Figure 31: One of the work stations observed during the user studies

Indoor and Outdoor Work

During the interviews it has been explained that approximately 70% of the work tasks are carried out under some sort of roof, where several interviewees explained that the majority of projects are carried out in an indoor environment.

In many cases, the construction worker does not know exactly what the workplace will look like in advance and could often face a wide range of different contexts when entering the project site. During an observation, the observed worker explained how the scaffolding was too low and that they were forced to work with bowed heads during the entire week, which also made it more difficult to wear a helmet.

One problem area that several people mentioned is that the electricity often goes down. During an observation where the observed workers were working in an old garage, one worker explained that the electricity had gone down several times during the day, thus limiting the effectiveness of the work.

6.2.4 Challenging Work Tasks

Results from the user studies show that the users of these heavy handheld machines consider the work to be very unergonomic and physically demanding. In this section, what challenges the concrete cutters experience with various work tasks are presented. In general, cutting has been explained as more tiring than drilling which is why this section describes more cut-related tasks than drill-related work tasks.

"It is extremely demanding and not ergonomic at all!"

A concrete cutter about using heavy handheld machines

Work Above Shoulder Height

In general, most users prefer working with the handheld power cutter centered in front of them at waist level since they consider this to be the least strenuous position. In this position, the user can stand upright with the hands in front of him or her. However, drilling and cutting above shoulder height have been described as one of the most challenging work tasks. See a picture of this work position in Figure 32. In this position, the power cutter is often placed close to the user's face, making it a dangerous work position.

Figure 32: A work task described as challenging

As previously mentioned, the workload is affected by whether the body can be used as a support point to tilt or press the machines against. When the machine can not be supported against the body, the work is usually considered to be more tiring, which is often the case when cutting or drilling above shoulder height. However, for vertical cuts, once the cut is ongoing and directed downwards, the machine's own weight contributes to making the cut, which facilitates the task.

When describing when work above shoulder height is performed with a handheld power cutter, cutting doors or window openings are recurring examples. The majority of the interviewees explain that the horizontal cut at the top of a vertical surface is the most difficult work task. Sometimes these cuts are carried out close to the ceiling which may require the concrete worker to stand on a ladder and to work with a bent neck. To lift the machine to the correct height and then continuously hold the machine at the same height for a long time while also pushing it sideways has been described to put a lot of strain on the shoulders, arms and back.

"It is not nice to cut above your head, your arms are dead after five minutes!"

A concrete cutter about demanding work tasks

Cutting in Floor

Another position that is described as very stressful is downward cutting in the floor. In this type of work position, the concrete worker often stands with his back bent and twisted. An interviewee has described that downward cutting in the ground is even more stressful when the cutting is performed in the direction towards the feet, since the worker needs to bend his back at a 90-degree angle. See a picture of this in Figure 33.

Figure 33: Cutting in the floor

Drilling on Vertical Surface

Drilling on a vertical surface such as a wall has been described as more tiring than drilling with the drill directed downwards. When the drill is directed downwards, such as when drilling in the floor, the body weight can be used to push the drill in the right direction. In this case, the drilling machine can also be supported against the body and the machine does not have to be lifted or held up, which is the case when performing vertical drilling. Additionally, drilling in the roof has also been mentioned as a demanding task.

Heavy Lifts and Transportation of Material

In general, some of the most challenging aspects of a concrete worker's industry have been described to be all the heavy lifts and transportation of machines and materials that occur. It has been explained that it is often the work carried out before and after the actual cutting or drilling that is the most tiring. The machines are usually heavy and have to be carried up and down several floors, especially when there are no elevators available. This is common when the project is carried out at new buildings or demolition sites. In these situations, unergonomic lifting and positions are difficult to avoid and the heavy lifts tend to result in back pain. Narrow spaces that are difficult to access properly and that force one into standing in awkward positions were also described as challenging.

Other Heavy Handheld Machines

In addition to handheld power cutters and core drilling machines, other heavy handheld machines are often mentioned as physically stressful to use. The breaker hammer is described as one of the most challenging handheld machines. This is due to the high vibrations that the user gets exposed to while using the machine. This type of machine is usually used for a longer time period as well.

6.2.5 Work-related Pain

In this section, findings about where the users experience the most pain and which injuries that are common are presented.

Painful Body Parts

The majority of the interviewees have stated that they often feel tired and that their bodies could feel worn out after a work day. The body parts that the majority of the interviewees have mentioned as most affected by the performed work are the shoulders, arms, and back. The knees and hands are also frequently described as areas in which the users often experience pain. In general, the upper body is considered to be most affected during specific work tasks, such as when making a cut. However, most interviewees have explained that although this could result in direct fatigue in the shoulder and arms, the pain often disappears after a short rest and the work can be resumed shortly afterward. In contrast, the general load on the back throughout the day often results in back pain that has been described to be more persistent and long-lasting.

Work-related Injuries

Several of the interviewees explain that they either have experienced work-related injuries or know a colleague that has work-related injuries. It has been described that problems such as lumbago or shoulder pain often result in people having to stay home from work for longer periods, which is costly for companies. It has also been mentioned that there is a risk of developing carpal tunnel syndrome, tennis elbow, or having to operate the wrists due to work-related musculoskeletal disorders. One interviewee explained that it is not uncommon for people that have been in the industry for more than 40 years to stop working as concrete cutter and change to another profession before retiring.

Vibration Exposure

Interviewees have expressed that having to work with tools that vibrate a lot is a part of the job, thus experiencing white fingers as a result of the vibration exposure from the machines is common. Several interviewees have explained that this is an issue that is especially critical during winter.

6.2.6 Measures to Prevent Injuries

The majority of the interviewees believe that not using the handheld machines at all is the best way of preventing work-related musculoskeletal disorders. However, additional measures have been described which are presented in this section.

Exercising

Several interviewees have emphasized that exercising is one of the best solutions for preventing pain and injury. The interviewees have described how those who exercise are less prone to getting injured. Furthermore, some interviewees have expressed that those who exercise tend to have a higher awareness of how to lift ergonomically, and which work positions are more dangerous than others. However, some interviewees have also expressed the opposite, that those that exercise less are more careful of how they perform various work tasks in order to not hurt themselves.

To provide exercise sessions in the morning for everyone at the construction site to take part of have been mentioned by several interviewees as an effective method to prepare the body for the upcoming day's physical work. Since the work tasks often include heavy lifts and demanding physical work, warming up the body in advance has been appreciated. These morning exercise sessions have been described as something that is usually performed at larger construction sites.

Work Rotation and Variation

Implementing work rotation is a measure that has been mentioned frequently during user studies. In addition to this, some have explained that planning properly is a great method in order to ensure that various tasks can be combined during a working day. However, these measures are not always possible to implement due to time pressure or few people being available at the project site.

Using Stands and Pallets

Lifts and stands can be used to better reach different levels in height and to ensure a more ergonomic work position. It has been described that these types of aids can facilitate using handheld drills and power cutters since being able to reach higher up allow the user to work with the machine closer to the waist and chest level instead of using the machines above shoulder height.

6.2.7 Other Machines, Tools and Aids

In this section, other tools and aids that have been mentioned by the interviewees are presented.

Weightlifting Belts

One type of ergonomic aid that has been mentioned at several occasions during the interviews is back-supporting belts such as belts used for weight training. Some of the interviewees have mentioned that they use these belts in order to prevent back pain or to facilitate recovery from a previous injury. However, these are most commonly used after one has already started to experience pain. Additionally, it has been explained that people have stopped using this type of ergonomic aid because they were afraid of putting too much load on other parts of the body or losing strength in the core.

Anti-vibrations Gloves and Wrist Protection

Several of the interviewees have mentioned the usage of anti-vibration gloves and wrist protection. However, few of the interviewees explain that they use the gloves in practice due to the discomfort these bring on the user.

Protective Equipment

The usage of protective equipment varies between workplaces. Several of the interviewees have expressed that safety equipment should be used more often, but that they are used less frequently due to the protective equipment limiting one's possibility to move freely or because they are considered too uncomfortable to wear.

Protective equipment that has been described as very common at the construction sites are safety helmets with a chin strap, safety shoes, protective clothing, protective glasses, and gloves. Additionally, visors, masks, and air masks with fan packages have been described as protective equipment which can be used in dusty environments. A harness is a piece of protective equipment that has been described to be used when working at heights or while using a lift.

During one of the observations, no helmet could be used since the scaffolding was too low, 180cm instead of the recommended 200cm, which resulted in the helmet hitting the roof. Another observation showed how only one of two colleagues was using a mouth guard while cutting out a hole in a brick wall. Furthermore, one of the observations showed how protective glasses were not used, which an interviewee explained is because the glasses easily get dirty, making it difficult to see anything while cutting and drilling.

Interviewees have explained that the majority of the protective equipment is owned individually due to practical and hygienic reasons. Exceptions exist when specialized work is performed and it is necessary to rent protective equipment. On these occasions, the protective equipment can be shared between different users.

Wall Saw

The majority of the interviewees use wall saws in their work. With a wall saw, the saw is attached to the wall and controlled by remote control by the user. However, these saws could also be attached to horizontal surfaces, see Figure 34. The wall saw is able to make deeper cuts than a ordinary handheld cutting machine and can have a depth-size with up to approximately 740 mm. However, carrying the wall saws and attaching them to the wall could be physically demanding since they weigh more than handheld power cutters. Furthermore, wall saws can not always be used properly if the material being sawn in is too porous or if the wall is too thin. Additionally, an interviewee explained that it could take several days longer to finish a project if a wall saw was used for each cut compared to if the same work was done with a handheld power cutter.

Figure 34: A wall saw attached to the floor

Battery Driven Machines

How often battery powered machines are used differ from company to company. Battery driven machines are often perceived as heavy since the battery results in an increased weight. Some interviewees expressed that they prefer machines that run on hydraulics as they are more durable and last longer. An interviewee further explained that the machines are usually thrown around a lot and that machines that are constructed of several separate parts break easily. On the other hand, some interviewees thought that battery powered machines are preferable as they do not have to haul large cables behind them when using the machines.

6.2.8 Attitude Towards Ergonomic Aids

Overall, many are positive about ergonomic aids such as wrist protection and weightlifting belts and believe that they are much needed within this industry. However, the majority also explains that these types of aids are rarely used in reality. Few people use it for preventive purposes and most people tend to use it after they have started to experience pain. Several interviewees draw parallels to other types of protective equipment that should be worn but that are not used. A harness is a recurring example of something that many people do not like to wear due to it being too uncomfortable, although it is recommended when working at higher altitudes.

"It's enough to wear a harness, people get pissed, they would rather fall from the roof."

A concrete cutter about wearing safety equipment

Age Differences

One supervisor further explained that the attitude towards ergonomic aids depends a lot on the individual, some being more careless than others. It is evident that age is a crucial factor when it comes to which attitudes people have towards aids and their work in general. A majority of those who have worked for a long time (+30 years) explain that they are more careful now than before. They spend more time preparing the work carefully and use stands and lifts in order to spare the body. However, one of the younger interviewees that had been in the industry for only a couple of years explained that he would consider using aids although he has not experienced any pains yet.

Time Pressure

Time pressure is another factor that affects whether aids are used or not. A limited time to perform one's job often results in having to choose a less ergonomic option in order to save time, such as not installing a stand and instead cutting with the machine above one's head. An interviewee explained that he could have ten minutes to drill a hole before the painter would arrive and that he had to be finished before that. Thus, if he was going to work on an uneven surface, there was not always time to establish anything more stable and safer to stand on. At a large construction site with approximately 100 construction workers, the aspect of time pressure was emphasized the most.

"Time is money, if you can get rid of that, it will get better."

A concrete cutter about the time pressure in the industry

6.2.9 Attitudes Towards Exoskeletons

In this section, findings about how the users perceive exoskeletons are presented.

General Thoughts about Exoskeletons

The majority of interviewees had never heard about exoskeletons before. Someone had seen it being used in an action movie while two had seen one of Husqvarna's competitors' exoskeletons on their website. However, no one had ever seen anyone wear an exoskeleton during work.

When the interviewees were asked if they would consider using an exoskeleton if that enabled them to work within their industry without injuries, all of them were positive about this. However, as an interviewee pointed out, there is a risk that it would not be used until after one has already started to experience pain. In general, people's attitudes could be described to vary on a spectrum of skepticism. No one is strongly positive about using an exoskeleton and believes that they would use it without hesitation, but no one is strongly opposed to trying it if they got the opportunity.

It was emphasized that the back-supporting exoskeleton could facilitate other tasks in addition to cutting and drilling such as shoveling or when using a breaker hammer. It was explained that some kind of help with all types of heavy lifts would be appreciated. However, an interviewee explained that the core of the problem would not be solved with an exoskeleton since all the heavy lifts of machines and material would still be necessary with or without an exoskeleton.

Requirements for the Design of an Exoskeleton

When asked about which requirements a design of an exoskeleton needs to fulfill in order to be used, many interviewees' initial answer was that it must be as flexible and smooth as possible to incorporate into their everyday work process. It has to be easy to put on and off. Some interviewees further explained that although the exoskeleton might facilitate the actual cutting process, they would not use it if other work tasks would become more cumbersome.

The aspect of weight was also mentioned by several concrete cutters, as many explained that one did not want something that adds too much extra weight. Furthermore, the majority pointed out that it is important that they can put on the product without the help of others.

The majority explained that the probability that they would use the product is small if it can not be worn throughout the whole work day. Having to put on an exoskeleton before a specific moment, especially if the moment itself only lasts for a few minutes, was not something that the majority would prefer. However, one interviewee pointed out that he could consider using it for a specific work task if it was very easy to put on, similar to the remote controls that are used for some of the robots where one just quickly pulls the console over one's neck before using it.

Several explained that, during winter, it can be difficult to use an exoskeleton if it should be worn beneath the clothes. An interviewee suggested that a jacket-like aid that could easily be taken on and off could be a possible solution. Additionally, many interviewees explain that an exoskeleton should not get stuck in any surrounding objects such as hoses and cables.

Perceived Risks with Exoskeletons

Several interviewees explained that if adjusting the exoskeleton during work tasks increases the risk of accidentally releasing the cutter, this could result in great health risk with a potentially fatal outcome. Additionally, if the exoskeleton causes one's movement patterns to change or makes the user less flexible, it could increase the risk of injuries. As an example, if one loses balance on a pallet or gets stuck with the cutter, not being able to move freely due to the exoskeleton, could result in severe safety risks.

Furthermore, if one relies too much on the exoskeleton contributing to extra strength, there is a risk that one is not careful enough with the usage of the machines. An interviewee expressed his concern that his ability to react to sudden movements from the machines would be impaired and gave the example that an exoskeleton that assists with holding a power cutter over his shoulders could potentially make it more difficult to lower his arms, resulting in a potentially dangerous situation.

Cost Aspects

The economic aspect of the exoskeletons is also emphasized. Interviewees have pointed out that smaller companies can rarely afford to invest in, for example, robots or other types of aids that can facilitate the work, which increases the probability of an exoskeleton not being purchased. However, a project manager at a smaller company explained that he would consider purchasing external aids such as exoskeletons if it made a real positive impact on his employees' health.

An owner of a construction company explained another reason why expensive machines or tools might not be invested in. If his company uses more expensive machines, it will become more expensive for the customer to hire them for a job. The interviewee continued to explain that customers would only accept a higher price if there existed rules that left the customer with no other option. For example, he explained that it did not become possible to start using demolition robots in projects until the Swedish labor union for construction workers, *Byggnads*, implemented a rule that made it forbidden to use the handheld breaker hammers for too long. Before that, customers were not willing to pay the higher price that was needed for using robots.

Social Acceptance

Some interviewees explained that they would get curious if they saw a colleague wearing an exoskeleton and that they probably would want to try it themselves. Those who shared this attitude also thought that it would not be considered too strange to wear it. An interviewee explained that within this industry, everyone knows that it is a heavy job, hence no one would question the decision to wear an ergonomic aid.

However, several interviews also explain that people would have been skeptical if they saw a colleague wear an exoskeleton. An interviewee explained that one should change jobs if the person is not able to use the machines properly without aid. Another interviewee stated that his colleagues would laugh at him if he would wear an exoskeleton since he would look like a robot if he wore one.

Thoughts About the Existing Exoskeletons on Today's Market

The majority believe that the existing exoskeletons on the market that were presented during the interviews would not be suitable for a concrete worker's type of work. Several pointed out that exoskeletons that help with work above shoulder height could benefit electricians who work in a similar position for long time periods, but that the work of a concrete worker is seldom so specific. Several concrete cutters also explained that if one were to perform a more monotonous work with a cutting machine, it would be more feasible to set up a stand or a wall saw instead.

In addition, some interviewees believed that the machines they use are too heavy to be combined with exoskeletons. Further, many people's spontaneous reaction to the exoskeletons' appearance was that they looked clumsy and inflexible. Someone drew the parallel of that it would make him feel stiff like a robot. It was also mentioned by several interviewees that the exoskeletons looked time-consuming to put on.

"I would already have finished the job before I would have managed to put it on."

A concrete cutter about the exoskeletons on today's market

However, some were positive about the back-supporting exoskeletons as they believed that they could have been helpful for all types of heavy lifts. For this type of exoskeleton, it was emphasized that it is important that it would still be possible to reach important tools in the work pants' pockets. It was also pointed out that there is a risk that one will get weakened in other parts of the back muscles if the exoskeleton only supports certain muscle groups.

6.2.10 Results from Survey

In this section, the results from the survey about ergonomics in relation to the usage of heavy handheld machines are presented.

Age Division

Figure 35 shows the age range of the participants. Almost 66% of the people who answered the survey were between 25 and 44 years old. None of the respondents were above 74 years of age. Everyone except for one participant are users of core drilling and/or power cutters as well as other heavy handheld machines.

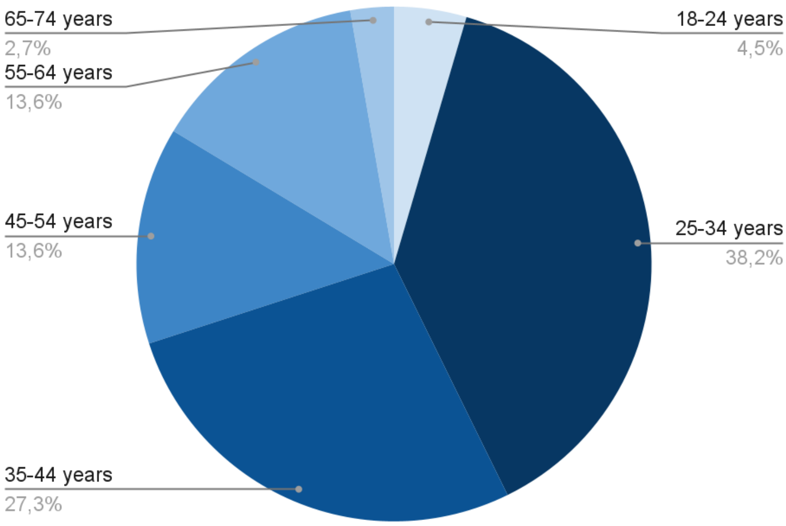

Figure 35: The age division among the respondents

Ergonomic Aspects

The majority of the respondents consider working above shoulder height to be the most tearing work task. This is a common result both for tasks performed with power cutters as well as core drilling machines, see Figure 36-37. Furthermore, cutting at knee and foot level was also considered to be a tearing work task.

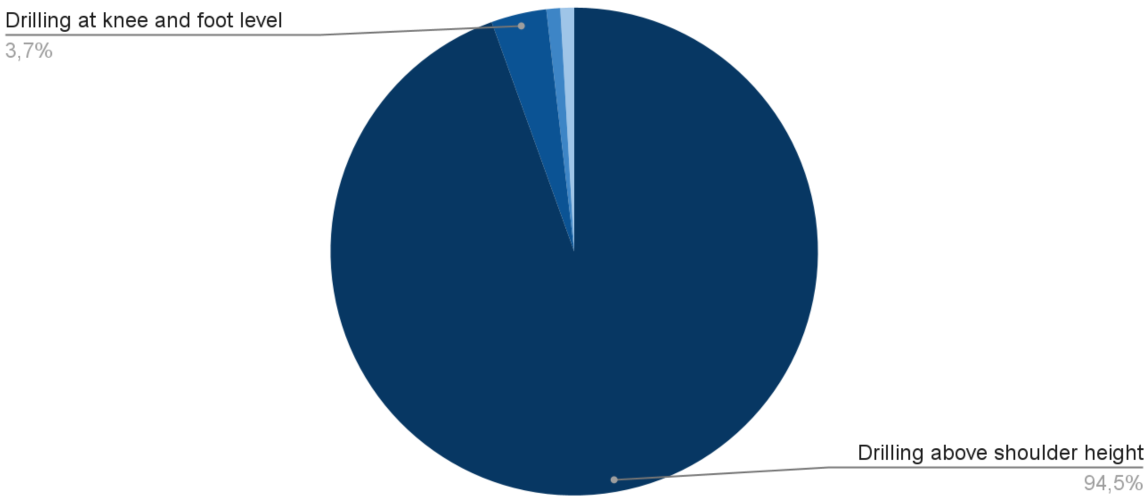

Figure 36: Which type of work with a core drilling machine that is the most tearing on the body

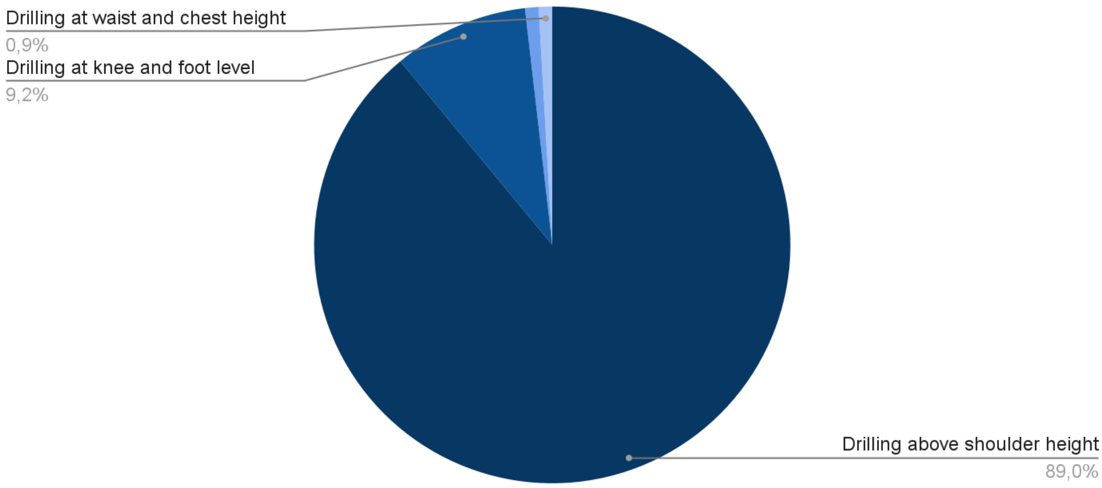

Figure 37: Which type of work with a power cutter that is the most tearing on the body

The majority of respondents answered that they feel pain in their shoulders and lower back after they have been using heavy handheld machines. The hands and neck are also critical body parts, see Figure 38. These answers correlate to the answers given to the question "*Which muscle group is in most need of relief when using heavy handheld machines during a workday*", see Figure 39. However, the neck was considered to be a critical area after using the machines but not during the work tasks themselves.

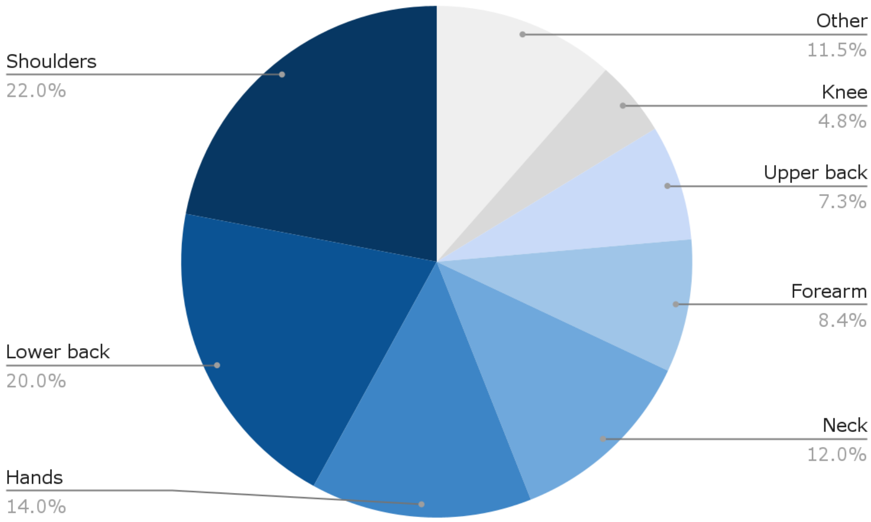

Figure 38: Which body parts that are most painful after having used heavy handheld machines

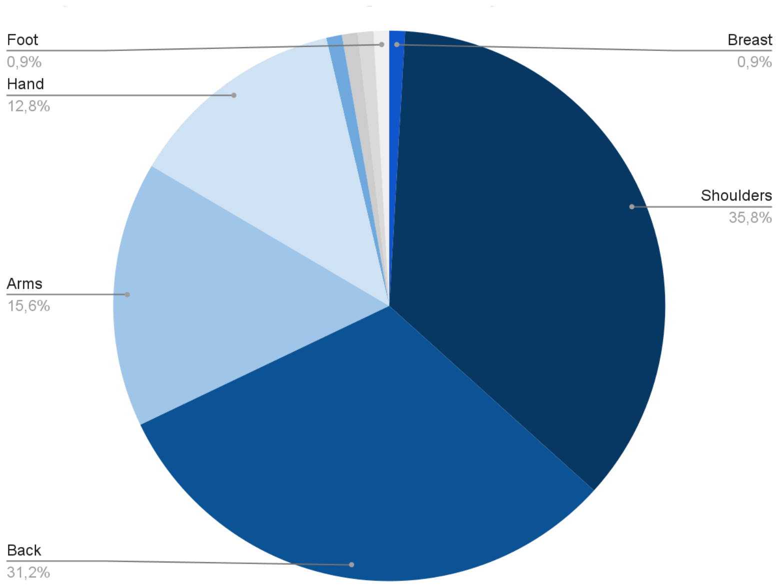

Figure 39: The muscle groups that are in the most need of relief when using heavy handheld machines

The majority of respondents are concerned that the long-term usage of these machines will limit their future ability to work within their profession, see Figure 40. Among 110 replies, only five respondents answered that they are not concerned.

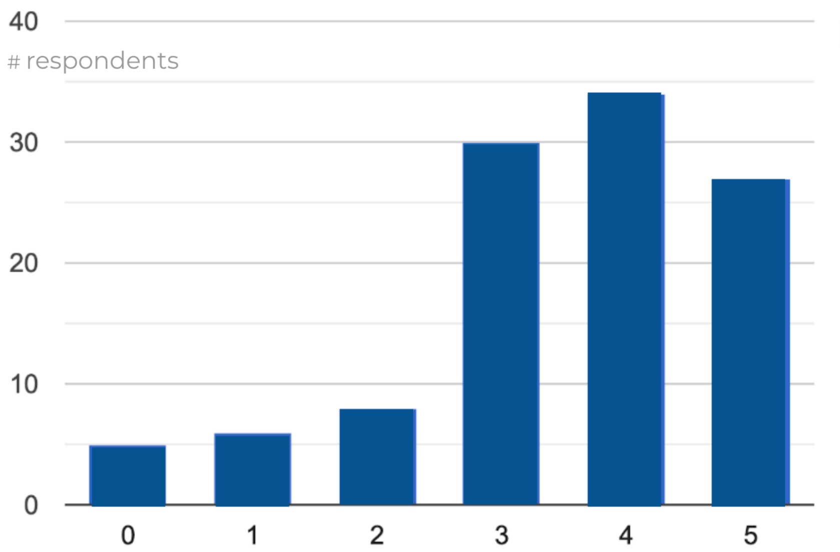

Figure 40: How concerned the respondents are about how using the machines could limit their future ability to work. 0 corresponds to "I'm not worried at all" and 5 to "I worry every day"

Other Machines, External Aids and Protective Equipment

The results from the survey showed that apart from power cutters and core drilling machines, the breaker hammer is the most commonly used heavy handheld machine used by the respondents. Other machines mentioned were the sanding machine, track saw, and hammer drill.

Furthermore, as can be seen in Figure 41, most respondents do not use any aid to reduce the risk of developing stress injuries. However, wrist protection and weight belts are used by a few respondents.

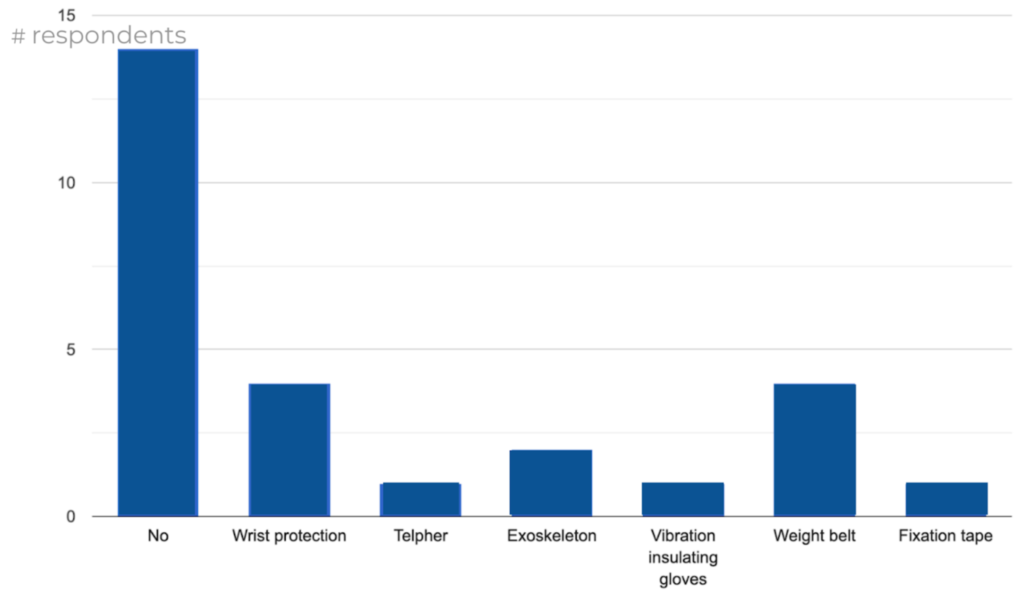

Figure 41: Whether any ergonomic aid are used or not, and which one

Among the respondents, the majority always use head protection in their work. Furthermore, protective gloves and helmets are also used by many people, see Figure 42.

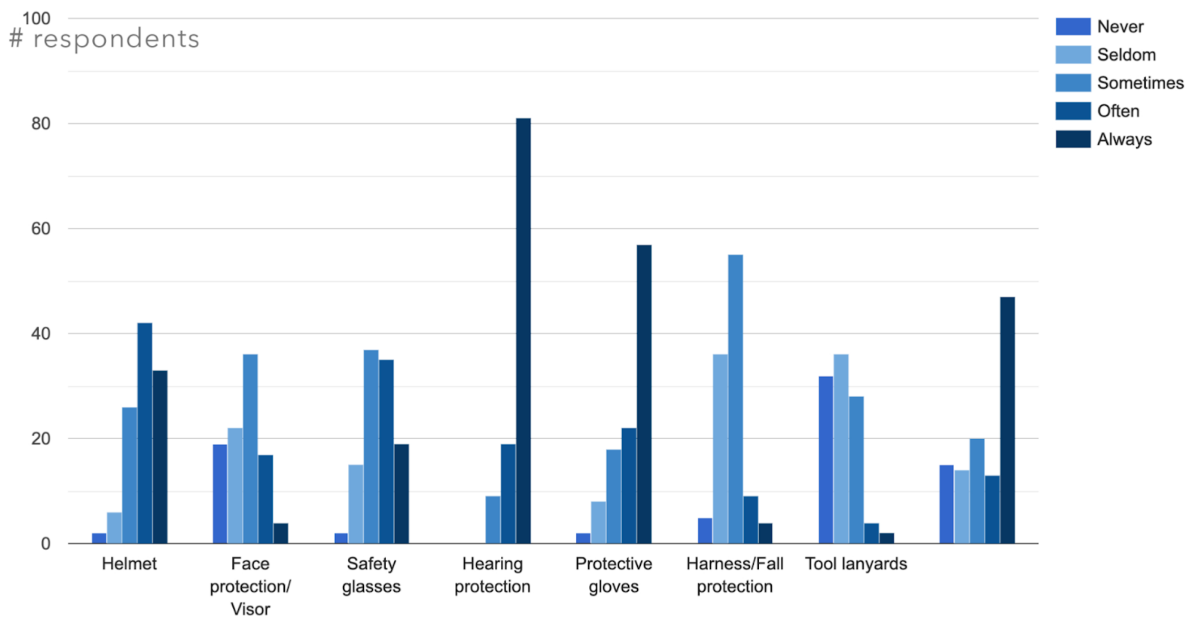

Figure 42: How often different types of protective equipment are used

Attitude Towards Exoskeletons

Among the respondents, 60% answered that they have heard of exoskeletons before, see Figure 43. However, approximately 50% were hesitant towards using an exoskeleton, see Figure 44. Only one of the respondents mentioned that he/she had used an exoskeleton before.

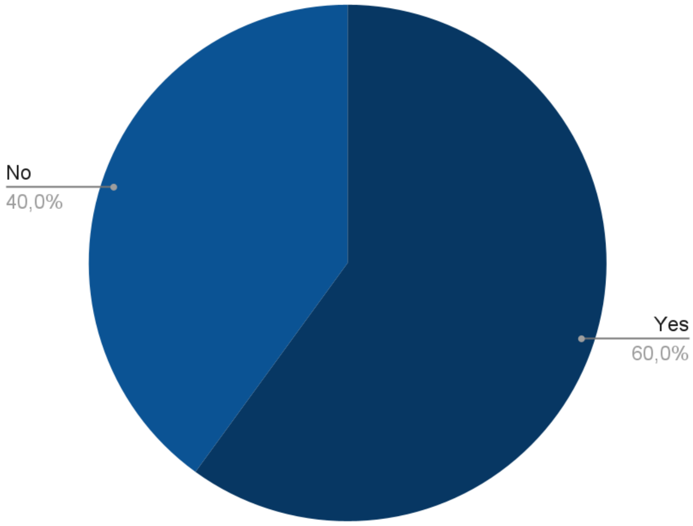

Figure 43: How many respondents that have heard of exoskeletons before

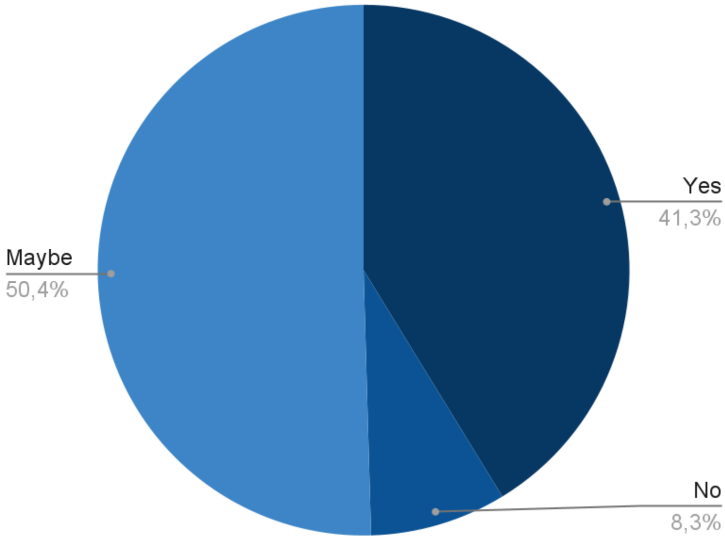

Figure 44: How many people would consider using an exoskeleton as an ergonomic aid

Figure 45 shows that the majority of the respondents consider being able to put on the exoskeleton by themselves as an absolutely crucial factor for them to consider using an exoskeleton. Good fit, high freedom of movement, and easy to adjust, are three other factors that are considered important. That it is socially acceptable to use as well as that it blends in with work clothes are not considered important by the majority of respondents.

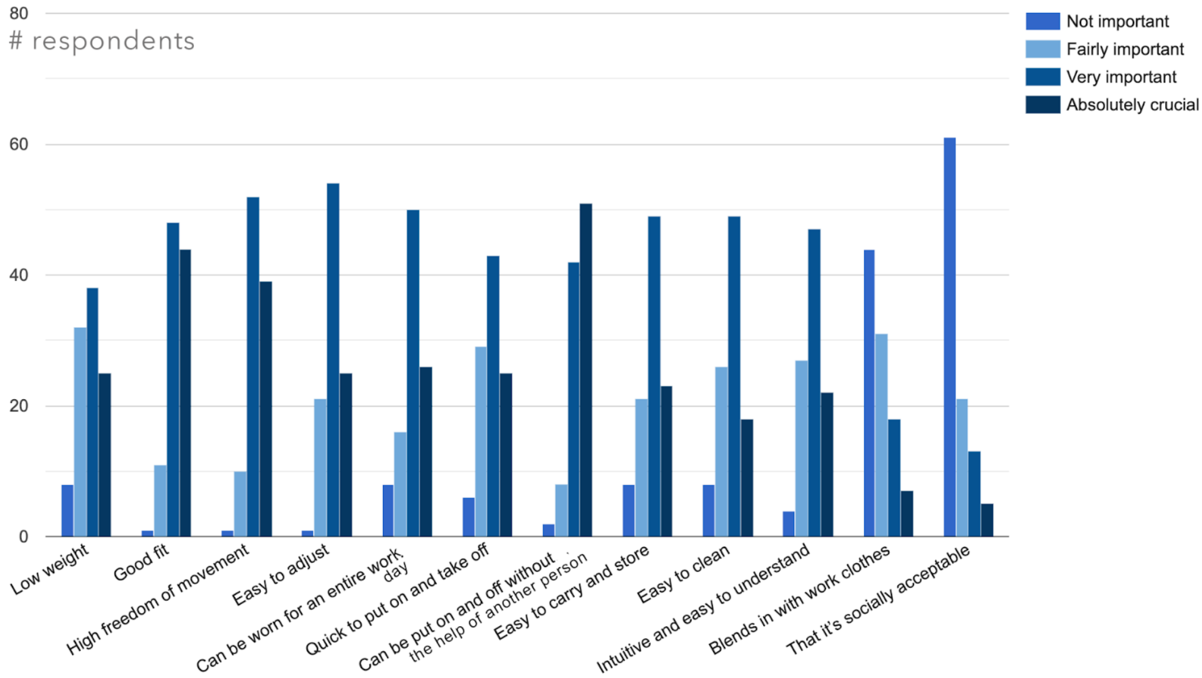

Figure 45: How important different factors are in relation to the usage of exoskeletons

Suggestions on External Aids

When answering the question "*Do you have a suggestion on an external aid that could reduce the workload that heavy handheld products could have on your body*?", three respondents suggested using robots such as robotic breaker hammers. Some respondents wrote that stands, lifts and tools that reduce the risk of working with one's hands above one's head could be beneficial. There were also suggestions on using vibration insulation gloves, planning one's work day properly and using machines with vibration insulation. One respondent wrote that physical exercise should be mandatory and cost-free for people working with heavy handheld tools and that this would benefit both the individual's health and the company's economy.

6.2.11 Persona

Two separate personas were developed based on empirical studies. These portrayed one fictional character of a middle-aged concrete worker who is positive towards ergonomic aids but does not use them himself, and an elderly concrete worker who has started to experience pain and therefore takes the time needed to perform the work tasks more ergonomically safe. The personas can be found in Appendix H.1.

6.2.12 Scenario

A scenario was made to illustrate the problems and context that a concrete worker could face during a work day, see Appendix H.2. This scenario highlights the time pressure and complex work environment that is faced by a concrete worker that is to cut out a door opening at a renovation site.

6.2.13 List of Guidelines

Two lists of guidelines were generated based on the analysis of user studies and literature research. One list includes more general guidelines for the development of an ergonomic aid in combination with handheld machines, see Appendix I.1. In this list, the guidelines are categorized into the following nine categories:

- Comfort
- Ease of use
- Combination with other products
- Storage, transportation and maintenance
- Durability
- Sustainability
- Safety
- Appearance
- Materials

The other list with guidelines is specifically made for any aid that is supposed to be used on the user's body. This list can be found in Appendix I.2.

6.3 Synthesis of Results from Problem Identification Phase

The results from the empirical studies indicate four main problem areas. These were analyzed based on the theory from the literature studies and compared with results from the survey and ergonomic analyses. In this section, a synthesis of the Problem identification phase is presented.

1. **Critical Working Positions**

One of the biggest problem areas is the unergonomic working positions that occur when cutting or drilling. As the results from the user studies shows, the users themselves believe that cutting above shoulder height is the most physically demanding work task. First of all, the machine's center of gravity gets located further away from the user, which makes the workload heavier. Secondly, in these positions, it is not possible to support the machine against the body, further making the work more tearing. Hence, it is only possible to work in these positions for a few minutes before it becomes too difficult.

The studies also show that although cutting above shoulder height should not be done due to safety reasons, this is something that is done by all those surveyed. If a door needs to be cut out, it is thus the horizontal cut at the top that is usually one of the most critical tasks. For horizontal cuts, the user does not get any contributing force from the machine's weight which further makes these tasks more demanding.

Additionally, cutting on the floor is also considered a difficult task. For this work task, the user needs to keep a twisted and bent back for a long time. The ergonomic analysis REBA performed on both cutting above shoulder height and on the floor indicate that these are two critical working positions in terms of unergonomic workload, posing a high risk of injury. Further, the literature study shows that work above shoulder height should be avoided completely. Working at chest height, with arms and hands close to the body, is a more optimal working position according to the literature review, which is further supported by the interviewed concrete cutters' own preferences.

2. Heavy Lifts and Transportation of Machines and Material

A second critical area concerns all the work that is performed before and after making the actual cutting and drilling. Many heavy lifts are generally performed both to, for example, lift the machine itself between different places, but also to transport concrete blocks and other material. This was also confirmed during the observations where it further became apparent that many aids are heavy as well. Wall saws, stands, and scaffolding that are supposed to contribute to reduced workload are in themselves heavy to carry and transport. Additionally, several of the concrete cutters claim that lifting heavy objects all day is more demanding than working with the actual machines.

Additionally, some concrete cutters could visit several different locations during one day, further putting demands on being able to carry a heavy amount of tools and machines every day in different work environments.

3. Attitudes Towards Work Tasks and Ergonomic Aids

A third problem area concerns the attitude that exists towards both the work itself and the usage of aids. The results show that the attitude towards aids is crucial for the acceptance of the exoskeleton. However, many concrete cutters have accepted that their profession is tiring, that it should be difficult, and if one can not manage the physical workload, one should change jobs.

Several interviewees share the attitude about aids being needed, but that it has to be as smooth and seamless as possible in order for them to incorporate it into their daily job. The result of this attitude could be observed during the observations, where aids such as mouth guards, helmets, and harnesses were not used although they were recommended. The concrete cutters themselves further explain that not using these aids is often due to their own laziness. Choosing the fastest route, such as using a handheld power cutter rather than installing a wall saw, is often preferred although one is aware of the potential health consequences of using a handheld heavy machine. However, this attitude also differs between individuals. As an example, it is notable that those that have experienced back pain make a bigger effort of choosing more ergonomic work alternatives than those who have not experienced work-related musculoskeletal disorders. Using ergonomic aids for preventive causes is hence uncommon.

4. A Diverse and Time Pressured Work Environment

Finally, the work environment itself is highly diverse, resulting in a more complex user context. Sometimes it is necessary to cut in a narrow corner where the roof is too low to wear a helmet. Other times the user has to stand on a wobbly stool to be able to reach as high as possible with the machine. Sometimes it is necessary to climb several meters in order to reach the work site. The machines further need to withstand a harsh environment since it is not unusual that machines are thrown around and therefore need to withstand high impacts. Additionally, the tight time schedule further increases the risk of choosing less time-consuming alternatives instead of more ergonomic ones.

Problematic Aspects with Today's Exoskeletons

The concrete cutters' attitude towards exoskeletons is similar to the attitude towards aids in general. They agree that there is a need for more ergonomic aids, however emphasizing that these products can not interrupt their work in order for them to use it. The survey showed that the majority of concrete cutters are worried that the usage of handheld machines could result in long-term health injuries, which is consistent with the concern expressed during the interviews as well. However, as stated before, although many seem aware of the health risks, this is something that the majority have accepted as a part of their job.

Out of 110 responses in the survey, only one respondent answered that they have used some type of exoskeleton. When this question is raised during the interviews, the majority answer that they have heard about one of Husqvarna's competitors' exoskeletons but have never seen anyone use it. This shows that exoskeleton is not a completely unfamiliar term within the industry. However, those existing in the current market are not considered suitable for this particular profession. For concrete cutters, whose industry is characterized by very varied work tasks where the user often is positioned in different work positions throughout the day, the current exoskeletons on the market are considered too stiff, restricting the movement of freedom. They are also considered to be too time-consuming to put on.

Additionally, concrete cutters are skeptical about if an exoskeleton would be able to help them with heavier handheld machines. The variation of work tasks and work environments, the weight of the machines, and the time aspect, are thus three major aspects that affect the attractiveness of exoskeletons within this industry.

Most Critical Body Parts

The results from the survey are largely consistent with the results from the interviews when it comes to which body parts the concrete cutters consider to be the most negatively affected by their work. The shoulders and lumbar spine are considered to be the two most critical areas, followed by hands, neck and arms. This is also consistent with the results of the literature study, where it was found that the lower back, shoulders, neck and hands are the most prone to work-related musculoskeletal disorders, with lower back injuries being the most common. The results also show that neck and shoulders are in the most need of aiding tools during the work itself, such as when cutting or drilling. However, the back is where a helping aid could result in a more long-term benefit. Figure 46 illustrates the summarized needs on a short-term and long-term basis.

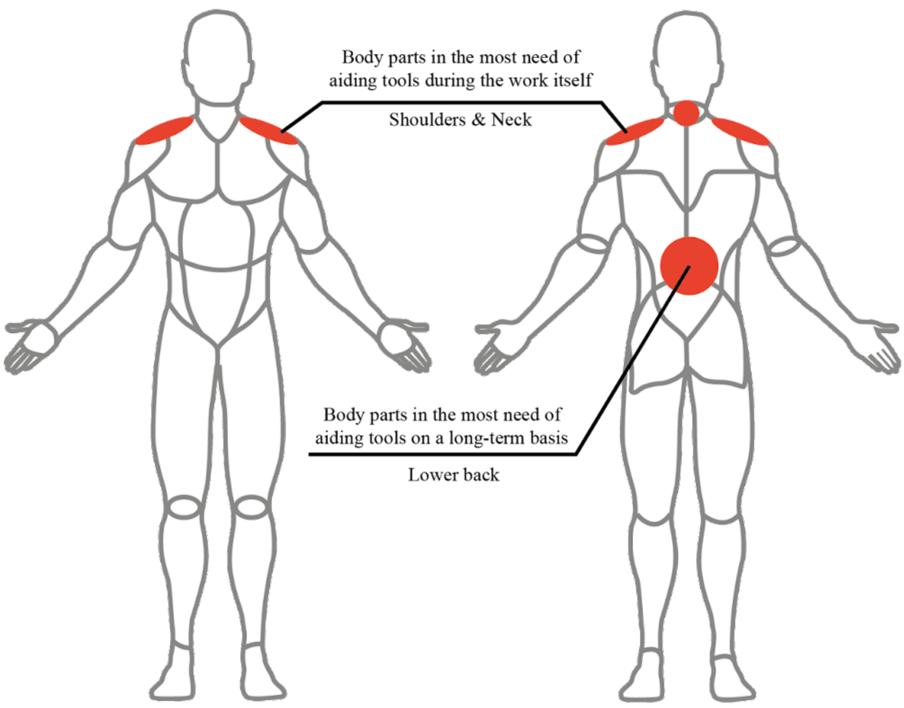

Figure 46: Affected body parts in need of support during construction work

Other Demanding Handheld Machines

The survey also indicates that several other handheld machines are considered heavy and demanding to use. This is consistent with the results from the interviews, where requests for aids for other heavy handheld machines such as the breaker hammer have been made. Additionally, several concrete cutters see a great advantage with aids that can facilitate working with several different types of machines. Developing an aid that could be used for more than cutting or drilling was hence considered beneficial. However, if a comparison is made between the core drilling machine and power cutter, the results show that the power cutter is considered to be the most difficult to work with.

6.4 Results from Ideation Phase

This section presents the result of the Ideation phase, including insights from different shop visits and some of the ideas from the brainstorming sessions and the workshop.

6.4.1 Shop Visits

In this section, insights from the performed shop visits are presented.

Sports Shop and Ergonomic Shop

The informal interviews held at the sports shop resulted in more knowledge regarding weightlifting belts and its impact on the body and posture. The interviews also clarified which kinds of belts construction workers often choose and why. Additionally, the visit to the ergonomic store contributed with complementary information from a more ergonomic point of view. Some of the most relevant insights are:

- Weightlifting belts are sometimes bought by construction workers to maintain a good posture for preventive purposes. But also after they have experienced a past injury. The majority of the users prefer a soft belt that can be worn during the whole work day compared to the belts which have a more rigid structure.

- The correct amount of rigidity and flexibility in the belts is important in order to provide the ability to move with a maximized support. Therefore, a belt with a softer front and a more rigid back-support could possibly benefit the user group the most.

- The implementation of more rigid parts within a softer back-supporting belt were discussed as another way of maximizing the support while still retaining the flexibility. Implementing these rigid parts on certain places within the back-supporting belt would give support where needed while a flexible material could be used as the main material.

- Wearing an aid for additional back-support may help the user to actively reflect over one's body position, especially if the aid is worn during the whole work day. By helping the user to maintain a good posture on a daily basis, this kind of aid could facilitate many different work tasks. However, there is a risk that the user relies too much on this kind of belt and hence forgets to keep a good posture while not using it.

Testing of an Exoskeleton

The project group trying a passive exoskeleton for the upper body contributed to a better understanding of how it feels to wear this kind of aid. The exoskeleton was tested while holding a handheld tool of approximately two to three kilos over the shoulders. The project group experienced that this exoskeleton contributed with added strength, facilitating holding the tool above one's shoulders for several minutes. Pulling down the arms from a lifted position was not considered challenging as the device did not hinder these types of movements.

6.4.2 Categories of Ideas

During the Ideation phase, a number of ideas were developed that could be categorized in three main categories depending on which kind of support they would provide for the user. Within all categories, both ideas concerning support when working specifically with the power cutter and the core drilling machine and aids supporting the workers throughout the day were included. These are shown in Table 2.

Table 2: The three categories that the ideas were divided in

Three categories of ideas
Aids supporting the back
Aids supporting the shoulders and arms
Aids supporting both back and the upper body

6.5 Results from Concept Evaluation Phase

An analysis of all ideas from the ideation session and workshop resulted in a compilation of nine main concept groups. The nine concept groups as well as the strengths and weaknesses with each of them are presented in Appendix J.1. This section presents the rest of the result of the Concept evaluation phase, including the six final concept groups chosen for evaluation with users as well as a summary of insights from the user evaluation.

6.5.1 The Final Concept Groups Evaluated with Users

After an evaluation of the nine concept groups, six final concept groups were chosen for an evaluation with the users, see Table 3. In this section, the six concept groups are presented together with an overview of the various concept alternatives within each concept group.

Table 3: The six final concept groups

Concept 1	Back-supporting exoskeleton
Concept 2	Back-supporting exoskeleton integrated in work clothes
Concept 3	Supporting belt integrated in work clothes
Concept 4	The supportive arm
Concept 5	The supportive stand
Concept 6	The extendable handle

Concept 1: Back-supporting Exoskeleton

This exoskeleton aims to facilitate heavy lifts and cutting performed at floor level. It is similar to the back-supporting exoskeletons on today's market with elastic straps elongating along the legs and back when the user bends, then pulling the user up by contracting on the way up. The exoskeleton could be used during the whole work day.

The exoskeleton is worn around the user's back in the form of a vest and is tied around the legs to redirect the load from the back to the legs. See Figure 47-48 for different alternatives of this concept group.

Alternative 1A: Figure 47 shows a concept alternative where a vest is attached to the upper body, which in turn is connected to the lower body by straps crossing sideways over the user's back.

Figure 47: Alternative 1A of the back-supporting exoskeleton

Alternative 1B: Figure 48 shows an alternative where the upper part of the exoskeleton is divided into two different parts which split when the user is bending. When the user is standing up straight the straps of the exoskeleton are hidden inside the vest. The straps are running straight down over the user's back.

Figure 48: Alternative 1B of the back-supporting exoskeleton

Alternative 1C: Figure 49 shows an alternative where the upper part of the exoskeleton has the design of braces. The upper part is connected to the bottom part with straps going on the side of the leg down to the part around the leg.

Figure 49: Alternative 1C of the back-supporting exoskeleton

Concept 2: Back-supporting Exoskeleton Integrated in Work Clothes

This concept is similar to the previous concept but with part of the exoskeleton being integrated in work clothes. This makes the aid more discreet since it would look like a pair of ordinary work pants. The braces are placed over the shoulders and then connected to the pants. The braces should be possible to remove and attach separately if one does not prefer wearing braces. See Figure 50.

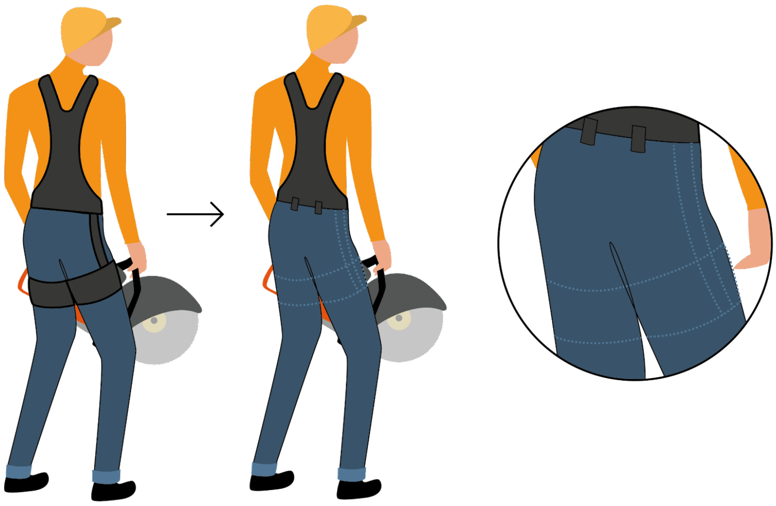

Figure 50: The back-supporting exoskeleton integrated in work clothes

Concept 3: Supporting Belt Integrated in Work Clothes

This concept consists of a belt similar to a weightlifting belt that supports and stabilizes the abdomen and back by enabling a more ergonomic posture. The belt is implemented in the work clothes in order to not be too visible as well as to not make the user have to put on additional devices. The aid further differs from the other concept groups since it does not contribute with any lifting power, but only makes it easier for the user to work in more ergonomic positions. See Figure 51.

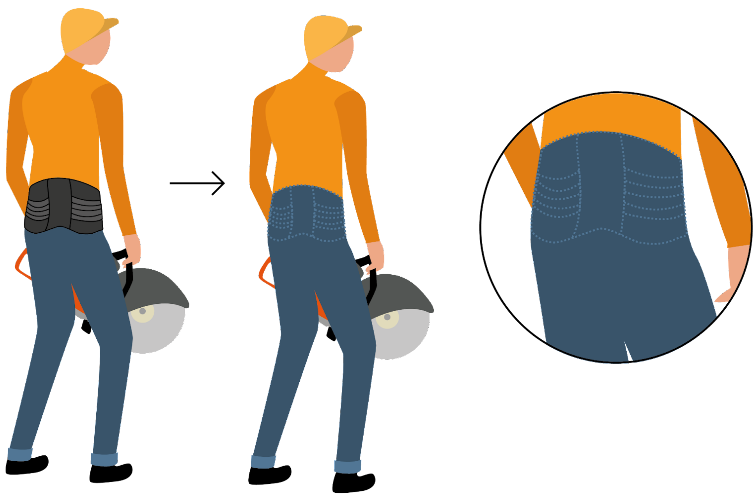

Figure 51: The supporting belt integrated in work clothes

Concept 4: The Supportive Arm

This concept consists of an extension connected to the user as an extra arm that helps the user by holding up the machine. The exoskeleton is attached around the waist, back, shoulders, and possibly also the legs depending on the model and amount of support needed. Different variants of this concept can be seen in Figure 52-54.

Alternative 4A: Figure 52 shows an alternative where the supportive arm is helping the user to hold the machine but where the user still maneuvers it with his hands.

Figure 52: Alternative 4A of the supportive arm

Alternative 4B: Figure 53 shows a similar variant as Concept 4A but with the difference that the machine can be maneuvered through an extra elongation making the user reach longer without lifting the arms.

Figure 53: Alternative 4B of the supportive arm

Alternative 4C: Figure 54 shows an alternative where the supportive arm is taking the full weight of the machine. Here the user is maneuvering the machine with a remote control.

Figure 54: Alternative 4C of the supportive arm

Concept 5: The Supportive Stand

This concept is an extendable arm similar to the one of Concept 4 but longer and attached to the surrounding environment instead of the user itself. Due to the length and flexibility of the arm, this concept can be used both when performing work in walls and at the floor. See Figure 55-56 for different alternatives of this concept group. The extendable arm could be maneuvered with a remote control or by hand.

Alternative 5A: Figure 55 shows an alternative where the arm is attached to a stand.

Figure 55: Alternative 5A of the supportive stand

Alternative 5B: Figure 56 shows an alternative where the arm is attached to a part of the surrounding scaffolding.

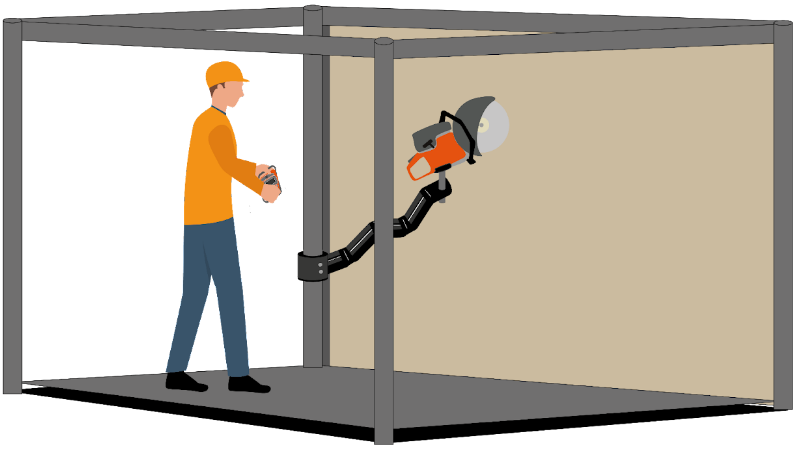

Figure 56: Alternative 5B of the supportive stand

Concept 6: The Extendable Handle

This concept includes an extendable handle that could either be permanently attached to the power cutter or attached and removed when needed. The aim is to make it possible to cut in the floor without having to bend down. The power cutter is transported around on wheels and can be controlled manually with buttons on the handle or by sliding the handle at different angles. See different variants in Figure 57-59.

Alternative 6A: This alternative includes a handle which can be attached to the machine when needed. Wheels are placed both in the front and the back for extra support and control. See Figure 57.

Figure 57: Alternative 6A of the extendable handle

Alternative 6B: This alternative is similar to Concept 6A, except that the wheels are only placed at the front of the power cutter. This could allow an easier way to tilt the machine forward. See Figure 58.

Figure 58: Alternative 6B of the extendable handle

Alternative 6C: This alternative includes a handle permanently attached to the power cutter. The wheels are placed similarly to Concept 6B. See Figure 59.

Figure 59: Alternative 6C of the extendable handle

6.5.2 Expert Evaluation

In this section, a presentation of the results of the expert evaluation of the six concept groups is given. First, each concept is presented separately, then the final ranking of the concepts is presented. At the end, a summary of what the users answered regarding topics such as attitudes toward aids and what measures are necessary to make people start using them are given.

Concept 1: Back-supporting Exoskeleton

The concept that was considered to be the most useful for many different work tasks was the back-supporting exoskeleton. Concept 1B was preferred by all interviewees since the straps at the back indicated a better support. This concept could possibly facilitate most kinds of heavy lifts and therefore be helpful for more work tasks than cutting and drilling. This means that the concept could be useful for more industry workers apart from concrete cutters. Additionally, for cutting in the floor, this concept was considered very helpful. Another strength was that it could be worn during an entire work day.

An issue that was raised by all interviewees was that it looked similar to the harnesses that are worn when working at higher heights, which often is considered uncomfortable to wear. Although it was described that they get used to wearing it after some time, many people are still hesitant to wear it. It was emphasized that especially the straps around the legs have to be as comfortable as possible, providing an optimal fit. The straps should be tight enough to not twist around the legs, but not too loose so that they slip along the legs. It should further be possible to reach one's pockets.

It was suggested to combine the exoskeleton with a supporting belt similar to a weightlifting belt. This could provide both extra support for lifting and result in a more ergonomic work posture. Since some people do not like to wear braces, being able to take these off would be appreciated. Furthermore, being able to adjust the product with gloves on, and not having to keep track of too many loose parts was also deemed as necessary.

Concept 2: Back-supporting Exoskeleton Integrated in Work Clothes

One main strength with integrating an exoskeleton in work clothes was that it would make it less visible. However, the users agreed that integrating the exoskeleton could make it less comfortable to wear, partly because it could become more difficult to adjust the straps around the legs. There is also a risk that the pants would become too uncomfortable when bending forward, since they would be attached to the exoskeleton's braces along the back and shoulders.

However, one of the interviewees was positive towards the possibility of not having to bring and put on an extra device. Being able to put it on first thing in the morning and then wear it the whole day could be a large advantage according to him. However, similarly to the previous concept group, it was also mentioned that it could be necessary to provide the possibility to remove certain parts, such as the braces, in order to increase the comfort throughout the day when one is not in need of the maximum support.

Furthermore, it was mentioned that integrating an exoskeleton in work clothes would increase the prices of these work clothes, making it crucial that they do not have to be replaced after a couple of months of usage. However, one interviewee explained that he would use these pants on days when he knows that he will be working with his back bent a lot, similarly to when he puts on fireproof clothes when working with welding, thus increasing the product lifetime of the device.

Concept 3: Supporting Belt Integrated in Work Clothes

Integrating a supporting belt in work clothes was deemed as a possible solution for making the users stand and lift in a more ergonomic posture. Being able to adjust the belt and tightening it before certain work tasks was considered useful, since this could make it feel less present throughout the day when not in use.

However, one problematic aspect that was mentioned was that it could result in users getting used to always having extra support for the back, hence limiting one's possibility to work without it. Additionally, since it does not give any extra strength, they explained that most people would probably not buy it unless they already experience back pain, which is the case with today's ergonomic aids and belts.

Remarks were made about what the results from the expert evaluation showed about the main difference between integrating an exoskeleton in work clothes compared to integrating a belt. The concept with the integrated exoskeleton was deemed too uncomfortable due to the risk of the braces pulling the pants upward during a bending movement with the back. With the belt however, this issue does not exist. In contrast, an external back-supporting exoskeleton was considered worth the effort of putting it on since it contributed to added strength, which is an advantage the external belt does not have.

Concept 4: The Supportive Arm

An attachable arm was regarded as a less convenient concept compared to the exoskeleton for the back and the integrated belt. The interviewees raised the issue that it could be beneficial to use while doing many repetitive tasks at a certain height, such as cutting windows, but that using it for other tasks would be difficult. Bending down while wearing it looked cumbersome, as well as walking around in general. Additionally, they described how it would be difficult to maneuver it and how the back muscles probably would have to work even harder to support the forward-leaning weight.

Two of the interviewees explained that they had difficulty seeing themselves wearing it, but would be open to trying it before disregarding it completely. In contrast, the third interviewee was more positive about it, further explaining that he could see potential with this concept if it could be used for drilling as well. Being able to place one's arms on it for support while drilling would be beneficial. Additionally, being able to easily detach the support would be necessary for him to consider using it.

Of the three alternatives shown, the users were the most positive towards Concept 4A due to the possibility to maneuver it with one's own hands. This would provide better precision. It was also emphasized that it would be preferred to be able to cut horizontally with the product since that is a more difficult task compared to cutting vertically.

Putting it on and off was also deemed more time-consuming than the other concepts. Another concern was about safety. Being attached to the power cutter felt dangerous and was not something the users would feel comfortable with.

Concept 5: The Supportive Stand

The concept that was deemed the least useful was the supportive stand. This was mostly due to the concept looking too time-consuming to install and too heavy to carry around. The interviewees explained that using a wall saw would be more feasible, since wall saws are able to cut deeper cuts compared to a handheld power cutter. Furthermore, this concept looked like it could get wobbly to control unless the user steered it with his own hands.

Concept 6: The Extendable Handle

The concept with the extendable handle was deemed useful for all kinds of tasks that included cutting in the ground. Especially electricity driven track saws were considered one major user area, and it was described how it is often necessary to work for many hours in a row when making tracks for power cables in office environments. However, being able to attach different types of saws would be more beneficial. For ordinary handheld power cutters, it would also be necessary to attach a water tank in order to perform wet cutting.

It was also emphasized that this concept has to ensure that the depth of the cuts is even despite using it on uneven ground. Having support wheels at the back of the product, as in Concept 6A, as well as making it heavy enough so that it does not wobble, were two further suggestions. Regarding if the product would be too heavy to carry around, the interviewees explained that if it worked well, the size of it would not be an issue since it looked more lightweight than a wall saw.

Summary and Rankings of Concepts

The three most useful concepts according to the rankings made by the interviewees are:

1. **Back-supporting exoskeleton:** Deemed to have the most user areas.
2. **The extendable handle:** Considered the most useful for specific work tasks.
3. **Supporting belt in work clothes:** Considered the easiest to wear all day with the lowest threshold for achieving high user acceptance.

These three concepts all have different strengths, making them useful for different work tasks and purposes. The rest of the concepts were considered to have a considerably higher threshold for user acceptance according to the interviewees. The supportive arm could be useful for very specific work tasks but would limit one's possibility to perform other tasks and to move freely. Integrating the exoskeleton in clothes was not considered as useful as wearing the exoskeletons separately from clothes. The supportive stand was deemed the least feasible compared to the other concepts.

The aspects that are common among the concepts that were considered the most useful are:

- Require little time to install for a first-time user and with a low learning curve.
- Do not have to be removed between tasks, more precisely, the user can move around freely after a task is done and use it throughout the whole day.
- Allow a large movement of freedom and usage in various body positions.
- Are similar in appearance to products that already are used by the user.
- Have the potential to facilitate the usage of different handheld machines.
- Can be transported easily between project sites.
- Can by small measures be adjusted to fit the user.

Attitude and Marketing

Since similar variants of several of the evaluated concepts already exist on the market, the interviewees got to explain some reasons for why they thought these were not being used. It was described that many people either do not know of these aids' existence, or do not know where to buy them. Those who have heard about exoskeletons are rarely aware of these devices being something that could benefit them in their profession. Hence, simply launching an ergonomic aid might not result in an increased usage unless other measures are taken. Different ways that were suggested by the users to increase the awareness of these aids are:

- Include ergonomic aids in the marketing material for other machines. As an example, in the videos Husqvarna makes about how to use their products, showing a person wearing an aid while demonstrating the usage of the machine could be one way to make people aware of the aid's existence and its relevance for this industry. This could also lower the threshold for first-time users, since seeing people in the same profession using it could make the product feel less foreign.

- Show these ergonomic products during fairs. Let people try the product and continuously work towards increasing the awareness of how these products could help concrete cutters in their work.

- Place the ergonomic products close to the machines that they could be combined with in the stores. Suggest that the user buys the aid when making a purchase of a handheld machine online.

- Inform the physiotherapists that work with construction workers about these ergonomic products. This could be done by collaborating with physiotherapists in order to develop a safe ergonomic aid.

It was also emphasized that in order to make people use these products, one has to be aware that the attitude towards these kinds of aids plays a crucial role. According to the interviewees, the market in Sweden could be more positive towards these types of ergonomic aids compared to many other countries. With an increasing awareness of ergonomic work and an increased number of regulations towards the prevention of musculoskeletal diseases in Sweden, the users stated that introducing ergonomic aids in their industry will have a higher acceptance rate today compared to some generations ago. However, the interviewees also mentioned that although the threshold for using ergonomic aid in this industry is decreasing, there are still many concrete cutters that would not prioritize using these products or that would be comfortable wearing it in public.

7

Discussion

The results showed that work-related musculoskeletal disorders are common within the construction industry and that experiencing pain in shoulders and lumbar spine during and after work is a recurring issue. The analysis of the empirical studies indicate that the users are aware that working with handheld machines could be unergonomic. This is also supported by the fact that the majority of users worry about the long-term consequences of using these products, further being positive towards measures that could enable better work situations. It is thus evident that there exists both a need and a desire for measures to increase ergonomic safety for concrete cutters.

This chapter includes reflections on the project scope, process and results. First, the validity and reliability of the process and methods are discussed. Secondly, an interpretation of the results is given, followed by a discussion about the potential safety risk and benefits with exoskeletons. Then, potential challenges with developing an ergonomic aid for concrete cutters are presented. Finally, ethical aspects will be discussed. Recommendations on future studies are given throughout the chapter.

7.1 Process and Methods

In this section, the scope of the project as well as the reliability and validity of some of the methods used are discussed.

7.1.1 Research Questions

To extensively investigate the work situation of concrete cutters and potential problem areas, research questions covering a wider research area where applied. This contributed to a broader investigation, which can be seen as beneficial for future product development since a deeper understanding of the user context and challenges have been reached. On the other hand, working with a more limited area of research could have resulted in a more in-depth investigation within certain areas, potentially taking the investigation closer to a final product concept. However, due to the early stage of the product development process, working with an exploratory approach was seen as beneficial. This since it allowed for new areas to be investigated as they emerged.

Another relevant area of discussion is the extent to which core drilling machines and power cutters have been of focus during the project. The project has to some extent been more directed towards investigating the power cutters, which was a joint decision made together with Husqvarna. Furthermore, the power cutter has been described by the users as the most commonly used machine as well as the most problematic machine of the two. However, further investigation of the core drilling machine could reveal information relevant to consider during future product development processes.

7.1.2 Participants

During the user studies, participants with different work experiences, ages and roles have been included. This was done to ensure that the majority of the target group was reached. Furthermore, participants from different sizes of companies have been considered. However, within the construction business, most of the workers are men. This has resulted in the majority of participants in this study being men. In a future study, a more gender-equal deviation among the participants would have been preferred to ensure a more inclusive design.

Additionally, including participants that have experience in using an exoskeleton would have been highly valuable. Since several of the users had not heard about exoskeletons before, their opinions about this device were based on the way the project group described and introduced this type of device to them. Hence, there is a possibility that their opinion about exoskeletons would have been different if they were introduced to it in another way.

7.1.3 Observations

During the user studies, observations have been used as a method to observe when different work tasks are carried out in a real user context. Furthermore, this has been used as a way of investigating if the information from the interviews corresponds with how work actually is carried out. During the observations, the workers have been aware that the project group has been present. This could have affected their behavior and way of working. One way of avoiding the workers getting affected by the project group's presence would have been to perform concealed observations. On the other hand, the current way of observing enabled the project group to ask questions throughout the observations which were considered beneficial.

7.1.4 Survey

A survey was distributed both within the Facebook group *Håltagare* and directly to companies of concrete work. Overall, the answers from the survey correlated with the information gathered during interviews, which indicates that the findings are reliable and representative of the target group.

7.1.5 Evaluation Method

The exoskeletons shown during the Problem identification phase were presented in an environment different from the one concrete cutters are familiar with and with a higher level of detail. For an increased validity of the final evaluation of the concepts with users, presenting the exoskeletons with an equal level of detail and in a similar context would have been preferred. Furthermore, during one of the expert evaluations, two users were evaluating the concepts together. An open discussion was taking place between the two interviewees, which could result in biased opinions. On the other hand, providing an environment for discussion was seen as beneficial since this could trigger ideas among the two interviewees.

7.2 Interpretation of the Results

According to the user evaluation, the three most useful concepts were the back-supporting exoskeleton, the extensive handle, and the supportive belt integrated in work clothes. Although the exoskeleton was ranked the highest, it was clear that the users saw different strengths and user areas with all three concepts, making it less evident to decide on which concept that is the most feasible to further develop in the future. As an example, while the back-supporting exoskeleton is considered to have more user areas compared to the extensive handle, thus also the potential to reach a larger customer segment, the extensive handle could have a higher user acceptance due to it being a product that does not have to be worn by the user.

In order to draw conclusions on what aspects of the concepts that could result in a more ergonomic safe work environment when developing a future ergonomic aid, the six concept groups evaluated by the experts are discussed based on the literature study and empirical studies made throughout the project. Additionally, what potential aspect that might have affected the expert evaluation and why this should be taken into consideration is also discussed in this section.

7.2.1 Back-supporting Exoskeleton

If a comparison is made between the results from the user studies made during the Problem identification phase and the expert evaluation during the Concept evaluation phase, some major differences about back-supporting exoskeletons could be observed. When the users were shown pictures of back-supporting exoskeletons that exist on the market today during the Problem identification phase, the majority were skeptical about how it would help them in their profession. Several of the users stated that it looked too bulky and that it probably would be more beneficial for people in other industries who perform similar work tasks everyday. However, when the illustrations of the back-supporting exoskeleton were shown during the expert evaluation, the users could see several advantages, further stating that they could see themselves using this aid. The reasons behind this contradiction in results is something that is discussed next.

First of all, the pictures of back-supporting exoskeleton evaluated during the Problem identification phase showed a warehouse worker lifting boxes, thus in a context dissimilar from the construction worker’s. In these pictures, the level of detail was greater compared to the illustrations shown during the expert evaluation, which could have resulted in the exoskeleton looking more complex and possibly bulky. In the illustrations for the expert evaluation however, the level of detail was less and the overall style simplistic. The illustrations also showed the user of the exoskeleton holding a power cutter and wearing clothes similar to the concrete cutters’. These differences in presentation methods could have played a major difference in the user’s response and attitude towards the exoskeletons, making the users favor the more simplistic and familiar illustrations. This is also supported by what was found in the literature review about visually complex exoskeletons having a less acceptance among users.

Secondly, out of the three users that evaluated the concepts in the expert evaluation, two of them had been interviewed during the Problem identification phase and thus previously seen pictures of similar back-supporting exoskeletons. When a comparison is made between their opinions regarding this type of device, it is possible to note that both users have a more positive view during the second interview. This could have been a consequence of the idea of wearing an exoskeleton being less unfamiliar during the final interview, indicating that the user group could become more positive towards the idea of using an exoskeleton with time. However, more evaluations with the intended user group is needed before drawing any conclusions about whether this is true or just a coincidence. Since most users stated that it is a forgin and new concept, it could be difficult to evaluate it properly without having tried using it first. Hence, developing a prototype and trying this with the intended user group should be emphasized.

Finally, since this concept, compared to the back-supporting belt and extendable handle, is an exoskeleton, further risks and benefits with this concept and exoskeletons in general are discussed in Section 7.3.

7.2.2 Supporting Belt Integrated in Work Clothes

The supporting belt integrated in work clothes has many similarities with the weightlifting belt that is already used by some concrete cutters. However, during the user studies in the Problem identification phase, the majority stated that they did not use this type of aid. The main reason why a supporting belt *integrated* in work clothes was believed to have more potential than an external weightlifting belt was because the user would not have to bring an extra device to put on, thus minimizing the amount of effort needed to wear it. This was confirmed during the expert evaluation where it was described how this concept could result in concrete cutters using an ergonomic aid more often.

If the main reason why users choose not to use the existing weightlifting belt is because they do not want to bring an extra device, then this concept could be beneficial. However, if there are other reasons that are more decisive, such as not seeing any value with wearing an ergonomic aid at all, then integrating the supporting belt in work clothes might not result in an increased usage. A future study should hence investigate what main issues that inhibit concrete cutters from wearing today's weightlifting belts. Other suggestions are to, similarly to what is mentioned previously, develop a prototype and let users wear this for a longer time period. This would also make it possible to analyze which kind of support is the most useful, such as a more rigid or soft one.

Finally, since the main purpose with this concept is to ensure that the user performs the heavy lift in a more ergonomic position without adding any extra strength, it could be argued that there is less risk of an unnatural load distribution on the body, which is the case with the back-supporting exoskeleton.

7.2.3 The Extendable Handle

The extendable handle greatly differs from the other two concept groups since it will not be worn on the body. Further, it is an aid that will be attached to the core drilling machine itself and thus not something that will either facilitate or hinder the usage of other machines. Additionally, since it has the possibility of decreasing the need of having to work with a bent back for longer time periods, it was considered as highly valuable by the users. This is an advantage that the other two concepts groups do not have, since they still require the user to bend one's back. In contrast, since a similar device, the trolley described in Chapter 2, already exists for power cutters, it could be beneficial to investigate why this product has not been previously mentioned by any of the participants during the user studies.

7.2.4 The Discarded Concepts

The concept with the supporting arm and stand were chosen for the expert evaluation to see whether the benefit of not having to carry the weight of the machine with one's hands would exceed the effort of putting on a more complex device that would inhibit the user's movement for freedom. Although the users could see how it could be beneficial for some limited tasks such as cutting windows, it was deemed as too inflexible to wear in-between work tasks and too time-consuming to put on and off. It was clear that using a product that facilitates one task while possibly making other tasks more difficult was not considered valuable. It could hence be concluded that an aid that can facilitate working with several different types of machines and that does not create any disturbance that affects other work tasks is essential.

Additionally, the user studies during the Problem identification phase showed that working above shoulder height is one of the most demanding tasks. However, the majority of the final concepts that were evaluated had the purpose of supporting the back and not shoulders. Choosing to evaluate these concepts was not only because the users stated that the back was where they experienced the most long-term pain, but also because Husqvarna recommends not using the machines above shoulder height. Working above shoulder height poses a great safety risk, mostly due to the risk of kickback, and it is thus recommended using a wall saw or standing on a lift when cutting at higher levels. Developing an ergonomic aid that would facilitate working above shoulder height, such as developing an exoskeleton that gives support to arms and shoulders, could thus be seen as unethical since it enables the users to put themselves in dangerous work positions.

However, since all study participants have stated that working above shoulder height is something they are required to do frequently, the need for a more ergonomic safe way of performing this type of task should not be neglected. This is why some concepts such as the supporting arm, were evaluated. This concept could potentially provide a possibility to incorporate a technical mechanism that could hinder a kickback, thus making it safer to use the machine above shoulder height. In contrast, an active exoskeleton that can support these types of heavy machines also puts requirements on more complex and heavier devices, which was not appreciated by the users. Future studies should thus not be limited to the design of exoskeletons, but rather investigate whether the handheld machines themselves could be redesigned or if other equipment, such as the wall saw and stands, could be improved to better help the user perform these challenging tasks.

7.3 Exoskeletons and Ergonomic Safety

In this section, a discussion about what effects exoskeletons could have on the ergonomic safety for users of heavy handheld machines is given.

7.3.1 Effect on Ergonomic Safety

Although the back-supporting exoskeleton was considered to have the most user areas according to the expert evaluation, there are certain remarks that should be made specifically for this concept and exoskeletons in general. The literature study showed that exoskeleton has the potential of decreasing muscle activity and thus increasing endurance. However, according to the literature review, there is little evidence of exoskeletons being able to prevent work-related musculoskeletal disorders within the construction industry. The majority of studies performed with exoskeletons have been done in laboratory settings during short time periods and for isolated tasks. Further, using an exoskeleton has been observed to result in several biomechanical side effects, such as spinal imbalance and an increase in physical load on joints to compensate for decreased demand on other joints. These counterproductive aspects should hence be further investigated along with the long-term usage of exoskeletons and its risks in industry settings.

Another suggestion is to include experts on biomechanics and physiotherapy when developing an ergonomic aid such as an exoskeleton. To include the expertise of for example physical therapists could be crucial to ensure that the aid does not risk affecting the user's movement patterns and physical ergonomics negatively. Further, before developing an exoskeleton, it could be beneficial to first investigate what potential safety risks physiotherapists see with exoskeletons and whether they actually would recommend using exoskeletons within the construction industry or not.

7.3.2 Consequences of Using Exoskeletons

It should be emphasized that a back-supporting exoskeleton will not assure an increased ergonomic safety since it might not prevent the user from performing heavy lifts ergonomically incorrect. Giving the user an increased feeling of strength could rather result in the user performing an increased number of lifts a day, or enabling the user to try to lift heavier objects than one has the ability to. Further, when the project group tried an exoskeleton, the increased strength made it feel like it would be possible to work for longer time periods without taking as many pauses. This could, according to the literature study, be harmful. Additionally, considering the time pressure that often is present at the work sites and that many users share an attitude about wanting to finish work tasks quickly, there is a risk that the exoskeleton is used to enhance productivity at work rather than to ensure a more ergonomic safe work situation. These are hence major aspects that should be investigated before drawing any conclusions about whether an exoskeleton could increase ergonomic safety for users of heavy handheld machines or not.

Future studies should also investigate whether an exoskeleton could prevent the user from working incorrectly. According to the benchmark, there exist active exoskeletons that incorporate systems that monitor the users work movements, informing the user when he performs any unergonomic moves. Another solution, as suggested during the user evaluation, could be to combine a back-supporting belt with a back-supporting exoskeleton in order to enable the user to perform the lifts more ergonomically correct.

7.3.3 Perceived Safety

An aspect that is crucial for how receptive the target group is to the product, is the level of perceived safety that the product enholds. The users' hesitation towards exoskeletons was partly based on the feeling of not being able to move freely, such as that gaining strength in one direction of movement would decrease the ability to move in the opposite direction. This was considered a major safety risk. Further, since the machines could be dangerous if used in the wrong way, it is of great importance that the design of the exoskeleton is forgiving so that it is possible to revert mistakes quickly. These aspects should be considered in future studies.

7.4 Other Challenges

Although a user-friendly ergonomic aid is developed, the results showed that it is not obvious that the users will buy it. Other barriers that could affect how well the product is received by the end-users should be discussed. Is the industry ready for these types of ergonomic aids? Are other measures needed to ensure that users see enough value with these products? What other challenges should be considered when developing an aid for a specific target group? These questions are discussed in this section.

7.4.1 Attitude Towards Ergonomic Aids

The attitude towards using ergonomic aids and protective equipment varies between users. Although many see benefits of using it, it is not always considered worth the effort. Hence, using it for preventive causes is uncommon. In general, taking the measures available to increase ergonomic safety is not as prioritized as the concrete cutters explain that it should be. The ergonomic alternative is often more time-consuming than the less ergonomic one. There is also an acceptance that a concrete cutter's profession should be tiring and physically demanding, further decreasing the chances of the user prioritizing the more ergonomic alternative. Although this shows the importance of making an aid that can be as smoothly incorporated in the concrete worker's daily work as possible, it is also a strong indicator that other measures could be needed apart from developing an ergonomic aid.

Since various ergonomic aids already exist on the market, one could ask why these are not used although there is an evident need for them. According to the survey, some people use weightlifting belts and wrist protection, but the majority do not use an ergonomic aid. Although these products are not specifically developed for the concrete cutters, the user studies also showed that it is not obvious to the user where one can buy these products and why it could be useful for them in their profession. This indicates that investigating how to increase the awareness of the benefits of ergonomic aids among concrete cutters could be of importance. Additionally, although the majority of the respondents in the survey claim that the aspect of social acceptance is not a crucial factor, the results from the interviews still indicate that there is a certain social stigma that could make a user uncomfortable wearing an aid. Thus, working towards decreasing this stigma so that the threshold for first-time users becomes lower could be necessary.

In general, it has been described by the users that the attitude towards using ergonomic aids and protective equipment within the Swedish industry is becoming more and more positive, with an overall increase in awareness of workplace ergonomics and regulations towards better ergonomics. This indicates that launching an ergonomic aid within the domestic market could be beneficial, especially if this trend continues to grow during the upcoming years. However, since this might not be the case in other countries and cultures, further studies are needed before drawing any conclusions on the general construction worker's attitude toward ergonomic aids.

In contrast, when it comes to the attitude users have towards exoskeletons, the survey showed that approximately 50% were hesitant toward using it. A majority had heard about it before, however, few have seen anyone use it. It is hence of importance to differentiate between the attitude towards ergonomic aids in general and exoskeletons. Although the results show a positive attitude towards ergonomic aids, this does not necessarily mean that the user acceptance towards an exoskeleton is similar to that of a wrist protection.

7.4.2 Complex User Context

From the empirical studies, it is evident that the user context is highly diverse. The machines can be used for a wide range of work tasks, putting the user in various different and often challenging work positions. The work environment is also challenging as well as the user's attitude towards work tasks and aids. When putting together the list of guidelines, it was thus evident that several of the guidelines could result in contradicting design requirements. For example, since the machines are heavy, developing an aid that could contribute with enough strength to hold the machine could require an active exoskeleton instead of a passive device. However, an active exoskeleton is usually heavier than a passive one, which would contradict the guideline about developing an aid that is as lightweight as possible.

From the expert evaluation, it is possible to get an indication of which guidelines and requirements that the users would most likely prioritize. However, the opinions among the users during the Problem identification phase varied depending on factors such as age, experience of work-related injuries and ergonomic aids. This means that developing an aid for the whole user group of construction workers could be difficult. Hence, dividing the user group in different user segments depending on which users that would be the most positive towards ergonomic aids could be necessary.

7.5 Ethical Aspects

In this section, ethical aspects regarding the project are discussed.

7.5.1 Ecological Footprint

Since the work environment is rough and tearing of the machines is common, the future product needs to be durable. This has been considered in the list of guidelines, where the importance of a long product life cycle has been taken into consideration both in terms of materials, reparations and durability. Furthermore, since Husqvarna is an international company with an impact on the future of product development within the construction industry, it is important that the whole product life cycle is taken into consideration during further development in order to reduce the ecological footprint.

7.5.2 Ethically Justified Products

Another ethical issue to consider is how the usage of exoskeletons could create a competitive advantage for larger companies that could afford to invest in exoskeletons. A company that is relying on exoskeletons might increase productivity, which could result in smaller companies not using exoskeletons demanding higher productivity of their workers in order to stay competitive, potentially resulting in aggravated work conditions. However, if an exoskeleton could be produced and sold to a price that benefits smaller companies as well, this could potentially decrease these risks.

Additionally, the implementation of exoskeletons that use artificial intelligence and sensors to monitor and adjust to its user, could result in enhanced workplace surveillance. If the exoskeleton is able to track one's movements, it could also be used to rank workers in relation to their productivity and make employees feel pressured to work as much as possible. Conflicts between exoskeletons being used to enhance the safety and well-being of workers and companies aiming to maximize productivity could occur and should be considered.

Although an exoskeleton might provide several physical benefits, it could also result in decreasing other parts of the user's well-being. As an example, an exoskeleton that enables someone to work five hours in row instead of two hours in a row, could result in the employee being present for too long in an otherwise unhealthy work environment, such as at a workplace with a lot of noise. This aspect should also be considered in future designs in order to assure ethically justified products.

7.5.3 Other Areas of Applications

Insights about this user group could possibly benefit other user groups as well. As an example, knowledge about which priorities and attitudes construction workers have towards safety equipment could be of value when designing for other user groups in other similar physically demanding industries. How to design exoskeletons so that it benefits the human body could also be useful when developing solutions for people with other physical limitations, such as elderly people that are in need of various types of physical support.

8

Conclusions

This study aimed to gain a deeper understanding of the users of heavy handheld machines and to investigate how ergonomic aids and exoskeletons could be designed and used to increase physical ergonomic safety for construction workers. By answering the four research questions on which the thesis was based, several conclusions could be made.

RQ1: What are the users of heavy handheld machines' needs concerning physical ergonomics?

The user studies have shown that the context of the user is highly diverse, with different types of work tasks and work environments. In general, some of the most critical work tasks regarding psychical ergonomic safety are:

- Performing heavy lifts of material, tools, and machines.
- Working with heavy handheld machines that require a bent and twisted back.
- Working with heavy handheld machines above shoulder level.

Among these three problem areas, cutting with a power cutter in a horizontal direction above shoulder level is considered the most critical task while heavy lifts are considered a more frequently occurring problem. The results also show that the shoulders and lumbar spine are the body parts where the users experience the most pain. However, the shoulders are in the most need of aiding tools during the work itself, such as when cutting or drilling, while it is in the back that people have the most pain in general. A conclusion is hence that developing an aid for the back could result in a more long-term benefit for this specific user group and industry. By screening literature about work-related musculoskeletal disorders within the construction industry, it is found that lower back pain is one of the most common problems, which further supports the conclusion about the back being in much need of support.

RQ2: Which aspects are important to consider when developing an ergonomic aid to increase ergonomic safety?

Empirical studies show that although the users are aware of the importance of ergonomic safety, the ergonomic guidelines are not always possible to follow. Three main reasons why these heavy handheld machines are used in non-ergonomic positions are:

- Time-pressure: It often takes less time to use a power cutter than to install a wall saw.
- Narrow and difficult workplaces: It is not always possible to work in positions that pose a less threat of injury.

- Attitudes: The users do not see enough value in using aiding equipment since they are used to a non-ergonomic work environment or believe that their profession should be physically demanding.

In order for ergonomic aids to increase the ergonomic safety for construction workers, it is necessary that the product is user-friendly and achieves higher user acceptance to assure long-term usage. By analyzing the results from the user studies, the design suggestions that should be of high prioritization when developing an ergonomic aid could be derived:

- The product should require little time to install or put on without the need of another person's help.
- The product should not have to be removed between tasks, more precisely, the user should be able to move around freely after a task is done and preferably be able to use it throughout the whole work day.
- The product should allow a large movement of freedom and be used in various body positions and work environments including narrow spaces and high heights.
- The product should have the potential to facilitate the usage of different handheld machines.
- The product should allow for easy transportation between project sites.
- The product should, if worn on the body, by small measures be adjusted to fit the user.

If these guidelines are met, a higher user acceptance could be reached. However, in future studies, more people from this user group should be included since opinions vary depending on factors such as age, experience of work-related musculoskeletal disorders, and previous usage of ergonomic aids.

RQ3: Which potential effects on physical ergonomic safety exist with the usage of exoskeletons?

The literature study showed that exoskeletons have the potential of decreasing muscle activity and increasing endurance for specific isolated work tasks. However, the majority of studies have been performed in laboratory settings and there is a lack of evidence that the exoskeleton increases ergonomic safety for construction workers using heavy handheld tools. Using an exoskeleton has also been observed to result in several potential biomechanical consequences.

Further, an exoskeleton that gives a feeling of added strength but that does not ensure that the user maintains an ergonomic work position, could result in the exoskeleton being used to enhance productivity at work rather than to ensure a more ergonomic safe work situation. These counterproductive aspects should hence be further investigated along with the long-term usage of exoskeletons and their risks in an actual industry setting. Moreover, if an exoskeleton is to be developed to fit this specific target group, the expertise of physiotherapists should be included to avoid the aid affecting the user's movement patterns and physical ergonomics in an unpredicted and negative way.

RQ4: What attitudes do construction workers have towards their work situation, ergonomic aids, and exoskeletons?

The users are aware of their profession being physically challenging and the majority worry about the consequences of using heavy handheld machines. However, although many see the benefits of using ergonomic aids, using them for preventive causes is uncommon. There is an acceptance that a concrete cutter's profession should be tiring and physically demanding, further decreasing the chances of prioritizing ergonomic safety. Although this shows the importance of making an aid that can be as smoothly incorporated into the concrete cutter's daily work as possible, it is also an indicator that other measures regarding user attitudes could be needed before successfully introducing an exoskeleton to this intended user group.

The attitude towards exoskeleton varies among users and approximately 50% were hesitant toward using an exoskeleton. Although a majority have heard about exoskeletons before, few have seen anyone use them in their work. Additionally, concrete cutters agree on the potential for many other occupational groups where the work tasks are similar in nature and repetitive. For their specific industry, however, they believe it could be challenging to incorporate it into their daily work unless it is customized for their specific profession.

Final Remarks

By answering the research questions, it can be concluded that the user context is characterized by diverse work tasks and a demanding work environment, making the user's needs complex. There is a clear need for an ergonomic aid but the attitudes towards this among concrete cutters are challenging. The results also show that an ergonomic product for the lower back could benefit this user group the most and that a back-supporting exoskeleton could reach a high user acceptance if it is customized to this specific target group. However, further investigation of the long-term usage of an exoskeleton in an actual industry setting is needed before concluding whether an exoskeleton could provide increased ergonomic safety or not.

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All other images in this paper are the authors' own pictures.

A
Appendix

A.1 Husqvarna's Power Cutters

Examples of power cutters and core drilling machines within Husqvarna Construction's product portfolio.

Husqvarna K1 PACE

Husqvarna K1 PACE is a battery driven power cutter that can be compared to a petrol powered one in terms of performance and power provided (Husqvarna Construction, n.d.-e). No direct emissions and low level of vibrations are two positive aspects of this machine. The PACE battery system, which is a fast-charging system from Husqvarna is used. The maximum saw depth is 145mm. Areas where K1 PACE is suitable are for example when cutting garden tiles in concrete or concrete pipes. For a picture of the model K1 PACE, see Figure 60.

Figure 60: The power cutter Husqvarna K1 PACE
Husqvarna Construction, (n.d.-f), reprinted with permission

Husqvarna K 770 and K 970

K 770 and K 970 are two of the petrol powered power cutters within Husqvarnas assortment (Husqvarna Construction, n.d.-a). Both variants are suitable for road works and can be combined with the cutting trolleys KV7 or KV 970 for increased control of straight or curved lines. K 770 has a maximum saw depth of 125mm while the maximum saw depth for the model K 970 is 155mm. The models K970 and K 770 are shown in Figure 61-62.

Figure 61-62: The power cutters Husqvarna K 970 and K 770
Husqvarna Construction, (n.d.-b), reprinted with permission
Husqvarna Construction, (n.d.-g), reprinted with permission

A.2 Husqvarna's Core Drilling Machines

Husqvarna DM 540i

Husqvarna DM 540i is a core drilling machine suitable for handheld drilling due to the balanced body of the machine and low weight (Husqvarna construction, n.d.-f). DM 540i is a powerful battery-driven core drill which is compatible with Husqvarnas batteries BLi200 and BLi300. This core drill can be used to drill holes up to 75mm when used by hand or up to a diameter of 100mm when used together with the drilling stand DS 150. DM 540i can be used for both dry and wet drilling in materials as tile or reinforced concrete. Areas of usage are, for example, narrow spaces or corners, holes for electrical outlets, pipes or cables. The core drilling machine Husqvarna DM 540i is shown in Figure 63.

Figure 63: The core drilling machine Husqvarna DM 540i
Husqvarna Construction, (n.d.-h), reprinted with permission

Husqvarna DM 200

Husqvarna DM 200 is a handheld, electric core drilling machine which can be used for both wet and dry drilling (Husqvarna Construction, n.d.-g). DM 200 is optimized for drilling holes with a diameter of 25-80mm and is suitable for applications such as cables, holes for power outlets, ventilation and pipes. The core drilling machine Husqvarna DM 200 is shown in Figure 64.

Figure 64: The core drilling machine Husqvarna DM 200
Husqvarna Construction, (n.d.-e), reprinted with permission

B

Appendix

B.1 Safety Equipment

Respiratory protection

Respiratory protection is a type of protective equipment used when there is a risk of oxygen deficiency or harmful pollutants in the air. Contaminants may exist in smoke, dust, fibers, aerosols, steam, or gas. Two different groups of respiratory protection are available, respirators and filter protection. Respirators are supplied with clean air, such as compressed air, while filter protection filters out harmful pollutants within the breathing air (Arbetsmiljöverket, 2022b).

Protective clothing

Protective clothing is used to reduce the risk of bodily injuries. Ordinary clothes are not seen as protective clothing. Protective clothing should be chosen according to requirements for comfort, mobility, and level of protection (Arbetsmiljöverket, 2020b).

High visibility clothing, Hi-Vis, is a type of protective clothing worn to make the user visible, both in daylight and in the dark. European standards apply to Hi-Vis clothing in regard to material properties and design (Procurator, n.d.).

Protective gloves

Protective gloves are an essential part of the protective equipment to prevent the hands from injuries. Large gloves can lead to difficult handling of objects, or the user getting stuck in moving machine parts. Therefore, the fit of the gloves is of importance (Arbetsmiljöverket, 2020c).

Hearing protection

Hearing protection is an equipment used when the noise levels are considered high (Arbetsmiljöverket, 2020d). Hearing protection is available in many different designs, such as ear muffs, earplugs, or as a part of the helmet. Hearing protection shall be used when the average sound level during an 8-hour working day is 85 dB or more and if the maximum measured sound level is 115 dB or higher. Hearing protection should also be used if the short-term noise peak during a working day, also called impulse peak value, is 135 dB or more.

Safety shoes

Protective shoes are a type of protective equipment used to prevent foot injuries (arbetsmiljöverket, 2021). Safety shoes are divided into different categories depending on protective properties and usage. Some types of safety shoes are equipped with a steel cap. Other properties are available such as spike protection and antistatic properties. Which loads the shoes can withstand depends on quality and area of usage. Safety shoes generally can withstand a load of more than 200 J, while light safety shoes can withstand a load of more than 100 J. The safety shoes are provided with different markings for clarification.

Helmet

Industrial helmets are a type of protective equipment, mainly used to protect against falling objects (Arbetsmiljöverket, 2020e). Protective helmets can also be used to protect against electrical voltage, crush damage, and molten metal. A chin strap should be available for a good fit of the helmet.

Eye and face protection

This kind of equipment is used to protect against damages to the face and eyes (Arbetsmiljöverket, 2020f). Aspects to protect against can be for example, dust, splashes of chemicals or flying particles to mention a few. Eyes and face protections exist in several different variants, including, basket glasses with a frame, glasses with or without protection on the sides, hood or visir. Variants where the face or eye protection is combined with the respiratory protection or helmet exists. The chosen protection should be in accordance with the task performed. Protection which closes tightly against the face might be needed in certain circumstances, for example when there is risk of chemical splashes.

C
Appendix

C.1 Examples of Work-related Musculoskeletal Disorders

Herniated disc

A herniated disc develops when part of the soft inner part of the disc flows out, which can cause pressure either on the nerves or the spinal cord (Bohgard et al., 2009a). This can lead to pain or in some cases partial paralysis. Herniated discs make up about five percent of all back disease cases. Herniated discs can heal on their own, but successful surgeries often occur. The discs age naturally, which often happens relatively early, which results in increased fragility and reduced damping ability.

Sciatica

The term sciatica is used to describe the body's largest nerve, the sciatic nerve, showing symptoms due to being pinched or irritated (Doktor.se, 2022). The sciatic nerve begins in the lower back and runs down to the toes, via the pelvis, the back of the thigh, and the lower leg.

Tendinitis

Irritation and inflammation in the origin of the muscle tendons or the attachment of the skeleton, so-called tendinitis, can occur when performing repetitive tasks with a moderate load (Bohgard et al., 2009a). Tendinitis can also affect the tendon itself, where a common location is the tendon in the shoulder joint. This type of injury is common when working with raised arms.

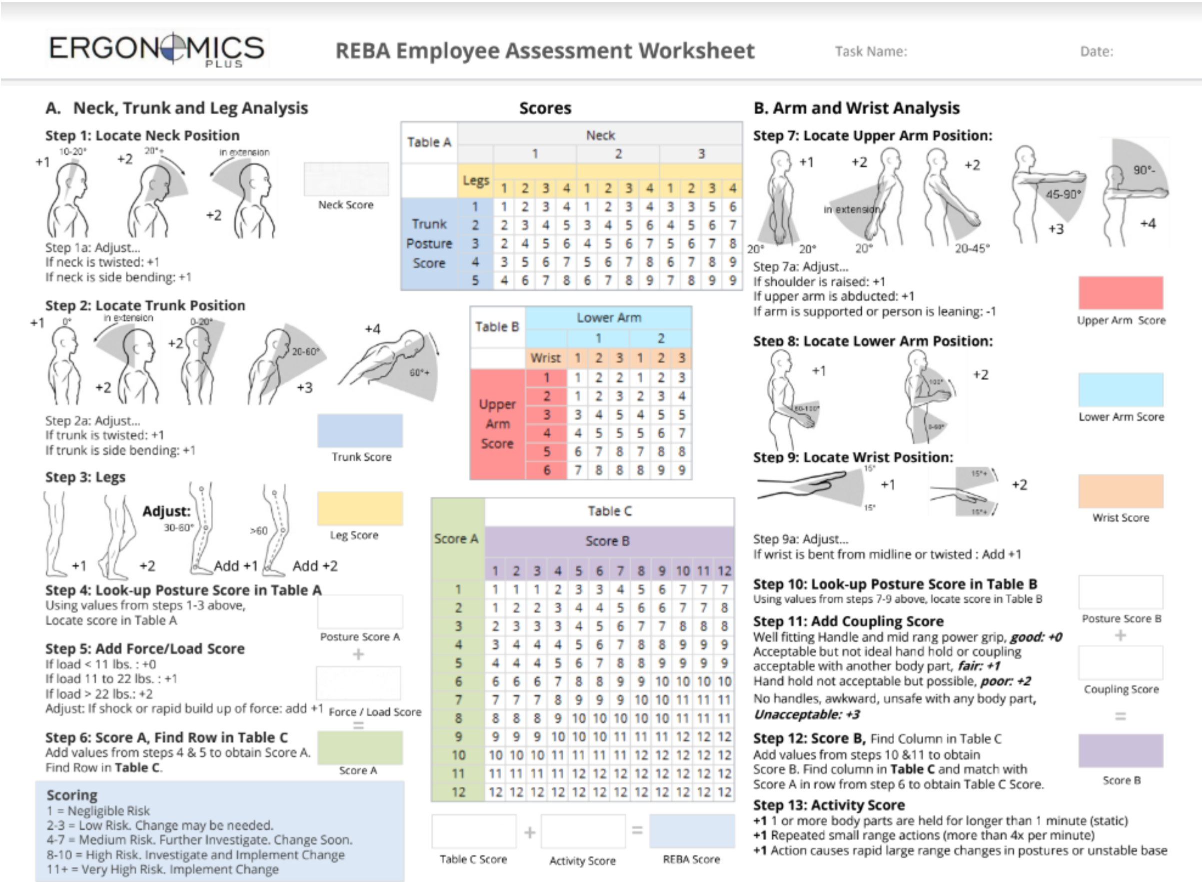
Another common location is the tendon which helps when lifting the thumb. Also, the wrist is a risk area where several of the tendons run through a narrow channel, the so-called carpal tunnel. There is a risk of a chronic increase in pressure in this area, which also affects the nerve that goes through the carpal tunnel. This can lead to weakness and numbness in the hand, called *carpal tunnel syndrome.* Work tasks with curved wrists especially in combination with high gripping force are risk factors that can trigger these problems.

Trigger finger

Trigger finger, also known as *stenosing tenosynovitis,* is a syndrome that occurs due to the space surrounding the tendon in the finger getting narrower due to an inflammation, which in turn might cause the finger to get stuck in a bent position or bending/straightening uncontrolled (Mayo clinic, 2020). Furthermore, developing trigger fingers are more common among women than men and the syndrome is connected to performing repetitive gripping movements.

D
Appendix

D.1 REBA template



ERGONOMICS PLUS

REBA Employee Assessment Worksheet

Task Name: Date:

A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position

Neck Score

Step 1a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Step 2: Locate Trunk Position

Step 2a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Trunk Score

Step 3: Legs

Adjust:

Leg Score

Step 4: Look-up Posture Score in Table A
Using values from steps 1-3 above,
Locate score in Table A

Posture Score A
+

Step 5: Add Force/Load Score
If load < 11 lbs. : +0
If load 11 to 22 lbs. : +1
If load > 22 lbs.: +2
Adjust: If shock or rapid build up of force: add +1

Force / Load Score
=

Step 6: Score A, Find Row in Table C
Add values from steps 4 & 5 to obtain Score A.
Find Row in **Table C**.

Score A

Scoring
1 = Negligible Risk
2-3 = Low Risk. Change may be needed.
4-7 = Medium Risk. Further Investigate. Change Soon.
8-10 = High Risk. Investigate and Implement Change
11+ = Very High Risk. Implement Change

Scores

Table A		Neck 1				Neck 2				Neck 3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B		Lower Arm 1			Lower Arm 2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Table C	Score B											
Score A	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score + Activity Score = REBA Score

B. Arm and Wrist Analysis

Step 7: Locate Upper Arm Position:

Step 7a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score

Step 8: Locate Lower Arm Position:

Lower Arm Score

Step 9: Locate Wrist Position:

Wrist Score

Step 9a: Adjust...
If wrist is bent from midline or twisted : Add +1

Step 10: Look-up Posture Score in Table B
Using values from steps 7-9 above, locate score in Table B

Posture Score B
+

Step 11: Add Coupling Score
Well fitting Handle and mid rang power grip, ***good: +0***
Acceptable but not ideal hand hold or coupling acceptable with another body part, ***fair: +1***
Hand hold not acceptable but possible, ***poor: +2***
No handles, awkward, unsafe with any body part, ***Unacceptable: +3***

Coupling Score
=

Step 12: Score B, Find Column in Table C
Add values from steps 10 &11 to obtain Score B. Find column in **Table C** and match with Score A in row from step 6 to obtain Table C Score.

Score B

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base

E

Appendix

E.1 Interview Template

*Questions or sections containing the symbole * have been added or removed from the template at some stage of the user study process.*

Vi vill inledningsvis börja med att tacka för att du ställer upp och hjälper oss i vårt projekt.

Beskrivning av projekt: Detta är ett examensarbete som utförs på Chalmers universitet i samarbete med Husqvarna Construction. Där vi undersöker ergonomiska aspekter relaterat till tunga handhållna verktyg, framförallt kärnborrmaskiner och kapmaskiner. Målet är att ta fram ett designförslag på en produkt som kan fungera som ett ergonomiskt hjälpmedel till användandet av dessa verktyg.

Om du vill hoppa en fråga eller avbryta så är det bara att säga till. Vi vill också informera om att vi inte sprider vidare ditt svar, studiens resultat hanteras enbart inom projektgruppen. För att få ett så bra underlag som möjligt vill vi gärna anteckna och spela in detta samtalet, är det okej för dig? Inspelningarna kommer raderas när projektet är slut innan sommaren.
Om du inte förstår frågan eller är osäker så tveka inte på att avbryta och fråga.

A. Användning av produkterna

1. Vilka arbetssysslor har du?
    - Roterande arbetspass?
2. Använder du kap- eller borrmaskiner i ditt arbete?
3. Hur länge har du arbetat med dessa maskiner?
4. Hur ofta använder du maskinerna?
5. Hur länge använder du maskinen?
6. Vilken typ av arbete med respektive maskin utför ni oftast (borrar i vägg, vilken höjd, mark etc)?
    - Våt eller torrkapning oftasts?
    - Utmaningar med respektive typ?

7. Vilken typ av miljö arbetar ni mest i?
    - Inomhus, utomhus, trånga utrymmen?

8. Hur förflyttar ni maskinerna från olika platser?
    - Hur ofta?
    - Var förvaras de efter dagen?

9. Vad utförs ofta innan och efter en kapning/borrning? Processen

10. * Använder ni batteridrivna maskiner eller ej?
    - om nej, varför? Laddning på plats?

B. Värk

1. Vilket typ av arbete är mest slitsamt? (arbetsuppgift/arbetsposition)
    - För respektive maskin?
    - Vilken kroppsposition?
2. Vilken muskelgrupp känner du mest i? Peka!

3. * Hur länge kan du jobba innan du känner obehag?

4. Behöver du ibland avbryta arbetet för att det blir för tungt?
    - När och varför?
    - Vad gör du då?

5. Hur känns din kropp efter en arbetsdag?
    - Om värk, Var?
    - Vad tror du det beror på? (tunga lyft, statiskt arbete, repetitivt arbete)

6. Vilka åtgärder tar du till för att minska risken för skador?

7. * Finns det någon arbetsuppgift/situation som du gärna undviker?

C. * Skyddsutrustning

1. Vilken del av skyddsutrustningen delar ni på i teamet?

2. Hade du föredragit egen utrustning helt och hållet? (bil?)

D. Exoskelett/hjälpmedel:

1. Hur ser du på att använda ett hjälpmedel som kan underlätta användandet av tunga handhållna produkter? (ex om modifierat en produkt)
    - Använder ni något liknande idag?

2. (Arbetsledare) Hade du kunnat tänka dig att köpa in ett externt hjälpmedel?

- Vilka krav ska den isåfall uppfylla för att det ska vara värt det?

3. * Om vi säger att du har ont i ryggen just nu, och kanske kommer behöva sjukanmäla dig i framtiden, hade du kunnat tänka dig att använda ett externt hjälpmedel för att slippa göra detta?
    - Vad måste hjälpmedlet uppfylla för att du ska använda det? Måste det ta bort värken helt för du ska använda det? Hur stor skillnad måste det vara?

    - Vilka faktorer är mest avgörande för dig? (Bekvämlighet? Synligt eller ej? Lätt ta på sig? Effektivt?)

4. Har du hört talas om exoskelett?
    - Vad är dina tankar kring detta?

5. (Visa bilder)
    - Upprepa samma frågor som D.3

6. Hur reagerar du om du ser en kollega använda sig av detta?

7. * Vad hade kunnat fått dig att använda ett exoskelett?

8. Fråga om kan markera vilka faktorer som viktigast från enkät (be tänka högt)

E. Öppna avslutande frågor

1. Har du tänkt på något som du hade velat förbättra med kapmaskinen/borrmaskinen?

2. Några idéer på hjälpmedel & exoskelett?

3. Är det något mer du vill tillägga?

Tack för att du ställer upp och hjälper oss i vårt arbete!!

F. Frågor om vi har mer tid

1. Märker du någon skillnad i ditt arbetssätt nu gentemot när du började? (maskiner, risker)

2. Upplever du att det någon gång är svårt att hålla balans?
    - Att underlaget är ojämnt eller att det blir snedbelastningar?

3. Hur ser en arbetsdag ut?
    - Varierar det från projekt till projekt? Dag till dag?

4. (Hade du kunnat tänka dig att använda ett externt hjälpmedel om det ingick i köpet av ex en kapmaskin?)

5. Skyddsutrustning: Behöver man ta av på flera gånger per dag?
    - Var förvaras utrustningen när den inte används?
    - Vad är din inställning till att förflytta/ta med utrustningen?

6. Vad för saker har ni på er?
    - Verktyg?

7. * Har du jobbat något utomlands och sett ifall byggarbetare har liknande/annan attityd (mot exoskelett, hjälpmedel, maskiner)

E.2 Explanations of the Pictures Shown during the Interviews

- **Picture A:** A soft back-supporting exoskeleton worn by a woman while she lifts a tool box in a warehouse. The exoskeleton is similar to a vest which is attached to a part around the legs. Thus this is an exoskeleton worn to support the back during lifting.
- **Picture B:** An exoskeleton for the upper body, placed on a man lifting his arms. The exoskeleton is attached around the waist and the arms with connecting parts following the back. This picture was shown with a white background and thus not placed in any particular environment.
- **Picture C:** An exoskeleton for the upper body worn by a man while he is attaching cables to the roof with lifted arms. The exoskeleton is attached around the waist and the arms with connecting parts such as ropes and springs in between.
- **Picture D:** An exoskeleton for the upper body, placed on a man lifting his arms while holding a screwdriver. The exoskeleton is attached around the waist and the arms with connecting parts following the back. This picture was shown with a white background and thus not placed in any particular environment.
- **Picture E:** A back-supporting exoskeleton worn by a woman while she is bending down to perform work in a warehouse. The exoskeleton is attached around the thighs, waist and the shoulders, with connecting parts in between.

E.3 Changes Made in the Interview Template

After the fourth interview some changes were made to the interview template. At this stage the question "*Is there any working task you try to avoid*" was added, see question 7 in section B. This question was earlier one of the questions asked in case of remaining time. In addition, one question was added to this last section regarding international work and differences in attitudes compared to Sweden, see question 7 under section F. Furthermore, at this stage, the scenario found under section D, question 3 was removed, the connected questions remained in the template.

During later stages of the user studies, questions regarding safety equipment were removed since many equal answers had been given during previous interviews and a broad understanding of this area had been gained, see section C. In addition, one question regarding important factors was added to the section of exoskeletons and aids, see question 7 under section D. Furthermore, one question regarding battery driven machines was added to the first section, see question 10 in section A. The question regarding battery driven machines was added to better understand attitudes throwarde battery driven products and the possibility to charge the products.

Before the last interview, additional changes were made.
Added questions included:

- *How is the surface that you often work on? Do you often stand on a stool, stairs or similar when drilling / cutting?*
- *Where do you think you would have kept an exoskeleton if they had been used on a construction site?*
- *If we ignore the actual cutting / drilling itself, what steps before and after the work do you think an exoskeleton could have been helpful for?*
- *Would you like to have an exoskeleton that you can use throughout the day or for specific tasks?*
- *Do you see any obstacles or situations when this would have become problematic?*

Removed questions included:
Questions 3, 4, 5, 7 and 8 under section A were removed. These changes were made since the previous interviews performed already brought extensive information regarding these questions. Therefore other questions were considered more important at this stage.

E.4 Observation Template

Denna template användes under observationer som ett hjälpmedel för att påminna projektgruppen om vilka aspekter som kunde undersökas.

Kapmaskiner (K1 PACE (Batteri), K770 (Bensin), K970 (Bensin)) Olika typer av kapning ● Våtkapning ● Torrkapning	**Kärnborrmaskin** (DM 540i (Batteri), DM 200 (Sladd)) Med och utan stödställning ● Vertikal ● Horisontell

Olika positioner ● Vertikal ● Horisontell ● Rör Olika produktvarianter (tung/lättare) ● Bensin ● Batteri	**Allmänt** Olika material/miljöer ● Ute/inne ● Plan mark ● Trångt, sidor, höjd **Säkerhetsutrustning** **För-och efterarbete** (Customer journey)

Saker att undersöka:
- Vad för saker har de på sig? Skyddsutrustning, verktyg mm?
- Hur länge används maskinerna, repetitioner mm
- Hur ser utrymmet ut där de jobbar (trångt, ojämnt underlag, väder)
- Visar personen tecken på obehag?
- Tiden mellan arbetet, för och efterarbete
- Vilka muskler är mest kritiska?
- Typ av arbete (böjningar, lyft, statiskt etc)?
- Arbetsrotation & arbetssysslor?
- Andra tunga handhållna verktyg?

Template (skriv ner på papper)
Aktivitet
Typ av arbete (Symmetrisk lyftning, asymmetrisk lyftning Statistik böjning, etc)
Tankar användare
Muskelgrupp
(Ålder, streckgubbar)

E.5 Survey Template

Del 1 av 6: Inledning

Användning av tunga handhållna maskiner
Denna enkät är en del av ett examensarbete som utförs på Chalmers tekniska högskola. Projektet går ut på att undersöka olika ergonomiska aspekter kring tunga handhållna maskiner (tyngre än 5 kg), framförallt kärnborrmaskiner och kapmaskiner.
Dina svar är anonyma och kommer enbart att delas inom projektgruppen.

Tack för att du hjälper oss med vårt projekt!

Ålder
- ☐ 18-24
- ☐ 25-34
- ☐ 35-44
- ☐ 45-54
- ☐ 55-64

- ☐ 65-74
- ☐ 74+

Könsidentitet

- ☐ Man
- ☐ Kvinna
- ☐ Annan könstillhörighet
- ☐ Vill ej uppge

Markera det som stämmer bäst. I mitt arbete använder jag:

- ☐ Handhållen kärnborrmaskin och/eller kapmaskin samt andra tunga handhållna maskiner
- ☐ Varken kärnborrmaskin eller kapmaskin men andra tunga handhållna verktyg

Avsnitt 2 av 6: Användare av handhållna kärnborrmaskiner & kapmaskiner

Vilken typ av arbete med kärnborrmaskin tycker du är mest påfrestande fysiskt?

- ☐ Jag använder inte kärnborrmaskin
- ☐ Borrning över axelhöjd
- ☐ Borrning i midje- och brösthöjd
- ☐ Borrning i knä- och fotnivå

Vilken typ av arbete med kapmaskin tycker du är mest påfrestande fysiskt?

- ☐ Jag använder inte kapmaskin
- ☐ Kapning över axelhöjd
- ☐ Kapning i midje- och brösthöjd
- ☐ Kapning i knä- och fotnivå

Vilka andra tunga handhållna maskiner använder du?

Svar:____________________________________

Avsnitt 3 av 6: Användare av andra typer av tunga handhållna maskiner

Vilka tunga handhållna maskiner använder du i ditt arbete?

Svar:____________________________________

Avsnitt 4 av 6: Ergonomiska aspekter

Om du har känningar i kroppen efter att du använt tunga handhållna maskiner under en arbetsdag, i vilka kroppsdelar brukar det vara? (Du kan markera flera alternativ).

- ☐ Jag har inga känningar
- ☐ Nacke
- ☐ Axlar/skuldror
- ☐ Överarm
- ☐ Underarm
- ☐ Bröst
- ☐ Hand
- ☐ Övre delen av ryggen
- ☐ Nedre delen av rygg
- ☐ Lår
- ☐ Knä
- ☐ Vader
- ☐ Fot

Markera den muskelgrupp som du hade behövt mest avlastning i när du använder tunga handhållna maskiner under en arbetsdag. (Markera endast ett alternativ).

- ☐ Nacke
- ☐ Axlar
- ☐ Skuldror
- ☐ Bröst
- ☐ Armar
- ☐ Hand
- ☐ Rygg
- ☐ Ben
- ☐ Kän
- ☐ Fot

Känner du en oro kring att en långvarig användning av dessa maskiner kommer begränsa din framtida förmåga att arbeta inom ditt yrke?

	0	1	2	3	4	5	
Jag känner ingen oro alls	○	○	○	○	○	○	Jag oroar mig dagligen

Avsnitt 5 av 6: Externa hjälpmedel & Skyddsutrustning

Hur ofta använder du följande typer av personlig skyddsutrustning i ditt arbete?

	Aldrig	Sällan	Ibland	Ofta	Alltid
1. Hjälm	○	○	○	○	○
2. Ansiktsskydd/Visir	○	○	○	○	○
3. skyddsglasögon	○	○	○	○	○
4. Hörselskydd	○	○	○	○	○
5. Skyddshandskar	○	○	○	○	○
6. Fallskydd / Sele	○	○	○	○	○
7. Verktygssäkring	○	○	○	○	○
8. Knäskydd	○	○	○	○	○

Använder du något ergonomiskt hjälpmedel för att minska belastningsskador (exempelvis handledsskydd, viktbälte/vulkanbälte)? Om ja, vilket?

Svar:______________________________________

Har du hört talas om exoskelett?

- ☐ Ja
- ☐ Nej

Avsnitt 6 av 6: Avslutande frågor

Beskrivning av exoskelett:
Ett exoskelett är ett externt hjälpmedel som bärs på kroppen för att avlasta olika muskler och leder under arbete. Vilka muskler och leder som avlastas beror på exoskelettets utformning.

Skulle du kunna tänka dig att använda ett exoskelett som ett ergonomiskt hjälpmedel i ditt arbete?

- ☐ Ja
- ☐ Nej
- ☐ Kanske

Hur viktiga är nedanstående faktorer för att du ska kunna tänka dig att använda ett exoskelett i ditt arbete?

	Inte alls viktigt	Ganska viktigt	Mycket viktigt	Helt avgörande
Låg vikt				
God passform				
Hör rörelsefrihet				
Enkel att justera				
Kan bäras under en hel arbetsdag				
Snabb att ta på och av				
Kan tas på och av utan andras hjälp				
Enkel att bära med sig och förvara				
Enkel att rengöra				
Lättförståelig och intuitiv				
Smälter in med arbetskläder				

Att det är socialt accepterat				

Har du någon idé på ett externt hjälpmedel som hade kunnat minska den arbetsbelastning som tunga handhållna produkter kan ha på din kropp?

Svar:____

Avslut

Stort tack för hjälpen!
Vi letar just nu även efter personer att intervjua till vårt projekt. Om du är intresserad av att hjälpa oss ytterligare så tveka inte att höra av dig! Det är mycket uppskattat!

E.6 Questions Presented at Workshop

The workshop was divided into two parts. The first part started with a five minutes individual ideation, which gave everyone a chance to reflect individually before sharing their thoughts with the group. This quiet brainstorming was followed by a round of presentations and discussion in groups with five participants in each group. The group discussions were used to share ideas and creatively reflect on each other's thoughts. Both project groups' members were placed in each of the groups for moderation and for taking notes. The duration of the first round was approximately 35 minutes. The second round of the workshop was carried out in the same way with another round of quiet ideation and discussion.

Round 1:
Inspiration for the first (quiet) brainstorming :
- Is it possible to facilitate heavy lifting?
- Is it possible to contribute to a reduced load for the back/shoulders/knees/hands etc?
- Is it possible to avoid work above shoulder height?

Questions for the first group discussion
- Is it possible to design the product so that it can be…
  … used in many different working positions?
  … integrated with existing workwear or safety equipment?
  … accepted by the users?
  … used in combination with other machines?

- How could one change the user's attitude towards aids and ergonomics? Can Husqvarna influence the user's attitude and acceptance towards exoskeletons? How?

Round 2:
Inspiration for the second (quiet) brainstorming :
- Does the product need to be placed on the body? Connected to the machine?
- Should the solution be electric or mechanically?
- Is it possible to adapt the solution to more work situations?
- Is it possible to combine the idea with another idea?
- Are there similar products in other industries who can inspire?

F
Appendix

F.1 Interview Template - Expert Evaluation

A. Back-supporting exoskeleton

Beskrivning: Ett hjälpmedel som är tänkt att underlätta tunga lyft och kapning i golv. Sitter på ryggen som tex en väst, sele, hängslen och kopplas runt ben. Bidrar till att dra upp tyngden från föremålet man håller i.

Spontan tanke!
När tror du kunnat underlätta mest?
Största nackdelar/fördelar? Ser du några problem? Potential?

Idéspecifika frågor:
Finns redan liknande på marknaden, vrf tror ej används? (Brister i marknadsföring? Attityd ej rätt? Ekonomiskt, för dyrt?)
Skulle du kunna se dig själv ha på dig den under en längre tid (en hel arbetsdag tex)?
Vilka av alternativen tror mest på? Varför?

B. Back-supporting exoskeleton integrated in work clothes

Beskrivning: Samma princip som innan men nu inbyggt i byxorna, så när man tar på sig byxorna så tar man automatiskt på sig ett exoskelett också. Sen kan man se det som att man trär på sig hängslen över ryggen. (kan potentiellt ta av sig hängslena)

Spontan tanke!
När tror du kunnat underlätta mest?
Största nackdelar/fördelar? Ser du några problem?

Idéspecifika frågor:
Hade varit värt att kombinera med kläder?
Tror du att det hade funnits några fördelar med att bygga in det i kläder?
Vill man koppla av sig ex hängslena eller alltid ha på sig?

C. Supporting belt integrated in work clothes

Beskrivning: Ett bälte liknande ett viktbälte eller midjebälte som stödjer och stabiliserar runt midjan för att man ska böja sig mer ergonomiskt. Inbyggt i kläderna. Skiljer sig från övriga koncept på det sättet att det ej bidrar med någon lyftkraft utan enbart underlättar för användaren att hamna i en mer ergonomisk position.

Spontan tanke!
När tror du kunnat underlätta mest?
Största nackdelar/fördelar? Ser du några problem?

Idéspecifika frågor:
Hade denna typen av ergonomiskt hjälpmedel varit relevant att implementera i kläder?
Vilka av dessa alternativ tror du mest på (exoskelett eller bälte)?

D. The supportive arm

Beskrivning: En armliknande förlängning som håller upp kapmaskinen åt användaren, sitter fast runt midjan, rygg axlar och ev ben. Olika varianter; Man hade kunnat styra med händerna på kapmaskinen, eller genom "en pinne", styr med kontroll.

Spontan tanke!
När tror du kunnat underlätta mest?
Största nackdelar/fördelar? Ser du några problem?

Idéspecifika frågor:
Se dig själv ha på dig den under längre tid?
Om armen kräver exoskelett på benen, hur ställer du dig till det?
Tidsmässigt, hur mycket ska underlätta för att känna värt att ha på sig?
I vilka arbetspositioner måste den tillåta dig att jobba i för att du skall vilja använda den?
Hur hade du känt för kapa i golv med denna? Horisontellt?
Maskinspecifikt, mest kap (vilka av koncepten skulle du vilja gick att använda med andra maskiner?)
Vilka av alternativen tror mest på i denna idégrupp?

E. Supportive stand

Beskrivning: Samma typ av arm som förra konceptet men potentiellt längre och som kan fästas i ställning eller medtagbar stång. Kan användas på vägg samt golv. Styrs här med en konsoll.

Spontan tanke!
När tror du kunnat underlätta mest?
Största nackdelar/fördelar? Ser du några problem?

Idéspecifika frågor:
Jämför med väggsåg?
Var går gräns för hur mycket extra kan ta med sig?
Vart skulle du vilja placera den för att det skall underlätta mest för dig?
När tror du att den hade varit svår att använda?
Maskinspecifikt, mest kap (vilka av koncepten skulle du vilja gick att använda med andra maskiner?)

Vilka av alternativen tror mest på (arm sitter på kroppen eller på en ställning)?

F. The extendable handle

Beskrivning: Ett förlängningsbart handtag implementerat i maskinen eller ett medtagbart handtag som kan fästas på en kapmaskin, som gör det möjligt att kapa i golv utan att böja sig ner. Rullas runt med hjul och hade kunnat styras manuellt med knappar på handtaget eller genom att skjuta handtaget i olika vinklar.

Spontan tanke!
När tror du kunnat underlätta mest?
Största nackdelar/fördelar? Ser du några problem?

Idéspecifika frågor:
Hade man investerat i detta om slipper böja rygg? Om säg kosta lite mer? Eller vill man ha något mer generellt?
Var hade du kunnat köra med denna och vart ej?
Hade du föredragit ett handtag som sitter på och kan förlängas, eller ett extra handtag som kan monteras på vid behov?
Vilka av alternativen tror mest på i denna konceptgrupp?

Jämförelse och urval

Placera ut idéerna på bordet/ visa alla jämte varandra

Nu ska du får rangordna idéerna utifrån vissa frågeställningar. Börjar med:
Rangordna de du skulle kunna se dig själv använda! Tänk högt! Följdfråga: Kunnat se kollegor använda?

- Vilken idégrupp tror har flest användningsområden?
- Vilken bidragit mest till bättre ergonomi på arbetsplats? Samma idéer?

Välj ut den konceptgrupp som du tror hade kunnat underlätta mest i stunden kontra under en hel dag?

- Vilken av alla dessa är du mest skeptisk till? Vilken tror du att folk hade känt mest motstånd till?

Ifrågasättande:
Arbete över axelhöjd- farligt o ej rekommenderat av Husqvarna. Men vi ser att finns behov, att ni sågar över axelhöjd, vad tycker du om detta?

Diskussion

Lite avslutande diskussionsfrågor:

- Något som skulle kunna bli ännu bättre med detta? Vad vill du ändra på om du fick?
- Om vi ska välja en grupp gå vidare med, vilken tycker du vi ska ta?

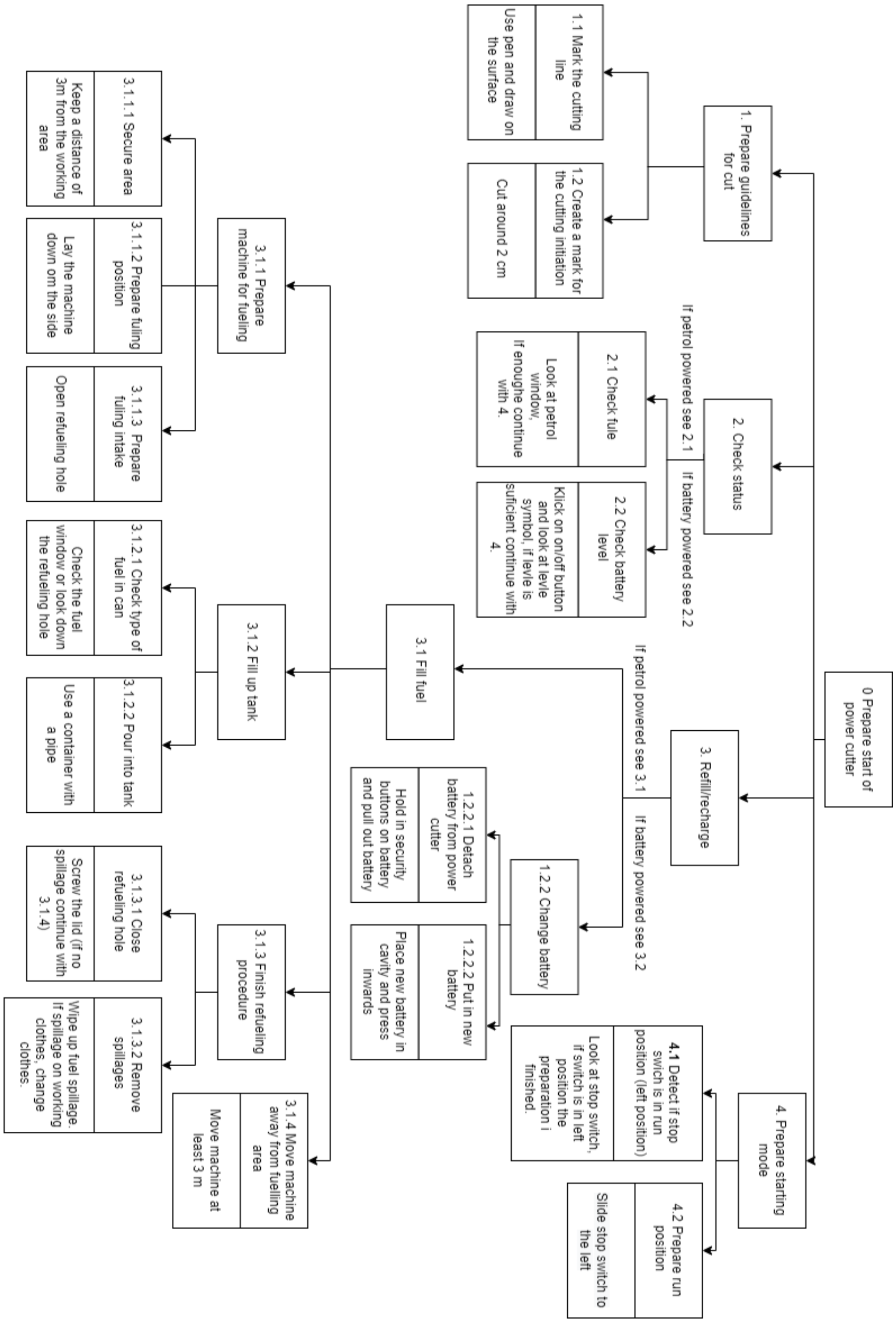
- Tror du det behövs göra något med attityd etc? Eller om lanserar liknanade i affär om
- 1 år, vad mer behövs för folk ska köpa? Vad hade varit den största anledningen till att inte folk hade köpt den, ifall den stod i butiken om 2 år?

G

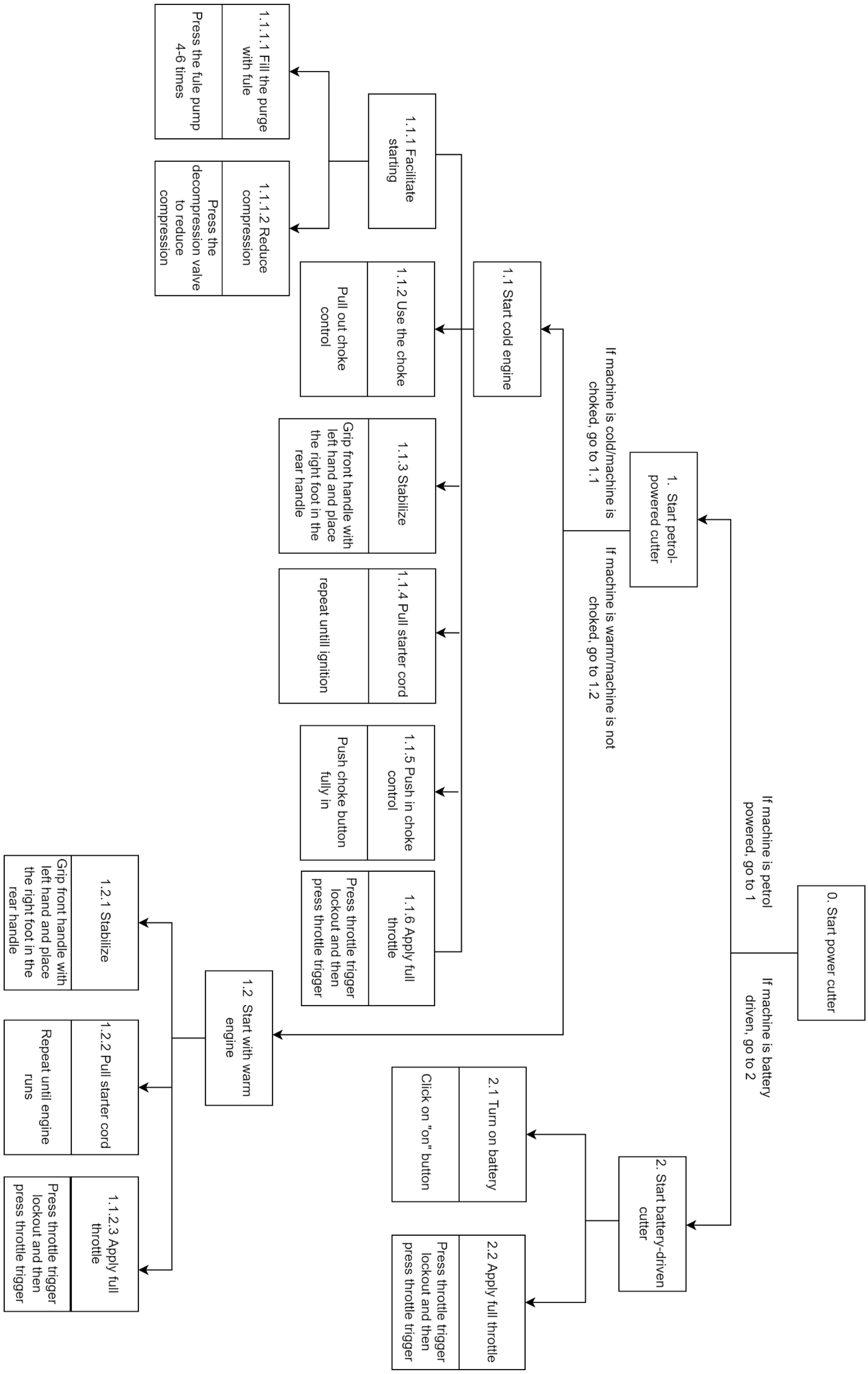
Appendix

G.1 HTA for Power Cutter

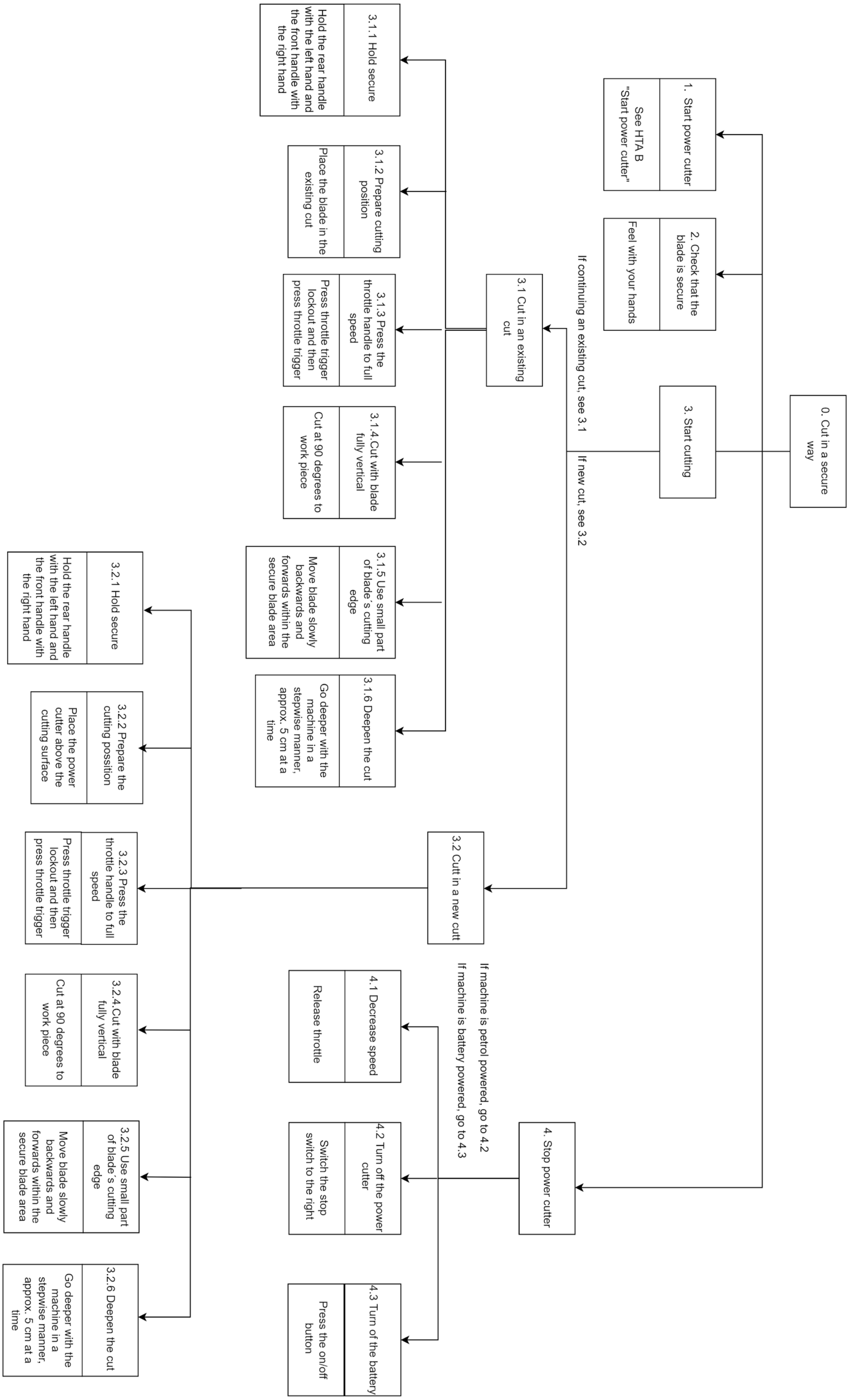
(A) Prepare cut [Power cutter]



(B) Start power cutter

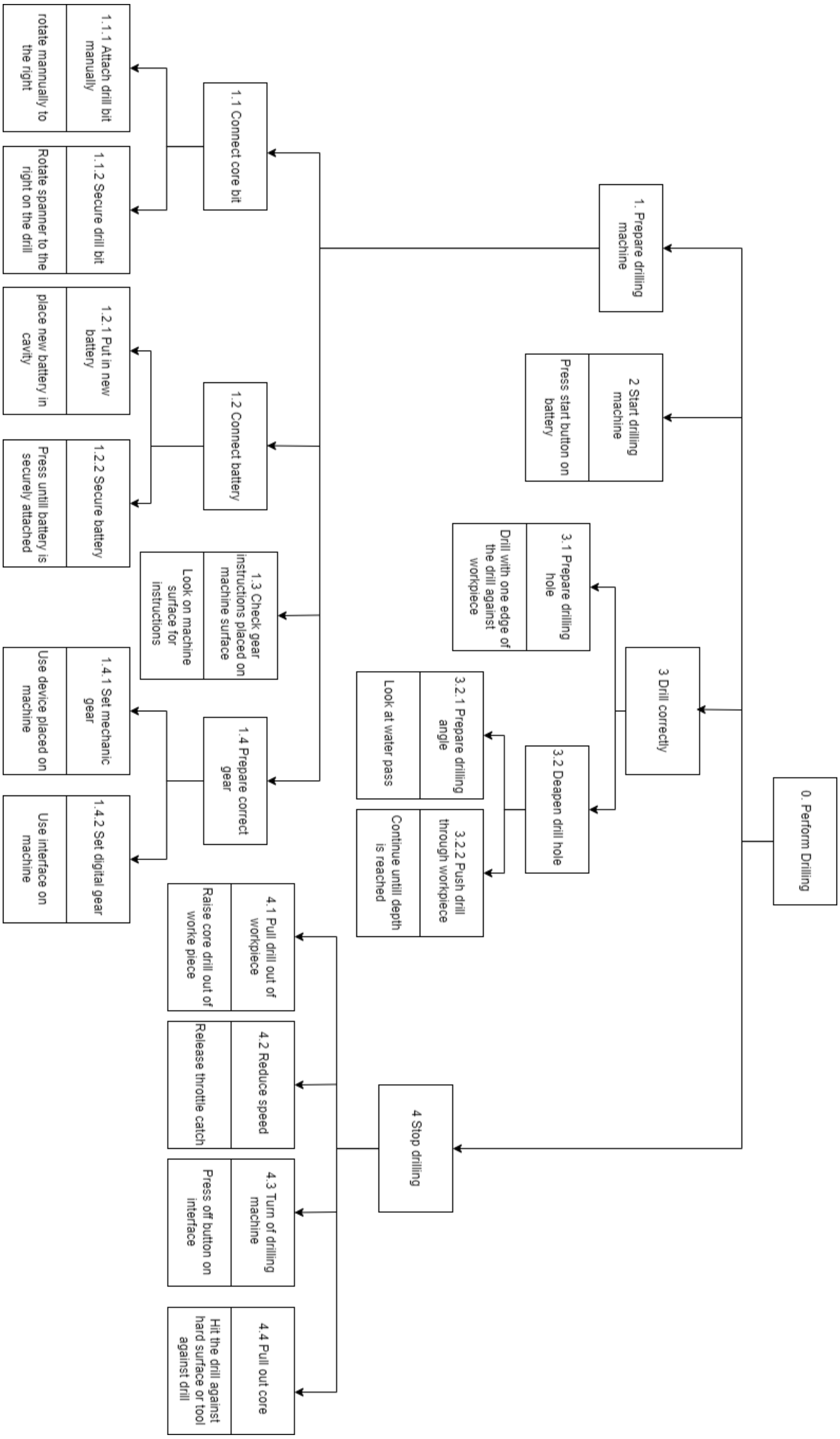


(C) Cut in a secure way [Power cutter]



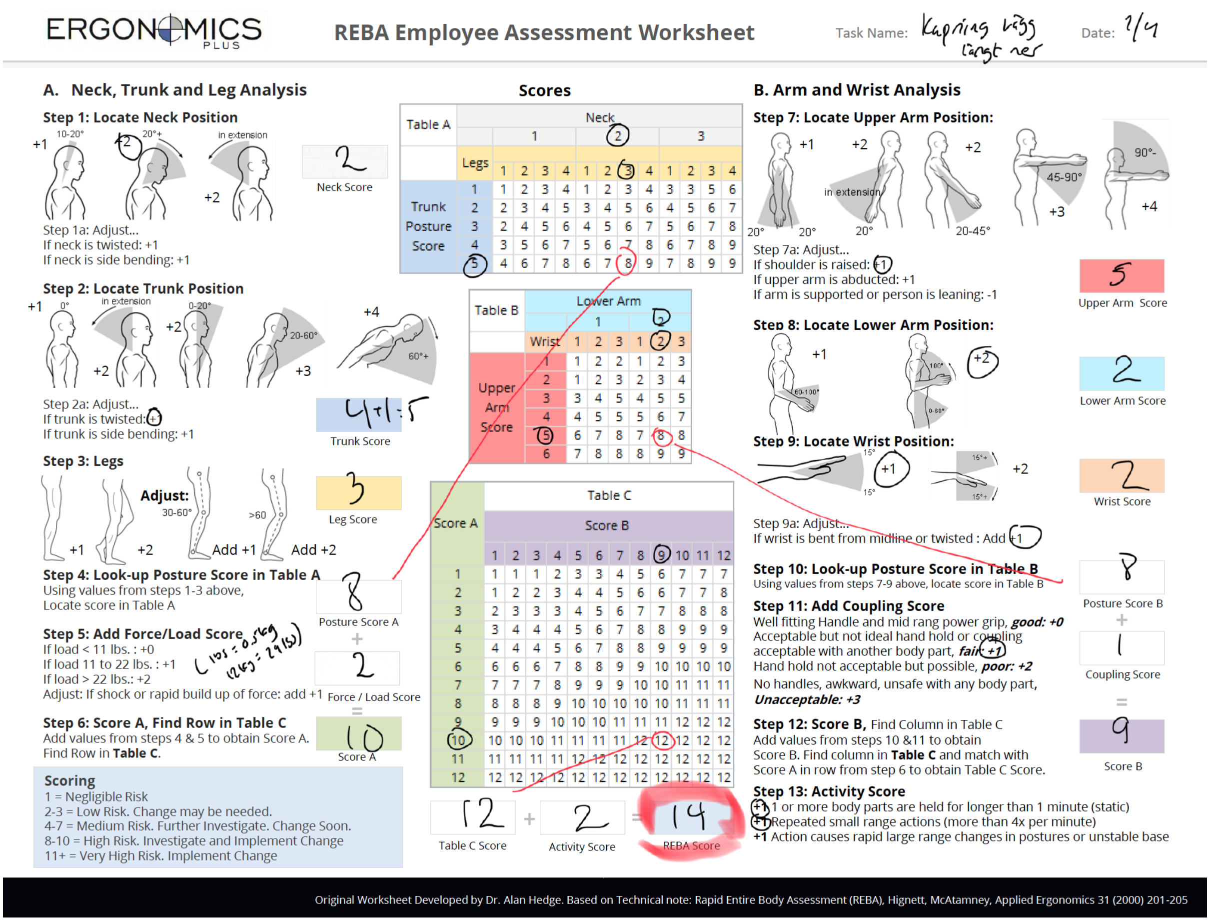
G.2 HTA for Core Drilling Machine

(D) Use drilling machine



G.3 REBA for Power Cutter

Cutting vertically at knee level



ERGONOMICS PLUS

REBA Employee Assessment Worksheet

Task Name: Kapning lägg längst ner   Date: 2/4

A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position
+1 10-20°; +2 20°+; +2 in extension
Neck Score: 2
Step 1a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Step 2: Locate Trunk Position
+1 0°; +2 in extension; +2 0-20°; +3 20-60°; +4 60°+
Trunk Score: 4+1=5
Step 2a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Step 3: Legs
+1; +2; Adjust: 30-60° Add +1; >60 Add +2
Leg Score: 3

Step 4: Look-up Posture Score in Table A
Using values from steps 1-3 above,
Locate score in Table A
Posture Score A: 8

Step 5: Add Force/Load Score
If load < 11 lbs. : +0
If load 11 to 22 lbs. : +1
If load > 22 lbs.: +2
Adjust: If shock or rapid build up of force: add +1
Force / Load Score: 2

Step 6: Score A, Find Row in Table C
Add values from steps 4 & 5 to obtain Score A.
Find Row in **Table C**.
Score A: 10

Scoring
1 = Negligible Risk
2-3 = Low Risk. Change may be needed.
4-7 = Medium Risk. Further Investigate. Change Soon.
8-10 = High Risk. Investigate and Implement Change
11+ = Very High Risk. Implement Change

Scores

Table A	Neck	1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B	Lower Arm	1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Table C: Score A \ Score B	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score: 12 + Activity Score: 2 = REBA Score: 14

B. Arm and Wrist Analysis

Step 7: Locate Upper Arm Position:
+1 20°; +2 in extension 20°; +2 20-45°; +3 45-90°; +4 90°+
Step 7a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1
Upper Arm Score: 5

Step 8: Locate Lower Arm Position:
+1 60-100°; +2 0-60° 100°+
Lower Arm Score: 2

Step 9: Locate Wrist Position:
+1 15°; +2 15°+
Step 9a: Adjust...
If wrist is bent from midline or twisted : Add +1
Wrist Score: 2

Step 10: Look-up Posture Score in Table B
Using values from steps 7-9 above, locate score in Table B
Posture Score B: 8

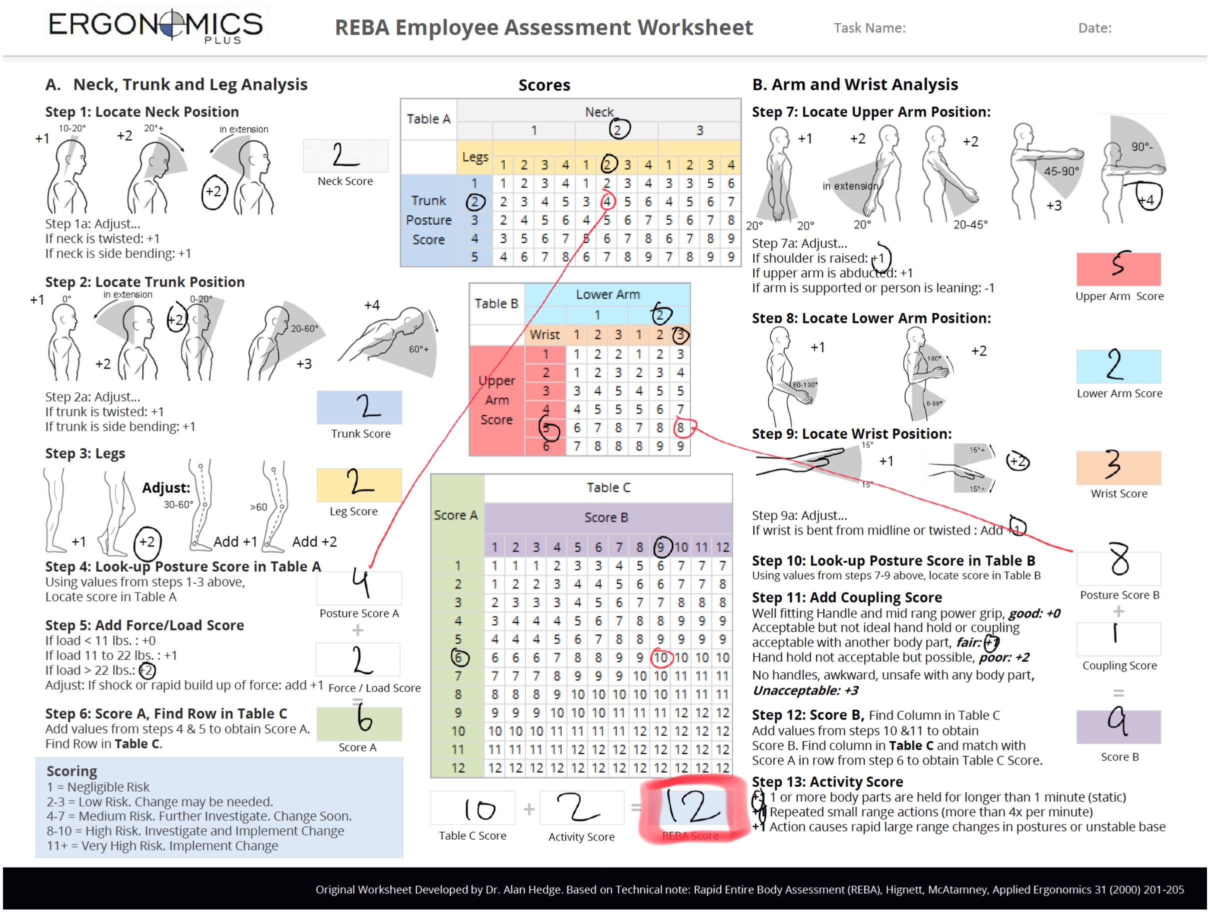
Step 11: Add Coupling Score
Well fitting Handle and mid rang power grip, ***good: +0***
Acceptable but not ideal hand hold or coupling acceptable with another body part, ***fair: +1***
Hand hold not acceptable but possible, ***poor: +2***
No handles, awkward, unsafe with any body part, ***Unacceptable: +3***
Coupling Score: 1

Step 12: Score B, Find Column in Table C
Add values from steps 10 &11 to obtain Score B. Find column in **Table C** and match with Score A in row from step 6 to obtain Table C Score.
Score B: 9

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base

Original Worksheet Developed by Dr. Alan Hedge. Based on Technical note: Rapid Entire Body Assessment (REBA), Hignett, McAtamney, Applied Ergonomics 31 (2000) 201-205

Cutting vertically above shoulder height



ERGONOMICS PLUS

REBA Employee Assessment Worksheet

Task Name:

Date:

A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position

+1 10-20° +2 20°+ +2 in extension

Neck Score: 2

Step 1a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Step 2: Locate Trunk Position

+1 0° in extension +2 0-20° +2 20-60° +3 +4 60°+

Trunk Score: 2

Step 2a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Step 3: Legs

+1 +2 **Adjust:** 30-60° Add +1 >60 Add +2

Leg Score: 2

Step 4: Look-up Posture Score in Table A
Using values from steps 1-3 above,
Locate score in Table A

Posture Score A: 4

Step 5: Add Force/Load Score
If load < 11 lbs. : +0
If load 11 to 22 lbs. : +1
If load > 22 lbs.: +2
Adjust: If shock or rapid build up of force: add +1

Force / Load Score: 2

Step 6: Score A, Find Row in Table C
Add values from steps 4 & 5 to obtain Score A.
Find Row in **Table C.**

Score A: 6

Scoring
1 = Negligible Risk
2-3 = Low Risk. Change may be needed.
4-7 = Medium Risk. Further Investigate. Change Soon.
8-10 = High Risk. Investigate and Implement Change
11+ = Very High Risk. Implement Change

Scores

Table A	Neck	1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B	Lower Arm	1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Table C												
Score A	Score B											
	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score: 10 + Activity Score: 2 = REBA Score: 12

B. Arm and Wrist Analysis

Step 7: Locate Upper Arm Position:

+1 20° 20° +2 in extension 20° +2 20-45° +3 45-90° +4 90°-

Step 7a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score: 5

Step 8: Locate Lower Arm Position:

+1 60-100° +2 100°+ 0-60°

Lower Arm Score: 2

Step 9: Locate Wrist Position:

+1 15° 15° +2 15°+ 15°+

Step 9a: Adjust...
If wrist is bent from midline or twisted : Add +1

Wrist Score: 3

Step 10: Look-up Posture Score in Table B
Using values from steps 7-9 above, locate score in Table B

Posture Score B: 8

Step 11: Add Coupling Score
Well fitting Handle and mid rang power grip, ***good: +0***
Acceptable but not ideal hand hold or coupling acceptable with another body part, ***fair: +1***
Hand hold not acceptable but possible, ***poor: +2***
No handles, awkward, unsafe with any body part, ***Unacceptable: +3***

Coupling Score: 1

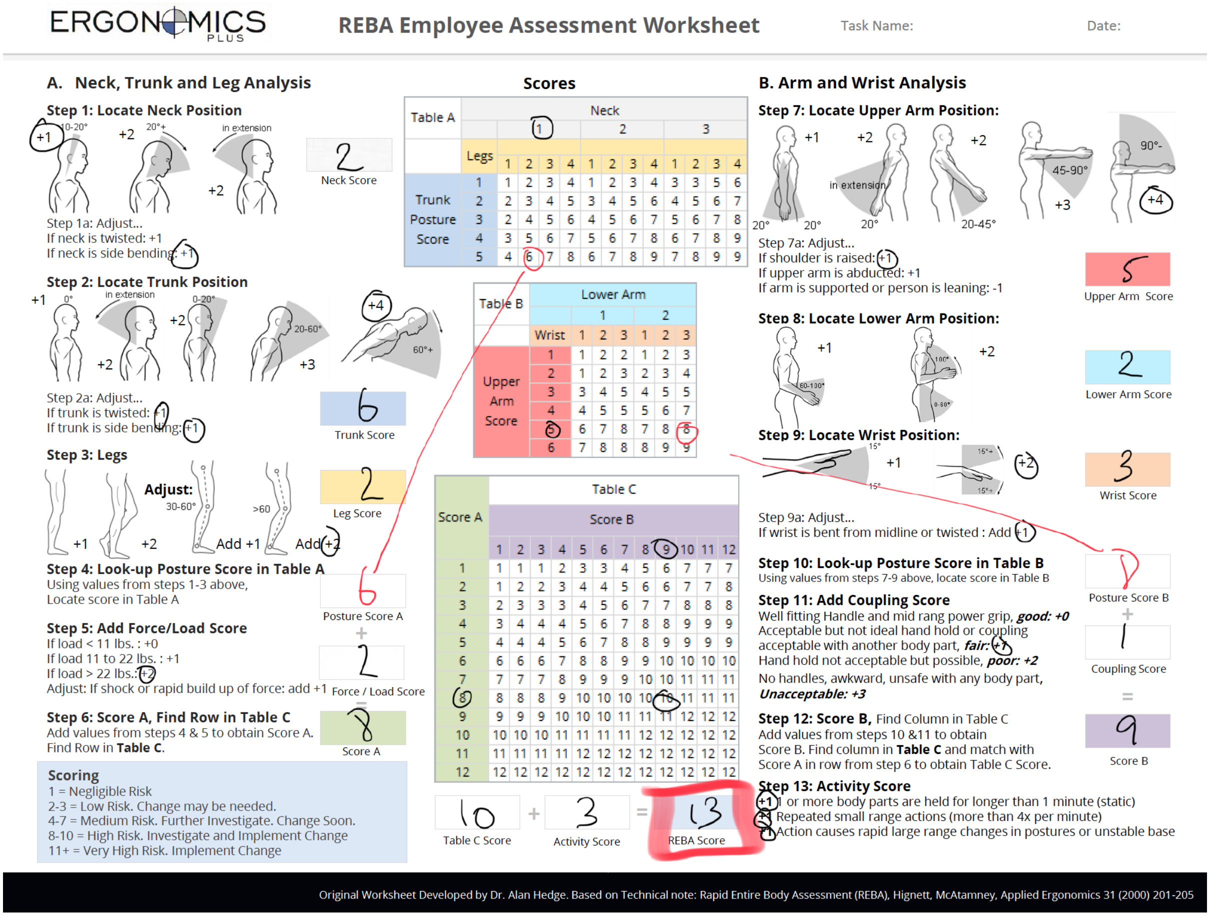
Step 12: Score B, Find Column in Table C
Add values from steps 10 &11 to obtain Score B. Find column in **Table C** and match with Score A in row from step 6 to obtain Table C Score.

Score B: 9

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base

Original Worksheet Developed by Dr. Alan Hedge. Based on Technical note: Rapid Entire Body Assessment (REBA), Hignett, McAtamney, Applied Ergonomics 31 (2000) 201-205

Cutting in floor



ERGONOMICS PLUS

REBA Employee Assessment Worksheet

Task Name: Date:

A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position

+1 (0-20°) +2 (20°+) +2 (in extension)

Neck Score: 2

Step 1a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Step 2: Locate Trunk Position

+1 (0°) +2 (in extension) +2 (0-20°) +3 (20-60°) +4 (60°+)

Trunk Score: 6

Step 2a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Step 3: Legs

+1 +2 Adjust: Add +1 (30-60°) Add +2 (>60)

Leg Score: 2

Step 4: Look-up Posture Score in Table A
Using values from steps 1-3 above,
Locate score in Table A

Posture Score A: 6

Step 5: Add Force/Load Score
If load < 11 lbs. : +0
If load 11 to 22 lbs. : +1
If load > 22 lbs.: +2
Adjust: If shock or rapid build up of force: add +1

Force / Load Score: 2

Step 6: Score A, Find Row in Table C
Add values from steps 4 & 5 to obtain Score A.
Find Row in **Table C**.

Score A: 8

Scoring
1 = Negligible Risk
2-3 = Low Risk. Change may be needed.
4-7 = Medium Risk. Further Investigate. Change Soon.
8-10 = High Risk. Investigate and Implement Change
11+ = Very High Risk. Implement Change

Scores

Table A	Neck	1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B	Lower Arm	1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Table C	Score B											
Score A	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score: 10 + Activity Score: 3 = REBA Score: 13

B. Arm and Wrist Analysis

Step 7: Locate Upper Arm Position:

+1 (20°, 20°) +2 (in extension) +2 (20-45°) +3 (45-90°) +4 (90°-)

Step 7a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score: 5

Step 8: Locate Lower Arm Position:

+1 (60-100°) +2 (100°+, 0-60°)

Lower Arm Score: 2

Step 9: Locate Wrist Position:

+1 (15°) +2 (15°+)

Wrist Score: 3

Step 9a: Adjust...
If wrist is bent from midline or twisted : Add +1

Step 10: Look-up Posture Score in Table B
Using values from steps 7-9 above, locate score in Table B

Posture Score B: 8

Step 11: Add Coupling Score
Well fitting Handle and mid rang power grip, ***good: +0***
Acceptable but not ideal hand hold or coupling
acceptable with another body part, ***fair: +1***
Hand hold not acceptable but possible, ***poor: +2***
No handles, awkward, unsafe with any body part,
Unacceptable: +3

Coupling Score: 1

Step 12: Score B, Find Column in Table C
Add values from steps 10 &11 to obtain
Score B. Find column in **Table C** and match with
Score A in row from step 6 to obtain Table C Score.

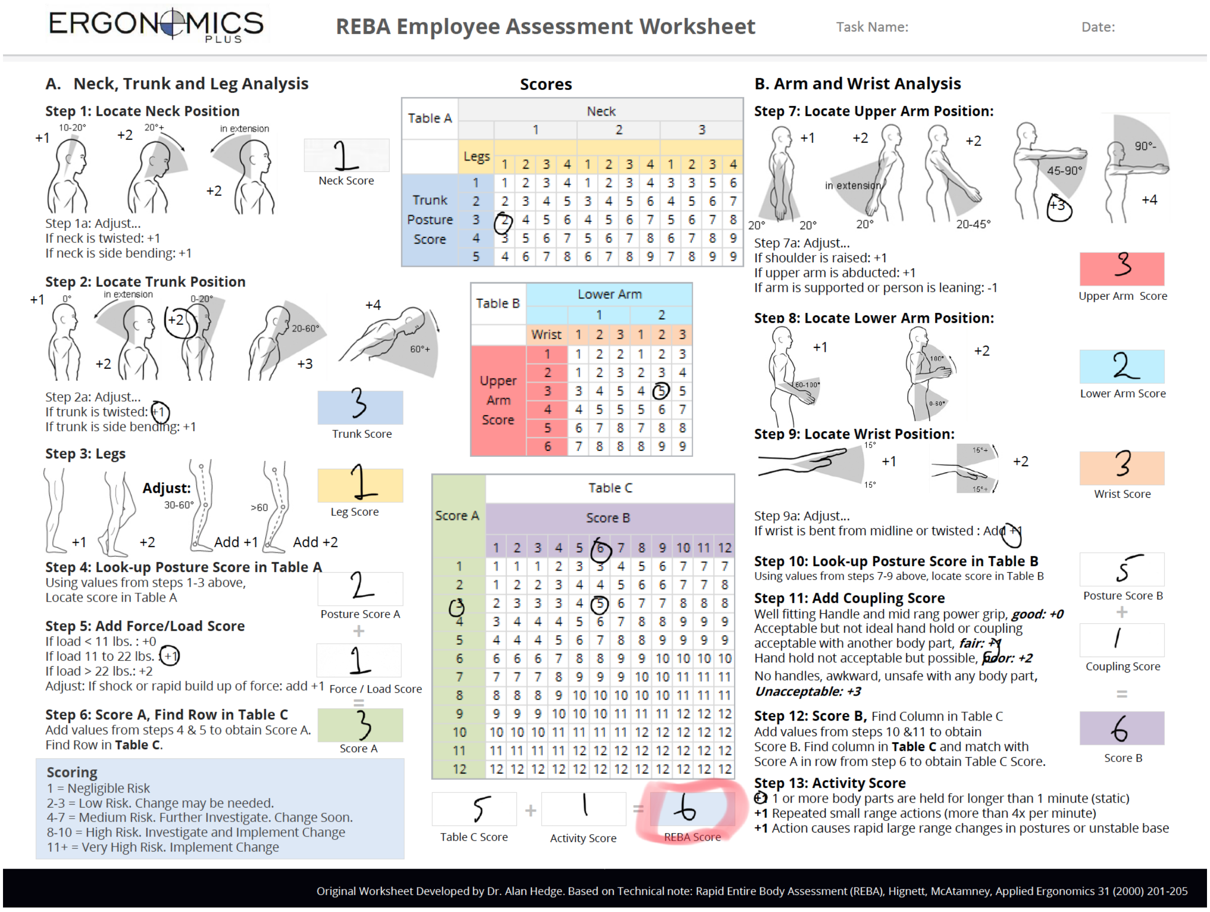
Score B: 9

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base

Original Worksheet Developed by Dr. Alan Hedge. Based on Technical note: Rapid Entire Body Assessment (REBA), Hignett, McAtamney, Applied Ergonomics 31 (2000) 201-205

G.4 REBA for Core Drilling Machine

Drilling above shoulder height



ERGONOMICS PLUS

REBA Employee Assessment Worksheet

Task Name: Date:

A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position

+1 10-20° +2 20°+ in extension +2

Neck Score (1)

Step 1a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Step 2: Locate Trunk Position

+1 0° in extension 0-20° +2 +2 20-60° +3 +4 60°+

Trunk Score (3)

Step 2a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Step 3: Legs

+1 +2 **Adjust:** 30-60° Add +1 >60 Add +2

Leg Score (1)

Step 4: Look-up Posture Score in Table A
Using values from steps 1-3 above,
Locate score in Table A

Posture Score A (2)

Step 5: Add Force/Load Score
If load < 11 lbs. : +0
If load 11 to 22 lbs. : +1
If load > 22 lbs.: +2
Adjust: If shock or rapid build up of force: add +1

Force / Load Score (1)

Step 6: Score A, Find Row in Table C
Add values from steps 4 & 5 to obtain Score A.
Find Row in **Table C**.

Score A (3)

Scoring
1 = Negligible Risk
2-3 = Low Risk. Change may be needed.
4-7 = Medium Risk. Further Investigate. Change Soon.
8-10 = High Risk. Investigate and Implement Change
11+ = Very High Risk. Implement Change

Scores

Table A	Neck	1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B	Lower Arm	1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Table C — Score A	Score B 1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score (5) + Activity Score (1) = REBA Score (6)

B. Arm and Wrist Analysis

Step 7: Locate Upper Arm Position:

+1 +2 in extension +2 20° 20° 20° 20-45° 45-90° +3 90°- +4

Upper Arm Score (3)

Step 7a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Step 8: Locate Lower Arm Position:

+1 60-100° +2 100°+ 0-60°

Lower Arm Score (2)

Step 9: Locate Wrist Position:

15° +1 15° 15°+ +2 15°+

Wrist Score (3)

Step 9a: Adjust...
If wrist is bent from midline or twisted : Add +1

Step 10: Look-up Posture Score in Table B
Using values from steps 7-9 above, locate score in Table B

Posture Score B (5)

Step 11: Add Coupling Score
Well fitting Handle and mid rang power grip, ***good: +0***
Acceptable but not ideal hand hold or coupling acceptable with another body part, ***fair: +1***
Hand hold not acceptable but possible, ***poor: +2***
No handles, awkward, unsafe with any body part, ***Unacceptable: +3***

Coupling Score (1)

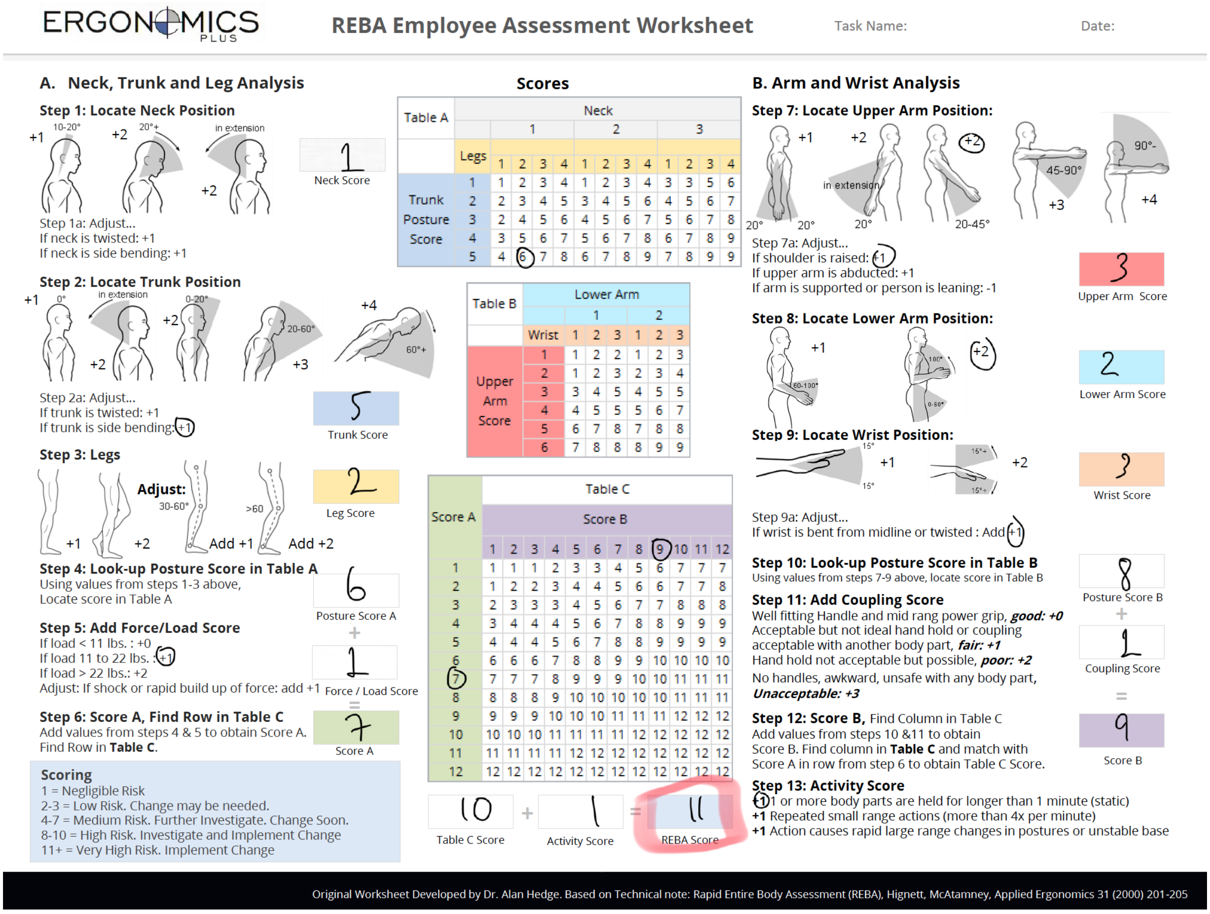
Step 12: Score B, Find Column in Table C
Add values from steps 10 &11 to obtain Score B. Find column in **Table C** and match with Score A in row from step 6 to obtain Table C Score.

Score B (6)

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base

Original Worksheet Developed by Dr. Alan Hedge. Based on Technical note: Rapid Entire Body Assessment (REBA), Hignett, McAtamney, Applied Ergonomics 31 (2000) 201-205

Drilling below waist height



ERGONOMICS PLUS

REBA Employee Assessment Worksheet Task Name: Date:

A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position

+1 10-20° +2 20°+ in extension +2

Neck Score: 1

Step 1a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Step 2: Locate Trunk Position

+1 0° in extension +2 +2 0-20° 20-60° +3 +4 60°+

Trunk Score: 5

Step 2a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Step 3: Legs

+1 +2 Adjust: 30-60° Add +1 >60 Add +2

Leg Score: 2

Step 4: Look-up Posture Score in Table A
Using values from steps 1-3 above,
Locate score in Table A

Posture Score A: 6

Step 5: Add Force/Load Score
If load < 11 lbs. : +0
If load 11 to 22 lbs. : +1
If load > 22 lbs.: +2
Adjust: If shock or rapid build up of force: add +1

Force / Load Score: 1

Step 6: Score A, Find Row in Table C
Add values from steps 4 & 5 to obtain Score A.
Find Row in **Table C**.

Score A: 7

Scoring
1 = Negligible Risk
2-3 = Low Risk. Change may be needed.
4-7 = Medium Risk. Further Investigate. Change Soon.
8-10 = High Risk. Investigate and Implement Change
11+ = Very High Risk. Implement Change

Scores

Table A	Neck	1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B	Lower Arm	1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Table C	Score B											
Score A	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score: 10 + Activity Score: 1 = REBA Score: 11

B. Arm and Wrist Analysis

Step 7: Locate Upper Arm Position:

+1 +2 in extension +2 45-90° +3 90°- +4 20° 20° 20° 20-45°

Step 7a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score: 3

Step 8: Locate Lower Arm Position:

+1 +2 60-100° 0-60° 100°+

Lower Arm Score: 2

Step 9: Locate Wrist Position:

15° +1 15° 15°+ +2 15°+

Wrist Score: 2

Step 9a: Adjust...
If wrist is bent from midline or twisted : Add +1

Step 10: Look-up Posture Score in Table B
Using values from steps 7-9 above, locate score in Table B

Posture Score B: 8

Step 11: Add Coupling Score
Well fitting Handle and mid rang power grip, ***good: +0***
Acceptable but not ideal hand hold or coupling acceptable with another body part, ***fair: +1***
Hand hold not acceptable but possible, ***poor: +2***
No handles, awkward, unsafe with any body part, ***Unacceptable: +3***

Coupling Score: 1

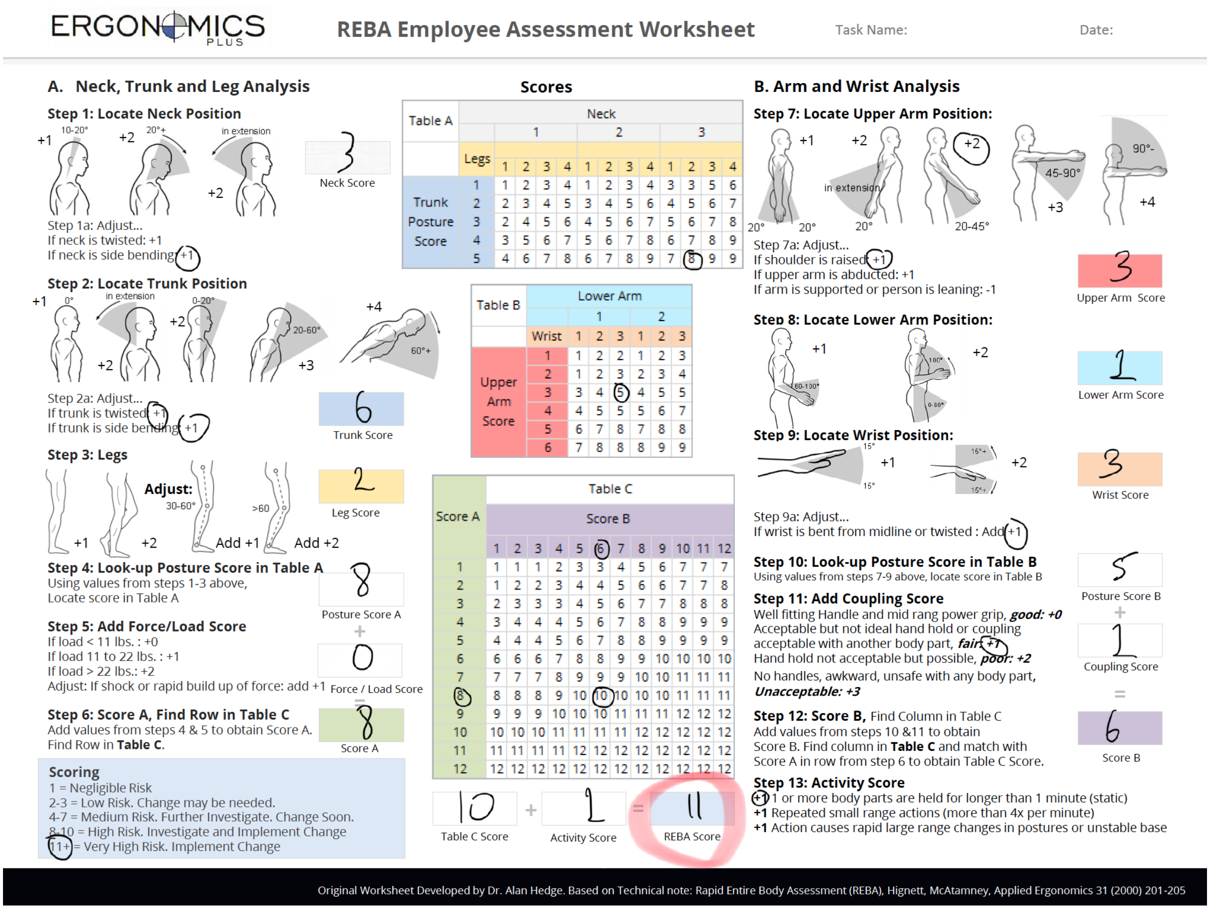
Step 12: Score B, Find Column in Table C
Add values from steps 10 &11 to obtain Score B. Find column in **Table C** and match with Score A in row from step 6 to obtain Table C Score.

Score B: 9

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base

Original Worksheet Developed by Dr. Alan Hedge. Based on Technical note: Rapid Entire Body Assessment (REBA), Hignett, McAtamney, Applied Ergonomics 31 (2000) 201-205

Drilling vertically



ERGONOMICS PLUS

REBA Employee Assessment Worksheet

Task Name: Date:

A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position

+1 10-20° +2 20°+ +2 in extension

Neck Score: 3

Step 1a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Step 2: Locate Trunk Position

+1 0° +2 in extension +2 0-20° +3 20-60° +4 60°+

Step 2a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Trunk Score: 6

Step 3: Legs

+1 +2 Adjust: 30-60° Add +1 >60 Add +2

Leg Score: 2

Step 4: Look-up Posture Score in Table A
Using values from steps 1-3 above,
Locate score in Table A

Posture Score A: 8

Step 5: Add Force/Load Score
If load < 11 lbs. : +0
If load 11 to 22 lbs. : +1
If load > 22 lbs.: +2
Adjust: If shock or rapid build up of force: add +1

Force / Load Score: 0

Step 6: Score A, Find Row in Table C
Add values from steps 4 & 5 to obtain Score A.
Find Row in **Table C**.

Score A: 8

Scoring
1 = Negligible Risk
2-3 = Low Risk. Change may be needed.
4-7 = Medium Risk. Further Investigate. Change Soon.
8-10 = High Risk. Investigate and Implement Change
11+ = Very High Risk. Implement Change

Scores

Table A	Neck	1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B	Lower Arm	1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Table C: Score A	Score B 1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score: 10 + Activity Score: 1 = REBA Score: 11

B. Arm and Wrist Analysis

Step 7: Locate Upper Arm Position:

+1 20° 20° +2 in extension 20° +2 20-45° +3 45-90° +4 90°-

Step 7a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score: 3

Step 8: Locate Lower Arm Position:

+1 60-100° +2 100°+ 0-60°

Lower Arm Score: 1

Step 9: Locate Wrist Position:

+1 15° 15° +2 15°+ 15°+

Wrist Score: 3

Step 9a: Adjust...
If wrist is bent from midline or twisted : Add +1

Step 10: Look-up Posture Score in Table B
Using values from steps 7-9 above, locate score in Table B

Posture Score B: 5

Step 11: Add Coupling Score
Well fitting Handle and mid rang power grip, ***good: +0***
Acceptable but not ideal hand hold or coupling acceptable with another body part, ***fair: +1***
Hand hold not acceptable but possible, ***poor: +2***
No handles, awkward, unsafe with any body part, ***Unacceptable: +3***

Coupling Score: 1

Step 12: Score B, Find Column in Table C
Add values from steps 10 &11 to obtain Score B. Find column in **Table C** and match with Score A in row from step 6 to obtain Table C Score.

Score B: 6

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base

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H

Appendix

H.1 Personas

Magnus

Ålder: 57
Företag: Medelstort betonghåltagningsföretag
Stad: Växjö
Livssituation: Fru och 2 barn på 29 & 31 år

Figur 65: Persona Magnus
[Photograph], by Robert Godwin, April 2, 2020, Unsplash

Magnus (se Figur 65) är en erfaren håltagare då han började arbeta redan vid 16 års ålder. Han har alltid varit intresserad av byggen och följde gärna med sin pappa och morfar ut för att vara delaktig när han fick chansen. Att följa i deras fotspår kom naturligt då han kände till jobbet sedan tidigt och var van att bära skitiga arbetskläder. Idag har han jobbat som håltagare i 41 år och han har känningar i nästintill hela kroppen från det slitsamma arbetet. Händerna värker vid kyla och ryggen är ett vardagligt problem. Att klaga kommer inte på frågan, men idag går arbetet helt klart långsammare än vad det gjorde för tio år sedan. Han har slutat stressa som han gjorde förr i tiden, "*"Det får ta den tid det tar"* ". Vad gäller arbetet så kör han på som han är van, då han har jobbat så länge och slutat reflektera över hur man ska göra.

Vad gäller externa hjälpmedel är han positiv och all hjälp ses som uppskattad. Han har slutat bry sig om vad andra tycker och han skulle mer än gärna prova ett potentiellt exoskelett.

Kristopher

Ålder: 34
Företag: Medelstort företag som håller på med rivning, betongarbete och sanering
Livssituation: En sambo och en vit golden retriever vid namn Bruno

Figur 66: Persona Kristopher
[Photograph], by Irene Strong, (July 31, 2019), Unsplash

Kristopher (se Figur 66) har jobbat med håltagning sedan 5 år tillbaka och trivs med friheten över att kunna jobba i olika projekt. Förr jobbade han som handläggare inom finans på ett kontor. Han ser däremot inte sig själv som någon som kommer jobba inom håltagningbranschen ända fram till pensionen. "*Det är så oergonomiskt det kan bli! Jag har haft tur och har inga känningar just nu, men det är bara en tidsfråga innan man får ont.*" Många av hans äldre kollegor har gått över till att köra grävmaskin för att skona kroppen, en framtid som han tror väntar honom med.

Kristopher har ofta tänkt på hur man hade kunnat göra för att det ska bli lättare att arbeta med maskinerna. Han och några kollegor har byggt en egen variant av takkap där de fäst en vanlig kapmaskin på en gipsmaksin. Det är tunga lyft överallt menar han så alla typer av hjälpmedel som minimerar antal lyft uppskattats. Däremot är han samtidigt skeptisk till de verktyg som försvårar andra delar av arbetet. Munskydd och hjälm är något han sällan bär, mestadels för han tycker att det är omständigt. Allt ska alltid gå så snabbt förklarar han, man har inte tid att sitta och pilla med smågrejor.

Varför han inte har börjat få ont i kroppen än tror han beror mycket på tur men framförallt för att han håller sig aktiv på fritiden. Ett arbetspass i sig är som ett gympass förklarar han, men att ta en springtur med hunden eller att gå och fiska, vilket är hans och sambons stora gemensamma hobby, är alla sätt att hålla igång kroppen. Det finns en risk att man kommer hem, sätter sig i soffan med en öl och blir kvar där resten av kvällen, men då är risken större att man skadar sig menar han.

H.2 Scenario

See illustrations of the scenario in Figure 67-70.

Figure 67: First step of scenario

This is Magnus. He is on his way to cut a door opening at a renovation site. Magnus has just carried all the machines and tools to the fifth floor. Since the elevator does not work, he has been walking up and down the stairs several times in order to bring all his tools.

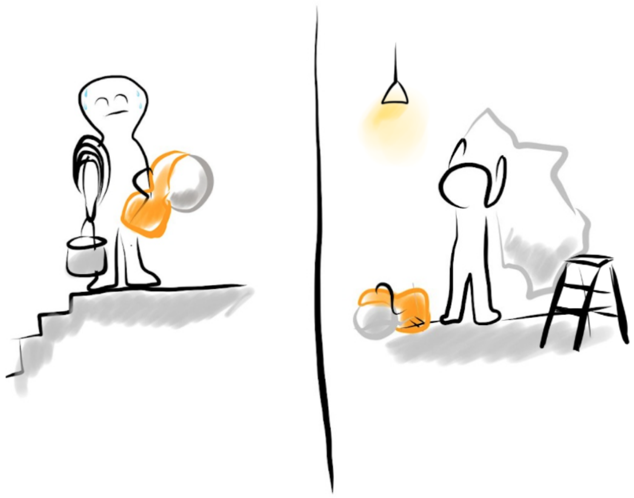

Figure 68: First and second step of scenario

Since the painter soon arrives, there is not much time to finish his task. Hence, Magnus chooses to go with the handheld power cutter instead of first installing a wall saw. He prepares the areas, attaches the water hose and starts cutting.

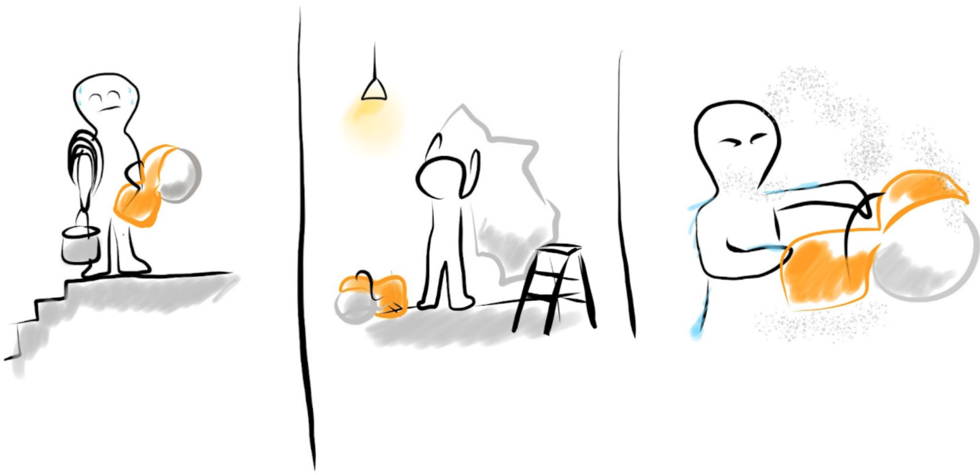

Figure 69: First to third step of the scenario

It is winter and the water from the power cutter increases the coldness. The concrete dust that is spreading in the air makes it difficult to breathe properly but Magnus has stopped wearing his protective mask since it is too uncomfortable.

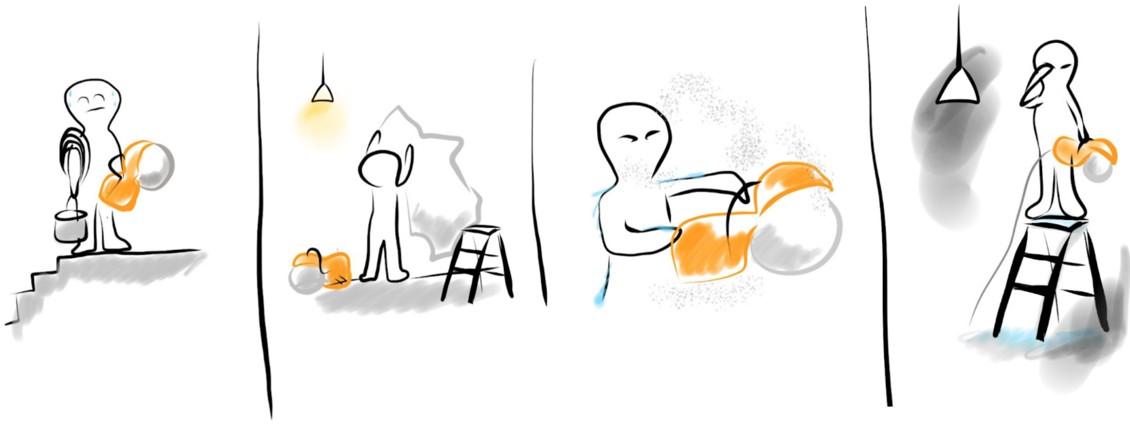

Figure 70: Illustration of all steps of the scenario

When he is about to cut the vertical cut at the top of the door opening, the electricity goes down. He climbs down the stool that he is standing on, drops the power cutter and hurries down to the cellar to turn on the electricity again. In an hour he has to be at the next project site to pull down a wall. The time is limited and he is starting to get stressed.

I

Appendix

I.1 List of Guidelines

1= Crucial, if this guideline is not met, the product will not function properly and not meet the user's main requirements.
2= Essential, if this guideline is not met, the user will most likely not use the product.
3= Desirable, guidelines that are not mandatory to be met but that would create added value for the user and increase user satisfaction.

Guidelines	Desired / Necessary	Comments
Comfort		
Should allow mobility	1	
Should relieve the body without giving rise to incorrect loading on other parts of the body	1	
Should not result in unergonomic movements patterns of the user	1	
Should not enhance any vibrations from the machine on the user	1	
Should be adjustable	2	
Should be as light-weight as possible	2	
Should not complicate the possibility of relieving the machine against support points on the body	3	
Should be able to be used continuously during a full working day	3	
Ease of use		
Should be possible to manage with wet/dirty hands	1	
Should indicate that the system is working	1	
Should allow safe usage at heights	1	The user often works at scaffoldings high up
Should be able to use in narrow spaces	1	The user often works in small corners where there is a limited amount of space
Should be possible to carry in narrow spaces	1	
Should minimize the risk of user error	1	
Should fit the 95th percentile of both men and women	1	
Should be easy to turn on and off	1	If the machine is electronical
Should be possible to see the status of the machine	1	E.g. the user should be able to clearly see the battery level
The learning time should not exceed the amount of benefit	2	
The preparation time before each use should not exceed the amount of benefit	2	
Should be possible to manage with hands covered in gloves	2	
Should be intuitive to use	3	Should allow a clear indication of how to use the product
Combination with other products		
Should be possible to combine with protective equipment	1	Such as helmet, harness, air mask with fan package and belt
Should not minimize the effect of protective clothing	1	
Should be in line with the ISO standards about reflective clothing on construction sites	1	
Should be possible to combine with other ergonomic aids	2	Such as wrist protection, weightlifting belt, vibration insulating gloves
Should be possible to use with other handheld machines	3	E.g. while using the smooth saw, the machine is often supported on the legs. The product should not minimize the possibility to use other machines
Should be able to be used while the user is wearing tools in his pockets	3	
E.g in the trunk of a car		
Should allow for convenient storage	1	E.g. some machines are stored in containers and others in the user's car
Should be possible to carry up and down to different floors	1	
Should allow for convenient transportation between work sites	1	E.g in the trunk of car
Should allow easy cleaning	2	There should preferably be no sharp edges and no deep parting lines
Should be possible to use in combination with different transporting methods at work site	2	E.g. a wheelbarrow
If the product entails any detachable parts, these should be easy to manage and store	3	
Durability		
Should be water resitant	1	
Should allow usage in dust-heavy environments	1	

Should resist impacts during transportation and storage	3	E.g. during transportation, there is a risk of the product getting hit by other machines and materials
Should resits impacts during usage	3	E.g. it should be possible to put the machine on the ground when not in use
Sustainability		
The product's material should allow recycling to an as high extent as possible	3	E.g. by making the product's part detachable and recycalble
The product should allow reperation	3	By making it rearable, it could be sued fpr a longer time-period
The materials should be recycled to an as high extent as possible	3	
The product should have a low ecological footprint	3	
Safety		
Should not put the user in risk of getting stuck in the surrounding environment or machines	1	
Should not get stuck in surrounding environment or machines	1	
Should be resitant towards sparks	1	The product might be used in work situations where sparks are common, fore example while
Should not imply false reliability	1	Should not risk the safety due to users relying to much on the produkt
Should allow stability	1	Should allow the user to stand securely and stable on uneven ground, legs need to be stand wide
Should not risk the user's safety	1	
Should not obscure the view of the user	1	
Should allow the users to regret manuevers	1	The deisgn needs to be forgiving so that making mistakes does not have serious consequences
Should be possible to use on a scaffolding	2	Scaffoldings usually have a hight of minimum 2 meters
The product design should increase the user's safety when using machines	3	
Appearance		
Should be in line with brand identity	2	
Should be compatible with cultural norms	2	
Should encourage usage	3	
Materials		
Colors and coatings should not be toxic or health-damaging	1	
Should be made of cleanable/stain resistance surfaces	1	
Should be made out of fire resistant materials	2	To minimize the risk of fire when the product is used in an environment where fuel is present

I.2 List of Guidelines for Products Worn on the User

Guidelines	Desired / Necessary
If the product is supposed to be worn on the body, it...	
Should allow proper attachment to body	1
Should not give rise to impaired balance for the user	1
Should not lmit the motions of the user	1
Should by small measures be adjusted to fit the user	2
Should be possible to put on without the help of another person	2
Should not add unnecessary weight on the user	2
Should be able to be carried in a sitting position	3
Should allow the user to work while on her knees	3
The contact areas should not cause discomfort	3
Should allow good ventilation	3

J

Appendix

J.1 Compilation and Evaluation of Nine Concept Groups

De nio konceptgrupperna utvärderades efter kravlistan där framförallt aspekterna nedan togs i beaktning:

- Comfort
- Ease of use
- Possibility to combination with other products
- Storage, transportation & maintenance
- Durability
- Safety
- Whether it facilitates the working position itself or not
- Whether it facilitates heavy lifting or not
- Time aspects (time to put on and off)
- Attitude and acceptance
- Multifunctionality

Nedan presenteras resultatet av utvärderingen där fördelar, nackdelar, faktorer att tänka på vid utvecklandet av konceptet samt alternativ av konceptet är presenterade.

1. Förlängd arm (aktiv eller passiv exoskelett)

Fördelar

- Möjlighet att slippa belasta armar och axlar med tyngden av maskinen
- Hade kunnat kopplas till olika maskiner
- Hade kunnat underlätta olika arbetspositioner
- Finns liknande produkter på marknaden, så grundtekniken finns

Nackdelar

- Risk att det blir lättare att arbete med händer ovanför axelhöjd och att man därför gör det under längre tider och oftare
- Risk att det blir stor obalans för användaren och att nya snedbelastningar uppstår
- Kan vara svårare att arbete i små utrymmen
- Väldigt synlig, risk för låg acceptans bland användare?
- Risk att den upplevs tidskrävande
- Risk att upplevs som för tung och otymplig (båda att ha på sig och att transportera)

- Risk att belastar andra muskler och leder
- Risk att blir svår att använda utöver arbetet (sitta, bära tunga saker)
- Tillkommer en ökad vikt på användaren

Att tänka på

- Designa så att den inte behöver styras med händerna ovanför axelhöjd
- Designa så att det ej skapas en för stor vibrationsöverföring från maskin till människa
- Hög krav på att armen är flexibel och ej hindrar rörelser
- Alla användare är olika uppbyggda och tyngdpunkten kan ändras
- Designa så att att den ej äventyrar användarens säkerhet, tex genom att man enkelt kan koppla loss den från kroppen ifall man skulle trilla eller ifall maskinen börja brinna
- Designa så att kickback från kap undviks och att säkerheten ökar
- Designa så att det ej blir för varmt att ha på sig den

Alt:

- Styra med en pekpinne
- Styr maskinen som vanligt genom att hålla i maskinen
- Styr maskinen med en kontroll
- Armen fästes på ett bälte
- Armen fästes på en väst/sele
- Fästet går ner runt benen för extra stöd
- Armen fästes på större delar av kropp (rygg, ben, lår etc)
- Armen kan enbart arbetar uppåt eller nedåt mot golv eller både och
- Att armen kan kopplas till olika maskiner eller specifikt till en maskin
- Att armarna är robotdelar som kan styras efter hur man själv vill (gorilla tripods-idén)

2. Passivt exoskelett inbyggt i kläder

Fördelar

- Har potential att underlätta arbete vid golv (likt exoskelett idag, drar en upp)
- Underlätta tunga lyft
- Slipper bära med sig extra delar eller utrustning
- Finns liknande produkter på marknaden så grundtekniken finns
- Kan bäras hela dagen
- Risken att fastna är mindre
- Kan användas i mindre utrymmen
- Mer diskret och lika kläder som användare redan har, högre acceptans
- Stabiliserar upp kroppen och bidrar till en mer ergonomisk hållning (om bälte)
- Hög flexibilitet
- Tillför endast en liten extra vikt
- Kan användas i sittande position

*Anledningen till att det kan vara smart att selen redan är fäst i byxorna är då kraftöverföringen från ryggen oftast behöver gå ner till benen för att åstadkomma en bidragande kraft på användaren, och för att slippa sätta dit selen längst med benen så är den redan inbyggd i ens byxor.

Nackdelar

- Underlättar ej arbete för armar och axlar
- Risk att den upplevs omständig att ta på sig
- Risk att belastar andra muskler och leder
- Ifall man vill ha en viss typ av specifik kläder så går det ej
- Risk att maskiner och material är så pass tungt att produkten ej ger en tillräcklig effekt (att den ej gör tillräckligt stor skillnad)

Att tänka på

- Designa så att den ej hindrar flexibiliteten
- Designa så att det ej blir jobbigare att utföra själva böjningen då de tar i i andra muskler
- Design så att det ej blir för varmt att ha på sig den
- Designa så att andra muskler ej belastas fel

Alt:

- Sele inbyggt som hängslen i byxor (exoskelett för tunga lyft- bidrar till att det blir mindre tungt att lyfta)
- Viktbälte inbyggt som bälte i byxor (bidrar till en mer ergonomisk kroppshållning)
- Designa så att hjälpmedlet kan användas separat från arbetskläderna
- Designa så att hjälpmedlet permanent sitter fast i arbetskläderna
- Designa så att byxorna kan omvandlas till shorts
- Exoskelett som kopplas till byxor (för att slippa bära med sig hela delen)

3. Bälte

Fördelar

- Potential att underlätta arbete i golv
- Bidra till en mer ergonomisk hållning
- Kan underlätta tunga lyft
- Slipper bära med sig extra delar eller utrustning
- Finns liknande produkter på marknaden så grundtekniken finns
- Kan bäras hela dagen
- Risken att fastna är mindre
- Kan användas i mindre utrymmen
- Mer diskret och lika kläder som användare redan har, högre acceptans
- Stabiliserar upp kroppen och bidrar till en mer ergonomisk hållning (om bälte)
- Hög flexibilitet

- Kan användas i sittande position

Nackdelar
- Viss misstänksamhet från byggarbetare (från intervjuer)
- Bidrar ej till ökad lyftförmåga
- Underlättar ej arbete för armar och axlar
- Risk att maskiner och material är så pass tungt att produkten ej ger en tillräcklig effekt (att den ej gör tillräckligt stor skillnad)
- Är en extra sak som användaren själv ska ta med sig och ta på sig

Att tänka på
- Designa så att den ej hindrar flexibiliteten
- Designa så ej skaver när böjer sig (uttryckt problem från viktbälten)
- Design så att det ej blir för varmt att ha på sig den
- Designa eventuellt så att den ger stöd långt ner
- Designa eventuellt så att det kan bli implementeras i kläder
- Designa så att andra muskler ej belastas fel

Alt:
- Gör en blandning mellan viktbälten och de mer ergonomiska bälten som finns
- Mjukare material där fram och hårdare platta där bak för ökad flexibilitet och stöd
- Två olika spännen på samma bälte för bättre omsultning (likt ergonomiska bälten)

4. Förlängningsbart handtag (för främst kapmaskin)

Fördelar
- Potential att underlätta arbete vid golv
- Användaren behöver ej ta med sig extra saker själv om handtaget redan är påkopplat maskinen
- Undviker arbeta med böjd rygg
- Undviker lyft av något slag (bara pressa)
- Kan medföra att användaren kan använda med händer i brösthöjd o nära kroppen

Nackdelar
- Blir mycket maskinspecifik om ej utvecklar något som kan passa många olika maskiner
- Underlättar ej arbete för armar och axlar
- Risk att den är svår att använda i mindre utrymmen
- Maskinen i sig blir tyngre
- Kan minska kontrollen av maskinen

Att tänka på
- Designa så man fortfarande kan bibehålla god kontroll av maskin

- Designa så man slipper böja sig för många gånger bara för att sätta på/stänga av/manövrera maskinen
- Designa så att handtaget är flexibelt så man kommer åt i trånga utrymmen
- Designa så ej blir vribationsöverföring
- Designa så att maskinen kan köras utan handtag vid behov (men då blir det en extra sak att ta med sig och släpa på)

Alt:

- Kunnat kombinera så går att höja maskinen så även kan användas som stativ (men då blir det tyngre och potentiellt större att bära med sig)
- Sätta på hjul så kan rulla maskin på marken, kan göra det enklare att släpa maskin

5. Fiskespö (över huvudet)

Fördelar

- Slipper lyfta med armar
- Möjlighet att slippa belasta armar och axlar med tyngden av maskinen
- Hade kunnat kopplas till olika maskiner

Nackdelar

- Risk att det försvårar arbete under midjehöjd om man styr den manuellt
- Horisontella snitt blir svåra
- Risk att den blir svår att använda i mindre utrymmen
- Maskinen i sig blir tyngre
- Kan minska kontrollen av maskinen
- Risk fastna i omkringliggande miljö
- Kan upplevas omständig att ta på sig
- Syns mycket, lägre acceptans av användare
- Kan medföra att det blir svårt att hålla balansen

Att tänka på

- Designa så man fortfarande kan bibehålla god kontroll av maskin
- Designa så att man kan behålla en god balans
- Designa så att andra muskler ej belastas fel
- Designa så ej blir vibrationsöverföring

Alt:

- Designa så man styr den med kontroll och kapen kan åka upp och ner längs en vägg automatiskt

6. Väst (likt traditionellt exoskelett för rygg med stöd vid benen)

Fördelar

- Finns liknande produkter på marknaden så grundtekniken finns
- Underlättar tunga lyft (drar en uppåt)
- Kan placeras nära kroppen
- Kan användas i trånga utrymmen
- Ej extra tyngd på användaren
- Kan has på hela dagen
- Potential att underlätta arbete vid golv
- Risken att fastna är mindre
- Hög flexibilitet

Nackdelar

- Risk att andra delar av kroppen blir felbelastade/ överbelastade
- Risk att användaren använder musklerna på "fel" sätt vid tunga lyft
- Kan upplevas obekvämt att bära något runt benen
- Synlig, risk för låg acceptans bland användare?
- Kan upplevas tidskrävande att ta på sig
- Underlättar ej arbete med armar och axlar
- Viss misstänksamhet från byggarbetare (från intervjuer)
- Underlättar ej arbete för armar och axlar
- Risk att maskiner och material är så pass tungt att produkten ej ger en tillräcklig effekt (att den ej gör tillräckligt stor skillnad)
- Är en extra sak som användaren själv ska ta med sig och ta på sig

Att tänka på

- Designa så enkelt kan ta på och av bendelen
- Designa så det ej blir jobbigt att böja sig fram
- Designa så att ej andra muskler belastas fel
- Designa så att exoskelettet följer människans uppbyggnad och rörelsemönster (för bidra till en mer naturlig och ergonomisk användning)
- Designa så ej blir extra varmt för användaren
- Designa så kan användas i sittande position
- Designa så den ej skaver när man böjer sig

Alt:

- Designa så ser ut som en vanlig väst som man enkelt tar på sig)där själva exoskslettstekniken finns gömd innanför)
- Designa så kan koppla bort benfästena snabbt så slipper ha dem på när man ej lyfter
- Designa så man har enkla band som drar upp en - ska ej bli jobbigt att böja sig

7. Stativ (höj, sänkbart för vägg)

Hitta lösning så att den ej behöver sättas fast i golv. Så att det blir som en extra arm men som löper från golv istället för människan. Annars blir det som en ny variant av väggkap. Den ska ej vara för tung att släpa med sig samt ej ta för lång tid att sätta upp.

Fördelar

- Möjlighet att slippa belasta armar och axlar med tyngden av maskinen
- Hade kunnat kopplas till olika maskiner
- Finns liknande produkter på marknaden så grundtekniken finns
- Möjlighet helt slippa använda kroppen under själva kapningen/borrningen

Nackdelar

- Utmaning att kapa horisontellt
- Kan vara svårare att arbete med i små utrymmen
- Risk att den upplevs tidskrävande att installera
- Tunga lyft kan vara nödvändiga för att montera maskinen på stativet
- Risk att upplevs som för tung och otymplig att transportera
- En extra sak som ska bäras med och ställas in
- Kan behövas monteras i golvet

Att tänka på

- Designa så att den inte behöver styras med händerna ovanför axelhöjd
- Designa så att den står stabilt utan att behöva sättas fast i underlaget
- Designa så att den blir rörlig och flexibel för att tillåta flexibel kapning
- Behöver var enklare att montera än en väggkap

Alt:

- Kombineras med någon form av vagnsystem så enklare att släpa med sig
- Styr maskinen som vanligt genom att hålla i maskinen
- Styr maskinen med en kontroll
- Olika typer av stativ- gorilla tripod, pixar lampa osv

8. Aktivt system i kläder

Någon form av klädesplagg, ex tröja, som ger extra styrka i användarens rörelser, som kan läser av vad användarens intentioner är.

Fördelar

- Underlätta arbete med armar och axlar
- Potential att underlätta arbete vid golv (likt exoskelett idag, drar en upp)
- Underlätta tunga lyft (eventuellt)
- Slipper bära med sig extra delar eller utrustning

- Kan bäras hela dagen
- Kan användas i mindre utrymmen
- Mer diskret och lika kläder som användare redan har, högre acceptans
- Stabiliserar upp kroppen och bidrar till en mer ergonomisk hållning (om bälte)
- Kan användas i sittande position

Nackdelar

- Risk att belastar andra muskler och leder på fel sätt
- Ifall man vill ha en viss typ av specifik kläder så går det ej
- Kan bli varmt om ska täcka armar under sommar
- Risk att maskiner och material är så pass tungt att produkten ej ger en tillräcklig effekt (att den ej gör tillräckligt stor skillnad)
- Krävs stor research för hitta rätt teknik
- Risk att upplevas som omständig att tas på om sensorer behöver vara nära kroppen
- Kan ta tid innan sensorerna eller liknande "ingriper" för att hjälpa
- Kan kräva internetuppkoppling
- Risk att läser av användarens intentioner fel och ger ökad styrka i fel lägen

Att tänka på

- Designa så att den ej hindrar flexibiliteten
- Designa så att det ej blir jobbigare att utföra själva böjningen då de tar i i andra muskler
- Design så att det ej blir för varmt att ha på sig den
- Designa så att andra muskler ej belastas fel
- Designa så endast tillför en liten extra vikt
- Säkerhetsaspekter

Alt:

- Något som varnar användaren vid oergonomiska arbetspositioner
- Något som styrs av en app
- Smart teknik där sensorer känner av vart användaren behöver extra hjälp

9. Sele/bälte som fäster i maskin

Sele, bälte eller väst där man kan hänga maskinen för att få extra stöd när man kapar längre ner, så man slipper anstränga armarna lika mycket

Fördelar

- Hjälper till att hålla upp vikten från maskinen
- Kan placeras nära kroppen
- Kan användas i trånga utrymmen
- Potential att underlätta arbete vid golv
- Kan utformas för att passa olika maskiner

- Slipper bära maskin med armar lika mycket

Nackdelar
- Risk att andra delar av kroppen blir felbelastade/ överbelastade
- Finns risk för snedbelastning
- Risk att ökar belastning på rygg på ett oergonomiskt sätt
- Risk att användaren använder musklerna på “fel” sätt vid tunga lyft
- Säkerhetsaspekter då man sitter fast i maskinen
- Synlig, risk för låg acceptans bland användare?
- Kan upplevas tidskrävande att ta på sig
- Underlättar ej arbete över midjehöjd
- Är en extra sak som användaren själv ska ta med sig och ta på sig

Att tänka på
- Designa så kan has på hela dagen
- Designa så enkelt kan ta på och av bendelen
- Designa så det ej bidrar till att bli med jobbigt att böja sig fram
- Designa så att ej andra muskler belastas fel
- Designa så att exoskelettet följer människans uppbyggnad och rörelsemönster (för bidra till en mer naturlig och ergonomisk användning)
- Designa så den ej gör det extra varmt för användaren
- Designa så att det kan kopplas bort från maskinen efter användning
- Designa så ej skaver när böjer sig (uttryckt problem från viktbälten)

Alt:
- Designa så att den kan användas till olika maskiner
- Designa så att man kan koppla bort maskinen efter användning
- Designa så att vikten fördelas ergonomiskt
- Designa så att det finns en säkerhetsutlösare om man vill koppla bort maskinen snabbt

Urval av konceptgrupper

De nio konceptrgupperna kan delas in i tre kategorier utifrån användningsområde. De grönmarkerade konceptgrupperna är de grupper som att analysera vidare med expertanvändare under konceptutvärderingsfasen.

1. **Koncept som kan underlätta vid specifika arbetsmoment**

Dessa koncept har potential att avlasta tyng vid vissa specifika moment.

- Förlängd arm
- Stativ
- Fiskespö

- Sele / bälte som fäster i maskin

Motivering av val:

- Vi har valt att jobba vidare med de två konceptgrupper som avlastar användaren mest. Detta är den förlängda armen samt stativet. Båda dessa koncept håller upp en stor del av maskinens tyngd.
- Sele/bälte som fäster i maskinen valdes bort då den inte bidrar till att hålla upp maskinen i samma utsträckning som armen och stativet. Dessutom belastar ryggen betydligt mer i redan kritiska arbetspositioner (när man har böjd rygg). Den bidrar inte till någon bärande hjälp över midjehöjd.
- Fiskespöt anses vara en otymplig lösning vilken kan vara svår att anpassa till kontexten. Det finns stora risker att fastna. Den hade även krävt en acceptans av användaren som i dagsläget ej existerar. Svårare att arbete mot golv. Mycket möda för ganska få arbetspositioner. Säkerhaspekter.

2. Koncept som kan underlätta med generella arbetsuppgifter en hel arbetsdag

Dessa koncept kan underlätta en del under själva kapning och borrning (främst i markhöjd) men även under andra moment. Kan bäras under dagen och underlätta lite hela tiden.

- Passivt system inbyggt i kläder
- Väst exoskelett
- Bälte
- Aktiva kläder

Motivering av val:

- Passivt system inbyggt i kläder valdes på grund av att det det är ett koncept där användaren slipper släpa på extra material, då det sitter på hela dagen. Ingår redan i något som användaren behöver ta på sig. Hjälper med tunga lyft vilket är en stor börda generellt under dagen.
- Exoskelett för rygg (väst) valdes på grund av att den kan bidra till underlättandet av tung lyft under arbetsdagen, samt då det finns möjlighet att göra den flexibel och följsam. Finns liknande på marknaden men används ej, är det för att det ej riktas mot byggarbetare eller för att den inte hjälper? Behövt kolla mer på detta. Därav är konceptet intressant att utforska mer.
- Ergonomiskt bälte finns redan idag i många olika varianter och utformningar men tycks ej användas så mycket. Ger ingen bidragande hjälp med själva lyften utan bidrar mest till mer ergonomiska lyft. Detta är snarare något som borde implementeras som en dellösning i ett annat concept.
- Aktiva kläder: Finns stor potential men skulle innebära teknik och konkreta lösningar som är utanför vårt kunskapsområde. Värt att kolla mer på i framtiden för Husqvarna men inget vi hinner göra ngt med under denna period (bortprioriteras i detta projekt). Kommer inte kunna bidra med jättestor lyftkraft gentemot idéerna i grupp 1.

3. Förändring av maskinen i sig /tillbehör på maskin

Detta koncept förändrar maskinen i sig.

- Förlängningsbart handtag

Motivering av val:

- Ett förlängningsbart handtag handlar mer om att på något sätt ändra maskinen i sig, på så finns det möjlighet för användaren att slippa bära med sig eller ta på sig en extra del. Denna kan underlätta släpande på själva maskinen mellan platser samt minska mängden situationer där användaren måste jobba med böjd rygg.

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