CHALMERS
UNIVERSITY OF TECHNOLOGY

Development of Exoskeleton for Loggers

User Centred Design of Passive Lower-Back Support for Motor-Manual Tree Felling, in collaboration with Husqvarna AB

Master's Thesis in Industrial Design Engineering

STEFAN RÖJGREN & ANTON WIDELL

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2022
www.chalmers.se

Master's thesis 2022

Development of Exoskeleton for Loggers

User Centred Design of Passive Lower-Back Support for Motor-Manual Tree Felling, in collaboration with Husqvarna AB

STEFAN RÖJGREN & ANTON WIDELL

Department of Industrial and Materials Science
Division of Design & Human Factors
Chalmers University of Technology
Gothenburg, Sweden 2022

Development of Exoskeleton for Loggers
User Centred Design of Passive Lower-Back Support for Motor-Manual Tree Felling, in collaboration with Husqvarna AB
STEFAN RÖJGREN & ANTON WIDELL

Supervisor & Examiner: Lars-Ola Bligård
Supervisor Husqvarna AB: Hans-Åke Sundberg

Master's Thesis 2022
Department of Industrial And Materials Science
Division of Design and Human Factors
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: Rendered image showing the front and rear of the final design concept H-EXO.

Typeset in LaTeX
Printed by Chalmers digitaltryck
Gothenburg, Sweden 2022

Development of Exoskeleton for Loggers
Stefan Röjgren & Anton Widell
Division of Design and Human Factors
Chalmers University of Technology

Abstract

This thesis was conducted in collaboration with Husqvarna AB, which is one of the biggest providers of products for forestry applications in Sweden. Aiming to be at the forefront of technical innovation, exoskeletons was seen as an area of interest for the company. The aim of the project was to investigate the possibilities of using an exoskeleton as a facilitator for prevention of musculoskeletal disorders (MSDs) for loggers performing motor-manual forestry work using chainsaws.

User evaluations and literature studies showed that MSDs in the lower back are frequently occurring among the user group, materializing as pain. Lower back pain can stem from a number of issues, where strain or spasms of back extensor muscles is common. The lower back is mainly affected by body posture and the physical load when performing work tasks with the chainsaw, frequently executed with a forward leaning posture and standing with bent legs. The tasks with the highest risk of postural strain are felling and limbing, where the working posture in combination with duration is classified as high ergonomic risk.

The project follows the Double diamond design process with great emphasis on the discovery and development phases. The theory of emotional design was implemented with behavioural design as the main focus and with the aim to achieve user acceptance by influencing via the visceral and reflective design levels.

The final design concept is a spring loaded passive exoskeleton supporting the lower back of the wearer, focusing on lowering back extensor muscle activity. The functionality is facilitated by using elastic bands as they can be worn close to the body across the back, allowing free mobility along the side areas of the body. The solution consists of a torso harness, a tool belt and two leg supports with inter-connectivity. The torso harness and tool belt use existing Husqvarna equipment as a base, modified to suit a forestry context and to facilitate the function of relieving strain on the lower back of the user.

While adaption of ergonomically correct working postures remain the most important factor for preventing MSDs and pains among loggers, it is concluded that an exoskeleton product could potentially give further support to the user and help prevent pains from materializing.

Keywords: Forestry, Chainsaw, Passive Exoskeleton, Musculoskeletal Disorder, Lower back, Ergonomics, Double Diamond, Emotional Design.

Acknowledgements

We would like to thank Husqvarna for giving us the opportunity to perform our thesis concerning an innovative product in such an interesting field as forestry, and for providing us with equipment and products that were of great value for the development process.

Special thanks is directed to Hans-Åke Sundberg for being our company contact and supervisor during the course of the project, providing crucial information and coordinating field trips and meetings with other Husqvarna personnel, as well as giving feedback and direction on the process.

Further, we would like to thank our supervisor and examiner Lars-Ola Bligård for guidance and helpful advice during the course of the entire thesis project.

Finally, we want to express our deepest gratitude to all chainsaw instructors, loggers and other forestry personnel as well as Husqvarna employees for contributing to this project by participating in the survey, interviews, observations and evaluations. Without their help and genuine interest the project would not have been possible to realize.

Stefan Röjgren & Anton Widell, Gothenburg, June 2022

List of Acronyms

Below is a list of acronyms that have been used throughout this thesis, listed in alphabetical order:

CAD	Computer Aided Design
DFA	Design Format Analysis
EM	Extensor Muscle
GDPR	General Data Protection Regulation
H-EXO	Husqvarna Exoskeleton
KIM (I & III)	Key Indicator Method
MSD	Musculoskeletal Disorder
OWAS	Ovako Working-posture Analysis System
PNI	Positive, Negative, Interesting
REBA	Rapid Entire Body Analysis
SEK	Swedish Krona
UB	Upper Body

List of Terms

Below is a list of terms and their definitions that have been used throughout this thesis, listed in alphabetical order:

Arborist	A specialist in the care and maintenance of trees
Autodesk Fusion 360	3D-modeling software
Biomechanics	Mechanical forces and their effects when applied to the human body
Blender	3D-modeling software
Branching	The act of removing branches from a felled tree
Bucking	Cutting up a tree stem into shorter segments
Clip Studio Paint	Digital software for visualization and photo editing
Exoskeleton	A wearable structure that supports and/or enhances the abilities of the wearer during use
Extensor muscles	Muscles in the lower back active during forward bending
Figma	Web-based vector graphics editor and prototyping tool
Flexion	Forward bending
Logger	Forestry worker, lumberjack, woodcutter
Lumbar spine	The spine section of the lower back region
User	Potential user of the product, in this case chainsaw operators/loggers
Vertebrae	Bone structures of the spine

Contents

List of Figures

All figures used with permission or created by the authors.

List of Tables

1

Introduction

This chapter gives the background to the project and the identified issues therein, as well as the aim and demarcations chosen for the thesis. Lastly, an outline of the report is presented.

1.1 Background

Husqvarna was founded in 1689 in Huskvarna in the municipality of Jönköping, and has since been producing a variety of products, ranging from weaponry and sewing machines to motorcycles. In 1959 the increased use of chainsaws in forestry created a rapidly growing demand, and with their expertise in engines an opportunity to enter a new market arose and that year Husqvarna's production of chainsaws took off. Today Husqvarna is an international company with 14 000 employees and has net sales of 47 billion SEK (Husqvarna, 2022c). Husqvarna is the world's leading producer of forest and garden products, offering an extensive range of products, including e.g. chainsaws, clearing saws and autonomous lawn mowers (Husqvarna, 2022b). Their equipment is used by house owners and private forest owners as well as professionals, and Husqvarna is always looking for new ways to improve and expand their product portfolio.

This thesis was conducted in collaboration with Husqvarna AB's Forest and Garden division, and focused on professional loggers in a forestry setting. For professional loggers who use tools such as chainsaws daily, intense physical work during prolonged periods of time is required. This may result in physical pains and ailments, with the *European Agency for Safety and Health at Work* identifying the work group as being one of the highest in risk of musculoskeletal disorders (Grzywiński et al., 2015). Forestry work also presents a higher risk of accidents compared to other industries (Landekić et al., 2021). It is therefore of value for these workers, as well as their employers, to reduce the amount of physical loads experienced in the field to prevent injury and fatigue. One approach to this issue is by lightening the physical loads and/or improving body posture by using an exoskeleton, which can give support to selected areas of the body, relieving muscles or selected joints and limbs.

Recent years has seen an increased activity on the exoskeleton market, where externally worn harnesses for physical support have been introduced in various settings, such as medical, military and industry. While still in its infancy, the market has seen a variety of startups presenting exoskeleton products for different manual labor situations, with some well-established companies having exoskeletons or similar aids in their product portfolio. Thus, Husqvarna aimed to explore the possibility of entering this market by performing a pre-study about the user needs for physical aid products in a forestry context. Husqvarna also wanted to gain knowledge about existing exoskeleton products on the market and explore their different solutions and features, to see if these are applicable in a forestry setting.

1.2 Aim

This thesis serves as part of the initial phase of investigating if an exoskeleton can serve a purpose as a tool for a healthier and more sustainable work environment for the user of Husqvarna products in a professional forestry setting. The aim of this thesis was to evaluate how the use of an exoskeleton can function as a facilitator for improving the working conditions by reducing physical strains on the body in order to create a healthier and more sustainable work environment within the forestry sector. Furthermore, the intention was to develop a conceptual design of an exoskeleton product that could work as an entry product for Husqvarna on the forestry market. The concept was to be grounded thoroughly on identified user needs, focusing on providing ergonomic support and usability while operating in a forestry context.

1.3 Objective

The objective of the project was to perform a literature review, benchmarking and user studies in order to determine the user needs and requirements for an exoskeleton product in a forestry setting. The result is presented as a well-defined concept with a medium to high level of detail in the form of a 3D model, using design language corresponding to Husqvarnas product portfolio.

The following research questions were examined in order to reach the objective:

- Could an exoskeleton product be a feasible solution for improving the working conditions and reduce the risk of physical strain and fatigue for loggers?
- How can an exoskeleton improve the physical working conditions, with regards to preventing physical strain and fatigue for loggers?
- Which design factors are most essential for an exoskeleton to be used in a forestry setting?
- Which product functions or features are most valuable to the user?

1.4 Demarcations

The project encompasses the context and environment for Swedish forestry workers, primarily those using Husqvarna tools in their profession. Professional forestry workers operating chainsaws in manual tree felling were considered as the main user group, and as such observations, field studies and interviews were primarily performed with focus on these users.

The literature review and benchmarking of exoskeletons mainly focused on passive models, i.e. products without an external power source. This was due to the fact that forestry work often is performed in remote areas, making reliance on power in the form of electricity or batteries an issue. Powered exoskeletons also tend to be heavier, which was not desirable for the user group.

Husqvarna wanted the resulting concept of this project to be an entry product for the market, with a comparatively low retail price for the customer. No exact price has been specified, but a retail price between 5000 and 10000 SEK was expressed as reasonable. This set restrictions on which technical solutions and production processes that could be used. However, no cost estimations or analysis have been performed on the final concept due to the early stage of development.

Despite arborists being a major group working frequently with chainsaws, the group was not considered in the project due to their working methods being severely different to those used by loggers, leading to entirely different needs. As such it was considered doubtful to be able to develop a concept that could meet the requirements of both user groups in this initial stage.

No physical testing of performance of the final concept has been made in this project, nor has any simulations regarding the same been performed. Instead, assumptions regarding performance have been made based on available literature.

Husqvarna has a long experience in producing workwear, tool belts and harnesses of high quality for the forestry sector. Therefore, the choice of materials are based on Husqvarnas existing products and no evaluation of the materials are included in this study.

1.5 Outline of the Report

The final design concept is presented in Chapter 2, explaining each component of the design and their functionality. This is followed by an in depth description of the user context in Chapter 3 and theoretical framework in Chapter 4, providing context for the identified problems of the users. Chapter 5 contains short descriptions of each method used during the course of the project, starting with the general design process followed by each method used in the different phases.

Chapter 6 is a chronological account of the process where the execution of each project phase is described. The results for the used methods and the analysis thereof is presented in Chapter 7 in terms of how these relate to the design decisions. Finally the result and execution of the project is reflected upon and discussed in Chapter 8 and the thesis ends with a conclusion, listing the main takeaways and recommendations for future development.

2

Final Design Concept

Figure 2.1: Front and rear view of Husqvarna Exoskeleton, worn on a mannequin.

The resulting design concept of the thesis project is named *Husqvarna Exoskeleton*, abbreviated as *H-EXO* in this report. The H-EXO is a passive exoskeleton that is combined with a Husqvarna Flexi logger tool belt and to some extent a harness, which are modified in order to accommodate user demands and increase comfort (Figure 2.1). By integrating the existing equipment the H-EXO works as a complete solution rather than being an add-on product, creating value for the customer. Being worn over the standard work wear, the exoskeleton aims to fit as many users as possible, as well as being easy to remove when forestry tasks other than felling are performed. The product is intended for usage by professional chainsaw operators within the forestry industry, particularly during the task of tree felling which involves many instances of forward bending postures. As this task may prove to be harmful for the lower back area in the long term, the H-EXO aims to reduce the risk of pain by relieving the back extensor muscles which are active during forward bending motions. In theory, the lowered activity of the back extensor muscles would reduce the risk of the muscles being overstimulated which can cause strain and spasms, leading to pain. Further, these muscles contribute the main part of compression forces acting on the lower spine, which in the long term may also lead to pain materializing in the area.

The aesthetics of the H-EXO is based on a *Design Format Analysis* as a foundation and is adapted to match the design of the Husqvarna Flexi tool belt and harness, and to an extent follow the look and feel of these products. The idea of this combination with the existing product is to create recognition for the loggers. With the visual appearance in combination with durable materials the aim is to exhibit a professional expression of the product. These factors and the overall functionality of the H-EXO should ideally lead to a higher acceptance level with regards to adapting a new product among the users. For locations and naming conventions of components used throughout the report, see Figure 2.2 and Table 2.1.

Figure 2.2: Locations of H-EXO components.

Code	Component
A1	Torso harness
A2	Activation clasp
A3	Back strap
A4	Sternum/shoulder strap
A5	Elastic band, spring mechanism
A6	Gear loops
A7	Size adjustment points
B1	Tool belt
B2	Openable pocket
B3	Ventilation ridges
B4	Belt buckle
B5	Lower back support structure
B6	Belt strap
C1	Connection strap top
C2	G-hook connection
C3	Connection point
C4	Connection strap leg
D1	Leg support
D2	Leg belt strap
D3	Leg belt buckle
D4	Buttocks cover
D5	Strap length adjustment point

Table 2.1: H-EXO component naming conventions and codes.

Figure 2.3: H-EXO with and without connection straps between torso harness and tool belt.

One main feature of the H-EXO is the option of having part of the tool belt load transferred to the shoulders, using four optional straps (C1) connecting the tool belt to the torso harness via g-hooks as shown in Figure 2.3. As loggers had different opinions concerning this topic, the choice is left to the wearer, creating customer customizability.

2.1 Technical Solution

The core functionality of the H-EXO is provided by elastic bands (A5) attached to straps (A3) placed on the back, connecting the torso and upper legs. The elastic elements function as artificial external muscles, giving relief to the back extensor muscles during forward bending. Kinetic energy is stored in the elastic bands during bending, where the bands expand as illustrated in Figure 2.4. The energy is then 'released' as the body is returned to a straight position. The bands thus act as a spring mechanism, making the product self-reliant with no further addition of energy sources.

Figure 2.4: Illustration of the H-EXO and the elastic spring mechanism extending during forward bending motion.

The clasps attached to the front side of the shoulders (A2) are designed to enable activation and deactivation of the elastic bands (A5). This functionality allows the exoskeleton function to be activated at will, to allow for deactivation during transportation and work pauses when the user is not in need of physical assistance. The strap connected to the spring gets activated when the clasp is pushed down/forwards and the elastic band gets stretched. The reasoning behind this function is to allow the user to move freely when not actively working, and avoid having the spring mechanism from the harness acting on the body. The environment in which loggers operate varies widely and can be demanding, where there might be dense vegetation and uneven ground which emphasizes the need of mobility for the user.

While the exoskeleton is in deactivated mode the logger can walk and navigate in the forest environment without any impact from the spring mechanism.

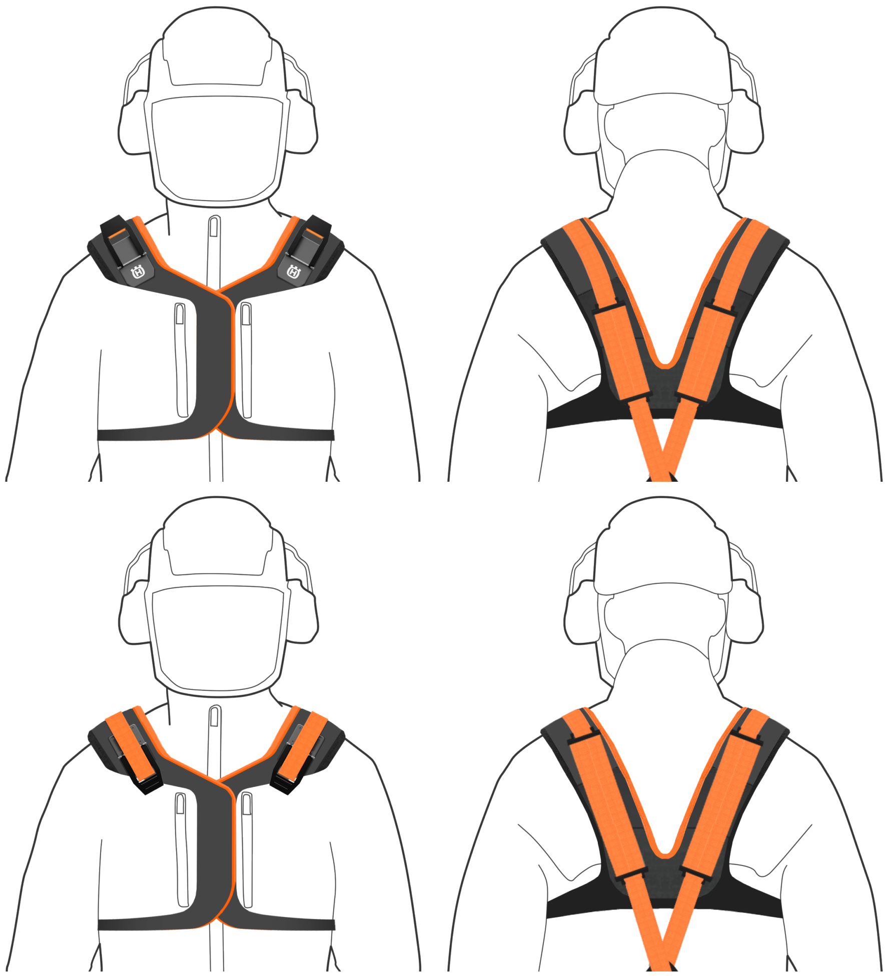


Figure 2.5: Illustration of the activation functionality, off (top) and on (bottom) state.

2.2 Torso Harness

The H-EXO is designed to be easy to wear, starting with the design of the torso harness (A1). The user puts their arms through the shoulder straps and snaps them together over the sternum using built-in magnets. Subsequently, the H-EXO is attached to the user by fastening three additional buckles, one on the waist and two for the leg supports. All straps are adjustable to enable the user to adjust the H-EXO to fit well. By allowing these adjustments the H-EXO should be able to accommodate a large variety of body types.

The design of the torso harness of the H-EXO aims to provide mobility of the arms, provide comfort for male and female users and to distribute loads. The shape of the sternum straps creates space for the arm to move unhindered in front of the body, allowing the operator to carry out tasks without interference. By centering the connection to the middle of the sternum the H-EXO should provide a comfortable fit to both female and male users. Additionally, as seen in Figure 2.7, the torso harness is designed to give easy access to jacket chest pockets, where the logger might store important equipment such as a phone and/or first aid kit. The placement of chest pockets are relatively standardized for this type of work wear, meaning that most users should have chest pocket access even when using the H-EXO. The sternum straps connect via magnets, securing the harness over the chest with the straps overlapping each other. The use of magnets allows the user to disconnect the sternum straps with one hand, which can be beneficial in the case of an accident, or when one hand is occupied with holding tools. Gear-loops connection points (A6 in Figure 2.2) are placed on the outer chest strap to allow attachment of equipment for easy access, e.g. cell phone holster or personal equipment of choice.

Figure 2.6: Illustration of the shoulder straps being attached.

Figure 2.7: Illustration of magnet location and chest pocket access.

The main function of the rear of the torso harness is to keep the spring loaded straps in a correct position. The garment is designed to cover as little of the back area as possible without impacting function and the comfort of wearing it. There are two reasons for reducing the size of the torso harness. Firstly, the less direct contact between the body and the H-EXO the better, as heat and sweat is accumulated in covered sections. Secondly, by reducing the amount of textile area, the weight of the H-EXO is lowered.

Figure 2.8: Upper back view of the torso harness.

The spring mechanism functions via elastic bands placed on the back of the harness, a solution that was chosen based on it being unobtrusive, lightweight, cost efficient and comparatively easy to produce. Compared to rigid exoskeleton solutions, such as the Laevo V2.5 and BackX (see Chapter 4.3), the elastic band solution allows for leaving the side areas of the body completely free for motion, which was deemed important in the context of chainsaw operation. The back straps containing the spring mechanism are colored orange to stand out visually and to highlight and indicate the function of the H-EXO.

An optional cover for the elastic bands was designed, intended to serve two purposes. Primarily, it can be used to protect the textile spring material from getting damaged during use, as a forest environment may cause wear and tear of the material. Secondly, when working the logger is obligated to wear high visibility clothing. These regulations exist to increase safety at the sites, making detection easier among the loggers and machine operators as well as for e.g. nearby traffic. The high visibility clothing also serves a purpose in case of an emergency, where it is essential for the logger to be visible to facilitate detection from rescue personnel, e.g. from a helicopter. By wearing the H-EXO the work wear beneath gets partially covered and the visibility of the user may thus be affected to some degree. The cover can compensate for the coverage by facilitating implementation of additional reflective high-visibility material on the product, represented by the white fields in Figure 2.9. The area may also serve as a spot for companies to expose logotypes. The cover may be an add-on product that can be neglected, as it does not affect the main function of the H-EXO. The cover should use lightweight material, preferably allowing ventilation via small air punctures as seen in Figure 2.9, so as not to influence the body heat issue. However, the cover was not one of the main focus points of the project, and has been left in an early concept stage, serving as inspiration for future work.

Figure 2.9: Upper back view of the torso harness with suggested cover design.

2.3 Tool Belt

The tool belt component (B1) is a redesigned version of the currently available Husqvarna Flexi logger tool belt. The belt is a common feature of the standard logger working equipment, used to carry appliances and necessary equipment during forestry work. The general shape of the belt, being thinner in the front to allow forward bending, has been kept in the redesign, together with the main belt buckle. However, the middle back area (B5) has been extended upwards in comparison to the Flexi belt, to provide better lumbar back support and improve posture while standing in an upright position. A padding structure has been added on the inside of the belt to improve comfort. The padding is designed using straight ridges (B3), evenly spread out around the inside of the belt. This is implemented to permit airflow between the body and belt, in order to reduce the heat and sweat accumulated in this area during use.

Figure 2.10: Illustration of padding and the openable pocket on the inside of the belt.

The hollow pocket in the back of the belt (B2, Figure 2.10) allows the back straps (A3) to run through, keeping them in place yet allowing them freedom of motion in the vertical direction. The pocket is openable to allow for detachment of the tool belt from the exoskeleton structure. Together with the g-hooks supplied connection straps (C1) connecting the belt to the rest of the exoskeleton, this makes it simple for the user to detach the belt and wear it separately when performing tasks that are not demanding on the lower back area. Both sides of the openable structure need to be of a semi-rigid structure in order to allow the back straps to move freely in-between without the risk of being pinched between the outer belt and wearer.

2.4 Leg Supports

The main function of the leg supports is to anchor the back straps, allowing them to transfer the upper body load via the elastic bands to the larger muscle groups of the thighs. The supports are attached around the upper parts of the thighs, and fastened via a quick release buckle. Being able to move independently of each other, the leg supports are not directly connected to each other, as this would hinder movement in a forest environment.

The leg supports are formed by a strap going around the thigh, and the larger section in the back area cover parts of the buttocks to provide comfort and support. The size of the leg straps aims to be small to reduce the accumulated body heat, but without affecting the comfort. The parts covering the buttocks connect the spring loaded straps to the legs (D4). The connection straps (C4) located along the hips are permanently attached on the leg straps, implementing a g-hook to connect to the tool belt, functioning as a lock to make the belt stay in position during forward bending, and enabling detachment from the tool belt.

Figure 2.11: Leg support shown from front, side and back view.

The user has the option to attach tools such as wedges or measuring tape to the leg supports, as the outer strap shares the same width as the corresponding one on the tool belt, which is compatible with Husqvarna's tool holsters. This enables customization for the user, which was deemed highly desirable. Tools attached to the leg straps may be more easily accessible compared to when placed on the rear of the belt, as illustrated in Figure 2.12.

Figure 2.12: Wedge tool holster attached to leg support.

3

User Context

This chapter aims to describe the environment, work tasks and equipment that the user group interacts with on a daily basis.

3.1 Forestry Practice

Forestry is the practice of planting, maintaining and harvesting trees in a forest context. The practice has a long history and remains an important industry today, with around 3.5 billion m^3 wood being harvested each year worldwide (Garland, 2018). In Sweden the harvest volumes reached about 93 million m^3 during 2019, grossing over 30 billion SEK, and in 2021 the volume is estimated at 96 million m^3 (Skogsstyrelsen, 2022). Harvested wood in Sweden mainly consists of spruce and pine, at 54% and 34% of the total harvested volume respectively (Riksskogstaxeringen, 2021). The number of employees within the forestry sector is estimated at 13.7 million globally, with an additional unknown number of unregistered workers performing forestry work (Garland, 2018). Swedish forestry worker numbers reached just above 28 000 as of 2020, 11% of which were women, while the number of forest owners count at least 300 000 (Skogsstyrelsen, 2022).

Motor-manual tree felling (i.e., use of chainsaw) remains the most common method in many countries where harvesters are not as frequent. In 2014 more than 80% of the wood harvest in Poland was felled using chainsaws (Grzywiński et al., 2017), whereas in Sweden the corresponding number is below 10% as harvesters are utilized to a far greater extent (Skogskunskap, 2022), being one of the most fully mechanized forestry industries in the world. Comparatively, North America and most other countries in Europe have a far lower rate of mechanization, relying more on motor-manual felling during harvest (Lundbäck et al., 2021). Example rates of forestry mechanization are 55% in France, 65% in Germany, 75% and 5% in Eastern and Western Canada respectively, 15% in the USA, 30% in South Africa and 45% in Brazil (Lundbäck et al., 2021), indicating that a majority of international industries have a higher frequency of chainsaw use.

Professional loggers (i.e., wood cutters) usually work independently, alone or in pairs, performing manual labor tasks which a harvester cannot access, and often in remote areas (Dimou et al., 2020a). The practice of tree felling can be divided into the following tasks: cutting, limbing (or de-branching) and bucking (cutting the stem into smaller pieces). Within Swedish forestry practice the bucking task is performed directly at the work site in the forest, whereas in many other countries this is only done once the wood has been transported to a factory location (Skogskunskap, 2022). Felling and related work tasks involve a lot of planning, in order to work in a safe manner and to facilitate optimal ergonomic conditions. This is for example done by, when possible, felling the tree in a direction that will ensure it landing on top of a previously felled tree, creating a more comfortable working height for the subsequent limbing and bucking (Skogskunskap, 2022).

3.2 Work Environment

Forestry work, and tree felling in particular, is considered a hazardous occupation with a high degree of accidents and resulting injuries compared to other fields of work, and has been categorized as “demeaning, dirty and dangerous” (Landekić et al., 2021). Laboring in a forest involves walking across, as well as working on, uneven and angled terrain, traversing obstacles such as branches, fallen trees and undergrowth (Calvo, 2009; Garland, 2018). The occupational hazards may be further increased by working in forests where trees have been storm-felled, leading to unpredictable situations with semi-uprooted trees and risk of falling branches and stems. Fatal injuries occur, and between five and ten people are killed annually in Sweden while performing forestry work (Gullberg, 2015), while 110 persons suffered occupational injury during 2020 (Skogsstyrelsen, 2022).

In the past, manual tree felling was a piecework, meaning that the worker got paid based on the amount of trees felled. This led to high stress and increased risk-taking (Interview). This way of setting wages has since been replaced in order to create a more sustainable and healthy work environment. Even though these changes decreased the workload, many loggers still describe their work as highly physically demanding (Survey, interviews).

With forestry work being performed outdoors year-round, loggers are exposed to a high variation of temperatures and weather conditions. Appropriate clothing is therefore needed, with more layers being worn during winter to counter the cold. However, loggers generate a large amount of heat while working, with many experiencing warm body temperatures and sweating regardless of the air temperature, leading to discomfort (Wästerlund, 1998).

Other factors impacting the work environment is the noise level produced by the tools, most notably the chainsaw, which can reach circa 119 dB in sound power level (Husqvarna, 2022a). Exposure to noise and vibrations produced by the chainsaw and other machines, as well as atmospheric conditions, may lead to the worker experiencing reduced hearing, onset of hand-arm vibration syndrome as well as other ailments concerning muscles and the vascular system (Iftime et al., 2020).

3.3 Equipment

The equipment in use by professional loggers mainly serves the purpose of personal protection and safety, as the work and the tools used may create dangerous situations and injury unless precautions are taken. Typical safety equipment and work wear worn during chainsaw operation includes helmet (with noise protection, eye visor and neck cover), high visibility jacket, chainsaw protection pants or apron chaps, work boots (with steel toes and chainsaw protection) and protective gloves (Garland, 2018; Gullberg, 2015). For a selection of tools used and carried during felling operations, see Figure 3.1.

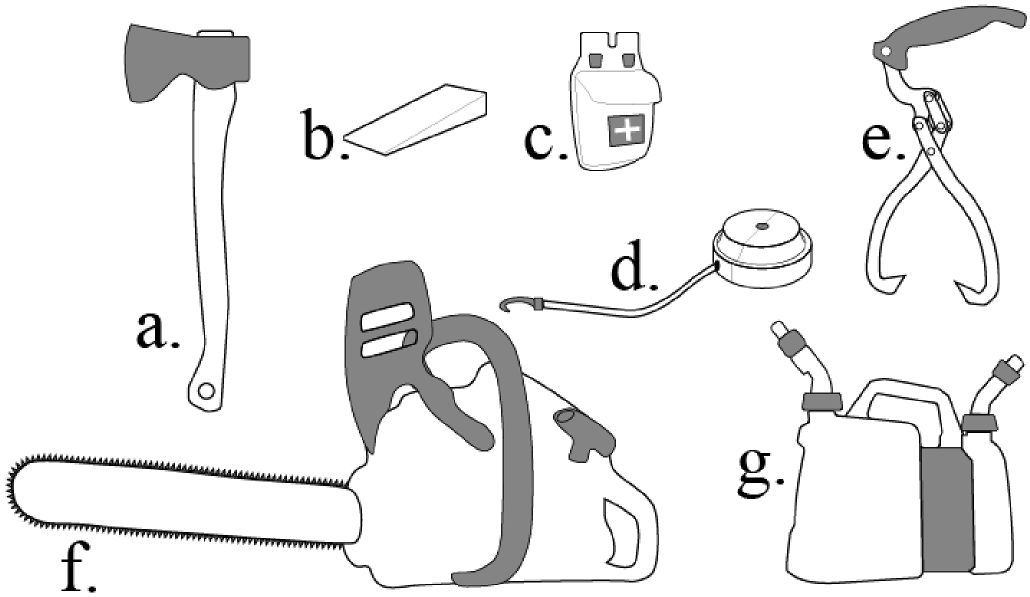


Figure 3.1: Visual representation of equipment carried and used by loggers.

Loggers usually wear a tool belt carrying this additional equipment, such as an axe or sledgehammer **(a)**, splitting wedges **(b)**, measuring tape **(d)** and lifting hooks and tongs **(e)**. Lifting tongs are used when transporting cut wood shorter distances, to get a better grip on the log while lifting or dragging. The measuring tape is used when bucking, to obtain logs of equal length in order to maximize the economic gain for the wood owner. The splitting wedge is a simple accessory used during felling to gain increased control over the felling direction, preventing the chainsaw blade from getting stuck under the tree weight, as well as providing leverage force (Gullberg, 2015). The belt may also store other equipment, for example for servicing and maintenance of the chainsaw. The logger also needs easy access to a first aid kit **(c)** and a mobile phone for emergency situations (Skogskunskap, 2022).

The main tool used for cutting, limbing and bucking is the chainsaw **(f)**. It comes in many variants and sizes, depending on the user needs, such as the type and thickness of the wood that is to be cut. Most chainsaws are powered by petrol, meaning that it is also necessary to bring a petrol can **(g)** with additional fuel to the working area for refilling purposes. An average fully assembled chainsaw with petrol weighs between 5 and 7 kg, and a filled petrol container weighs up to 8 kg (Husqvarna, 2022a). Electrically powered chainsaws have increased in numbers on the market in recent years but are yet to reach the prevalence of petrol-powered models.

Figure 3.2: Example of tool belt and tool layout during work.

Figure 3.3: Husqvarna Flexi logger tool belt with harness (Husqvarna, 2022d).

As shown in Figure 3.2, loggers generally prefer to place equipment mainly on the rear and side areas of the tool belt. As such, the tools do not obstruct movement and forward bending during work, but are still within reach when needed. The exact tool position on the belt is customized by the user, depending on personal preferences and situation. Figure 3.3 displays *Flexi*, a reference logger tool belt developed by Husqvarna, in use by many loggers today. The belt itself consists of an inner broad semi-rigid band intended to give some ergonomic support to the wearer, with an outside strap connecting the belt around the user's waist. The strap is also used as an attachment point for tool holsters, specifically designed for tools such as wedges and lifting tongs. These can be placed along the strap according to personal preference. The belt has four connection points where a shoulder harness can be attached, giving the user the option to transfer some of the tool belt load from the hips to the shoulder area (Husqvarna, 2022d). A tool belt complete with equipment may weigh 2-4 kg.

3.4 Ergonomics

Ergonomics encompasses adapting and adjusting human labor in order to prevent risks of illness and accidents. It includes planning and organization of the work environment and how tasks therein are performed, including physical, organizational and mental aspects of the work. Here, mainly the physical ergonomics, i.e. work posture, is considered.

Figure 3.4: Example of posture adapted during initial stage of felling.

Loggers working with motor-manual tasks such as tree felling adapt body positions and postures which are necessary to achieve accurately placed cuts to the stem and branches. This often involves working close to the ground during felling, and leaning across the stem during limbing (Skogskunskap, 2022). Forward leaning, crouching, and bending and/or twisting of the back is common. An example of such a posture is shown in Figure 3.4. A study by Grzywiński et al. (2017) showed that 47% of loggers adapted a posture with straight legs and bent back, and 34% with legs bent, as they give the greatest range to the upper limbs and provide the highest work efficiency. The same study suggested that other postures such as squatting and kneeling on one knee during felling resulted in a lower heart rate and workload, but the authors do not recommend them for long-term use due to higher strain, e.g. on knee joints (Grzywiński et al., 2017).

The safety aspect of working with a chainsaw heavily impacts body posture and position in daily forestry work. The chainsaw is seldom used above hip height, and is explicitly prohibited to use above shoulder height due to the risk of kickback motion and resulting injury to the face and neck area (Gullberg, 2015). During felling the necessity of resting the chainsaw on the stem is often emphasized, to transfer the tool load away from the body. Furthermore, the guide bar and chain should not be positioned adjacent to the body, while the main housing and handles often need to be supported on the legs or hips to provide stability and satisfactory working procedure as well as reducing the risk of kickback motion (Interview).

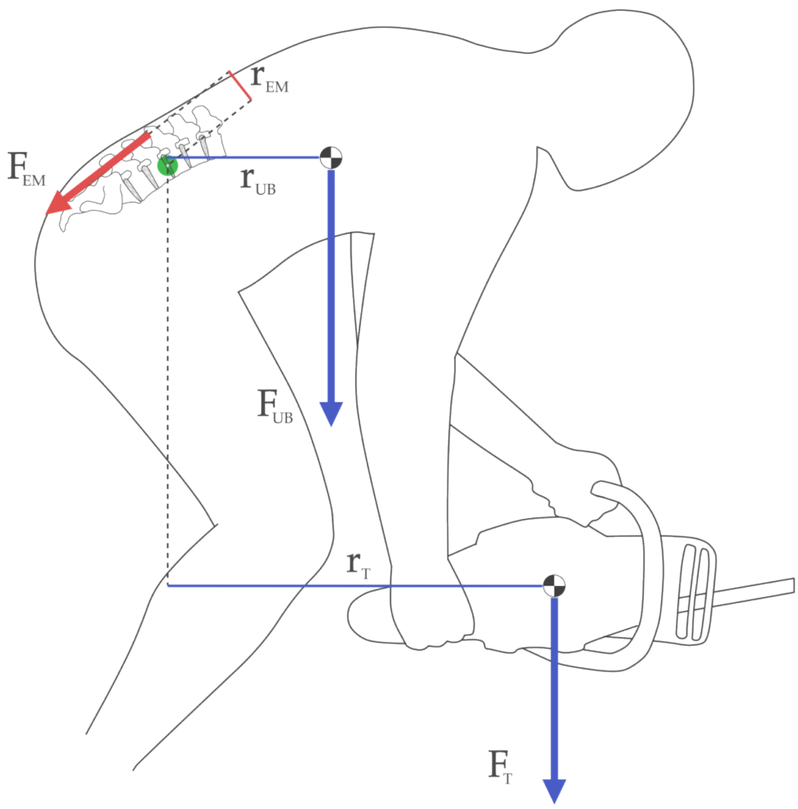


Figure 3.5: Simplified view of forces and moment arms acting on the lumbar spine during felling.

As shown in Figure 3.5, a normal felling posture results in forces from the upper body and tool (F_{UB} and F_T, respectively) creating a moment acting on the lumbar spine, which needs to be counter-balanced by the back muscles (F_{EM}). The biomechanical system can be described by the following equilibrium equation:

$$F_{EM} * r_{EM} = F_{UB} * r_{UB} + F_T * r_T \tag{3.1}$$

This is further elaborated upon in Chapter 4, Sections 4.2 and 4.3.2 specifically.

4

Theoretical Framework

This chapter aims to describe the related theory needed to contextualize the identified user needs.

4.1 Musculoskeletal Disorders

Musculoskeletal disorders (henceforth referred to as *MSDs*) is an umbrella term covering a range of conditions affecting muscles, joints, bones and other body areas, and which can be temporary or permanent in nature. MSDs often present in the form of pain and limited mobility in limbs or areas of the body (WHO, 2021), and thus may have large implications on the general health for the individual. Worse, it may lead to an inability to work as well as impeding on leisure activities and other forms of societal involvement. Bevan (2015) states that there also exists a link between mental health and MSDs, where people suffering from MSDs for example are "*more likely to have depression or anxiety problems*".

There is a strong correlation between MSDs and the work environment. MSDs may develop as a result of heavy lifting, repetitive tasks and inconvenient work postures, such as bending and twisting, performed under pressure of stress or time limitation, and without sufficient resting time in-between tasks (Nunes & Bush, 2012; Bevan, 2015). Vibrations and extreme temperatures are other contributing factors (Schneider et al., 2010; Bevan, 2015), and as such, manual labor is a common reason for the development of MSDs.

Pain in the lower back area is a frequently occurring problem within the Swedish population, with 80% being affected at some point during their lifetime (Jenssen & Kwak, 2019), whereas WHO (2021) cites a number of 568 million people worldwide suffering from the ailment. Lower back pain is one of the most common reasons for work absenteeism and is often a recurring ailment. The underlying factor of these problems is rarely a severe disease and it is often hard to identify the exact cause of the pain. Research has shown that both physiological and psychological aspects have a triggering effect that may cause these pains (Jenssen & Kwak, 2019; Gallis, 2006). The ailments can often have a negative economic effect, not only for the affected employee in the form of sick leave, but also to a loss of production for the employer. Furthermore, this problem is also costing the society large amounts of money; according to Jenssen & Kwak (2019) the total cost related to back pain in

Sweden averages at 44 billion SEK in a year.

4.1.1 MSDs in Forestry Work

MSDs have been frequently reported among loggers, and for various body areas, including hands, shoulders, knees, elbows and neck (Grzywiński et al., 2010), with frequently occurring pains in the lower back being experienced by 47% of respondents. The lower back is mainly affected by body posture and the static load when performing tasks using the chainsaw, as work is frequently executed with a forward leaning posture and standing with bent legs (Gallis, 2006; Grzywiński et al., 2010). The tasks with the highest risk of postural strain are felling and limbing, where the working posture in combination with duration is classified as high ergonomic risk (Grzywiński et al., 2015). Researchers have documented varying percentages of forestry workers suffering from lower back MSDs; 52% (Dimou et al., 2020b), 38% (Lagerstrom et al., 2019), 66% (Grzywiński et al., 2016), and 50% (Gallis, 2006), all of which have used the *Standardized Nordic Questionnaire* (Kuorinka et al., 1987) or modified versions thereof to evaluate the occurrence of MSDs within forestry work. The available research has been conducted in different geographic areas with varying approaches to the issue, but the consensus of the cited articles is that manual labor with chainsaws in forestry correlates with a high risk of developing MSDs in the lower back. According to Grzywiński et al. (2015), reduced weight and redesigns of the chainsaw itself has not shown significant impact on reducing MSDs in the lower back among forestry workers.

4.2 Anatomy and Biomechanics of the Lower Back

The lower back, also known as the lumbar region, centers around the lumbar spine (see Figure 4.1) with its five vertebrae, *L1* to *L5*. These constitute the largest bone structures of the human spine. The lumbar spine serves several functions, including supporting the upper body and distributing body weight, allowing body movement and creating a protective shell for the spinal cord (Sassack & Carrier, 2021). The lumbar spine allows for movement in several directions; flexion (bending forwards), extension (bending backwards), rotation, and side bending. Intervertebral discs placed between vertebrae function as cushions for the spine, providing support and shock absorption during movement and lifting of loads, distributing forces over the lumbar spine (Jensen, 1980). At the end of the lumbar spine the L5 vertebrae borders the sacral base, known as *S1*, which forms the upper end of the sacrum. This connection, commonly referred to as *L5/S1* or the lumbosacral joint, bears a majority of the weight during load of the spine, and is exposed to more movement compared to other areas of the same. As such, this area more frequently develops injuries, such as herniation in the intervertebral disc situated between L5 and S1 (Bogduk, 2005).

In order to counterbalance forward bending motions (flexion) and gravitational forces acting on the torso, back extensor muscles (*erector spinae*, labeled *EM* in Figure 4.1) activate and elongate (Bogduk, 2005; Näf et al., 2018). The back extensor muscle force F_{EM} acts with the lever arm r_{EM}, creating a moment around the center of the spine. Being connected to the vertebrae, these muscles create most of the compression forces acting on the lumbar spine during forward bending of the upper body (Lamers et al., 2018). It has been measured that while carrying a load of 15 kg such lumbar spine forces can reach up to 5000 N (Näf et al., 2018). Increase in back extensor muscle activity is proportional to higher pressure in the intervertebral discs, and a forward bending motion is the greatest cause for such pressure increase (Bogduk, 2005).

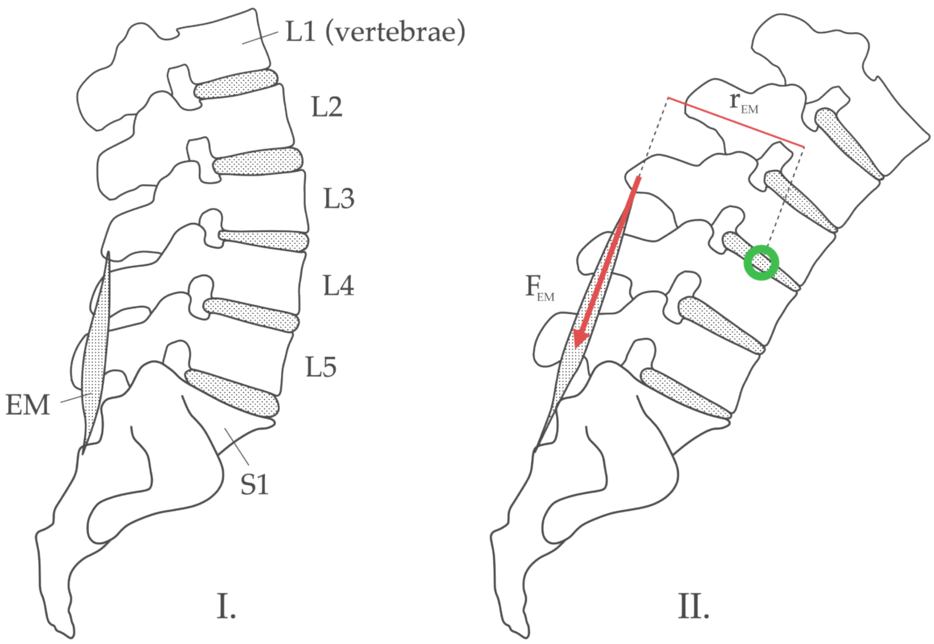


Figure 4.1: Lumbar spine during rest (I) and forward bending (II).

This extensor muscle activity may, after many repetitions, cause spasms or strain of the muscle, which can lead to pain. Straining can occur if a muscle is overstretched or if it tears from overuse (Sassack & Carrier, 2021), and spasms describes a state where the muscle becomes hyperactive and performs involuntary motions, which can be likened to cramps (Bogduk, 2005). Muscle spasms may also create a physical imbalance, leading to a tilt of the body (N.A. Spine Society, 2022).

Other sources of low back pain include damage to vertebrae, intervertebral discs, ligaments, nerves etc. Current treatments to lower back pain include prescribing rest, i.e. avoiding physical activity, applying ice or heat to the area, physical therapy, medication, steroids or, if necessary, surgery (Sassack & Carrier, 2021). However, staying active is most often recommended, and exercise can often help in easing of pain (N.A. Spine Society, 2022).

4.3 Exoskeletons

This section aims to explain the terms and usage areas of exoskeletons, as well as introducing available product examples and performance data.

4.3.1 Definition and Adoption

De Looze et al. (2016) defines an exoskeleton as a "*wearable, external mechanical structure that enhances the power of a person*", while Madinei et al. (2020) defines the term as "*wearable rigid and/or soft structures designed to augment or support the wearer during various physical activities*". Exoskeletons can be categorized into *active* and *passive* systems, which differ in method of physical enhancement. The active systems utilize actuators, powered by electricity, hydraulics, pneumatics or similar to apply external forces to the wearer. A passive system uses basic mechanical devices, such as springs and levers, for storing and applying kinetic energy produced by the motions of the wearer (Kermavnar et al., 2021; Madinei et al., 2020). Passive models are advantageous in that they are more lightweight, less complex and therefore less expensive to produce (Ali et al., 2021). As such, safety risks are lowered due to the lack of actuators (Antwi-Afari et al., 2021), whereas active models however can assist with higher amounts of force. Exoskeletons are often anthropomorphic in their design, i.e., following and aligning to human limbs and muscles to maximize freedom of movement, but there also exists non-anthropomorphic alternatives, where for example an extra limb is attached for holding or manipulating equipment (De Looze et al., 2016).

Early ideas for exoskeletons appeared already in the 19th century, but it is only in the late 20th and early 21st century that they have seen a broader implementation. Exoskeletons are currently used in contexts such as strength enhancement of military personnel, for physical assistance and rehabilitation of patients in medical settings, and for manual labor tasks within industry (Voilqué et al., 2019). Automotive manufacturers have, for example, introduced devices for aiding workers during overhead assembly tasks, focusing on alleviating the arms and shoulder areas (Ferguson, 2018; Huysamen et al., 2018). Other exoskeleton types have been developed for different areas of the body, such as legs (SuitX, 2022b), hands (Bioservo, 2022), trunk or torso (Laevo, 2022) and back (Ottobock, 2022; SuitX, 2022a). However, use of exoskeletons is not yet widespread, which may stem from several factors; users experiencing discomfort and reduced overall movement, current exoskeletons being complicated to use and taking too much time to put on, and a lack of versatility when used during varying work tasks (Ali et al., 2021; Näf et al., 2018).

4.3.2 Passive Exoskeletons for Lower Back

Passive exoskeletons made for supporting the lower back of the user exist in different variants, utilizing a range of technical solutions. For a selection of currently available models with respective technical solution and location thereof, see Table 4.1. A common denominator is a system relying on springs, usually attached to a soft harness worn by the user, adhering to an anthropomorphic design. The theory behind these designs is to alleviate the back muscles and surrounding areas by creating a torque or extension moment around the lumbar spine during flexion (Zelik et al., 2022). This reduces the force of the back extensor muscles during the operation, leading to the lumbar intervertebral discs being exposed to less compression, as well as alleviating muscle fatigue (Kermavnar et al., 2021).

Manufacturer	**Product**	**Technology**	**Location**
Auxivo (2022)	Liftsuit	Elastic bands	Back
ErgoSanté (2022)	HAPO Posture	Flexible spring rods	Hips, sides
HeroWear (2022)	Apex	Elastic bands	Back
Laevo (2022)	Laevo V2.5	Gas springs	Hips, sides
Ottobock (2022)	Paexo Back	Mechanical clutch	Back, hips
SuitX (2022a)	BackX	Gas springs	Hips, sides

Table 4.1: Selection of passive exoskeleton models for lower back support.

HAPO Posture, Laevo V2.5, Paexo Back and BackX place mechanical joints and/or clutches at the hip joint position, to allow forward bending movement when lifting loads. Structures attached to this joint connect the torso and the thighs, allowing for the load of the torso to be transferred to the legs during flexion. The Laevo V2.5, Paexo Back and BackX employ rigid structures while placing mechanical devices at the hips (Laevo, 2022; Ottobock, 2022; SuitX, 2022a). Such hip located devices often protrude a considerable amount from the body. Such rigid structures can also misalign with the wearer's joints, leading to motion and lifting technique potentially being impacted negatively (Abdoli-Eramaki et al., 2007). The HAPO Posture instead utilizes flexible spring rods made of composite fibers placed along the sides of the body, allowing bending and adherence to movements of the wearer (ErgoSanté, 2022).

Differing from exoskeletons with rigid structures, models exist which do not change the kinematics and movements of the user, where forces are instead transferred via tension in elastic parts (Näf et al., 2018). Exemplifying this, the Liftsuit and Apex models add an additional force along the back via elastic bands, connecting the torso and thighs, to relieve the extensor muscles during flexion and lifting (Auxivo, 2022; HeroWear, 2022), as described by Abdoli-Eramaki et al. (2007) and Lamers et al. (2018) and as illustrated in Figure 4.2. This way, the exoskeleton force F_{EXO} acts with the lever arm r_{EXO}, where $r_{EXO} > r_{EM}$. The system acting on a point in the lumbar spine can then be described by the following equilibrium equation (compare Equation 3.1):

$$F_{EXO} * r_{EXO} + F_{EM} * r_{EM} = F_{UB} * r_{UB} + F_T * r_T \tag{4.1}$$

where UB and T indicate *upper body* and *tool*, respectively. Assuming that other values remain unchanging, the extensor muscle force F_{EM} acting on the lumbar spine can be lowered by increasing the force F_{EXO} and/or the distance r_{EXO}.

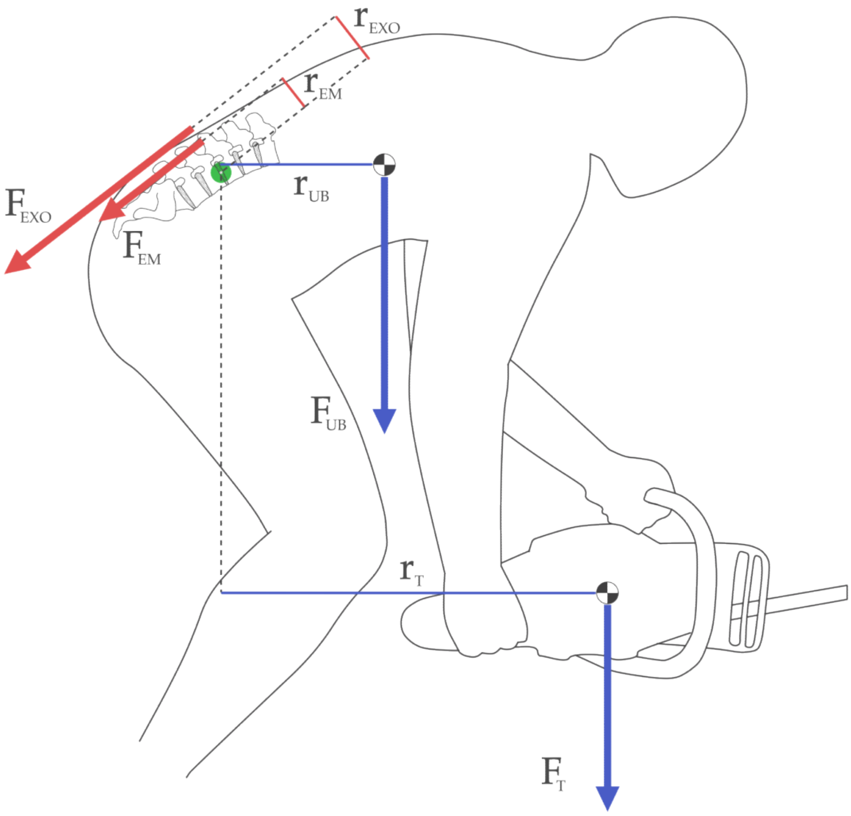


Figure 4.2: Default and exoskeleton forces and moment arms acting on the lumbar spine during felling.

4.3.3 Performance

An ever-expanding amount of research exist regarding the performance and potential capacity of exoskeletons to relieve the lumbar spine during bending and lifting tasks. Experiments and tests have been executed with varying parameters and scenarios, almost exclusively in laboratory environments. In the literature review performed by Kermavnar et al. (2021) a total of 33 papers on active (n=8) and passive (n=8) industrial back-support exoskeletons were reviewed, where the most common method of assessing performance was to measure changes in back extensor muscle activity, via electromyography using surface electrodes. The review findings from Kermavnar et al. (2021) show that active exoskeletons reduce muscle activity more during dynamic tasks such as lifting (mean change at -25% for active and -18% for passive), whereas passive models tended to give better results during static bending with a mean change at -36% for passive and -12% for active. However, the latter figure is based on a single study, and the former varied with the angle of flexion. The L5/S1 moments were shown to be reduced by up to 23% for passive models during lifting, and compression forces in the lumbar spine reached -17% during static bending.

An increased activity in abdominal muscle groups were found in some studies, indicating that the decreased muscle activity in the back extensor muscle may be balanced out elsewhere. This should be seen as a negative side effect, as the abdominal muscles will contribute to the compression forces of the lumbar spine (Kermavnar et al., 2021). However, some studies showed an decreased activity for both back extensors and abdominal muscles during testing. Other findings of the review show that endurance time increased, especially during static bending, using passive back-support exoskeletons. Similar inconclusive results were shown for leg muscle activity.

In the literature review by Ali et al. (2021), surveying 69 articles covering 18 active and 16 passive back-support exoskeleton models, it was found that the Paexo Back gave the most significant reduction in back muscle activity, but the authors state that further tests with dynamic tasks would give a more exhaustive view of its performance.

In general, the studies show positive results for both reduced muscle activity and expended energy (metabolic cost), with a mean change of -11% for the latter category. However, the data points and results fluctuate, likely due to the differing study scenarios. Many studies feature lifting tasks of objects in order to test the exoskeletons, but the study design vary to a high degree. It should also be noted that only five of the exoskeleton models in the literature review by Kermavnar et al. (2021) were commercially available products, and that many studies are instead done on prototypes in academic settings. The long-term effects of wearing an exoskeleton during work tasks is an area of study that has not been extensively explored, mainly due to the relative recent introduction of the product category.

4.3.4 Subjective Measures

Subjective measures of the users have also been recorded during exoskeleton performance research. This includes perceived exertion, capacity and task difficulty, but also factors such as comfort, freedom of motion, usability and product versatility. Kermavnar et al. (2021) notes that a comparison of ten studies shows that the users' perceived exertion was lowered significantly for the lower back (-36%) during lifting, with the same number for the abdominal area and -25% for lower limbs. The perceived physical capacity saw an increase of +7%, and the task difficulty during repetitive lifting and static bending saw great reductions at -67% and -51% respectively. Various movements, such as shifting from sitting to standing position as well as rotation of the torso saw an increase in perceived difficulty. Additionally, several studies showed that users had negative opinions on the attractiveness, usability and effort of donning the passive exoskeletons, with some stating that factors like these would make using such a product during work unlikely.

5

Methods

This chapter presents the methodology used in this project. It describes the overall design process and the methods used within each phase.

5.1 Design Process

5.1.1 Double Diamond

The design process known as Double diamond was developed by the Design Council and launched in 2004 (Design Council, 2022). The methodology puts the focus on the end user and is an iterative process. The process is divided into four phases from start to final concept and is illustrated in Figure 5.1.

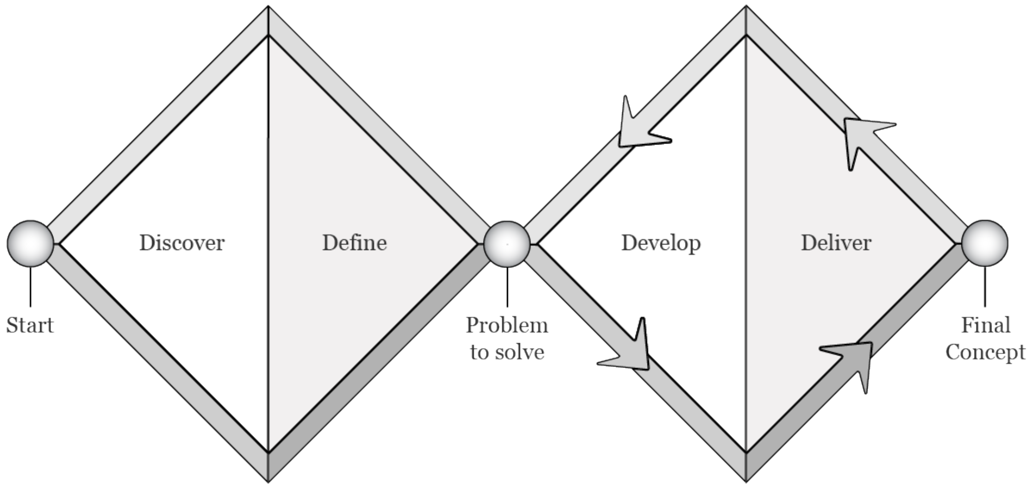


Figure 5.1: Double diamond design process phases.

Discover: The first phase emphasises the need to understand the problem. This phase focuses on understanding the user, and how they are affected by the problem.

Define: The insight gained during the discovery phase can help define the problem to be solved and provide an understanding of the context in which the problem occurs.

Develop: The development phase encourages creativity as a mean to find new ways to solve the defined problem from the first diamond.

Deliver: This phase involves testing and evaluation of different solutions, eliminating those that will not solve the problem and improve those those that will. The remaining ideas will be iterated back to the development phase again in order to be improved upon with more detailed solutions.

5.1.2 Emotional Design

Norman's theory of emotional design is divided into three levels; visceral, behavioral and reflective design (Norman, 2004).

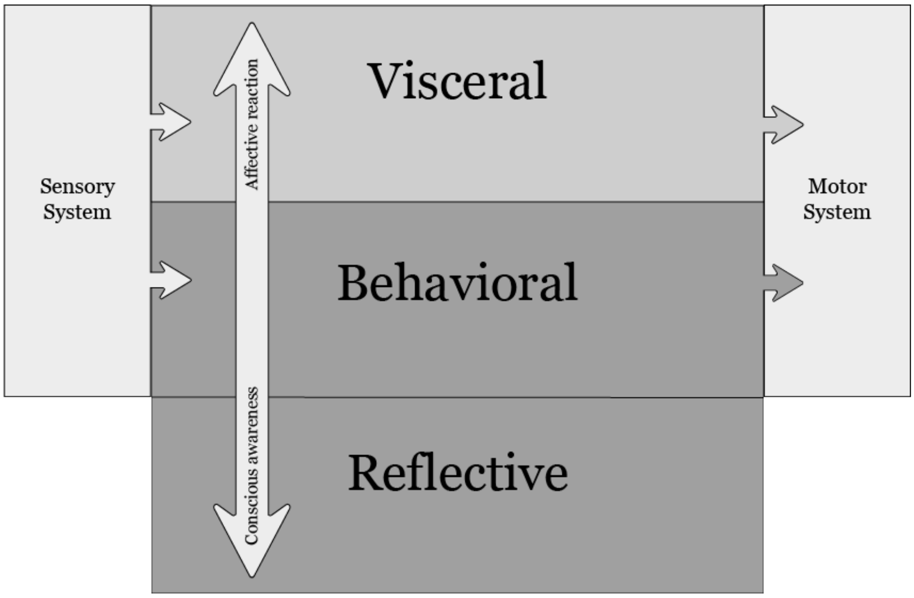


Figure 5.2: Illustration of Norman's three levels of design.

"*Visceral design is what nature does*" (Norman, 2004), signifying that this level of design is about the initial reaction a product produces. People tend to like things that are considered pretty, and they tend to want what looks good and adheres to their attitudes, beliefs and feelings. This makes physical features such as look, feel and sound dominating in order to attract the consumer. Design at this level aims to trigger subconscious reactions.

Behavioral design is about how a product is used and its functions, and as such the appearance of the product is not as important on this level. What matters more are the four components of good behavioral design: function, understandability, usability and tactile sensation. In order to successful create good behavioral design it is necessary to understand how people will use the product. Therefor an iterative design process with a user focus is the key to effective behavioral design.

Reflective design is all about the message, the culture and the meaning of the product rather than the usage, i.e., whether the user can tell a story about the product.

On this level the importance lies on fulfilling personal remembrance or self-image. The overall impact of a product comes through the user's own reflections (Norman, 2004).

5.2 Pre-study Methods

5.2.1 Literature Review

A literature review is a methodical and critical scrutiny of available literature written in a scientific context or with a scholarly purpose on a specific subject. These include scientific publications, such as theses and articles in scientific journals, as well as conference papers. In a design project the literature review is a tool to gather and synthesize existing research within fields related to the project (Martin et al., 2012).

5.2.2 Benchmarking

Benchmarking as a method is used either to investigate how competitors solve similar problems or to seek inspiration and new ideas on how to design a product. This is done by searching information in literature and online. The purpose of the method is to inspire and expand the solution space and provide a wider understanding of the problem and how it can be solved. Johannesson et al. (2013) describes the method as rational and easy to use.

5.3 User Study Methods

5.3.1 Survey

A survey is utilized to collect quantitative data in the discovery phase, as it is an efficient tool for quickly gathering insights from a large sample of users (Martin et al., 2012). A survey may contain questions with predefined answer options or free text answers, depending on which type of data is needed. Answers to these questions should be analyzed in a quantitative and qualitative way, respectively. It is of importance to formulate unambiguous, neutral and non-biased questions, to make sure that the respondent can only interpret the question in the correct way (Bohgard et al., 2015).

5.3.2 Interviews

An interview is a qualitative research method for direct contact with the user, performed in order to collect information about personal experiences, opinions, attitudes and perceptions (Martin et al., 2012). Interviews are mainly used to gain a deeper understanding of a problem or situation of which the user has experience. It can vary from a structured format, closely following a prepared set of questions, or being an unstructured interview where the conversation is more flowing and unpredictable. The latter option, or a semi-structured variant, is often appropriate to use in the exploratory phase of a design project. Interviews are often recorded for future transcribing, or if several researchers are available notes may also be written during the course of the interview (Bohgard et al., 2015).

5.3.3 Observation

The method of observation is used to gather information and insights into how users behave in a real-life situation in a specific context or with a certain product. The observer can learn how the users interact, and gain knowledge which might not be attained via interviews or surveys, as some behaviors are exhibited with no self-reflection from the user (Johannesson et al., 2013). An observation can be structured in various ways, and may even include the observer as a participant, and should be well documented via notes, photographs or video footage. The observational study may also be alternated with interview questions, if there are specific points of interest for the researcher (Martin et al., 2012).

5.4 Analytical Methods

5.4.1 Affinity Diagramming

Affinity diagramming is used to summarize and cluster insights from interviews and observations. The insights, observations, concerns and request are captured on post-it notes and categorized, based on their interrelations, into groups (Martin et al., 2012) . This method provides a visual overview of the users' needs and requests as well as a mean of reaching consensus within the design team. When the affinity diagram is complete it can be referred back to as the voice of the user.

5.4.2 Functional Analysis

This type of analysis contains three categories of functions: main-, sub- and additional functions. The main category is the primary functionality of the product that needs to be fulfilled in order for the product to work (Österlin, 2016). The sub-functions are functions that enable the main function, and the additional function are adding supplementary properties to the product without being dependent on the main function. The functions are presented using a verb and a noun, and rated as needed or desirable (Österlin, 2016).

5.4.3 Ergonomic Analysis

The ergonomic evaluation methods were chosen based on the characteristics of the working environment and body positions identified therein. The analytic methods used for the ergonomic evaluation were OWAS, REBA (Hignett & McAtamney, 2000), KIM I (Arbetsmiljöverket, 2012) and KIM III (Arbetsmiljöverket, 2012). The reasoning for using a combination of evaluation methods was that each are measuring different aspects of the work task. As stated by Enez & Nalbantoğlu

(2019), OWAS is an easier method to use in a forestry setting "[...] but REBA provides a more accurate assessment."

The methods were selected as they were deemed most appropriate for analyzing the entire body from an ergonomic perspective. The ergonomic evaluations can be based on photographic and/or video material, with the aim to identify which working tasks are most harmful based on working posture, angle of limbs, weight of tools, duration and number of repetitions.

5.4.4 Activity Mapping

The method aims to break down the user's workflow into tasks. Each task is further divided into actions and interactions, system response and work environment in order to map elements of the human behavior (Martin et al., 2012). In a design context the method focuses on gaining insights into user and task process. The results are presented in a task analysis grid, providing a visual overview of the components included in the overall workflow (Martin et al., 2012).

5.4.5 Design Format Analysis

A Design Format Analysis (DFA) aims to analyze and identify the design language and visual product identity of a brand, using an existing product family as reference. The method manages design element identification, ranking, typicality and a final assessment. The result of the analysis is a list of design formats or features that are needed to visually represent the product identity of the brand for the product in development, to create recognition for the customer (Warell, 2006).

5.5 Ideation Methods

5.5.1 Brainstorming

The aim of brainstorming is to generate a wide variety and large amount of ideas, with no room for criticism in the early phase of the process, as it might affect the amount of ideas generated (Österlin, 2016). The method promotes unconventional and new solutions to the problem at hand, and suggested ideas can easily be merged or modified to create further solutions (Johannesson et al., 2013).

5.5.2 Sketching

Sketching can be an effective tool for structuring and formulating new ideas on paper, but also to facilitate communication of these ideas to other stakeholders. The method allows for exploring forms and shapes, and to quickly generate new designs during ideation (Martin et al., 2012).

5.5.3 Prototyping

Prototyping encompasses creating low-fidelity physical models for communicating and testing ideas. Low-fidelity prototypes can be used through the entire ideation phase of a project. Prototyping can provide insights that are hard to identify in a 2D sketch, such as scale and proportions. High-fidelity prototypes are often used representing the appearance of the final product and can have basic functionality and can be used for evaluation of aesthetics, usability and interaction with the users (Martin et al., 2012).

5.5.4 CAD Modeling

With CAD (Computer Aided Design) a digital 3D-model is created, representing the design concept. Creating a model digitally can be faster and more precise than making rapid prototypes, facilitating implementation of changes in the design. It can also be an efficient tool when ideating a variety of ideas by using the same basic structure. There are possibilities to test basic functionality by using animations and simulations on the model, which can help identifying problems in the solution that can be adjusted before making the more time consuming and expensive physical prototypes (Johannesson et al., 2013). Finally, 3D models can be rendered into realistic visual representations of the final concept, showcasing it from different angles.

5.6 Evaluation Methods

5.6.1 Focus Group

A focus group serves as a qualitative tool where invited participants are able to express their opinions and general feedback on a topic through association and experiences (Martin et al., 2012). The method takes the form of a group discussion or interview, with a moderator in charge of presenting topics and themes, directing the discourse and making sure everyone is participating actively. Mediating objects can be useful for sparking discussion, and the focus group is preferably performed in a loose and relaxed manner. The method should result in a large range of input from the participants, listing requirements and identified issues which can be processed in the iteration of the ideation process (Bohgard et al., 2015).

5.6.2 Kesselring Matrix

A Kesselring evaluation matrix is used to weigh different solutions and concepts, comparing them based on different criteria, and creating a comparative ranking (Johannesson et al., 2013). Desirable features are listed in a column, weighted according to their importance for an optimal product performance. Each concept is awarded points, from 1 to 5, for each desirable feature, where a higher value is better. The method gives a clear overview of the positive and negative aspects of the concepts, establishing a starting point for further improvements (Johannesson et al., 2013).

5.6.3 PNI

When a set of ideas is generated PNI can be used as a fast and easy method for evaluating the different ideas. The group discusses the different ideas and note positive, negative and interesting aspects of the solutions (Österlin, 2016). After evaluating all ideas, the comments are reviewed and the insights can be used to generate new ideas on how to fulfill the positive and interesting aspects and avoid the negative aspects in a new concept.

6

Execution

This chapter describes the design process as it was carried out in chronological order, divided into the different phases.

Husqvarna as a company had no previous experience developing exoskeletons but professed an interest in evaluating the potential of introducing such a product for forestry workers. This thesis serves as part of the initial phase of investigating if an exoskeleton can serve a purpose as a tool for a healthier and more sustainable work environment for the user of Husqvarna products in a professional forestry setting. Therefore, the idea of the thesis was to place the emphasis on the research and user study, and approach this broadly, in order to gain a solid foundation needed for the later design stage. However, as the company requested a suggestion for a concept for an entry product for the market, the design phase was allotted a proportionally large amount of time. Based on the characteristics of the project, the Double Diamond design process was used as a framework, though slightly modified. Discovery and development were the focus areas, as indicated by the relative sizes in Figure 6.1, and one main iteration was performed after the first development and deliver phase. Here, the design concept was reworked according to user feedback and then passed through another ideation and evaluation cycle.

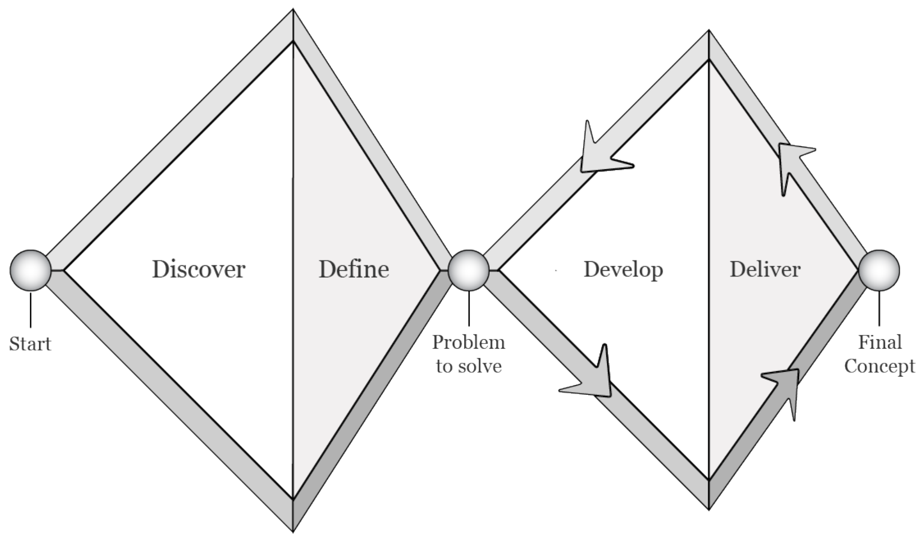


Figure 6.1: Visual representation of the design process of the project.

A study by Neely & Wilhelmson (2006) concluded that small-scale forestry workers in Sweden often did not use all prescribed safety equipment, showing that protective pants and gloves were least likely to be used, while ear, eye (helmet visor) and foot protection were most commonly used. In their study on construction workers Wong et al. (2020) state that reasons "[...] for not using PPE [personal protective equipment] include convenience, physical comfort, time saving and effort saving." Such attitudes to work equipment would likely be a factor in designing a new product for a forestry setting. To ensure that the final design would meet these and other less tangible requirements, the theory of emotional design by Norman (2004) was used as a framework for the project, with the aim to design for all three levels if possible. The main focus remained on behavioral design, as this was deemed to be the most central factor for making the product accessible to the users, but with elements of the design impacting the visceral and reflective levels as well.

6.1 Pre-Study

The pre-study was approached broadly as the initial project brief was of an open nature, with Husqvarna having no previous experience in this product segment. The aim of the pre-study was to get a broad overview of existing exoskeletons on the market and their functions, understanding the work tasks and environment of the loggers, and to map which MSDs are most frequent and understand how and why they occur.

A literature review was performed, with the aim to screen the research done in the fields of exoskeletons and forestry work. Articles regarding MSDs in loggers caused by workload in combination with sub-optimal work postures were of particular interest. The literature review also included research on general ergonomics and anatomy, focusing on how and why injuries and fatigue arise and how it can be prevented. The literature for reviewing was found on Google Scholar and the Chalmers Library using the following combinations of search words: *Forestry + Musculoskeletal disorder*, *Chainsaw + MSD*, *Forestry + Injury*, *Forestry + Fatigue*, *Lower back + Exoskeleton*, *Trunk + Exoskeleton*, *Lumbar Spine + Pain*, *Lower Back Pain.* Furthermore, relevant articles were found using the references in reviewed articles as well as in the citations of articles of interest. The latter worked as a method to find the newest research done within each field.

Video reviews were done via studying of material uploaded to YouTube, using the following search words: *Husqvarna*, *chainsaws*, *tree felling*, *limbing* and *forestry.* The purpose of the review was to get a clearer perception of how the tasks of loggers are carried out and to understand the terminology used in forestry, specifically within the task of tree felling. The video review provided insights into which work postures are the most frequent during the sub tasks, and to understand which of these postures may have the most negative effect on the workers, potentially leading to MSDs, stress injuries or fatigue over time.

A benchmarking of existing exoskeleton products was performed to scan the market and explore strengths and weaknesses of current solutions, as well as seeing average price points. Furthermore, the different technical solutions were evaluated based on how applicable they would be in a forestry setting.

6.2 User Study

An initial online survey (n=31) was used to investigate the users' experiences with work-related injuries, the working environment and which aids are currently in use to prevent injury and strains. The survey was distributed to several professional logging operators in Sweden, as well as to chainsaw instructors. The latter group was selected in order to get insights from the most experienced chainsaw users. The experience of the users are of importance as MSDs develop over time and therefore more experienced users may have more personal experience with this issue, as well as a good view of the related counter-measures implemented within the field. The survey included both general and specific questions on the subject, with both multiple choice questions and questions requiring free text answers. Respondents were, for example, asked about their work experience within the industry (in years), their subjective opinion of the workload, if the work had resulted in strain on the body, and if they could think of any tool or equipment that could help with their physical work environment. For the full survey in Swedish, see Appendix A.1.

Interviews were used in order to gain a deeper understanding of the users and their work situation, as well as their view on physical aid devices in their labor. Three interviews were conducted, each one recorded and transcribed with the consent of the interviewees and the data was handled according to GDPR regulations. The interviews were of a qualitative nature, conducted with a semi-structured approach and held via telephone. The semi-structured approach was used in order to get the relevant information while still being a conversational and personal experience for the interviewee (Martin et al., 2012), and with the added possibility of being able to probe deeper when appropriate. The interviewees were selected from a list of instructors who work with educating new chainsaw operators. These instructors are generally very familiar with the different ergonomic aspects involved in all forestry related activities. They have also been active in the industry for a longer period of time, allowing them to have observed the development and changes that have occurred with regards to safety and work methodology for loggers over time. Three instructors were selected and contacted for interviews.

An interview guide served as a foundation during the interviews, but as these were conducted in a semi-structured manner the guide was not strictly adhered to at all times. Examples of questions asked included "*Which is the most physically demanding work task within forestry?*", "*Which parts of the body endure the heaviest strain during work?*" and "*Which tools are used today to reduce strain and injury risk?*". For the full interview guide in Swedish, see Appendix A.2.

An observational study was arranged with professional forestry workers in their typical working environment. The aim of the visit was to get a better understanding of the context in which the work is performed and to observe what a workday encompasses, with regards to tasks, postures, environment, sound levels, visual conditions etc. These factors were difficult to perceive through video or text, and therefore a naturalistic observational study was of great importance. The observation was carried out during two hours and included observation of the tasks of tree felling, limbing and bucking, together with short unstructured interviews with the personnel. The interviews were conducted between the different tasks where the interviewee explained how each task is performed and which risks to consider. The observation was documented via notes, photographs and video. The photo and video material served as the foundation for ergonomic evaluations of the work postures as well as estimation of the number of repetitions and time consumption for performing the tasks.

All participant data in the user study was anonymized. Use of photo and video material from the observational study was handled with the consent of the participants, in compliance with the General Data Protection Regulation (GDPR).

6.3 Analysis

The results from the user studies were analyzed via affinity diagramming. The affinity diagram was created in *Figma* as a method to systematically sort information gained during the user study phase of the project. The aim was to identify the different components of the problem and to find necessary functions for a product intended to solve these. Quotes, comments, insights and observations were noted on digital post-it notes and then sorted into categories based on affiliation. The three main categories were *Work Environment*, *Safety & Injuries* and *Aids/Equipment*, and within these a number of subcategories were created to achieve more specific areas of interest. The affinity diagram resulted in a function analysis that created a foundation for the ideation and evaluation of the design concepts.

To get an overview of the different tasks involved in the day to day work of a logger, an activity map was created, see Figure 7.3. The main tasks were divided into categories of transport, cutting, limbing, bucking, gathering of wood and skidding. Furthermore, each task was then divided into constituent.

The ergonomic analysis performed on video footage of forward bending cutting postures captured during the observational study can be viewed in Appendix A.3. This analysis aimed to identify the most critical working postures and tasks, to judge the severity of the ergonomic postures. The use of several ergonomic analysis methods were necessary, as they take different parts of the body and tasks into consideration. While the ergonomic analysis provided insight on injury risk, no particular part of the body was indicated to be more exposed than others.

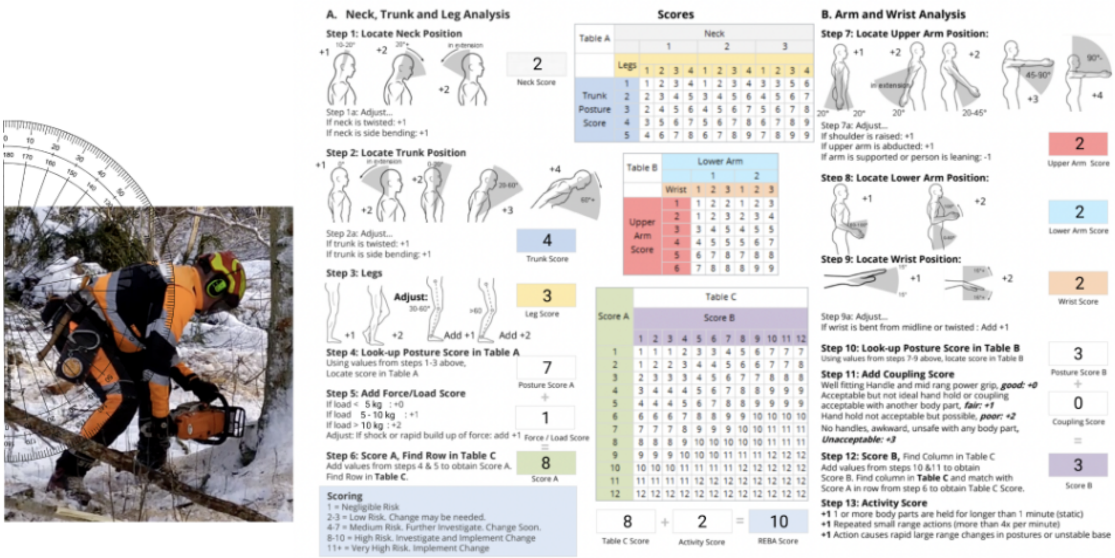


Figure 6.2: Example of the ergonomic evaluations using REBA (Hignett & McAtamney, 2000).

Taking the data from pre-study, user study and analysis phases, a list of product functions was created in order to create a framework for the future ideation phase. This list served as a prototypical requirements list and included main functions as well as sub- and additional functions, which were categorized as either necessary or desirable. Functions deemed to be necessary included *allow movement*, *allow compatibility with current equipment* and *withstand the work environment*. For the full function analysis list, see Appendix A.4.

Before beginning the ideation stage of the project, a *Design Format Analysis* (DFA) was performed, surveying Husqvarna products in order to define a design language for the concept generation. Products included in this analysis were selected on the basis of being in the range of forestry equipment and tools, and included work wear, chainsaws, helmets and logging tool belts. The DFA showed that the most frequent form elements were the orange and grey color scheme, color and value contrasted parts and a prominent logotype. For the element typicality list and format assessment, see Appendix A.5.

6.4 Ideation I

Initial ideation methods included brainstorming and sketching. During these sessions ideas and designs were continuously generated with the function analysis and DFA as a basis. Throughout this initial phase of ideation there were a set of minor iterations as further information was gathered. A human figure template, using a digital 3D model showing the body from the front, back and side planes, was created in order to act as a base for sketching of design concepts. Using this template, a variety of sketches were made, exploring different solutions and ideas. For a selection of sketches, see Appendix A.6. Apart from ideating realistic solutions, other themes were explored during the sketching sessions, such as *opposites* (maximum vs minimal solution), *reversed* (making the situation worse) and attempting to generate solutions in other similar contexts. All these sketching themes were used to encourage creativity and open up the solution space as well as relieve pressure on creating an immaculate solution.

The results from the brainstorm and sketch sessions were categorized into different groups. The groups with the most feasible solutions were chosen as the concepts to be further ideated upon. By combining ideas from different solutions the concepts were narrowed down to three main concepts (Figure 7.2) that were evaluated structurally.

6.5 Evaluation I

All generated sketches within each concept group (1-3) were displayed on a wall. Each idea was discussed individually focusing on one positive, negative and interesting (PNI) aspect of that particular idea. The more ideas evaluated, the less new aspects arose as many of the ideas were similar in functionality. This evaluation narrowed down the number of solutions by sorting out those which, due to various factors, were not likely to solve the problem in a satisfying manner. Finally, the best solutions for the design of the front and back were selected based on feasibility, function and perceived comfort. In this way, the ideas of what the concepts would be were clearly communicated and defined for the next evaluation step.

A Kesselring matrix was used for evaluation of the concepts based on how well they can enable the functions listed in the function analysis. Each function was weighted based on their importance for the main function, to reduce risk of MSDs, and the answers from users in the survey and interviews. The function was weighted on a scale from 1-5 where 1 is not important for the main function and 5 is essential for the main function. In the second step each concept was given a score from 0 to 3 based on how well the concept can fulfill each function, where 0 = *will not be fulfilled*, 1 = *will be fulfilled poorly*, 2 = *will be fulfilled satisfyingly*, and 3 = *will be fulfilled well.*

Weight	Function
5	Reduce MSDs
5	Improve Working Posture
5	Allow Movement
5	Allow Adjustment
5	Prevent Bending & Twisting of Trunk
5	Withstand Work Environment
5	Minimize Weight
4	Guide Back/Trunk
4	Prevent Overheating
4	Enable Versatility
4	Allow Interaction
4	Relieve Tool Weight
4	Withstand Moisture
4	Allow Compatibility
4	Relieve Shoulders
4	Avoid Protrusive Parts
3	Distribute Weight
3	Improve Visibility
3	Allow Activation/Deactivation
2	Stabilize Trunk
2	Ease Transportation
2	Allow Tool Transportation
2	Allow Cleaning
2	Enable Storage
1	Preserve Heat
1	Enable GPS Tracking

Table 6.1: Weighting of the functions used in the Kesselring matrix.

6.6 Ideation II

After the evaluation and selection of concept, the process was iterated back to a new ideation phase. This ideation was focused on the different components of the product and how they should be designed and function in order to reach the best possible end result. The concept was divided into front, back, legs, straps, buckles and back cover. Each part was ideated upon separately and a number of different designs were produced. The ideation also contained exploration of the visual design of the concept focusing on colors and a professional expression based on the DFA.

The separate parts were designed digitally in *Clip Studio Paint*, made in relative scale to each other. The reason for this was to facilitate comparison of different designs with each other when placed on an image of a human figure in full logger gear. The sketches were printed and cut into parts, and then cemented onto thicker paper for stability. The idea of creating a cut out doll (see Figure 6.3) was to create an interactive mediating tool to present to the users in the evaluation phase. It was hypothesized that being able to combine different designs and physically interact with the objects might lead to a better understanding and increase the engagement of the users.

Figure 6.3: Cut-out doll produced as a mediating tool for evaluation with users.

A primitive prototype was produced using a modified version of Husqvarna's Flexi logger tool belt combined with shoulder harness. The attachment for the legs were cut out from a sleeping pad and connected to the tool belt and harness by straps and clasps. Elastic bands were added to the back and the leg attachments. The prototype enabled testing the comfort, freedom of movement and to a lesser extent the back support functionality of the harness, and allowing for being used as a mediating tool in the evaluation with the users.

Figure 6.4: Production of prototype for evaluation with users.

6.7 Evaluation II

For the second evaluation interviews were conducted with potential users of the product. Four interviews were conducted in different settings; one online, two as physical meetings and one as a group evaluation. The group interview was conducted in a forest near Jönköping together with Husqvarna logging personnel. The interview was unstructured in nature due to a separate chainsaw test being carried out in parallel on the same location. The prototype was used to present the concept, and the reflections, insights and opinions of the users were recorded.

The physical interviews were semi-structured using questions as a guideline but with room for the interviewee to speak freely about their thoughts and insights. The concept was first presented, explaining the reasoning and findings leading to the design decisions, as well as showing existing passive exoskeleton on the market and sketches of the concept. Next, the prototype and cut out doll were used as mediating tools for the participants to interact with. For the online interview the concept was presented digitally using screen sharing, making it possible, though slightly more difficult, to explain the functionality of the product.

Figure 6.5: User testing of the prototype.

Lastly, a focus group was held at the Husqvarna headquarters in Huskvarna together with five participants; four engineers and one logger. The session was structured in the same way as the physical interviews, with a short presentation of the project and physical representations of the concept. The basic functionality was further explained by using the prototype. An open discussion with the participants was initiated after the presentation. The discussion was moderated using open questions, and the cut out doll was used as a mediating tool for the participants to interact with as well as a tool for the moderator to navigate the discussion through each part of the concept. The session ended with the participants evaluating the concept based on semantic terms, with focus on functionality and expression. The individual interview sessions and focus group were audio recorded to enable transcribing, and all input was analyzed using an affinity diagram. After analysis, the final design decisions were made in order to create a final concept.

The final concept was designed, modeled and rendered in *Blender* to create a visual representation of the concept, with some complementary digital sketching to present functionality. Some components were designed in *Autodesk Fusion 360* and then incorporated into the main assembly in *Blender*.

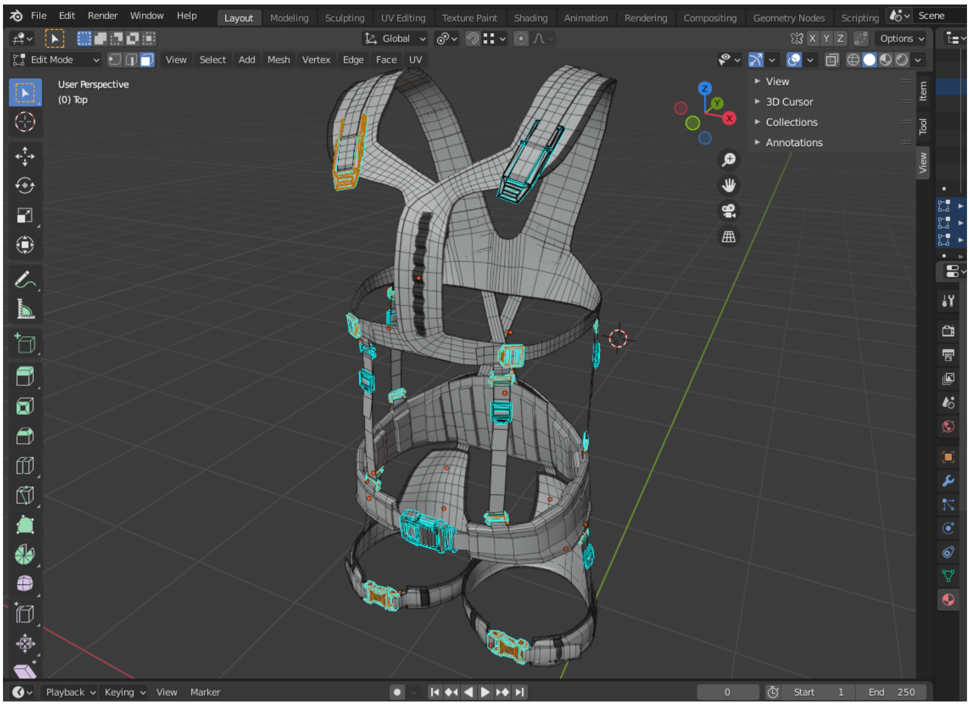


Figure 6.6: Modeling of the final concept in Blender.

7

Results

This chapter contains the design decisions made throughout the project, why they were made and the results thereof. For an overview of the final design, see chapter 2.

Figure 7.1: Visual representation of factors impacting the product design.

Figure 7.1 shows an overview of factors that had an impact and influence on the design of the product concept. Main functions are listed in white boxes, with sub-factors listed in green and yellow. These include findings and insights acquired from users and research during the course of the project. The underlying reasons behind the main factors and how the concept is designed to fulfill the demands will be elaborated on in the following sections, making connections to the methodology used in the project. The impact of the sustainability factors are addressed in Chapter 8 of this report.

The ergonomic evaluations using REBA, OWAS, KIM I and KIM III, revealed that the common postures adapted during cutting, i.e., forward bending in order to apply the cut close to the ground level, were categorized as a risk behavior. All four evaluations showed that the task of cutting results in a high physical load on the body that increases risk for injuries, and that change should be implemented in order to prevent negative long-term consequences. Specifically, KIM I and III scored this posture within the 25 to 50 point interval, indicating an *"Increased load situation, possibility of overload for persons of standard capacity. Enhancement of work tasks and environment recommended."*; the REBA average score was 10, signifying a *"high risk: investigate and implement change"*, whereas OWAS pointed to a value of 3 or 4, suggesting *"corrective actions for improvement required"*. However, note that neither analysis tool takes time and repetition into account, meaning that tasks such as limbing might still arguably be considered more harmful, being performed during far longer periods of time than cutting. Answers from interviews and survey supported this claim, as well as available literature, e.g. Grzywiński et al. (2015).

The user study as a whole, including interviews and survey, indicated that the lower back was the area where most users experienced pain and fatigue, and the literature (Section 4.1) showed that lower back pains are frequently reported among loggers. 71% of survey respondents (n=31) claimed that the lower back is exposed to the highest loads during the work day, and of those who experience physical ailments approximately 53% had issues related to the lower back. The data pointed to this area as being in need of improvement, where an exoskeleton could potentially be used as an aid to revise the working conditions and reduce the risks of MSDs. Statistics regarding sick leave, such as the fact that back pain is the cause for the highest proportion of *"years lost to disability"* (Bevan, 2015), indicate that a reduction of such cases would have a positive effect on both an individual and societal level. Based on this it was decided to focus on supporting the lower back area of the users.

7.1 Main Functionality

The lower back support functionality of the product was an integral part of the final design concept and therefore it was the starting point of the development phase. (Focused on the behavioral level of Norman, with functionality as the main priority)

The main functionality using elastic bands was chosen as the technical solution based on research of existing exoskeletons and articles evaluating their function and usability, as presented in Section 4.3.2. The research focused on investigating techniques and applicability of these solutions in a forestry context. The demarcation of keeping a low pricing, in addition to the remote working locations of the users, lead to focusing on developing a passive exoskeleton, where no batteries or other energy sources would be needed. Based on the literature review and benchmarking a technical solution applying the use of elastic bands was chosen, as this technique was deemed suitable for the user context. The elastic bands can be worn close to the body across the back and allows free mobility along the side areas of the body. Limiting protruding parts as far as possible was seen as beneficial in order to avoid the wearer getting tangled up in branches and undergrowth of the forest environment. Lastly, the elastic bands are lightweight, keeping the overall weight of the product down to a minimum which was listed as a user requirement. However, the thesis does not present new performance data, due to time limits and difficulties in procuring available reference products.

Three main concept groups, implementing the technical solution in different ways, were developed, as described in Section 6.4 and shown in Figure 7.2, where light grey fields indicate textile material, dark grey indicates elastic band components, and lined areas indicate tool belt.

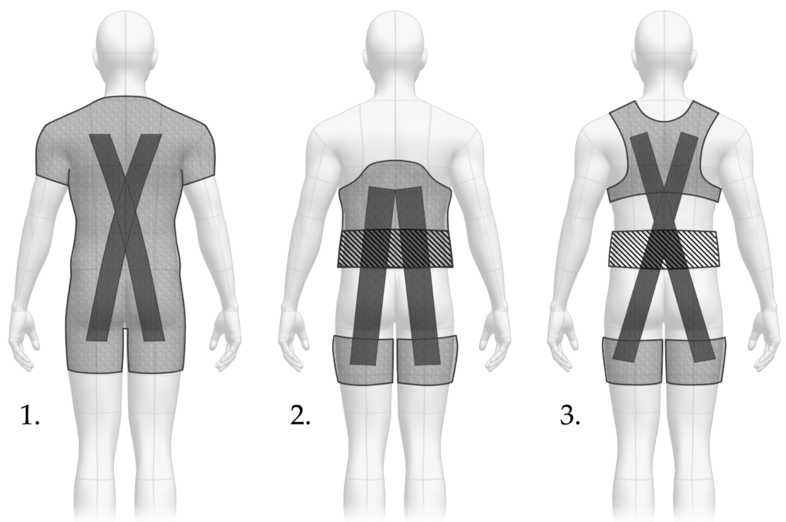


Figure 7.2: Low fidelity representation of the three initial concepts in numerical order.

Concept 1: An exoskeleton worn underneath the clothes and functioning as an undergarment, covering the thighs and the upper body, with elastic bands added on top to create a single piece garment. The concept was discarded as the undergarment principle makes the product difficult to interact with and adjust during usage. This led to high demands on the concept to be versatile and function in all different tasks during the day without needing adjustments, which seems unfeasible in a forestry setting. Wearing it close to the body also sets high demands on size and fit to make it comfortable for a large variety of body types. Furthermore, wearing a tight fitting garment covering the torso and upper parts of the lower body would likely generate and contain unwanted heat.

Concept 2: An exoskeleton worn outside of the work wear, covering the lower back up to the lower parts of the shoulder area. The concept can be combined with a tool belt. The concept seemed interesting based on the fact that the shoulders are frequently mentioned as an area that is at risk for MSDs among the users. However, by not using shoulder straps it is more difficult to fixate the exoskeleton in a correct position to the torso, making the functionality dubious, as the elastic bands require solid positioning between torso and legs to function. This problem could possibly be resolved by using an exoskeleton design with rigid structures connecting to the torso, but as such a solution was previously decided against this concept was judged as difficult to make adhere to the function analysis (Appendix A.4).

Concept 3: An exoskeleton that is combined with a tool belt. The exoskeleton is donned on the outside of the work wear, giving the user easy access to all buckles and straps, providing easy adjustment during the work day, as well as the ability to don the product only when necessary. The main components of the concept includes a torso harness, a tool belt, leg supports and connections in between, allowing the torso and thighs to be connected for transfer of loads. Concept 3 exceeded the others in allowing adjustment, interaction, versatility and enabling compatibility with tools and work wear.

The Kesselring evaluation resulted in the following outcomes: Concept 3 received the highest score with 230 points while concept 1 and 2 received 173 and 189 points respectively. For the full table, see Appendix A.7. Concept 3 was selected as the concept to be further iterated upon in ideation II (Section 6.6), focusing on how the different components of the concept would support and connect to the main functionality without affecting its performance. As for the belt inclusion, it was decided to use Husqvarna's logger tool belt Flexi (Figure 3.3) as a basis, due to its familiarity to the user as an established product on the market and compatibility with the tool holsters designed by Husqvarna.

Varying design possibilities of extending the leverage of the spring were explored. By creating a greater distance between the back and the spring loaded band, the length of the lever arm r_{EXO} would increase, giving a larger resulting moment of the elastic bands, in turn requiring less force contributed by the extensor muscles (see Figure 4.2 and Equation 4.1). It has not been validated if lengthening of this distance would improve the main function significantly. The initial idea of keeping the elastic bands close to the body might be fully adequate with the appropriate spring load. Furthermore, the disadvantage of extending the moment arm r_{EXO} is that such a solution would need protruding parts in the back, which would make the design more obtrusive and possibly complicating the combination with equipment stored at the rear of the tool belt. In the end it was deemed difficult to include a longer moment arm in the final concept of this project. For future development it is however an area of the design that might be able to provide improved performance if explored.

7.2 Flexibility

The thesis and design process had tree felling and its sub-tasks as a main focus, involving many varying tasks as seen in Figure 7.3. Additional tasks are involved when not working purely with tree felling. From a design perspective, this meant that the final concept needed to be flexible in its design in order to adapt to these different tasks, without the user needing to remove the product during certain periods of time.

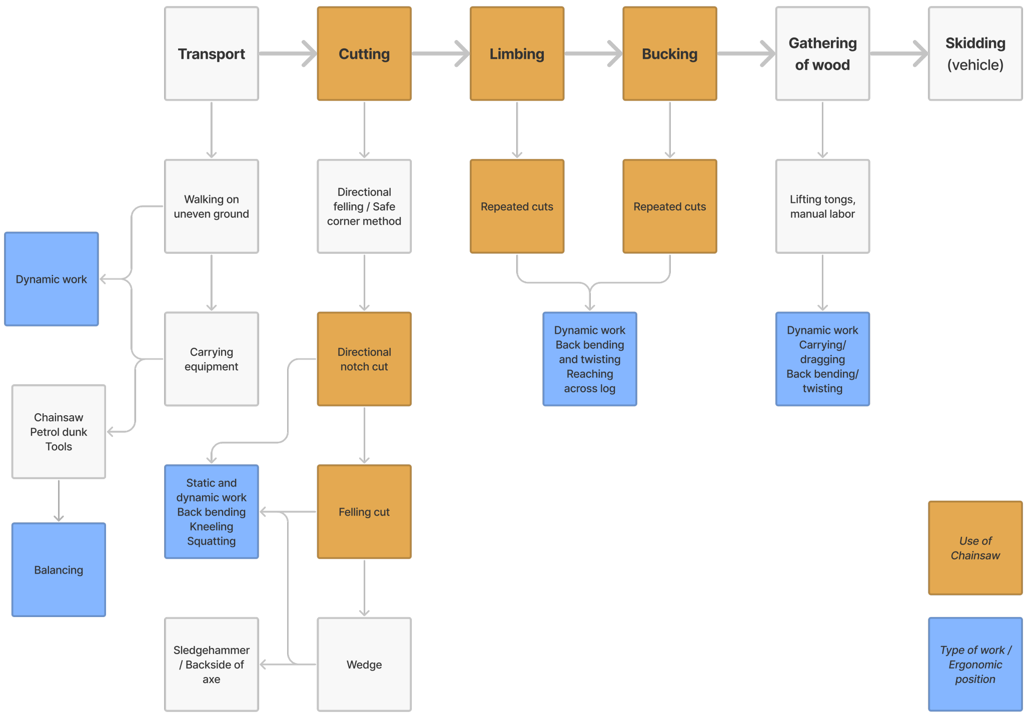


Figure 7.3: Overview of tasks relating to tree felling.

The main function of the design concept is intended to alleviate the back muscles during forward bending, while tasks when moving around in an upright position might need less attention. However, due to the uneven ground plane of a forestry harvest area, traversing the forest floor with the elastic band straps stretched out over the back and bottom could hinder movement and severely impair walking motions. Therefore, an activation system was deemed to be desirable, adding the ability to switch between engaged and disengaged modes. The observational study suggested that such a feature would require easy accessibility and functionality, being able to be handled by an operator dressed in full protection gear including working gloves.

The resulting design solution to these factors is two torsion spring loaded adjustment clasps located on the shoulder areas of the torso harness, as shown in Figure 2.5. Connecting to the main function straps leaping over the shoulders, these clasps are intended to activate or deactivate the spring mechanism via stretching of the elastic bands in the back. The measurements of the clasps in order to provide the intended effect when activated was not investigated further due to the conceptual nature of the project.

7.3 Customizability

During the user study it became clear that each user have their own preferred setup of tools, equipment and ways to approach the work tasks. As was found in interviews, a majority of users had also previously modified their working gear in various ways to better support their personal working methodology. The variation of work tasks also created a need for customizability of personal equipment. Therefore it was deemed desirable to support the user's ability for customization on the design concept itself. As such, one aim of the design was to facilitate a large variety of options for the tool setup carried on the body. The strap of the tool belt is compatible with the current tool holsters of Husqvarna. By adding the same type of straps to the legs supports, the user is able to wear smaller equipment on the leg supports, which in some instances is more accessible compared to a position on the rear of the belt. A couple of gear-loops are placed on the chest of the torso harness to enable optional attachment of equipment that needs easy access, e.g. mobile phone and first aid kit (see A6 in Figure 2.2).

Based on the survey (30% of respondents), literature review (Gallis, 2006; Grzywiński et al., 2016) and interviews, the shoulders are frequently mentioned as an area affected by MSDs and fatigue. However, by including the shoulders in the product design allows the weight of the tool belt to be shared across the torso, creating a more even load distribution. Via interviews, users expressed differing opinions on the prospect of relieving the tool belt weight via transferring the load from the hips to the shoulders, where some found it unnecessary and others greatly preferred it, giving conflicting statements; *"Do not put too much weight on the hips, it reduces mobility"* (User in Evaluation II), versus *"It is completely wrong with a harness for shoulders. Relieve the shoulders, have as little pressure as possible there when working. [there are] Lots of nerves and blood circulation there."* (User in interview).

As such, it was decided that the user should have the option to choose for themselves, which is accomplished by the implementation of g-hook equipped straps (see C2 in Figure 2.2). Using these, the wearer can choose if they want some of the load transferred to the shoulders or if the hips should carry all the weight of the tool belt. This makes the design concept versatile, and the same product can be worn in different compositions to suit different personal needs and preferences of the users.

7.4 Compatibility

The need of designing the product to be compatible with the context of forestry work was of utmost importance. The product should not obstruct the user's working postures nor the access to tools and equipment, as shown in Figure 7.4. This is the main reason behind the choice of the elastic band as facilitator of the main function, due to its unobtrusiveness. Furthermore, the focus of the overall design was to limit the amount of parts placed in front and on the sides of the user, as these areas are frequently occupied by the operator's arms and equipment during logging tasks, particularly when in flexion in combination with frequent changes in chainsaw position.

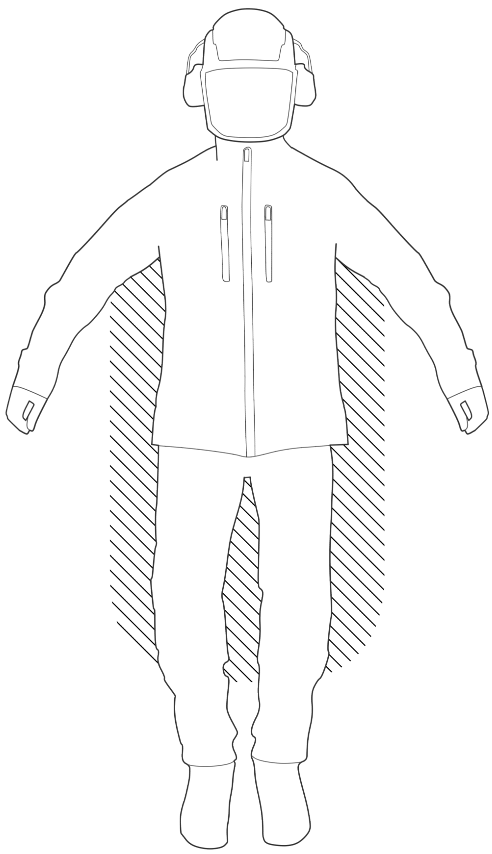


Figure 7.4: Illustration of space (lined area) necessary to keep clear for movement and equipment placement.

The placement of chest pockets are similar on most work wear jackets worn during chainsaw operations, though variations naturally can be found. From interviews and observations it was found that these are utilized by some users to store phone and/or first aid kit due to the easy accessibility of the pockets as well as immediate protection from tools and chainsaw movements. With the phone and first aid kit being essential tools in an emergency situation, and therefore necessary to be able to reach quickly, the pockets should preferably not be covered by the torso harness.

Different designs of the torso harness were ideated upon and shown to users during interviews and evaluation sessions. The outcome of these suggestions and the feedback received was a torso harness design where shoulder straps connect in a single merged strap placed centrally over the sternum (see Figure 2.5), instead of the more classic layout of two straps running in parallel across the chest. Another reason behind this design was to allow further freedom of motion for the arms. It was also theorized that this solution could possibly transfer some of the load from the shoulders to the sternum during bending, which was considered a positive side effect. However, no testing or further research was performed on this specific feature.

Finally, it was decided that the final concept should be designed to be compatible with all of Husqvarna's existing tools and holsters. Thus, the user may transfer existing equipment to the H-EXO without the need of purchasing any additional products. This might lower the threshold for the user to adapt the product as a natural addition to the work gear.

7.5 Ease of Use

Ease of use was a common requirement as described by the users, and is of importance for acquiring user acceptance. As stated in Section 4.3.4, some available exoskeletons have received criticism for being too complex during donning, which could potentially prevent them from being used. The first step taken to address this was to make the design and use of the H-EXO resemble Husqvarna's current product portfolio aesthetically; implementation of familiar design features aimed to create recognition in order for users to adapt to the new product.

Secondly, the H-EXO is easy and intuitive to put on, resembling a back pack in donning, and has four buckle points (chest, waist and both legs) needed to be closed before usage. This was seen as important, with for example one user in Evaluation I stating: *"It must be quick and easy to put on"*. All adjustment points are located on the front or sides and are within reach while wearing the H-EXO. Having access to the buckle points makes it easy to remove the exoskeleton during breaks or in the case of an emergency. Furthermore, by fastening the torso harness straps over the sternum using magnet connections, the harness is possible to be removed quickly using only one hand, which was deemed desirable in some situations.

With the logger needing to be able to move unhindered, a main reason for the design of the activation/deactivation functionality was identified. The ability to lock the length of the elastic bands in the buckles enables ease of use, meaning that the user only need to adjust the spring load once. This function ensures that the user gets the same spring load amount produced by the harness during each use occasion. This was seen as positive by interviewed loggers, exemplified by a user in Evaluation II: *"That kind of thing is really important. You don't want to adjust the straps a couple* *of times a day".*

7.6 Durability

Observational studies and interviews revealed that users generally do not take particular care of working equipment such as tool belts or harnesses, beyond the elemental practice of brushing off apparent dirt, leaves etc. Washing of the equipment appeared to be rare and usually not considered necessary, even though used for several years at a time. Work wear, i.e., clothes, endure more wear and tear, being of thinner material than tool belt and similar, and thus need to be replaced more frequently. The users, when asked, expected the same durability and product life span of an exoskeleton harness as that of a tool belt or other similar equipment of longer duration.

The most sensitive part of the H-EXO is likely the elastic springs. The exact construction of the springs is yet to be determined, due to problems to procure existing solutions for testing and evaluation. The relevant existing passive exoskeleton from the benchmarking (Auxivo Liftsuit and HeroWear Apex) utilizing textile elastic bands have not been physically evaluated during the thesis project.

The decision of designing a cover for the elastic bands is based on the assumption that the springs may be sensitive to external damage. As such, a cover would mainly function as an extra protection for the elastic bands. Such a cover could also provide surface space for placement of a logotype and/or reflective materials, increasing the visibility of the wearer. Alternatively, the cover could also be customized to fit individual logging companies, displaying brand logotypes or similar. Several designs were generated for the cover, exemplified in Figure 7.5 (see Appendix A.8 for a full view), with a final design shown in Figure 2.9.

Figure 7.5: Selection of back cover designs.

The choice of material for the H-EXO is based on Husqvarna's Flexi logger tool belt and harness, using semi-rigid textile materials suited for physical labor. However, the choice of materials has not been an area of focus for this project, as Husqvarna already has experience of developing products that withstands the conditions of forestry work, and it was deemed that specific materials would be better suited for selection in an eventual later stage of development.

7.7 Comfort

The H-EXO should be able to be worn for long periods of time during the work day, emphasizing the great importance of the product to be comfortable for the user during use. There are a range of adjusting point on the H-EXO, enabling correct and comfortable wearing for a variety of body sizes. The design of the connection in the front of the torso harness is made to suit both men and women. Most equipment designed by Husqvarna today are designed for male user, based on males being a vast majority of the user group. However, the aim of this design was to be inclusive and suited for as many users as possible.

Using a simple prototype provided important insights regarding the comfort, even though the main functionality was not provided. The need of a strap connecting the leg support to the belt (C4 in Figure 2.2) was essential as it ensures the belt to stay in position during forward bending. This was not the case during tests of the prototype, leading to the belt sliding upwards when the elastic band were activated, causing discomfort for the user.

One of the most frequently reported reasons for discomfort among the users is heat and resulting sweat, caused by the highly physical labor. Due to regulations the loggers are compelled to wear security rated high visibility clothing which somewhat limits the ability to adapt to high temperatures. Even during work in low outside temperatures many users experience that body heat is quickly generated, leading to dressing in layers of clothing to be able to balance the body temperature. To deal with the heat issue it was requested that the solution should minimize the area of parts in direct connection to the body, exemplified by a user during evaluation II: *"You get soaked on your back while you work. [...] I absolutely believe in the variant with the least fabric"*. This have had a great impact on the size of the harness and leg strap, as they are minimized as far as possible without affecting the function or comfort.

The design of the new tool belt, on the other hand, has become larger than the Flexi tool belt, and inside padding has been added. The reason for this is to improve comfort and lumbar support for the back in standing positions, giving assistance higher up the back, as this has been request by the user in the interviews. As one user stated, this was desirable as long as the heat issue was not exacerbated: *"I believe that extra support in the lower back would be nice, as long as the heat doesn't become a bigger problem"*.

To avoid causing more heat issues by increasing the tool belt size, the shape of the inside padding for the tool belt is designed to reduce the heat generated around the hip area during use. The spacing between the pad ridges functions as air ventilation, where airflow can extract the heat (see Figure 2.10). The pad ridges should be rigid but with an outer soft surface for comfort. Furthermore, by actively reducing the size on the components of the H-EXO as far as possible, the weight of the complete product will be comparatively low. The low weight will likely also have a positive impact on the comfort of wearing the H-EXO, as well as improve mobility.

As discussed by Elstub et al. (2021), reducing heat retention by minimizing contact areas can have a direct impact on comfort. The authors go on to suggest that a mode-switching interface, where the exoskeleton harness can be loosened during periods of inactivity, could result in a more comfortable experience to the wearer with less distress caused by heat. This has not been a point of focus of the thesis, but may be considered for future development. The overall comfort of the product naturally also needs to be further evaluated via high fidelity prototyping.

7.8 Feedback

While the main function of the product, i.e., providing support to the lower back, remains central, it was found during the development work that a feedback system indicating the performance while in use might be of interest to the user. Questions regarding such a feature were asked during interviews with loggers. Some responded positively to such an inclusion, stating: *"[...] anything that reminds you to bend your knees instead of your back is good"* and *"the elastic bands probably help, but a reminder [to use correct posture] maybe helps just as much"*. Others were less enthused, providing answers such as *"I bet there are people who enjoy getting feedback [on work postures] via an app or similar, but not me"* and *"If at the end of the day you feel less strain in the back, that's enough"*, indicating that these users prefer a design with good performance and more basic features.

The feedback feature was ideated on primarily during the focus group in the later stage of the project, where ideas regarding providing haptic or visual information to the user were discussed. Such information to the user could also serve as a reminder to utilize correct working postures, by for example highlighting when work has been performed in harmful ways. This could be done by implementing measuring equipment, such as accelerometers or gyroscope sensors on the product, registering positional data such as angles and similar, or even by limiting extreme movements via length adjustments of the rear straps. The former measuring devices can be used to transfer appropriate information to the user e.g. via an app. This app can present the performance during the day by showing body position, movements, duration and more.

A haptic or fully restraining solution, limiting some harmful movements, might be able to provide more direct feedback to the user. However, such a function might be counterproductive to the end goal, as it might result in users discarding the product all-together. As one user in Evaluation II stated: *"It's good to promote correct working postures, but limiting movement might be irritating to the wearer"*.

In the end, it was decided that these features should remain proposals for future development, as the feedback to the user is secondary to the main function and therefore more suited for development at a later stage. Therefore it was not further worked upon during the project due to time constraints and prioritization of the previously listed design factors.

8

Discussion

This chapter aims to discuss the result of the project in relation to the introduction as well as other considerations, such as ethical and sustainability related factors. Furthermore, the discussion will reflect on the execution of the project, where each phase of the design process will be discussed, focusing on the applied methodology and implementation thereof.

8.1 Fulfillment of Objectives

While an exoskeleton such as the H-EXO by most accounts seems like a feasible solution in order to assist in prevention of MSDs in the lower back, it is debatable if it is the optimal one with regards to performance and cost considerations. As stated by a majority of users, ergonomic work postures and correct handling of equipment most likely remain the single most critical factors for preventing MSDs at work, and knowledge and early education efforts of such is central for preventing muscle and body exertion in chainsaw operators. Other approaches to dealing with the issue have not been explored in this thesis due to the limits set by the initial framework. However, a more holistic approach to the problem should be considered for future work. This could include a deeper look into, and potential overhaul of, chainsaw handling education with regards to ergonomics provided to new operators by instructors, as this does not appear to be entirely standardized as of today. Such an intervention directed at what might be considered the root cause of the issue may prove to be more fruitful long-term, as well as less costly for the operators themselves. On the other hand, it is possible that usage of a product like the H-EXO may also serve as a reminder to the wearer regarding use of appropriate work postures, in that sense serving a passive as well as physically active role for relief of the lower back. Regardless, due to the fact that some postures within logging activities do require forward bending and similar sub-optimal postures, an exoskeleton giving support and relief to the lower back may likely be beneficial.

The use of an exoskeleton must also not supplant correct ergonomic work methods and should not encourage users to undertake erroneous postures, being under the impression that the external support system will rectify any such undertakings. Likewise, if the use of a product of this type should render the user less physically fatigued, this must not be seen as an incentive for working longer hours or significantly increasing the work tempo. Doing so could potentially result in an unaltered status quo with regards to lower back issues, which is an undesirable scenario. As such it is recommended that, should the product be further developed and realized, detailed and clear instructions of its use cases and limitations need to be provided with the procurement so as not to unintentionally mislead the customer.

Another potential side effect of using an exoskeleton of this type is the increase of muscle activity in other areas of the body, i.e., a transfer of the muscle load from the lower back extensor muscles to other muscle groups of the body, such as abdominal and thigh muscles. Creating excessive activity in other muscle groups due to the use of an exoskeleton is undesirable, as this could add to the compression forces acting on the lumbar spine, as stated by Kermavnar et al. (2021). Relatively little previous research has been performed in this area, and no conclusive results exist, meaning that a solution like the H-EXO would need extensive testing with such a focus before a final product is launched.

The physical work environment and execution of tasks should not be affected by the H-EXO. The effect of using H-EXO will rather improve the conditions for performing the tasks in a sustainable manner regarding working postures and physical load over time. The long term effects of using this exoskeleton aims to prolong the physical fitness of the user and reduce sick leave, leading to an increase in the quality of life.

Limbing is most often perceived as the most physically straining task by loggers, as it involves chainsaw maneuvering around the tree trunk, and thus requires bending across the same, and the duration of its execution is often extensive. As stated in Chapter 7, this task was not judged the most critical using the ergonomic analysis tools. However, as these did not take repetitions and the time aspect into account, no definite conclusion regarding which work task is most demanding for the lower back can be drawn. As such, both cutting and limbing were approached as critical tasks during the course of the project.

The H-EXO will provide assistance when bending by reducing the muscle activity. What is still unknown and thus needs to be evaluated are the effects that the exoskeleton have on the body during twisting motions. Twisting motions occur throughout the work day, often in combination with bending, and may be, according to the ergonomic evaluations, more harmful. The main focus of the project has been on the bending motions, as a vast majority of the previous research concerning exoskeletons has focused on this type of motion. For a future continuation of the development process it is recommended to evaluate and, if necessary, improve the product support for preventing strain during twisting motions. The long-term effects of wearing an exoskeleton during work tasks also needs to be evaluated.

8.2 Impact of Demarcations

A demarcation regarding the targeted user group was set early, with the choice to focus on Swedish professional loggers and their specific work environment. This has influenced the project in several ways, including assumptions about equipment standards, work methodology and behavior, as well as economic factors leading to the approximate price point of the final product. The biggest market share might not be Sweden, however, due to the fact that the national forestry industry is one of the most fully mechanized in the world. As stated in Section 3.1, other countries in Europe as well as North America conduct harvesting operations to a comparatively greater extent using chainsaws. Therefore a larger user base might be found in other areas than Sweden. However, personal protection and equipment standards, as well as work procedure, may vary heavily. Together with variations in economic resources, these factors could potentially make it necessary to adjust the design of the product to comply with local conditions in order to reach the users.

Arborists, the other major user group working with chainsaws apart from professional loggers and private wood owners, has not been a focus in the project, due to their substantially differing working methods. Using climbing and rope equipment to cut down trees working downwards from the top, arborists face different challenges and adapt divergent body postures compared to loggers. However, it cannot be ruled out that the H-EXO would not also be applicable in an arborist context, and some interviews performed with arborists indicate that an exoskeleton solution could very well be desirable for the users. This would likely necessitate some change in the design, e.g. the implementation of fall protection gear and similar.

To limit the scope of the pre-study it was decided to focus research mainly on passive exoskeleton models. Thus, active models powered by batteries and other energy sources have not been considered, except for comparative performance data in Section 4.3.3. With chainsaws and other power tools increasingly being released as battery powered models, and batteries themselves being improved upon, it is possible that the ecosystem for including such power sources in future forestry devices will be enhanced in coming years. With such an evolution it could be worth exploring the area of active exoskeletons more, as these can provide larger amounts of additional force to the wearer than passive models. This might be deemed desirable in work tasks such as manual transportation of logs and similar.

With the concept design supposed to be an entry product on the market, the estimated cost was set to be lower than many other available exoskeleton products. This impacted many decisions taken during the course of the project. However, manufacturing costs are reliant on volumes as well as other factors, meaning that a deeper market exploration would be necessary before further development is undertaken. Potential future products in the segment may also be more advanced in nature, if user acceptance has been gained and the product type established in the forestry sector.

No testing of product performance was performed in this thesis, due to it being the initial development stage, with decisions instead based on available literature. This makes the thesis quite theoretical in its approach, which could arguably be considered as negative when developing a highly physical product. However, with the product type being entirely new to the company and setting, this became a necessary delimitation in order to approach the subject broadly. Furthermore, it was judged that simulations of product performance would be too inaccurate and far removed from reality to be of actual use, while demanding a heavy time investment. As literature concerning exoskeletons and their efficiency serves as a base for the design decisions made, this makes the reports in question quite central. It should be noted that some of the available literary documentation has been performed in cooperation with companies developing the tested exoskeleton products in question, potentially rendering some aspects of the reports biased. However, many other relevant papers are purely academic in nature, and with much of this thesis being based on literature reviews that have compiled and analyzed the results of both kinds this is not considered a significant issue.

8.3 Ethical Considerations

The decision to develop an exoskeleton can be seen as a means to legitimize potentially harmful work. An exoskeleton is, arguably, solving the symptoms of a harmful behavior rather than changing the activities causing it. To effectively decrease the amount of MSDs within motor-manual forestry work, the execution and methodology would need to be changed fundamentally. This will not be done in a trice, so therefore the H-EXO can be seen as a facilitator of a sustainable work environment, until the source of the problem is changed.

The H-EXO may enable continued work while suffering from a minor injury or ailment, due to the relief of the physical loads on the lower back. As such, the risk would be enabling users to continue working for too long, potentially leading to worsening of the injury. Another potential effect of the use of H-EXO is that it could lead to higher workload due to a perceived lowered physical exertion. These possible side effects of using H-EXO are unwanted. To avert these risks of misuse, information of correct usage needs to be provided to the user, though responsibility still lies with the individual logger and management to provide a healthy and sustainable work environment.

The price of H-EXO aims to be relatively low compared to the other exoskeletons reviewed in this thesis. However, the price for the customer would still likely be comparable to all other work wear put together. This might be an investment too costly for the user making work health potentially become a matter of money. In the future it is possible that exoskeletons will become more commonly used within industry, which could lead to a different market with lower prices.

8.4 Sustainability

This section describes the different kinds of sustainability considerations that may be impacted by the developed concept.

8.4.1 Environmental Considerations

Forestry work, especially concerning harvesting methods, may have a negative impact on ecosystems and environment, depending on how it is carried out. There is currently a debate in Sweden about the sustainability of the national forestry practice (Holmgren, 2021), though the contentious points concern the strategy of the amount of wood that is cut down and how it shapes the landscape and contributes to changes in climate. Regardless, wood harvesting will be a necessary and pervasive practice for the foreseeable future, and as such enabling the workforce to avoid injury, if possible, is still considered a desirable outcome of the thesis.

The ecological footprint of manufacturing a product like the H-EXO is another sustainability factor, in order to aim for a sustainable development. Here, minimizing the amount of materials has been prioritized, along with including existing Husqvarna equipment features in order to be able to re-use tooling. Additionally, being a highly modular design, exchanging of parts or components should be relatively easy. It could be argued that it would be preferable to develop an add-on product for existing Flexi belts, to prevent users from buying a new kit even though their old belt still works. However, the necessary re-design of the belt, to enhance ergonomic support of the back as well as accommodating the exoskeleton function via the back straps, meant that a new tool belt had to be developed.

8.4.2 Social Considerations

The H-EXO could work as a means to make the motor-manual forestry work more inclusive. By, albeit slightly, reducing the need for physical strength, the H-EXO allows the possibility for a larger group of people to work in forestry. The product would likely have a greater impact in this regard in later release stages where the exoskeleton can provide more force than in this conceptual initial version. Another potential effect on the societal level of sustainability is the increased quality of life if the user has more energy for leisure activities after working hours due to a lessened physical workload.

8.4.3 Economical Considerations

If the H-EXO can have the effect of decreasing time spent off work due to ailments it will not only have positive effects on the well-being of the user, but also on economical sustainability. Facilitating healthier working conditions could have positive economic effects for the user, employer and society, as discussed in chapter 4.1, by reducing the percentage of personnel suffering from physical pain. Though buying the product itself may require a comparatively large one sum transaction for the user or company, the H-EXO would likely be able to last for a longer period of time than other work wear. The cost should also be weighted against the cost of sick leave caused by lower back pains; as one user in evaluation II hypothesized, *"the cost of [acquiring] a product like this compared to the cost of a week in the sickbed - it will pay off quickly"*.

8.5 Design Process

The structure of this project follows the Double diamond design process (Design-Council, 2022), considered as a suitable method based on the project brief. The project emphasizes the discovery and development phases as Husqvarna primarily wanted to understand the user needs and to gain knowledge about existing exoskeletons on the market. Further, Husqvarna wanted the result to be delivered as a design proposal of a well defined concept that could work as an entry product on the market. The Double diamond process proved to be satisfactory for this project, used with continuous iterations as new knowledge and insights were gained. Due to Covid-19 pandemic related restrictions, all tasks could not be executed according to the initial project plan and the project schedule was revised continuously. The restrictions had a severe impact in the initial phases of the project, with delays of observational field studies that were planned to be held in cooperation with Husqvarna personnel.

The theory of Emotional design by Norman (2004) was used as a guide to ensure that the final concept involves design at each level. The main focus of the ideation and development work was focused on behavioral design as the usages and function are the most critical features to obtain to make the concept trustworthy. The visceral and reflective level were also considered during the design process with the aim to increase user acceptance. Recognition and professionalism were the key semantics that the concept shall communicate through the design to appeal to the more conservative group of users, discussed in the interviews. If the H-EXO succeeds in communicating these properties and if they affect the acceptance is yet to be evaluated.

The following sections discuss various aspects of the design work, divided into the four phases of the Double diamond process.

8.5.1 Discover

A deficiency in the benchmarking was the inability to acquire existing physical products due to high pricing or availability, leading to the benchmarking being more theoretical in approach. The scholarly evaluations of available exoskeletons in the literature review differed in aspects of study design, methods, demographics and purpose, which may affect the findings and making performance difficult to assess. The functionality of the H-EXO is based on reliance on existing products and the validation of these products in the reviewed reports. Even though the assumption of technologies, functionality and performance is well substantiated, the properties are still left to be defined and tested. The reviewed studies are mainly focusing on lifting tasks, while the tasks performed by loggers are more versatile. Therefore testing of the available solutions put in a forestry setting is recommended. As this is a new field for Husqvarna to explore, existing products and eventual patents were used as inspiration rather than demarcations for this project.

Reaching out and getting in contact with the users was a pervasive problem in the project. Most of the initial contacts were conducted via email, with a comparatively low reply rate. Supposing that the user group can not be described as highly digitized, there might be other, more efficient ways to reach out to the users that would generate higher reply rate and a larger sample of users, which would be beneficial for this type of project.

The contact information found online were mostly that of instructors, foremen and managers, resulting in a limited spread in age and experience of respondents (n=31) in the survey. 64.5% of the respondents were over 50 years old and 71% had more than 20 years of experience. Another problem that was not foreseen is the fact that a considerable part of loggers operating in Sweden are of foreign descent and do not communicate in English or Swedish, which prevented them from answering the survey. It was considered to be too time consuming to translate the survey into other languages, leading to focusing on a Swedish speaking users. While the aim of the survey was to get insights from a wide range of users, this was arguably not fully achieved.

The interviews were conducted with instructors with long experience in forestry. The choice of this segment of users was deliberate for this part of the user study, as long term effects of manual logging with chainsaw were a focus of the research. This user group has experience of working with ergonomics and safety, which was considered valuable knowledge in order to get the most information and insights out of the interviews. Additional interviews with younger loggers would likely have provided somewhat different input, and also perhaps more varying and challenging views on ergonomic aids, which could have been beneficial for the end result.

The observational field study was delayed and rescheduled, caused partly by Covid-19 related restrictions at Husqvarna and later by scheduling problems with users. The results of the field observations has shown to be of great value, and therefore the observations could arguably have been expanded in numbers, but with the thesis being performed and written in Gothenburg adjacency to forestry work and workers was not plentiful. As such, there is a risk that the findings from the observational study is not entirely representative of tree felling in general. However, the observations seem to correspond to a high degree when compared to video material, literature and video observations of the same tasks, and Swedish loggers in general follow the same base principles during tree felling.

A general reflection is that all users involved in the study were highly willing to provide insight into their work and work environment, showing pride concerning their field of work and interest in the topic at hand. All of them had thorough experience of the industry and were willing to help to improve the working conditions, providing a large amount of qualitative data.

Recording of interviews performed on site at tree felling locations proved to be more difficult than initially anticipated. Audio recording was neigh impossible due to high noise levels emitted from other chainsaw activities in the area, and with the user study taking place during winter note taking proved to be difficult as well, due to low temperatures and freezing fingers. This may have had an impact on the notes from these interviews, but the authors still consider the core input and insights to be included in the project.

8.5.2 Define

Affinity diagramming was seen as an efficient method for sorting and analyzing the qualitative data obtained from the user study. Providing a good overview of the data, categories could be identified and the problem areas pinpointed, to create a framework for the ideation.

During the observation the versatility of the daily operations performed by the loggers were noted. By sorting out the different tasks and their constituents this way, a visual representation of the context was produced, helping to understand the complexity of the work. Furthermore, it put emphasis on the importance of designing for flexibility and compatibility in order to create a product for this application.

To focus more on a functional analysis instead of a requirement list was seen as more beneficial, as the project is the initial part of exploring the use of exoskeletons in a forestry context. Focusing on functions provided more freedom in these early development stages. The use of a requirement list will be more adequate in later stages of the development process, as it entails more highly detailed requirements with clearly defined values that shall be measurable.

There was no single ergonomic method available for evaluating all ergonomic aspects of the working task. Each method used was focusing on different factors while not considering others, which is why multiple evaluation methods were used, in order to cover all hazardous elements in the working tasks. This does not provide a definite result on the exact load exposed to the user during the task, but as all the evaluation forms scored equally high, it could be assumed with high probability that the tasks performed entails a high risk of stress injuries and MSDs. While there exists other analysis tools, such as the *Lifting Fatigue Failure Tool* which take repetitions into account, they were not used, as estimating repetitions for each work task during a working day proved highly difficult.

The range of products used in the Design Format Analysis varied between clothes, safety equipment and tools. This is sub-optimal for a DFA, which ideally should be performed on a single product family. This led to basing the design more on the existing Flexi tool belt and harness than strictly following the result of the DFA. The reason for this focus was to ensure the impact of the visceral and reflective levels of the Emotional design theory.

8.5.3 Develop

The selected ideation methods were of a quite standard level, meaning that they mainly consisted of realistic solutions that were deemed to fit a professional forestry context. Though some more radical solutions were explored initially, such as non-anthropomorphic designs where a separate external arm would be able to hold the chainsaw, the main part of the ideation sessions concerned more feasible devices. This might have limited the solution space to a degree, but was all the same deemed necessary considering the project demarcations and user input.

For the sketching sessions, a model showing front, back and side views of a human body was printed on paper as a template for sketching. The use of the template facilitated reasonably accurate sketches with regards to proportions and anatomy, saving time. Another advantage of using a template is that all sketches were done in the same size and views, making the comparison of features and ideas far easier.

The use of a cut-out doll was highly appreciated in comparison to digital models during the evaluations. Facilitating interaction with the different design proposals and enabling combining different components together made for an active engagement of the participants. The impression was that the users were reflecting on a more detailed level when compared to evaluations using digital representations.

The project could have benefited from building a prototype of higher detail level, to be used in the evaluations to provide a representation of the concept and its function. The evaluation could, naturally, have been improved from letting the user perform tasks while using a highly developed prototype, recording muscle activity and similar data. Within the time frame of this project such a prototype could not be produced, and is therefore recommended for future considerations. The prototype that was built, though simple in execution, worked well as a mediating object communicating intended function to users during evaluations.

8.5.4 Deliver

An important aspect is how the users perceive an exoskeleton product, i.e., user attitudes. Some users might be hesitant to use a device like the H-EXO due to the increased weight of equipment and perceived incompatibility with the work tasks. Due to the choice of using elastic bands and the size reduction of each part the total weight should not increase significantly compared to the existing equipment, and one main aim of the design was to be compatible with current tools and work methodology.

Another apprehension with the H-EXO is a conceivable perceived negative impact on the user's professional self-image. Interviews revealed a common conservative attitude towards change within the user group, especially concerning topics such as personal health and sustainability among younger operators. Norman's emotional design was used in this project to approach these factors. The measure implemented to overcome the attitude barrier is the applying of design features that are well-known to the users. The visual appearance, i.e., resembling existing equipment, and the inclusion of the tool belt as an integrated part of the product might impact the visceral and reflective perception of the product. If these measures are enough to persuade the conservative users is yet to be determined. Further, it was suggested that a product like the H-EXO should be introduced to users via instructors and well-known figureheads in the forestry community. This would likely be more successful in convincing younger loggers to adapt a new product, as inspiration from experienced users is a common and proven method to gain such attention. This could be considered to use the final level of emotional design, triggering reflection and further thought in the user concerning personal health.

How the long term effects of wearing an exoskeleton affect the body in terms of muscle mass over time, are unknown. The assumption of the effects of using H-EXO over the years is that there shall not be a radical impact on muscle mass. The ability of the user to switch between activated and deactivated mode of the harness should lead to the body muscles still being active for a majority of the work time. Additionally, while using the activated harness the user's lower back muscles are still exerted, as the exoskeleton does not compensate for all of the forces while moving to or from a bending position. The H-EXO is also intended to only be worn during logging, meaning that any non-work related physical activity is performed without external support, leading to a natural build up of muscle.

By making the tool belt removable from the rest of the exoskeleton the product, with minor modification, can function in other contexts. This is not considered a part of this project, but can be a point of interest to evaluate during the further development to broaden the area of use.

9 Conclusion

While adaption of ergonomically correct working postures, and active reflection and consciousness of these, remain the most important factor for preventing musculoskeletal disorders and pains among loggers, it is concluded that an exoskeleton product could potentially give further support to the user and help prevent pains from materializing. The H-EXO is likely to fulfill this product type role in a logger context, by including familiar Husqvarna elements and tool belt functionality. However, further research is necessary, including the testing of a working prototype in a real life context including data collection of muscle activity, such as back extensors and other muscle groups, to measure performance and potential side effects.

Recommendations for future work:

- Test similar available products in a forestry context, measure performance.
- Create a working prototype for testing and evaluation of comfort and functionality.
- Evaluate the long-term effects on the individual of wearing an exoskeleton during work.
- Explore the possibility of adding a longer moment arm r_{EXO} between springs and lumbar spine to increase the balancing momentum around L5/S1.
- Explore if elastic bands need to be covered.

Bibliography

Abdoli-Eramaki, M., Stevenson, J. M., Reid, S. A., & Bryant, T. J. (2007). Mathematical and empirical proof of principle for an on-body personal lift augmentation device (plad). *Journal of Biomechanics*, *40*(8), 1694–1700.
URL: https://www.sciencedirect.com/science/article/pii/S0021929006003228

Ali, A., Fontanari, V., Schmoelz, W., & Agrawal, S. K. (2021). Systematic review of back-support exoskeletons and soft robotic suits. *Frontiers in bioengineering and biotechnology*, *9*, 765257–765257. 34805118[pmid] PMC8603112[pmcid] 765257[PII].
URL: https://pubmed.ncbi.nlm.nih.gov/34805118

Antwi-Afari, M. F., Li, H., Anwer, S., Li, D., Yu, Y., Mi, H.-Y., & Wuni, I. Y. (2021). Assessment of a passive exoskeleton system on spinal biomechanics and subjective responses during manual repetitive handling tasks among construction workers. *Safety Science*, *142*, 105382.
URL: https://www.sciencedirect.com/science/article/pii/S0925753521002265

Arbetsmiljöverket (2012). KIM III - Riskbedömning av repetitivt arbete med stöd av nyckelindikatorer.
URL: https://www.av.se/globalassets/filer/checklistor/riskbedomning-repetitivt-arbete-kim-3-checklista.pdf?hl=kim%203

Auxivo (2022). The auxivo liftsuit.
URL: https://www.auxivo.com/liftsuit

Bevan, S. (2015). Economic impact of musculoskeletal disorders (msds) on work in europe. *Best Practice & Research Clinical Rheumatology*, *29*(3), 356–373.
URL: https://www.sciencedirect.com/science/article/pii/S1521694215000947

Bioservo (2022). Ironhand.
URL: https://www.bioservo.com/professional

Bogduk, N. (2005). *Clinical Anatomy of the Lumbar Spine and Sacrum*. Elsevier/Churchill Livingstone.
URL: https://books.google.se/books?id=UYC_NpoFfAsC

Bohgard, M., Karlsson, S., Lovén, E., Mikaelsson, L.-A., Mårtensson, L., Osvalder, A.-L., Rose, L., & Ulfvengren, P. (2015). *Arbete och teknik på människans villkor*. Stockholm: Prevent, 3 ed. 3. uppl. 2015-09-28T12:59:18.059+02:00.
URL: `http://urn.kb.se/resolve?urn=urn:nbn:se:liu:diva-121398`

Calvo, A. (2009). Musculoskeletal disorders (msd) risks in forestry: a case study to propose an analysis method. *Agricultural Engineering International: the CIGR Ejournal*, *XI*(April, 2009).

De Looze, M. P., Bosch, T., Krause, F., Stadler, K. S., & O'Sullivan, L. W. (2016). Exoskeletons for industrial application and their potential effects on physical work load. *Ergonomics*, *59*(5), 671–681. Doi: 10.1080/00140139.2015.1081988.
URL: `https://doi.org/10.1080/00140139.2015.1081988`

Design-Council (2022). The design process: What is double diamond?
URL: `https://www.designcouncil.org.uk/news-opinion/what-framework-innovation-design-councils-evolved-double-diamond`

Dimou, V., Malesios, C., & Pispa, S. (2020a). Assessing forestry-related musculoskeletal symptoms in specific body areas. *International Journal of Forest Engineering*, *31*(3), 233–241. Doi: 10.1080/14942119.2020.1789393.
URL: `https://doi.org/10.1080/14942119.2020.1789393`

Dimou, V., Malesios, C., & Pispa, S. (2020b). Monitoring self-reported musculoskeletal symptoms in forestry operations. *International Journal of Forest Engineering*, *31*(2), 106–113. Doi: 10.1080/14942119.2020.1745530.
URL: `https://doi.org/10.1080/14942119.2020.1745530`

Elstub, L. J., Fine, S. J., & Zelik, K. E. (2021). Exoskeletons and exosuits could benefit from mode-switching body interfaces that loosen/tighten to improve thermal comfort. *International Journal of Environmental Research and Public Health*, *18*(24).

Enez, K., & Nalbantoğlu, S. S. (2019). Comparison of ergonomic risk assessment outputs from OWAS and REBA in forestry timber harvesting. *International Journal of Industrial Ergonomics*, *70*, 51–57.
URL: `https://www.sciencedirect.com/science/article/pii/S0169814118301963`

ErgoSanté (2022). Hapo posture harness.
URL: `https://ergosante.fr/en/harnais-de-posture-hapo/`

Ferguson, A. (2018). Exoskeletons and injury prevention.
URL: `https://www.safetyandhealthmagazine.com/articles/17370-exoskeletons-in-the-workplace`

Gallis, C. (2006). Work-related prevalence of musculoskeletal symptoms among Greek forest workers. *International Journal of Industrial Ergonomics*, *36*(8), 731–736.
URL: `https://www.sciencedirect.com/science/article/pii/S0169814106001065`

Garland, J. (2018). *Accident reporting and analysis in forestry: guidance on increasing the safety of forest work*, vol. 2 of *Forestry working paper*. Rome: FAO.

Grzywiński, W., Jelonek, T., Tomczak, A., Jakubowski, M., & Bembenek, M. (2017). Does body posture during tree felling influence the physiological load of a chainsaw operator? *Annals of Agricultural and Environmental Medicine*, *24*(3), 401–405.
URL: https://doi.org/10.5604/12321966.1235177

Grzywiński, W., Sawastian, K., & Turowski, R. (2015). Analysis of postural strain of loggers during timber harvesting in a spruce stand. *Forestry Letters*, *108*, 1–6.

Grzywiński, W., Wandycz, A., Tomczak, A., & Jelonek, T. (2016). The prevalence of self-reported musculoskeletal symptoms among loggers in Poland. *International Journal of Industrial Ergonomics*, *52*, 12–17.
URL: https://www.sciencedirect.com/science/article/pii/S016981411530007X

Grzywiński, W., Wandycz, A., Tomczak, A., Jelonek, T., Szaban, J., & Jakubowski, M. (2010). Occurence of musculoskeletal disorders in woodcutters.
URL: https://www.formec.org/images/proceedings/2010/Ab089.pdf

Gullberg, T. (2015). Complement to working with chain saw.
URL: https://sakerskog.se/wp-content/uploads/2016/01/Complement-chainsaws-AFS-1512-ver1.pdf

HeroWear (2022). Herowear Apex.
URL: https://herowearexo.com

Hignett, S., & McAtamney, L. (2000). Rapid entire body assessment (REBA). *Applied Ergonomics*, *31*(2), 201–205.
URL: https://www.sciencedirect.com/science/article/pii/S0003687099000393

Holmgren, P. (2021). Svenskt skogsbruk är inte hållbart. *Svenska Dagbladet*.
URL: https://www.svd.se/svenskt-skogsbruk-ar-inte-hallbart

Husqvarna (2022a). Husqvarna chainsaws.
URL: https://www.husqvarna.com/ca-en/chainsaws/

Husqvarna (2022b). Husqvarna forest and garden division.
URL: https://www.husqvarnagroup.com/en/husqvarna-forest-garden-division

Husqvarna (2022c). Husqvarna group.
URL: https://www.husqvarnagroup.com/en/about

Husqvarna (2022d). Tool belt flexi carrier kit.
URL: https://www.husqvarna.com/ca-en/tool-belts-and-accessories/tool-belt-flexi-carrier-kit/

Huysamen, K., Bosch, T., de Looze, M., Stadler, K. S., Graf, E., & O'Sullivan, L. W. (2018). Evaluation of a passive exoskeleton for static upper limb activities. *Applied Ergonomics*, *70*, 148–155.

URL: https://www.sciencedirect.com/science/article/pii/S0003687018300334

Iftime, M. D., Dumitrascu, A.-E., & Ciobanu, V. D. (2020). Chainsaw operators' exposure to occupational risk factors and incidence of professional diseases specific to the forestry field. *International Journal of Occupational Safety and Ergonomics*, (pp. 1–12). Doi: 10.1080/10803548.2019.1703336.
URL: https://doi.org/10.1080/10803548.2019.1703336

Jensen, G. M. (1980). Biomechanics of the lumbar intervertebral disk: A review. *Physical Therapy*, *60*(6), 765–773.
URL: https://doi.org/10.1093/ptj/60.6.765

Jenssen, I., & Kwak, L. (2019). Arbetshälsoekonomiskt analysverktyg.
URL: https://mynak.se/wp-content/uploads/2019/11/Analysverktyg_landrygg-1.pdf

Johannesson, H., Persson, J.-G., & Pettersson, D. (2013). *Produktutveckling: Effektiva metoder för konstruktion och design*. Stockholm: Liber AB, 2 ed.

Kermavnar, T., de Vries, A. W., de Looze, M. P., & O'Sullivan, L. W. (2021). Effects of industrial back-support exoskeletons on body loading and user experience: an updated systematic review. *Ergonomics*, *64*(6), 685–711. Doi: 10.1080/00140139.2020.1870162.
URL: https://doi.org/10.1080/00140139.2020.1870162

Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sørensen, F., Andersson, G., & Jørgensen, K. (1987). Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. *Applied Ergonomics*, *18*(3), 233–237.
URL: https://www.sciencedirect.com/science/article/pii/000368708790010X

Laevo (2022). Laevo v2.5 wearable chest and back support.
URL: https://www.laevo-exoskeletons.com/en/laevo-v2-1

Lagerstrom, E., Magzamen, S., Brazile, W., & Rosecrance, J. (2019). Active surveillance of musculoskeletal disorder symptoms in the development of safety interventions for professional loggers. *Safety*, *5*(2).

Lamers, E. P., Yang, A. J., & Zelik, K. E. (2018). Feasibility of a biomechanically-assistive garment to reduce low back loading during leaning and lifting. *IEEE Transactions on Biomedical Engineering*, *65*(8), 1674–1680.

Landekić, M., Martinić, I., Mijoč, D., Bakarić, M., & Šporčić, M. (2021). Injury patterns among forestry workers in Croatia. *Forests*, *12*(10).

Lundbäck, M., Häggström, C., & Nordfjell, T. (2021). Worldwide trends in methods for harvesting and extracting industrial roundwood. *International Journal of Forest Engineering*, *32*(3), 202–215.
URL: https://www.tandfonline.com/doi/full/10.1080/14942119.2021.1906617

Madinei, S., Alemi, M. M., Kim, S., Srinivasan, D., & Nussbaum, M. A. (2020). Biomechanical evaluation of passive back-support exoskeletons in a precision manual assembly task: "expected" effects on trunk muscle activity, perceived exertion, and task performance. *Human Factors*, *62*(3), 441–457. Doi: 10.1177/0018720819890966.
URL: https://doi.org/10.1177/0018720819890966

Martin, B., Hanington, B., & Hanington, B. (2012). *Universal Methods of Design: 100 Ways to Research Complex Problems, Develop Innovative Ideas, and Design Effective Solutions*. Rockport Publishers.
URL: https://books.google.se/books?id=uZ8uzWAcdxEC

Neely, G., & Wilhelmson, E. (2006). Self-reported incidents, accidents, and use of protective gear among small-scale forestry workers in Sweden. *Safety Science*, *44*(8), 723–732.
URL: https://www.sciencedirect.com/science/article/pii/S0925753506000282

Norman, D. A. (2004). *Emotional design: why we love (or hate) everyday things.*. New York: Basic Books, 6th ed.

Nunes, I., & Bush, P. (2012). *Work-Related Musculoskeletal Disorders Assessment and Prevention*, book section 1, (pp. 1–26). IntechOpen.

Näf, M. B., Koopman, A. S., Baltrusch, S., Rodriguez-Guerrero, C., Vanderborght, B., & Lefeber, D. (2018). Passive back support exoskeleton improves range of motion using flexible beams. *Frontiers in Robotics and AI*, *5*.
URL: https://www.frontiersin.org/article/10.3389/frobt.2018.00072

Ottobock (2022). Paexo back.
URL: https://paexo.com/paexo-back/?lang=en

PEC (2022). Acute low back pain.
URL: https://www.spine.org/KnowYourBack/Conditions/Low-Back-Pain/Acute-Low-Back-Pain

Riksskogstaxeringen (2021). Forest statistics 2021. Report, Swedish University of Agricultural Sciences.

Sassack, B., & Carrier, J. (2021). Anatomy, back, lumbar spine.
URL: https://www.ncbi.nlm.nih.gov/books/NBK557616/

Schneider, E., Irastorz, X., & Copsey, S. (2010). Osh in figures: Work-related musculoskeletal disorders in the EU — facts and figures.

Skogskunskap (2022). Gallring för självverksamma.
URL: https://www.skogskunskap.se/skota-barrskog/gallra/gallring-for-sjalvverksamma/

Skogsstyrelsen (2022). Skogsstyrelsens statistikdatabas.
URL: http://pxweb.skogsstyrelsen.se/pxweb/sv/Skogsstyrelsens%20statistikdatabas/?rxid=03eb67a3-87d7-486d-acce-92fc8082735d

SuitX (2022a). BackX v3.
URL: https://www.suitx.com/backx

SuitX (2022b). LegX.
URL: https://www.suitx.com/legx

Voilqué, A., Masood, J., Fauroux, J., Sabourin, L., & Guezet, O. (2019). Industrial exoskeleton technology: Classification, structural analysis, and structural complexity indicator. In *Wearable Robotics Association Conference (WearRAcon)*, (pp. 13–20).

Warell, A. (2006). Identity recognition in product design: An approach for design management. In *Proceedings of the 13th International Product Development Management Conference*. Politecnico di Milano.

WHO (2021). Musculoskeletal conditions.
URL: https://www.who.int/news-room/fact-sheets/detail/musculoskeletal-conditions

Wong, T. K. M., Man, S. S., & Chan, A. H. S. (2020). Critical factors for the use or non-use of personal protective equipment amongst construction workers. *Safety Science*, *126*, 104663.
URL: https://www.sciencedirect.com/science/article/pii/S0925753520300606

Wästerlund, D. S. (1998). A review of heat stress research with application to forestry. *Applied Ergonomics*, *29*(3), 179–183.
URL: https://www.sciencedirect.com/science/article/pii/S000368709700063X

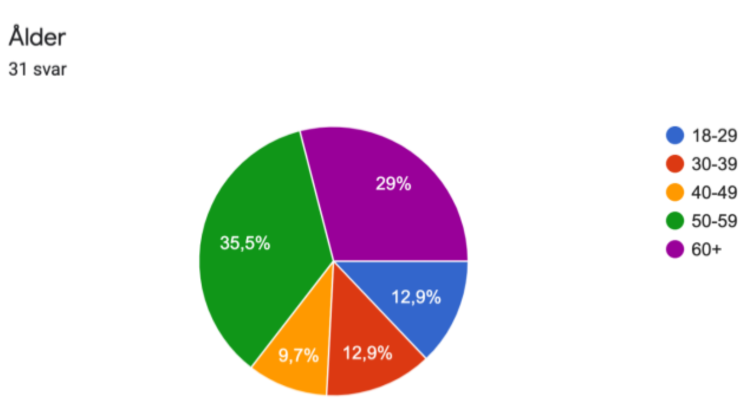
Zelik, K. E., Nurse, C. A., Schall, M. C., Sesek, R. F., Marino, M. C., & Gallagher, S. (2022). An ergonomic assessment tool for evaluating the effect of back exoskeletons on injury risk. *Applied Ergonomics*, *99*, 103619.
URL: https://www.sciencedirect.com/science/article/pii/S0003687021002660

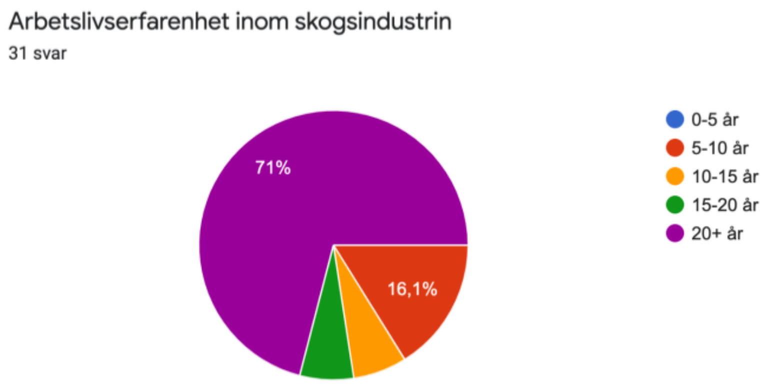
Österlin, K. (2016). *Design i fokus: Varför ser saker ut som de gör?*. Stockholm: Liber AB, 4 ed.

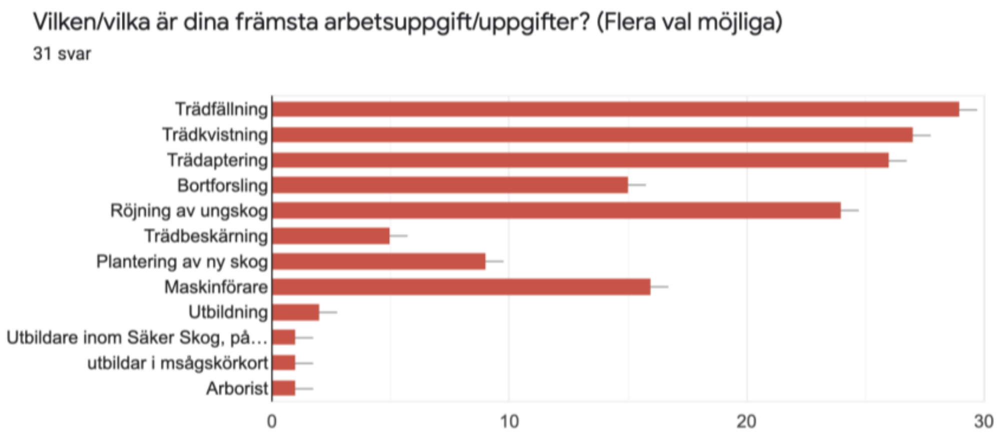
A

Appendix

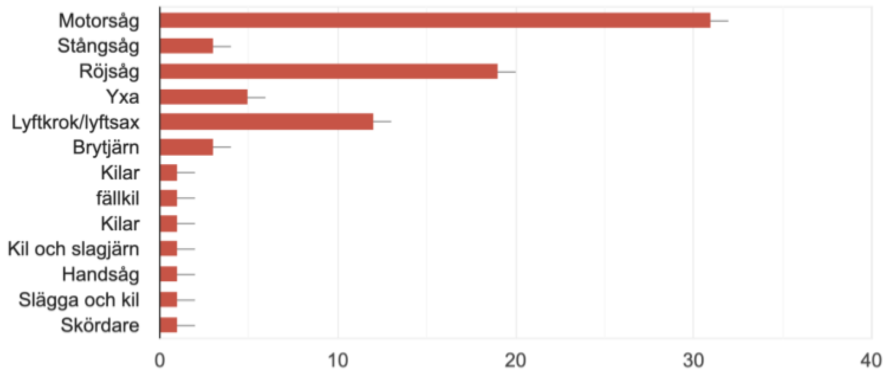
A.1 Survey Results, Presented in Swedish



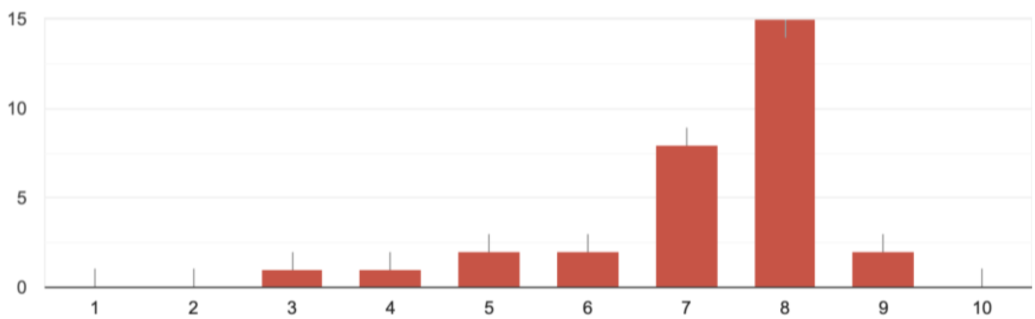

Arbetslivserfarenhet inom skogsindustrin
31 svar
71%
16,1%
0-5 år
5-10 år
10-15 år
15-20 år
20+ år


Vilken/vilka är dina främsta arbetsuppgift/uppgifter? (Flera val möjliga)
31 svar
Trädfällning
Trädkvistning
Trädaptering
Bortforsling
Röjning av ungskog
Trädbeskärning
Plantering av ny skog
Maskinförare
Utbildning
Utbildare inom Säker Skog, på…
utbildar i msågskörkort
Arborist
0
10
20
30

Vilket/vilka verktyg används mest frekvent i ditt dagliga arbete? (Flera val möjliga)
31 svar

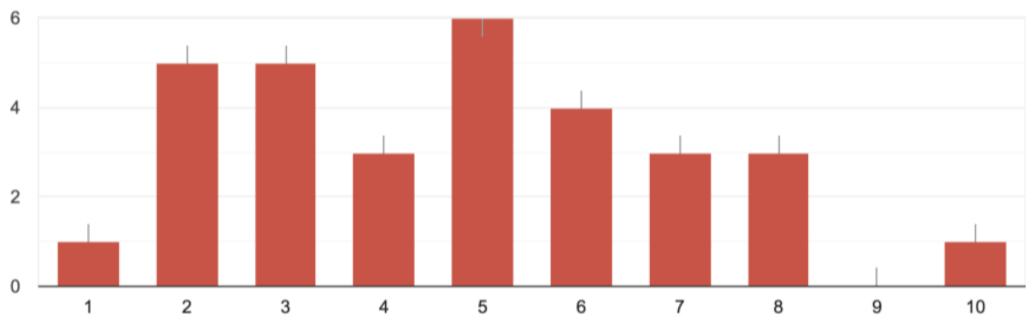


Hur upplever du den fysiska belastningen i ditt arbete?
31 svar



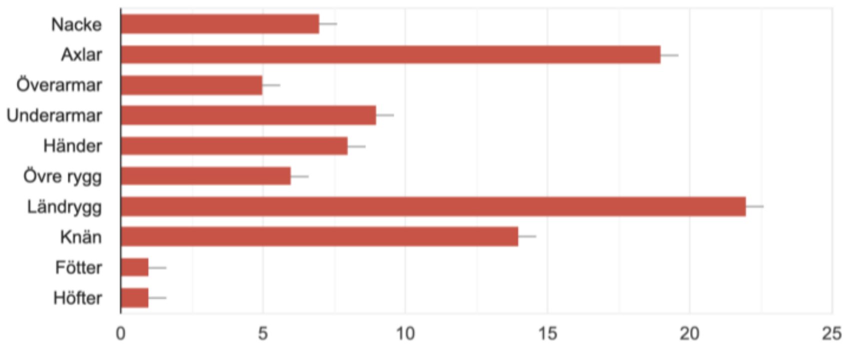
Hur upplever du stressbelastningen i ditt arbete?

31 svar



Vilken del/vilka delar av kroppen utsätts för mest belastning i ditt arbete? (Flera val möjliga)

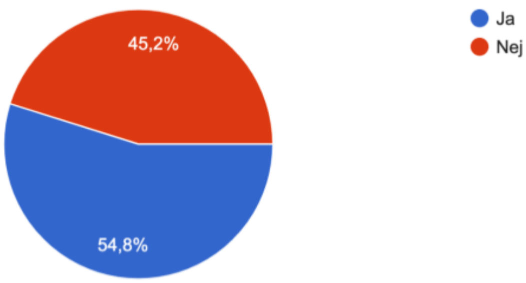
31 svar



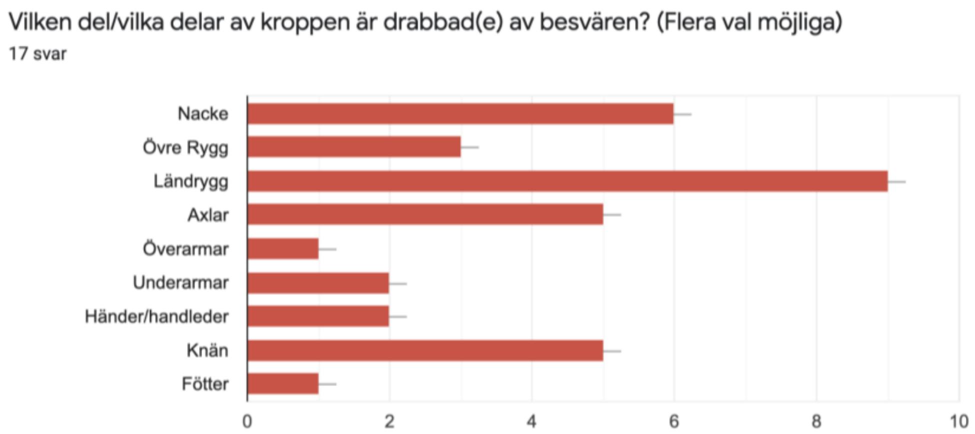
Vilket dagligt arbetsmoment är mest fysiskt krävande?

- Fällning
- Kvistning
- Kvistning
- Gå i eländig terräng
- brotsling
- Kvistning o. kapning
- Brossling
- Brossling
- Full dag med röjsågen är påfrestande.
- Kvistnig
- Kvistning av träd
- Kvistning och brossling
- Kvistning och brossling
- Klättring. Hantering av motorsåg i träd.
- Kvistning när trädet ligger på marken
- Kvistning
- brossling
- Sågningen vid grova träd.
- Värme om det är varmt ute
- Bära all utrustning
- Röjning med röjsåg
- lyfta tungt
- Fällning
- Att jobba i kraftigt kuperad terräng med motorsåg, röjsåg, plantering.
- Fällning
- Fällning
- Manuellhuggning
- Långa dagar/heldagar med motorsåg med fällning,kvistning,aptering under samma moment.
- Ungskogsröjning
- Klättring i träd

Har du eller har du haft några fysiska besvär relaterade till ditt arbete?
31 svar




Om du haft fysiska besvär, var det/de relaterat till en olycka eller belastning över tid?
17 svar
70,6%
11,8%
Olycka
Belastning över tid
Belastning vid ett tillfälle
Får ont i ryggen ett par gånger om året.
Ryggskott vid arbetsmoment


Vilken del/vilka delar av kroppen är drabbad(e) av besvären? (Flera val möjliga)
17 svar
Nacke
Övre Rygg
Ländrygg
Axlar
Överarmar
Underarmar
Händer/handleder
Knän
Fötter
0
2
4
6
8
10

Vilka hjälpmedel använder du idag för att minska arbetsbelastning eller skaderisk?

- Nej
- Kilar, slägghammare tillsammans med den allmänna säkerhetsutrustningen
- Rätt utbildning, arbetsteknik och fysisk träning
- Röjsele som jämnar ut belastning
- kil
- Försöker arbeta så ergonomiskt korrekt som möjligt
- Gallringsslinga
- Kilar
- man har inte största sågarna längre!!!
- Kilar
- Motorsågskörkort
- Sjukgymnastik löste frosen shoulder, har inget hjälpmedel
- Hypro prossesor
- Arbetsteknik med motorsåg. Foot ascenders
- inget l
- Kilar och vinsch.
- Kil
- Inget
- Inga
- yxa och kil vid fällning
- Försöker använda det som finns.
- Bästa selen på marknaden gällande röjsågen. Försöker alltid välja den lättaste motorsågen, röjsågen men med tillräcklig kraft för det aktuella uppdraget. Sparar ryggen väldigt mycket och miljön då mindre sågar alltid drar mindre bränsle.
- Så lätt såg som möjligt men fortfarande med hög effekt
- Så lätt såg som möjligt men fortfarande med hög effekt
- Använt handledsskydd
- Använder nya, moderna saker som finns på marknaden. Använder Kilar och slägga det mesta
- Den modernaste utristningen som finns
- En bra yxa Att kunna slå in kilarna långt med.
- Kilar och bra kvistningteknik

Saknar du något hjälpmedel som skulle kunna förbättra din arbetsmiljö?

- Nej x5
- Arbetet med motorsåg ser i stort sett ut som på 1970-talet, men såväl motorsåg som säkerhetsutrustning har stadigt förbättrats. Svårt att se några markanta förändringar även under kommande decennium. Med tiden lär batterisågarna närma sig bensinsågarna vad gäller prestanda, men lär troligen dröja 5-10 år. På klädsidan handlar det bl.a.om längre hållbarhet, stövlar/kängor som inte är svinkalla på vintern. Direktlarm med GPS bör utvecklas och vara obligatoriskt, åtminstone vid ensamarbete i skogen.
- verktygsbälte som är som typ röjsele
- Någon form av stöd för mina knän
- Lättare motorsåg och röjsåg
- Går att skapa lätt
- mer omväxlande arbete
- Knappstart på bensinsåg
- Lättare, mer välbalanserad motorsåg. Lägre reaktionskrafter från motorsågen (kedjan). Bra kommunikationsutrustning.
- Vet inte riktigt vad som finns på marknaden.
- Inte vad jag kan komma på.
- Lättare storsågar
- Inga hjälpmedel i den bemärkelsen utan bättre betalt från skogsbolag till entreprenörer så man ej behöver slita ont och stressa bara för att det ens ska gå ihop sig rent ekonomiskt.
- Nej vet inte vad skulle kunna vara.
- Jag saknar smidiga, lätta men ändå starka batterivinschar vid trädfällning.
- Jag saknar kraftfulla motorsågar och röjsågar som drivs av batteri och som klarar en hel dags användning utan batteribyten.
- Det känns som det mesta finns på marknaden. Däremot känns det som att det går att förbättra saker. Öka hållbarhet på tex kläder och kängor och öka hållbarhet på slitage delar på exempelvis motorsåge.
- Ja! Sågarna vi klättrar med har ej värme i handtagen. Det blir väldigt kallt om händerna på vintern. Jag skulle vilja att det fanns värme på klättersågarna. Nu kör jag med stihl. Men om husqvarna släppte en klättersåg med värme i skulle jag byta direkt till den

A.2 Interview Guide

Intervjumall - Skogshuggare/Utbildare
Vi är två studenter på Chalmers tekniska högskola i Göteborg på masterprogrammet Teknisk Design. Vi genomför just nu vårt examensarbete tillsammans med Husqvarna och tittar på om man skulle kunna skapa produkter för en säkrare och mer hållbar arbetsmiljö för skogsarbetare. Målet med arbetet är att skapa ett hjälpmedel som minskar risken för belastningsskador vid arbetsmoment inom trädfällning med motorsåg. Därför genomför vi just nu intervjuer med erfarna användare som helst använder sig av motorsåg i det dagliga arbetet, för att ta reda på vilken förbättringspotential som kan finnas. Frågorna kommer delvis handla om arbetsbelastning och egna erfarenheter. Det finns inget tvång att svara på frågorna om det skulle kännas obekvämt.

Ålder?
Svar:

Hur länge har du arbetat inom skogsarbete?
Svar:

Vilka är dina arbetsuppgifter?
Svar:

Hur ser en vanlig arbetsdag ut?
Svar:

Vad är den vanligaste arbetsuppgiften i skogsarbetet?
Svar:

Vilket eller vilka verktyg/maskiner används mest frekvent i arbetet?
Svar:

Hur upplever du den fysiska belastningen i arbetet? På en skala från 1 till 10, där 10 är mycket hög.
Svar:

Vilken eller vilka delar av kroppen utsätts för mest belastning i arbetet?
Svar:

Vilket arbetsmoment är mest fysiskt krävande?
Svar:

Vilka fysiska besvär är relaterade till arbetet?
Svar:

Av dessa fysiska besvär, är de relaterade till olyckor eller belastning över tid?
Svar:

Vilka delar av kroppen är drabbade av besvären?

Svar:

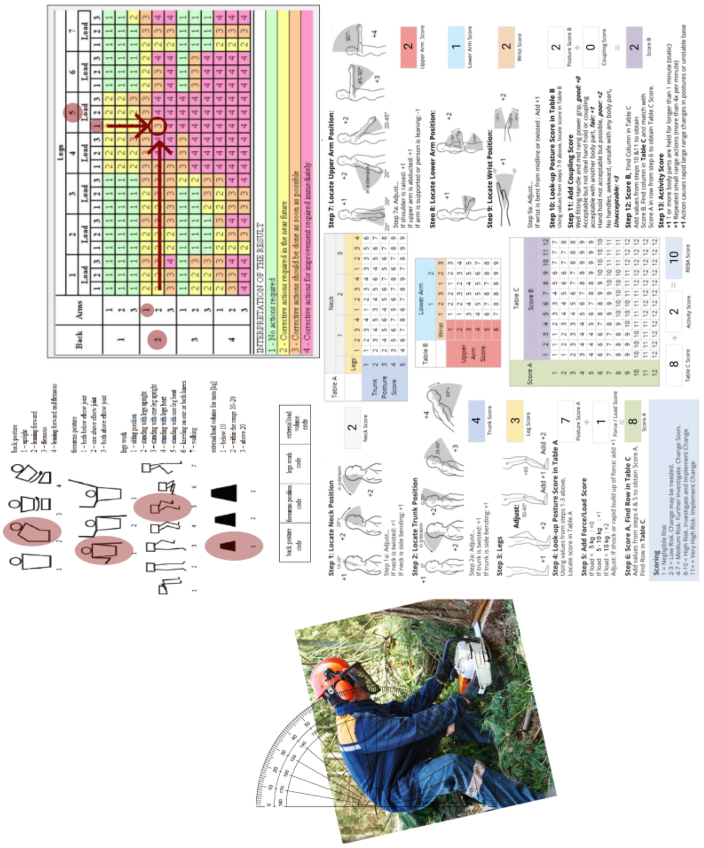
Vilka hjälpmedel används idag för att minska arbetsbelastningen och skaderisker?
Svar:

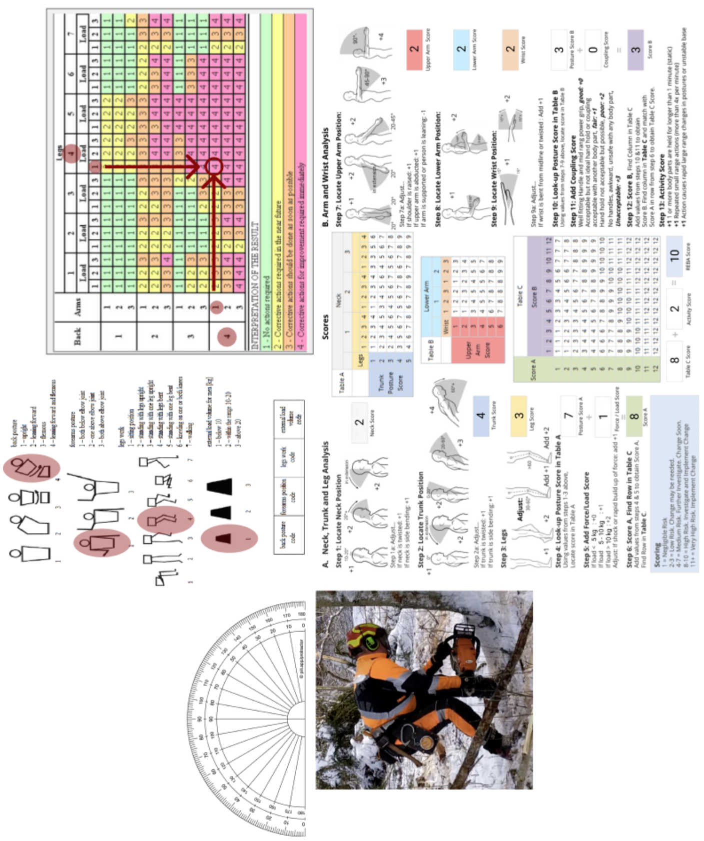
Saknas något hjälpmedel som skulle kunna förbättra arbetsmiljön?
Svar:

Hur ser generella attityder ut hos skogsarbetare när det kommer till säkerhet och säkerhetsutrustning?
Svar:

Vilken förändring anser du skulle ha störst inverkan för att skapa en bättre arbetsmiljö?
Svar:

A.3 Ergonomic Analysis





Bedömning av manuell hantering med stöd av nyckelmoment

Version 2008

Om det finns ett antal individuella aktiviteter som innebär stor fysisk ansträngning måste de bedömas separat.

Arbetsmoment / aktivitet: Fällning

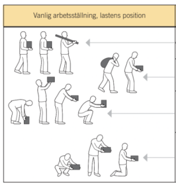
Datum för bedömning: ________ Bedömd av: ________

Steg 1: Bestämning av tidspoäng (Välj endast en kolumn!)

[ ] Att lyfta eller flytta laster (< 5 s)		[x] Hålla (> 5 s)		[ ] Bära (> 5 m)	
Antal gånger per arbetsdag	*Tidspoäng*	*Totalt tid under arbetsdagen*	*Tidspoäng*	*Totalt avstånd under arbetsdagen*	*Tidspoäng*
[ ] < 10	1	[ ] < 5 min	1	[ ] < 300 m	1
[ ] 10 till < 40	2	[ ] 5 till 15 min	2	[ ] 300 m till < 1km	2
[ ] 40 till < 200	4	[x] 15 min till < 1 h	4	[ ] 1 km till < 4 km	4
[ ] 200 till < 500	6	[ ] 1 h till < 2 h	6	[ ] 4 till < 8 km	6
[ ] 500 till < 1000	8	[ ] 2 h till < 4 h	8	[ ] 8 till < 16 km	8
[ ] ≥ 1000	10	[ ] ≥ 4 h	10	[ ] ≥ 16 km	10
Exempel: • mura, • placering av arbetsstycken i en maskin, • ta lådor ur en container och placera dem på ett transportband		**Exempel:** • hålla och styra ett stycke gjutjärn vid arbete med en slipmaskin, • användning av en handslipmaskin, • användning av en ogräsrensare		**Exempel:** • bärande av möbler, • leverans av byggnadsställnings-komponenter till en bygg-arbetsplats	

Steg 2: Bestämning av bedömningspoäng för belastning, arbetsställning och arbetsförhållanden

[ ] Lastens vikt	Lastpoäng
[ ] < 5 kg	1
[x] 5 till < 10 kg	2
[ ] 10 till < 15 kg	4
[ ] 15 till < 25 kg	7
[ ] ≥ 25 kg	25



Vanlig arbetsställning, lastens position	Arbetsställning, lastens position	[ ] Bedömningspoäng arbetsställning
	Upprätt överkropp, ej vriden • När lasten lyfts, hålls, bärs och sänks är den nära kroppen	[ ] 1
	• Lätt framåtböjd eller vriden överkropp • När lasten lyfts, hålls, bärs och sänks är den nära kroppens mitt	[ ] 2
	• Låg böjd kroppsställning eller långt framåtböjd • Lätt framåtböjd samtidigt som överkroppen är vriden • Lasten är långt från kroppen eller över axelhöjd	[x] 4
	• Långt framåtböjd samtidigt som överkroppen är vriden • Lasten är långt från kroppen • Begränsad stabilitet när arbetaren står upprätt • Hukande eller på knä	[ ] 8

För att bestämma bedömningspoängen för arbetsställningen ska den arbetsställning som är vanligast användas. Om arbetaren intar olika arbetsställningar med lasten måste en sammanvägning göras, använd inte tillfälliga extrema värden.

Arbetsförhållanden	[ ] Bedömningspoäng arbetsförhållanden
Goda ergonomiska förhållanden, d.v.s. gott om utrymme, inga fysiska hinder i arbetsområdet, jämnt och fast underlag, tillräcklig belysning, låg halkrisk	[ ] 0
Utrymmet för rörelser är begränsat och ogynnsamma ergonomiska förhållanden förekommer (t.ex. 1: utrymmet begränsat på grund av för låg takhöjd eller ett arbetsutrymme som är mindre än 1,5 m^2, eller 2: arbetsställningen är instabil på grund av ojämnt golv eller mjukt underlag)	[x] 1
Mycket begränsat rörelseutrymme och/eller instabil tyngdpunkt hos lasten (t.ex. flytt av patienter	[ ] 2

Steg 3: Utvärdering – Fyll i poängen och beräkna

Lastpoäng:	2
+ Bedömningspoäng arbetsställning:	4
+ Bedömningspoäng arbetsförhållanden:	1
= Totalt:	7

Totalt: 7 x Tidspoäng: 4 = Riskpoäng: 28

Med stöd av beräknad poäng och tabellen nedan är det möjligt att göra en grov bedömning. Allt eftersom antalet bedömningspoäng stiger, så ökar även risken för överbelastning av muskler och benstomme. Gränserna mellan riskområdena är flytande på grund av individuell arbetsteknik och prestationsförmåga

Riskområde		Riskpoäng	Beskrivning
1	○	< 10	Låg belastningssituation, fysisk överbelastning är osannolik.
2	○	10 till < 25	Ökad belastningssituation, fysisk överbelastning är möjlig för personer med lägre fysisk kapacitet. För denna grupp är det fördelaktigt att ändra arbetsplatsens utformning.
3	●	25 till < 50	Kraftigt ökad belastningssituation, fysisk överbelastning möjlig. En ny utformning av arbetsplatsen rekommenderas.
4	○	≥ 50	Hög belastningssituation, fysisk överbelastning är sannolik. Arbetsplatsens utformning måste ändras.

Bedömning av manuell hantering med stöd av nyckelmoment

Version 2008

Om det finns ett antal individuella aktiviteter som innebär stor fysisk ansträngning måste de bedömas separat.

Arbetsmoment / aktivitet: Kvistning

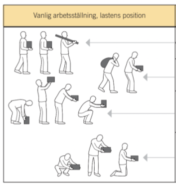
Datum för bedömning: ________ Bedömd av: ________

Steg 1: Bestämning av tidspoäng (Välj endast en kolumn!)

[ ] Att lyfta eller flytta laster (< 5 s)		[x] Hålla (> 5 s)		[ ] Bära (> 5 m)	
Antal gånger per arbetsdag	*Tidspoäng*	*Totalt tid under arbetsdagen*	*Tidspoäng*	*Totalt avstånd under arbetsdagen*	*Tidspoäng*
[ ] < 10	1	[ ] < 5 min	1	[ ] < 300 m	1
[ ] 10 till < 40	2	[ ] 5 till 15 min	2	[ ] 300 m till < 1km	2
[ ] 40 till < 200	4	[ ] 15 min till < 1 h	4	[ ] 1 km till < 4 km	4
[ ] 200 till < 500	6	[ ] 1 h till < 2 h	6	[ ] 4 till < 8 km	6
[ ] 500 till < 1000	8	[x] 2 h till < 4 h	8	[ ] 8 till < 16 km	8
[ ] ≥ 1000	10	[ ] ≥ 4 h	10	[ ] ≥ 16 km	10
Exempel: • mura, • placering av arbetsstycken i en maskin, • ta lådor ur en container och placera dem på ett transportband		**Exempel:** • hålla och styra ett stycke gjutjärn vid arbete med en slipmaskin, • användning av en handslipmaskin, • användning av en ogräsrensare		**Exempel:** • bärande av möbler, • leverans av byggnadsställnings-komponenter till en bygg-arbetsplats	

Steg 2: Bestämning av bedömningspoäng för belastning, arbetsställning och arbetsförhållanden

[ ] Lastens vikt	Lastpoäng
[ ] < 5 kg	1
[x] 5 till < 10 kg	2
[ ] 10 till < 15 kg	4
[ ] 15 till < 25 kg	7
[ ] ≥ 25 kg	25



Vanlig arbetsställning, lastens position	Arbetsställning, lastens position	[ ] Bedömningspoäng arbetsställning
	Upprätt överkropp, ej vriden • När lasten lyfts, hålls, bärs och sänks är den nära kroppen	[ ] 1
	• Lätt framåtböjd eller vriden överkropp • När lasten lyfts, hålls, bärs och sänks är den nära kroppens mitt	[x] 2
	• Låg böjd kroppsställning eller långt framåtböjd • Lätt framåtböjd samtidigt som överkroppen är vriden • Lasten är långt från kroppen eller över axelhöjd	[ ] 4
	• Långt framåtböjd samtidigt som överkroppen är vriden • Lasten är långt från kroppen • Begränsad stabilitet när arbetaren står upprätt • Hukande eller på knä	[ ] 8

För att bestämma bedömningspoängen för arbetsställningen ska den arbetsställning som är vanligast användas. Om arbetaren intar olika arbetsställningar med lasten måste en sammanvägning göras, använd inte tillfälliga extrema värden.

Arbetsförhållanden	[ ] Bedömningspoäng arbetsförhållanden
Goda ergonomiska förhållanden, d.v.s. gott om utrymme, inga fysiska hinder i arbetsområdet, jämnt och fast underlag, tillräcklig belysning, låg halkrisk	[ ] 0
Utrymmet för rörelser är begränsat och ogynnsamma ergonomiska förhållanden förekommer (t.ex. 1: utrymmet begränsat på grund av för låg takhöjd eller ett arbetsutrymme som är mindre än 1,5 m^2, eller 2: arbetsställningen är instabil på grund av ojämnt golv eller mjukt underlag)	[x] 1
Mycket begränsat rörelseutrymme och/eller instabil tyngdpunkt hos lasten (t.ex. flytt av patienter	[ ] 2

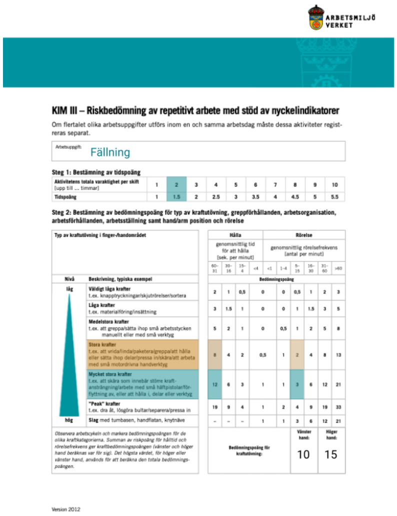
Steg 3: Utvärdering – Fyll i poängen och beräkna

Lastpoäng:	2
+ Bedömningspoäng arbetsställning:	2
+ Bedömningspoäng arbetsförhållanden:	1
= Totalt:	5

Totalt: 5 x Tidspoäng: 8 = Riskpoäng: 40

Med stöd av beräknad poäng och tabellen nedan är det möjligt att göra en grov bedömning. Allt eftersom antalet bedömningspoäng stiger, så ökar även risken för överbelastning av muskler och benstomme. Gränserna mellan riskområdena är flytande på grund av individuell arbetsteknik och prestationsförmåga

Riskområde		Riskpoäng	Beskrivning
1	○	< 10	Låg belastningssituation, fysisk överbelastning är osannolik.
2	○	10 till < 25	Ökad belastningssituation, fysisk överbelastning är möjlig för personer med lägre fysisk kapacitet. För denna grupp är det fördelaktigt att ändra arbetsplatsens utformning.
3	●	25 till < 50	Kraftigt ökad belastningssituation, fysisk överbelastning möjlig. En ny utformning av arbetsplatsen rekommenderas.
4	○	≥ 50	Hög belastningssituation, fysisk överbelastning är sannolik. Arbetsplatsens utformning måste ändras.


ARBETSMILJÖ VERKET

KIM III – Riskbedömning av repetitivt arbete med stöd av nyckelindikatorer

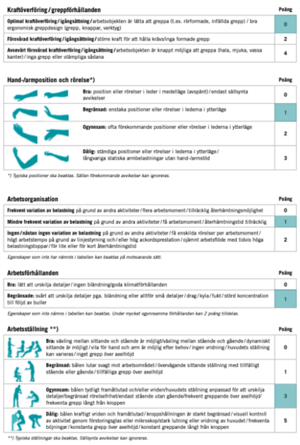
Arbetsuppift: Fällning

Steg 1: Bestämning av tidspoäng

Steg 2: Bestämning av bedömningspoäng för typ av kraftutövning, greppförhållanden, arbetsorganisation, arbetsbetsförhållanden, arbetsställning samt hand/arm position och rörelse

Vänster hand: 10 Höger hand: 15

Version 2012


Kraftöverföring / greppförhållanden

Hand-/armposition och rörelse

Arbetsorganisation

Arbetsförhållanden

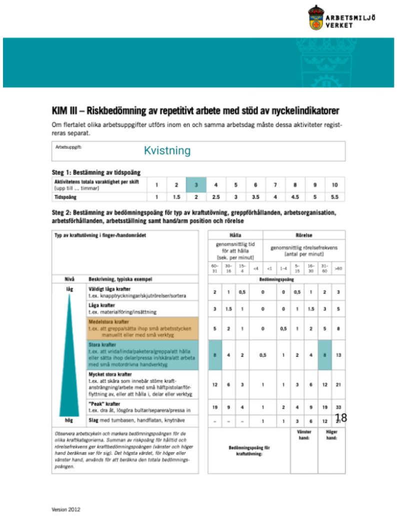
Arbetsställning


Steg 3: Värdering

Typ av kraftutövning(ar) i finger-/handområdet	15
+ Kraftöverföring/Greppförhållanden	0
+ Hand-/armposition och rörelse	1
+ Arbetsorganisation	1
+ Arbetsförhållanden	1
+ Arbetsställning	3
= Summa	21

21 x Tidspoäng 1,5 = Riskpoäng 31,5

Publicerat av Bundesanstalt für Arbeitsschutz und Arbeitsmedizin 2012 www.baua.de


ARBETSMILJÖ VERKET

KIM III – Riskbedömning av repetitivt arbete med stöd av nyckelindikatorer

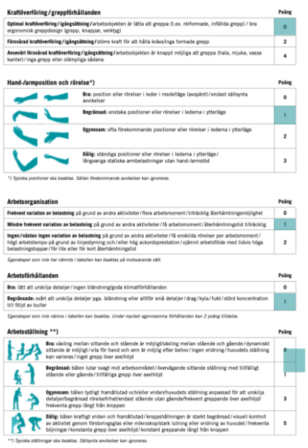
Arbetsuppift: Kvistning

Steg 1: Bestämning av tidspoäng

Steg 2: Bestämning av bedömningspoäng för typ av kraftutövning, greppförhållanden, arbetsorganisation, arbetsbetsförhållanden, arbetsställning samt hand/arm position och rörelse

18

Version 2012


Kraftöverföring / greppförhållanden

Hand-/armposition och rörelse

Arbetsorganisation

Arbetsförhållanden

Arbetsställning


Steg 3: Värdering

Typ av kraftutövning(ar) i finger-/handområdet	18
+ Kraftöverföring/Greppförhållanden	0
+ Hand-/armposition och rörelse	1
+ Arbetsorganisation	1
+ Arbetsförhållanden	1
+ Arbetsställning	3
= Summa	24

24 x Tidspoäng 2 = Riskpoäng 48

Publicerat av Bundesanstalt für Arbeitsschutz und Arbeitsmedizin 2012 www.baua.de

A.4 Function Analysis

Verb	*Noun*	*Classification*	*Limitation*	*Rank*
Reduce	MSDs	MF	Lower back	N
Improve	Working posture	SF	Ergonomic correct postures	D
Distribute	Weight	SF	To large muscle groups	D
Stabilize	Trunk	SF	Ergonomic correct postures	D
Allow	Movement	SF	Not hinder work	N
Guide	Back/Trunk	AF	Ergonomic correct postures	D
Allow	Customization	AF	Allow for personal placement/selection of equipment	D
Allow	Ventilation	AF	Support air flow, reduce heat	D
Enable	Versatility	AF	Combination of functions	D
Allow	Adjustment	AF	Varying work tasks	D
Allow	Interaction	AF	While wearing gloves	D
Relieve	Tool weight	AF	Chainsaw weight	D
Withstand	Moisture	AF	Sweat, rain, snow	N
Ease	Transportation	AF	Easy to carry when not in use	D
Allow	Compatibility	AF	With tool belt, equipment	N
Allow	Tool transportation	AF	Chainsaw transport	D
Prevent	Twisting/bending of trunk	AF	Obstuct harmfull positions	D
Improve	Visibility	AF	Reflecting material	D
Withstand	Work environment	AF	Wear and tear	N
Enable	GPS tracking	AF	Safety feature	D
Allow	Cleaning/washing	AF	Keep clean	D
Enable	Storage	AF	Hang while not in use	D
Minimize	Weight	AF	Lightweight materials	D
Allow	Size adjustment	AF	Varying body sizes	D
Relieve	Shoulders	AF	Prevents shoulder MSD	D
Allow	Activation/Deactivation	AF	Mode for on/off	D
Avoid	Protrusive parts	AF	Avoid getting tangled up	D
Allow	Wearing while driving	AF	Suit to follow body	D
Ease	Dressing	AF	Fast and easy to put on	D
Create	Longlivity	AF	Avoid UV-sensitive materials (eg. plastics)	D
Allow	Pocket access	AF	As far as as possible	D
Allow	Tool attachment	AF	Via gear loops on belt, vest and legs	D
Allow	Detachment of toolbelt	AF	If user desires	D
Indicate	Function	AF	Highlight spring parts via color/text	D
Trigger	User reflection	AF	On work postures	D

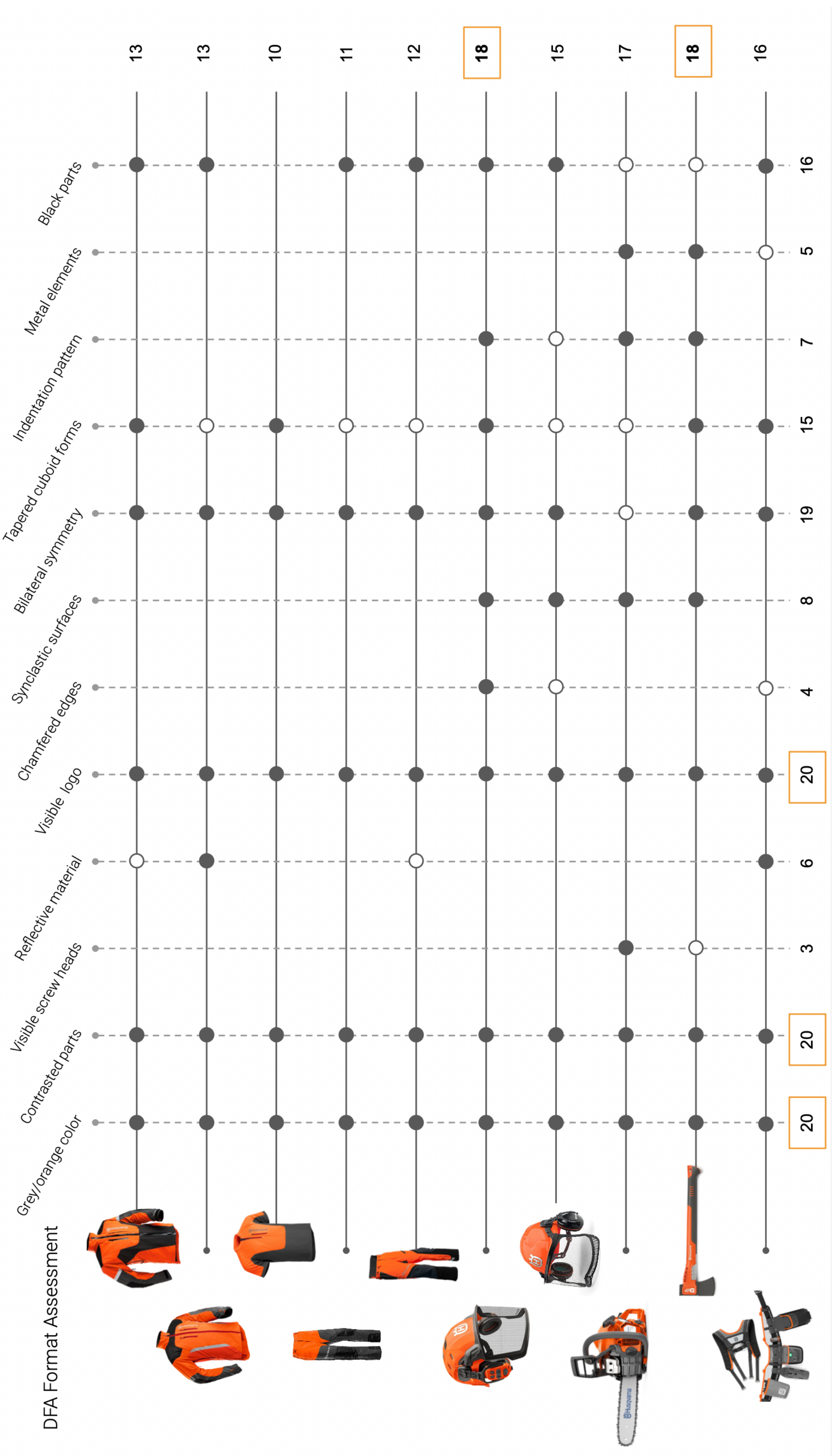
MF Main function
SF Sub-function
AF Additional function

N Necessary
D Desirable

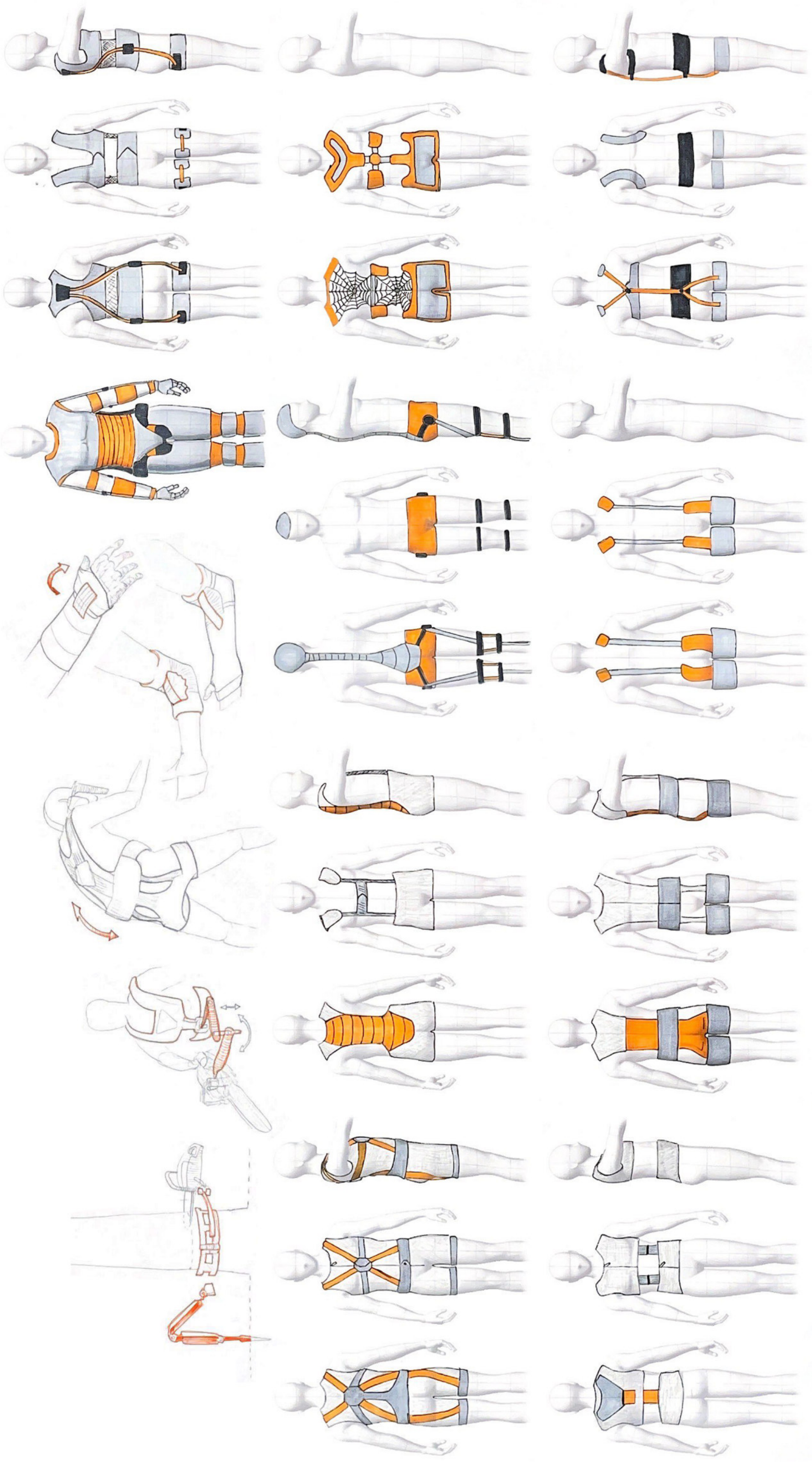
A.5 Design Format Analysis

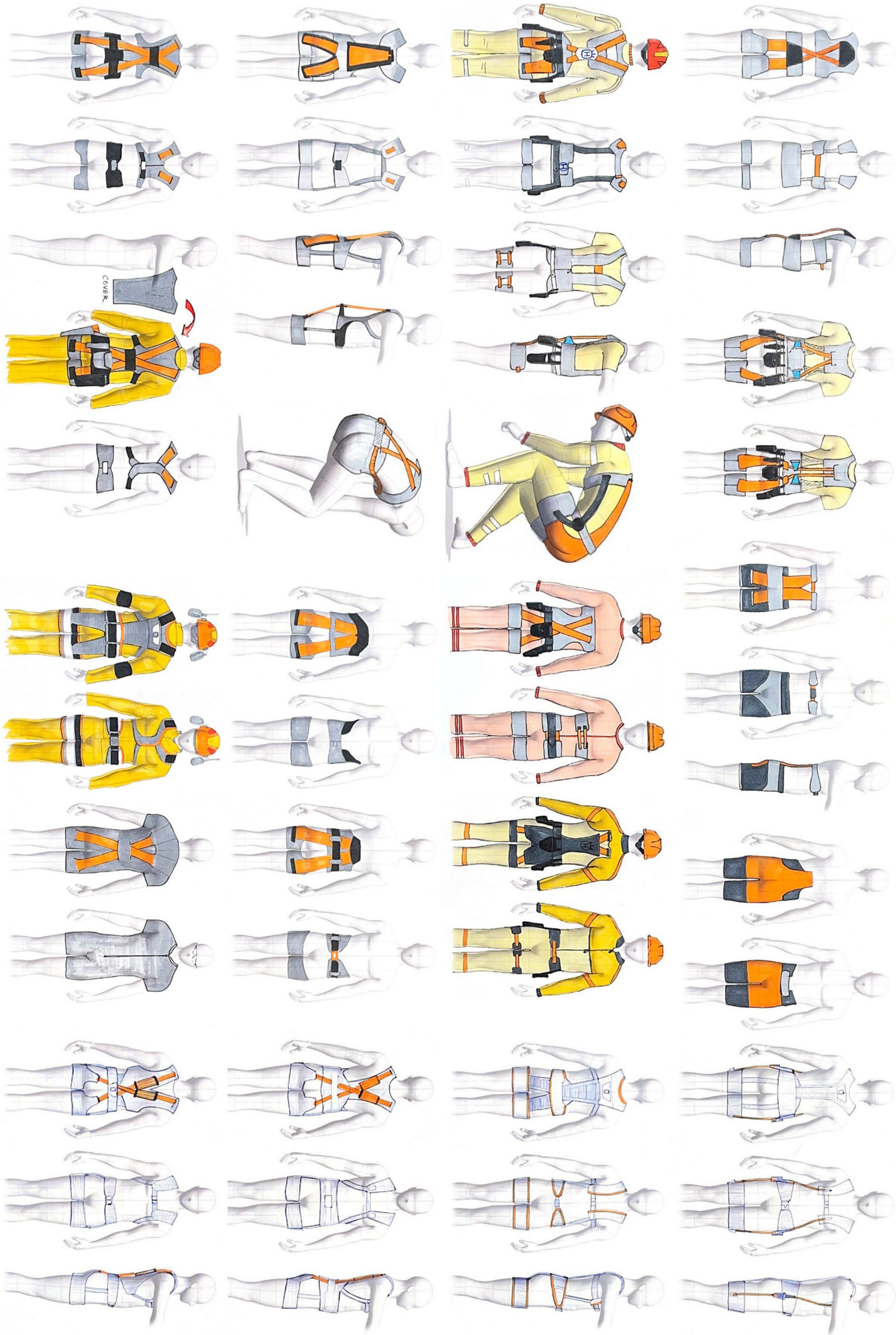
DFA Element Typicality

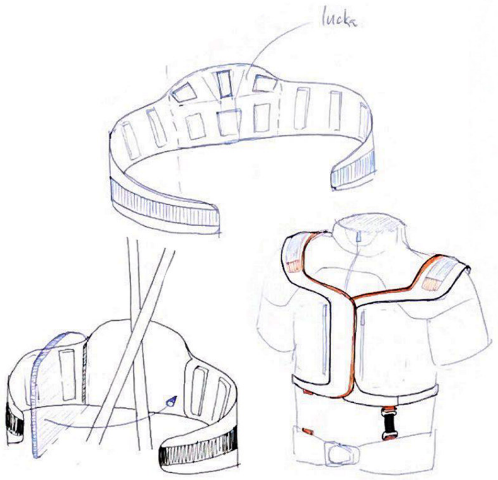
Form element	Times	Frequency	Occurrence value	Normalized occurrence value
Grey/orange color scheme	13	1.00	13.00	1.00
Contrasted parts	13	1.00	13.00	1.00
Visible logo	13	1.00	13.00	1.00
Bilateral symmetry	12	0.92	11.08	0.85
Tapered cuboid forms	11	0.85	9.31	0.72
Black parts	10	0.77	7.69	0.59
Reflective material	6	0.46	2.77	0.21
Synclastic surfaces	4	0.31	1.23	0.09
Indentation pattern	4	0.31	1.23	0.09
Visible screw heads	3	0.23	0.69	0.05
Chamfered edges	3	0.23	0.69	0.05
Metal elements	3	0.23	0.69	0.05
Ventilation grid	1	0.08	0.08	0.01
Ridged handle bar	1	0.08	0.08	0.01
Circular adjustment switches	1	0.08	0.08	0.01

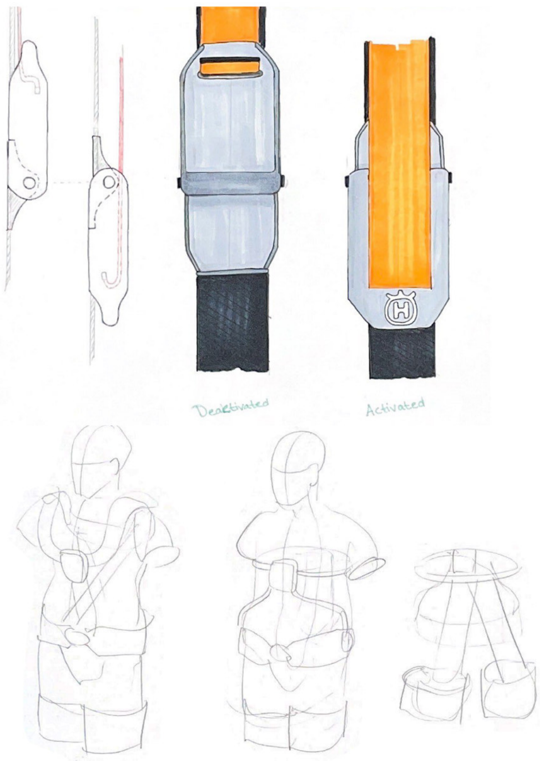

DFA Format Assessment
Grey/orange color
Contrasted parts
Visible screw heads
Reflective material
Visible logo
Chamfered edges
Synclastic surfaces
Bilateral symmetry
Tapered cuboid forms
Indentation pattern
Metal elements
Black parts
20
20
3
6
20
4
8
19
15
7
5
16
13
13
10
11
12
18
15
17
18
16

A.6 Selection of Sketches






locks


Deactivated
Activated

A.7 Kesselring Matrix

Verb	Noun	Rank	Weight	Concept 1: Under	Concept 2: Lower Body	Concept 3: Over		Concept 1: Under	Concept 2: Lower Body	Concept 3: Over
Reduce	MSD	N	5	3	3	3		15	15	15
Improve	Working posture	D	5	3	1	3		15	5	15
Distribute	Weight	D	3	2	1	3		6	3	9
Stabilize	Trunk	D	2	3	2	2		6	4	4
Allow	Movement	N	5	2	2	3		10	10	15
Guide	Back/Trunk	D	4	3	2	3		12	8	12
Preserve	Heat	D	1	3	1	2		3	1	2
Prevent	Overheating	D	4	1	3	2		4	12	8
Enable	Versatility	D	4	0	2	3		0	8	12
Allow	Adjustment	D	5	1	2	3		5	10	15
Allow	Interaction	D	4	1	2	2		4	8	8
Relieve	Tool weight	D	4	0	1	3		0	4	12
Withstand	Moisture	N	4	2	2	2		8	8	8
Ease	Transportation	D	2	3	2	2		6	4	4
Allow	Compatability	N	4	1	2	2		4	8	8
Allow	Tool transportation	D	2	0	2	2		0	4	4
Prevent	Twisting/bending of trunk	D	5	2	2	2		10	10	10
Improve	Visibility	D	3	3	2	2		9	6	6
Withstand	Work environment	N	5	2	2	2		10	10	10
Enable	GPS tracking	D	1	2	2	2		2	2	2
Allow	Cleaning/washing	D	2	1	1	1		2	2	2
Enable	Storage	D	2	3	2	2		6	4	4
Minimize	Weight	D	5	3	2	2		15	10	10
Allow	Size adjustment	D	5	1	2	2		5	10	10
Relieve	Shoulders	D	4	1	3	2		4	12	8
Allow	Activation/Deactivation	D	3	0	1	3		0	3	9
Avoid	Protrusive Part	D	4	3	2	2		12	8	8
				49	**51**	**62**		**173**	**189**	**230**

A.8 Back Cover Designs

DEPARTMENT OF DESIGN AND HUMAN FACTORS
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY