Reform, refine, reforest

Designing ergonomic equipment for manual reforestation

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Luleå University of Technology
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ABSTRACT

Reforestation is typically performed by manually planting seedlings of desired trees by a small team of workers. The workers, referred to as planters, has a very physically demanding job that requires navigating through tough terrain and carrying varying loads in different positions throughout a full work day. This master thesis project is performed for SCA, Sweden’s largest private owner of forest land, and the reforestation equipment manufacturer BCC. A part of SCA’s work is a new project called ZERO, which aims to improve the working environment and safety for all affiliated workers of the company. Many planters use old equipment that is not satisfying the ZERO-project demands thus leading to the importance of improving the planters’ equipment.

The objective of this master thesis project is to improve the way manual reforestation with the usage of seedling trays is performed, with focus on improving the user’s work environment through improved ergonomics and efficiency. The equipment is designed under the brand Pottiputki, owned by BCC, which is dominating the Swedish market for manual reforestation equipment. The final result was expected to be a conceptual 3D model, focusing on communicating its functions rather than being finalised for manufacturing.

The design process that was used in this project is an iterative design cycle of five steps and was heavily focused on implementing user-centred design thinking. The cycle was repeated for every included component in the equipment to achieve a reliable result. Using information gathering such as interviews, surveys and testing of equipment the user needs have been mapped on which the ideation process is based. With access to a workshop and several useful materials the project is centred around the creation of prototypes and letting users test these said prototypes.

A deeper study of the current state showed that the current equipment is very unergonomic and for the planter to keep a high productivity the equipment is used in ways that reduce the ergonomic properties even further. From the performed context analysis, an overwhelming majority of users are displeased with the current equipment and many users are specifically complaining on insufficient ergonomic properties. To solve these problems a reforestation harness and planting tube has been developed with higher comfort that reduce demanding and clumsy actions and improving usability. When used together with each other the harness and tube combines a main idea which is to distribute the strenuous workload more evenly across the body to avoid strain-related problems for the user.

The improvement in ergonomics and efficiency have been proved in various user tests. No new way of increasing productivity apart from the improved working environment was found to be a valid addition for the equipment. In order to increase productivity, SCA is recommended to make sure that the planting task is performed systematically. Furthermore the growing system using seedling trays is a limiting factor for productivity improvement out on the clear-cuts and is recommended to be reviewed.

KEYWORDS: Reforestation, Product Development, Ergonomics, Prototyping, Research, Productivity, User-Centred Design
SAMMANFATTNING


Syftet med detta examensarbete är att förbättra sättet manuell skogsplantering med användning av odlingskassetter utförs, med fokus på att förbättra användarens arbetsmiljö genom bättre ergonomi och effektivitet. Utrustningen är designad under varumärket Pottiputki, ägt av BCC, som dominerar marknaden för manuell skogsplanteringsutrustning i Sverige. Slutresultatet förväntades vara en konceptuell 3D-modell som fokuserar på att förmedla de tänkta funktionerna än att vara färdigställd för produktion.

Designprocessen som användes i detta projekt är en iterativ designcykel bestående av fem steg och hade ett tydligt fokus att implementera användarcentrerad design. Cykeln upprepades för varje del i utrustningen för att erhålla ett pålitligt resultat. Genom att använda informationsinsamling som bland annat intervjuer, enkät och utrustningstester har användarnas behov identifierats och vilka sedan har varit grunden för utvecklingsarbetet. Med tillgång till verkstad och många användbara material är detta projekt centrerat runt skapandet av prototyper och att låta användare testa dessa prototyper.

En djupare undersökning av nuläget visade att nuvarande utrustning är väldigt oergonomisk och för att plantören ska kunna hålla ett högt tempo måste utrustningen användas på sätt som försämrar de ergonomiska egenskaperna ytterligare. Från kontextanalysen visade det sig att en överväldigande majoritet av användarna är missnöjda med nuvarande utrustning och många användare klagar speciellt på bristfälliga ergonomiska egenskaper. För att lösa dessa problem har en skogsplanteringssele och planteringsrörl överlagrats med högre komfort som minskar krävande och klumpiga handlingar samt förbättrar användbarheten. När selen och röret används tillsammans är huvudtanken att omfördela ansträngande arbete jämnt över kroppen för att undvika belastningsproblem för användaren.

Förbättringen i ergonomi och effektivitet har påvisats genom olika användartest. Inget nytt sätt att förbättra produktiviteten annat än genom förbättrad arbetsmiljö ansågs vara legitima alternativ för utrustningen. För att öka produktiviteten rekommenderas SCA att se till att planteringsarbetet utförs systematiskt. Vidare är växtsystemet med hjälp av odlingskassetter en begränsande faktor för produktivitetsökningar ute på hyggena och rekommenderas att ses över efter förbättringar.

NYCKELORD: Skogsplantering, Produktutveckling, Ergonomi, Prototyptillverkning, Undersökning, Produktivitet, Användarcentrerad Design
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1 INTRODUCTION
1 INTRODUCTION

This master thesis project was made in cooperation with SCA and BCC and involved developing equipment for manual reforestation, based on SCA’s way of producing seedlings in seedling trays or so-called cassettes. The equipment used by the planters to carry these trays and plant the seedlings are outdated and designed with low regard for user ergonomics. The end result of this thesis aims to improve the working environment, ergonomics and efficiency for the user while still being economically viable for the employer or private landowners.

1.1 PROJECT INCENTIVES

The forestry industry in Sweden is large and it covers some of the country’s largest exports in the form of wood and paper (SCB, 2015). These materials come directly from trees growing on privately, corporately or governmentally owned lands, where the trees are cut down in large areas leaving clear-cut areas of land. To make the land economically viable and a renewable resource, reforestation of the clear-cuts has to be made (Sveaskog, n.d.). Swedish Cellulose Company (SCA) is the largest private owner of forest land in Sweden with over two million acres of lucrative forest land. Every year barely 20000 acres of SCA’s land are reforested with tree plants.

Reforestation is typically performed by manually planting seedlings of desired trees by a small team of workers, hired by the landowners (SCA, 2014). The workers, referred to as planters, has a very physically demanding job that requires navigating through tough terrain and carrying varying loads in different positions throughout an eight hour work day. A part of SCA’s work is a new project called ZERO, which aims to improve the working environment and safety for all affiliated workers of the company, including standalone entrepreneurs. SCA is actively working towards ensuring that all affiliated reforesting entrepreneurs meet the requirements and laws from the Swedish department of forest care.

The current planters use equipment mostly developed during the early 70’s and 80’s (Figure 1) which can look different and have different functions depending on which method of seedling planting is used (BCC, 2016). BCC is a Swedish company that specialises in manufacturing machines for seedling production. Since a few years back BCC acquired the Finnish brand Pottiputki; a company specialising in equipment for manual reforestation. Since then BCC has carried on producing Pottiputki equipment.

Figure 1: A planter using early equipment from Pottiputki. Source: BCC
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The equipment has not been through many changes in the past 35 years since development on recent years tends to lean towards trying to make the reforestation process mechanical (Safrani & Lideskog, 2011). These mechanical solutions are seen as too unreliable in their current forms by many forestry corporations and manual reforestation still dominates the industry. This master thesis project will therefore focus only on the development of new equipment for manual planting of seedlings under the brand of Pottiputki.

The master thesis project has been implemented by two persons, hereafter called the design team. One had no prior experience of manual reforestation and the other had previously performed reforestation as a summer job during several summers. Victor, who has the previous experience has worked for Holmen, Sveaskog and most recently SCA, who all use different methods and views regarding reforestation.

1.2 CURRENT STATE

Currently reforestation can be performed with a couple of different methods. There are two major methods, which are dependent on the seedling producer’s choice of storing, packing and shipping. The first method, which SCA utilises, is growing their seedlings in seedling trays, and ship their trays directly, in stackable frames that contain 60 trays each. The other method is used by e.g. Holmen who repack their seedlings into cardboard boxes and only use the trays to grow seedlings. These cardboard boxes are then placed in a freezer to freeze the plants so they don’t die before shipping. When the boxes arrive at desired location they are opened for the plants to thaw and be planted in the weeks to come. The way a planting tube is used does not differ between both storing solutions.

For planting with seedling trays the planting team need specific gear (Figure 2). Besides the equipment shown in figure 2, the planters also need a transporting harness to load 10-12 trays at max capacity for hauling the plants from the truck if the clear-cut is far away (Figure 4). They also need to bring their planting tube and planting harness to be used for the actual planting.

Figure 2: Equipment from BCC used when planting. Source: BCC
The planting harness can vary from being a waist belt with leg pads to a full body harness with shoulder straps for extra support (Figure 3). The waist belt seems to be the most used\(^1\), and on each side of it there are two tray holders which hold the trays of seedlings that will be put in the ground. The tube that dominates the market is the Pottiputki tube, which is about 1 meter of steel tubing with a cone shaped jaw at the bottom. The jaw is opened by pressing a lever with your foot, and closed by a mechanism that runs up alongside the tube to a trigger by the handle (Figure 2).

When planting with boxes, the boxes are carried out to the clear-cut either by hand or by using a transporting harness suitable for boxes. There are existing solutions where you can place the boxes directly in a frame on the side of the planting harness, but these are not commonly used. For the more commonly used equipment, the plants have to be lifted over from the box into the carrying equipment. This equipment can be bags, such as the ones in figure 3, or buckets fastened on the side of a harness, or a contraption called "Banana" which is a plastic banana shaped carrier. This "Banana" is carried on the back, only by a thin strap and has a hole for refilling at the top and the curvature comes around the front of the body with an opening for plucking the seedlings.

SCA’s seedling trays contain either 67 or 128 plants, these trays are named Jackpot and Powerpot (Figure 2), while boxes contain around 300 depending on manufacturer and size. There are disputes between seedling producers about which method of growing trees is better and which way of planting might be better\(^2\). A reforestation worker, planter, using either method seems to place about the same amount of seedlings in the ground\(^3\).

The typical way of performing manual reforestation is described in figure 4. Depending on how far away the clear-cut is from the seedling tray supply, planters need to use the transporting harness as pictured in Step 1. A typical seedling tray weighs around 3-5 kilograms\(^4\) depending on moisture level, which results in the harness weighing somewhere between 30-50 kilograms when fully loaded. The planting tube is attachable to the harness to make carrying of equipment easier. Commonly, the planters also carry personal belongings when walking for the first time to the clear-cut, such as rainsuit and backpacks with food and water. When the planters have reached the area to be reforested, they leave their transporting harness on the ground to start the actual planting procedure.

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\(^1\) Based on Victor’s previous knowledge

\(^2\) Conclusion from personal communication with seedling producers.

\(^3\) Based on personal communication with seedling producers.

\(^4\) Measured using a digital scale.
Depending on which kind of planting harness the planters use, they can either wear the planting harness simultaneously as the transporting harness or need to put on the planting harness when arriving to the clear-cut. When fully dressed, the planter picks up a seedling tray and secures it to the holder using a hook attached to a rubber band. The hook is fastened wherever the planter finds suitable for the seedling tray to be fully secured.

The actual planting is then performed by plucking a seedling out of the seedling tray, dropping the seedling into the closed planting tube and then thrusting the tube in the ground, as pictured in Step 3. If the soil is rocky or rugged, the planter could then need to push the tube even further down in the soil depending on how deep the plants need to be for high survivability, by striding on the jaw lever for extra force. The lever will then open up resulting in the seedling sliding out into the created pothole. The diameter of the pothole is often somewhat larger than the diameter of the seedling, therefore it is important to trample the pothole edges to let the seedling come in contact with surrounding soil which reduces environmental impact on the plant.

The design team refer to the seedling tray currently in use as the active seedling tray. When the active seedling tray runs out of seedlings, as one tray has in Step 4, there are a number of different ways to switch active tray which is further discussed later on in this master thesis project. When all seedlings are put in the ground and the transporting harness no longer has any full trays, the planter has to walk back to the seedling tray supply area to refill and start over.

Figure 4: The different steps for a typical manual reforestation operation.
1.3 PROJECT STAKEHOLDERS

For this master thesis project there were two cooperating clients, NorrPlant, which is the sub-division of SCA tasked with the manufacturing and distribution of their seedlings. The second client was the equipment manufacturer for Norr-Plant, BCC who is the major manufacturer and distributor for reforestation related equipment in Sweden.

The following groups would be affected as described if the final result manages to become the new industry standard:

- **Planters**, who are the direct users that will handle the equipment, will be affected with improved work environment and efficiency.
- **Reforestation entrepreneurs** employed by landowners, who provide manpower to corporations such as SCA, could potentially take on more work since planters could increase the planting rate.
- **Landowners** who deal with reforestation could potentially be provided with a better growth. Simply because planters could stay more fresh and alert, which would ensure higher quality of seedling placement throughout the whole day.
- **Seedling producers** who use seedling trays as a method for growing and planting are affected since more area of clear-cuts could be reforested every season from increased efficiency, which would lead to increased demand of seedlings.
- **Equipment manufacturers** would be affected if the industry standard would change by adapting their products to the new standard.
- **Equipment retailers** who sell reforestation equipment might see an increase in sales if new and improved equipment is presented to the market.

1.4 PROJECT OBJECTIVES AND AIMS

The objective of this thesis project was to improve the way manual reforestation with the usage of seedling trays is performed, with focus on improving the user’s work environment through improved ergonomics and efficiency. In this context, efficiency was considered as increased planting rate and less time handling the equipment while planting.

The results were achieved through an iterative design process with recurring phases of research, idea generation, concept development and prototyping. Ideas and concepts are then tested during the summer of 2016 in the form of simple prototypes. The final result was expected to be a conceptual 3D model, focusing on communicating its functions rather than being finalised for manufacturing.

SCA stated a couple of aims for this master thesis project:

- The end result should be focused on compatibility with the method of reforestation using seedling trays.
- The main focus should lie with the improvement of the user’s carrying equipment mainly by improving ergonomics, but the planting tube is also of interest.
- The end result should be economically viable.
- To have prototype(s) created to be tested during the summer months of 2016.

Furthermore, SCA wanted the project to result in a change for a better industrial standard for manual reforestation.
Additional aims added by the design team:

- The carrying equipment should fit the most commonly used seedling trays.
- An increase in efficiency for the user which leads directly to an increase in efficiency for the employer.
- Conformability of the carrying equipment to fit for various body types to a certain degree.

Research questions:

- How can currently existing equipment for reforestation be reformed to ensure improved working environment, ergonomics and efficiency for the user?
- How can we verify that the results of the project will have the desired effect?
- Is development of a whole new product or technique required to deliver the desired effect or are current methods sufficient?
- Is the final result compatible with existing equipment and techniques or is additional change needed?

1.5 PROJECT SCOPE

This master thesis project was carried out by two MSc thesis students at 100% pace of studies during a 20 week period. As one of the requested aims for the thesis was to deliver prototype(s) for testing during the summer months, the initial work had to be fast paced to fulfil the request. The project was focused on the harness and tube used when planting. The harness used for carrying seedling trays to the clear-cut was not included in this project due to the limited time.

The project was also delimited to include no design or development of the existing seedling trays since making changes to these would according to SCA be very costly to implement due to having to replace all existing trays and equipment needed to fill them with seedlings. All Properties of the final design that were considered during this master thesis project were categorised in design properties, internal properties and external properties (Figure 5).

Figure 5: Relevant properties related to the entire product development phase, inspired by Hubka & Eder (1984/2012).
Categorising the properties are inspired by Hubka & Eder’s (2012) way of structuring a technical system. These delimiting properties are later explained when describing the design specification.

Since BCC wanted to avoid any major cost-related increases in the most possible way when changing the design, the materials used in their previous designs were also a limiting factor for the new design unless the design would be in need of a radical change compared to their equipment. Any environmental impacts related to materials and manufacturing methods would therefore not be studied unless the final design required such studies to be made.

1.6 THESIS OUTLINE

This thesis contains 7 chapters, each structuring everything from relevant theories and discussions of how the final result relates to them.

Chapter 1 gives an introduction to the context of the project. It presents who the stakeholders are, which aims and objectives are set, which research questions has been stated and the scope of the project is also included.

Chapter 2 presents the scientific foundation of this thesis which is a theoretical framework of relevant areas. The chapter starts with a quick description of what industrial design engineering is to provide readers without previous experience more understanding of the field.

Chapter 3 describes the process and planning of the thesis, followed by methods used for needfinding, gathering of information about the current state and literature review for finding relevant theories. The chapter continues with describing methods for generating ideas, concept development, testing, evaluation and selection. The chapter ends with methods used for detail design before stating what’s been done to ensure reliability and validity in the process and results.

Chapter 4 contains the results of methods used described in chapter 3.

Chapter 5 shows the final result which in this case is the final design of the products.

Chapter 6 discusses the previous chapters by positioning the results, discussing their relevance, reflecting over the project and recommendations for further development.

Chapter 7 concludes the thesis by giving a recap of, and answering the stated research questions one by one. It also retells how and if the set objectives and aims have been achieved.
2 THEORETICAL FRAMEWORK
2 THEORETICAL FRAMEWORK

This chapter contains the theoretical aspects of the master thesis project, obtained by gathering information through literature containing research and expertise in relevant areas. The information is collected, presented and related to support and strengthen the arguments made, claimed improvements and obtained results throughout the project.

2.1 INDUSTRIAL DESIGN ENGINEERING

When developing products, it is important to understand which factors are determining if a product is going to be a success or failure (Rochford & Rudelius, 1997). Tovey (1997) describes an industrial design engineer as a person working with the process of designing industrial products. According to Tovey, the industrial branch of design develops products that are manufactured by industrial processes. In an attempt to define the area of engineering design, Dym, Agogino, Eris, Frey & Leifer (2005) wrote the following:

"Engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints." (p.104)

As stated in the definition, an engineering designer takes into account the manufacturability of a product as well as numerous other factors that influence the product development process. That being said, the term industrial design engineering might seem a bit fuzzy for a person without decent knowledge of the area, even when using the definition above. Using the very simplified description of engineering design given by Hazellrigg (1998) that the process only consists of two steps: defining all possible designs and then deciding which design is the best, one could ascertain that an industrial designer is a vital part of the product development process.

2.1.1 Design for manufacturability

The procedure of continually optimising the design of products with manufacturing in mind is, according to Belay (2009) called design for manufacturability. O’Driscoll (2002) mentions that in order for a product to be designed for production, the designer must think of how to reduce the cost of manufacturing, and how to simplify the process of manufacturing the product.

Dieter & Schmidt (2013) claim that a solid and well-structured engineering design process has three major purposes for improving product manufacturing and development: price reduction, increased product quality and decreased product cycle time. Dieter & Schmidt mentions that decisions made during the design process will have a low cost while possibly having major consequences on the total product (Figure 6).

Figure 6: interpretation of Dieter & Schmidt’s (2013) product life cost-diagram.
A well-executed design process can impact product quality. The authors describe old ways of ensuring product quality as an inspection of the final product coming out of the factory. The way of designing for manufacturing nowadays, according to Boothroyd (1994), is an ongoing process throughout the design phase to ensure a high quality final product and to avoid any manufacture-related problems originating from the earlier stages of the design process. Chen, Miller & Sevenler (1995) mention that a product designed with producibility in mind will have a higher probability of being fully functional, cheaper to produce and having higher quality compared to a product developed with no thoughts of producibility.

2.1.2 Revolutionary and evolutionary design

There are, according to Henderson & Clark (1990) and Bohgard et al. (2010) two major practices when performing innovative design: Evolutionary and revolutionary innovation. They can almost be seen as opposites of each other in the context that revolutionary innovation is promoting radical changes while evolutionary design is more focused on reinforcing existing designs (Henderson & Clark, 1990).

Revolutionary design is, according to Verganti (2008), a design and/or technology-driven push innovation where the designers propose a new previously unheard way of solving a problem to the market through either implementing new technology or by bringing new meaning to existing technology. Verganti continues to mention that evolutionary design is more focused on market pull-inventing where the designers are focusing on user needs and thereafter searches for solutions that could solve the needs by improving existing products to better satisfy user needs compared to competitors.

A design project does not have to be fully focused on either innovation category. Every successful design project will, according to Verganti (2008), have a mixture of both paths in some way which makes the bridge between the both ways vague.

2.2 USER-CENTRED DESIGN

Products that are supposed to be used by humans should also be designed to fit the intended users. When defining user-centred design, authors tend to have various ways of expressing the definition. According to Redström (2008), the main foundation for user-centred design is to strive to predict the way users will make use of the product. A way of making accurate predictions is to involve potential users in the development process or in other ways gather information of user needs.

When approaching a user-centred design process, Kaulio (1998) mentions three different ways:

- **Design for**: A process where the product development is done for the user. This kind of approach often includes studies of customers, such as observations or interviews.
- **Design with**: Follows the same way of focusing on the customer as a Design for approach, but also involves customer reactions to concepts and ideas from the developer.
- **Design by**: In this type of product development, potential users are participating a lot in the designing of the end result.

Furthermore Kaulio (1998) states that the designer has an important role when analysing requirements of use and users, instead of striving for an engineering based solution. In order to determine a solution’s rate of fulfilment, the use of field tests can be applied to get a grip of user needs and expectations and as Norman (2002) states:

“There is no substitute for interaction with and study of actual users of a proposed design” (p.155)

A wider perspective of user-centred design can be found in the ISO 9241-210:2010 “Ergonomics of human-system interaction - Part 210: Human-centred design for interactive systems” where the expression “human-centred design” is used. The difference is stated to be that human-centred design includes the potential impact on other parties than users, such as employers.
2.3 NEEDFINDING

The needfinding process is, according to Faste (1987), a paradoxical activity where the developer explores circumstances where something is missing. To formulate a need, the missing object or function must be envisioned by someone. As Faste (1987) mentions, the word Needfinding depicts the two fields that is comprised by needfinding. First there must be a need for something, then comes the task of recognising and visualising the need.

2.3.1 Perceiving needs

Faste (1987) declares that needs can be registered in two different ways. First there is the Needer, a person experiencing an issue and therefore finding a need. Secondly there is the Needfinder, an observer noticing a need based on another person or persons. In order to conduct a useful needfinding, the needfinder generally must be able to relate to the needs in either a personal or professional way (Faste, 1987).

2.3.2 Four stages of needfinding

Another way of approaching needfinding is described by Patnaik and Becker (1999). They say that needfinding can be divided into a four-stage process. Each stage has a general goal that the designer should aim to achieve:

- **Frame and prepare**: Here, the goals of the research should be determined and the customers should be studied.
- **Watch and record**: Observe user’s behaviours in the desired environment without interfering, in order to get a good understanding of the situation.
- **Ask and record**: Since observations does not always give the entirety, additional interviews might be needed to understand why the user acted in a certain way.
- **Interpret and reframe**: Findings from the collected data must be analysed in order to fine-tune the understanding of the performed research.

2.4 USABILITY

Norman (2002) explains that one of the most important purposes of new technology should be to simplify and structure tasks. Norman mentions that one way of analysing the interaction between a product and the expected user is to ascertain the product’s usability. According to Nielsen (1994) usability must be seen as a system of multiple features, with five fundamental attributes that all should be satisfied for the product to have high usability:

- **Learnability**: A product or system should be easy and fast to learn how to use.
- **Efficiency**: After learning how to use the product or system, the user should be able to work efficiently.
- **Memorability**: A user that once learned how to use the product or system should be able to use it after a longer absence without having to relearn it again.
- **Errors**: There should be a low frequency of errors, and if errors occur the users must manage to solve the issue.
- **Satisfaction**: The users should like to use the product and feel pleased with the product’s performance.

To ensure the usability of a product, Dumas & Redish (1999) mentions the importance of including users throughout the design process. The user’s needs and opinions should be an important deciding factor to where the design process is heading. Another way of ensuring usability is to include a representative for the intended users in the design team (Dumas & Redish, 1999).
2.5 ERGONOMICS

There are many ways of defining the area of ergonomics. Some authors like Pheasant & Haslegrave (2016) describe the area as the interaction between humans and tools or environments that are intended for human use. A broader definition of ergonomics would be:

"Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance."

(International Ergonomics Association, IEA (2016))

The meaning of this definition would be that ergonomics is used to further understand and adapt products and systems for human use. Sanders & McCormick (1998) argue that the area of ergonomics has an important role in engineering design. They point out two significant goals of implementing ergonomics in product design. Firstly, ergonomics strive to amplify worker’s effectiveness and productivity through improved learnability and ease of use. Secondly, ergonomics aim to improve human interaction with the intended design through increased comfort and minimising risks of injury, to mention a few interactions.

Gazzoni, Afsharipour & Merletti (2016) draw the conclusion that preventing musculoskeletal disorders is one of the main goals with applying ergonomics, which could be obtained by gathering and analysing relevant information regarding muscular work. Furthermore, Sanders & McCormick (1998) claim that maintaining an ergonomics approach in product design means that the designed products should be evaluated to make sure they meet the demands and intended aims.

2.5.1 Integrating ergonomics in product design

When integrating the area of ergonomics in product design, there are some things the designer must take into consideration. A theory presented by Pheasant (2003, p.10) mentions that there are five common fallacies that a designer might encounter when trying to design ergonomic matter:

"This design is satisfactory for me - it will, therefore, be satisfactory for everybody else."

This fallacy is highlighting the matter that many designs often will not be tested by a sufficient amount of representative users, which might lead to the launch of a product that won’t meet the user needs. Another approach to this first fallacy is mentioned by Porter & Porter (1998, p. 391);

"The design is not satisfactory for me - it will, therefore, be unsatisfactory for everybody else."

The next fallacy is closely related to the first:

"This design is satisfactory for the average person - it will, therefore, be satisfactory for everybody else."

The reason being that people tend to see themselves as average (Högberg, 2005). Pheasant & Haslegrave (2016) also mention that the evaluation of a design suggestion is commonly based only on subjective opinions.

"The variability of human beings is so great that it cannot possibly be catered for in any design - but since people are wonderfully adaptable, it doesn’t matter anyway."

While people truly are adaptive, there might be other similar products on the market where the users will not have to sacrifice comfort. Pheasant & Haslegrave (2016) also states that improper ergonomics can lead to musculoskeletal disorders such as repetitive strain injuries.
"Ergonomics is expensive, and since products are actually purchased on appearance and styling, ergonomic considerations may conveniently be ignored."

As mentioned in chapter 2.4 Usability, usability is an important factor in customer satisfaction. To design a product with ergonomics in mind is not necessarily equivalent to increased product cost.

"Ergonomics is an excellent idea. I always design things with ergonomics in mind - but I do it intuitively and rely on my common sense so I don’t need tables of data or empirical studies."

This fallacy reminds of the first two. In order to achieve usability, the designer should use other resources than their own subjective thoughts, as stated in 2.4 Usability.

Pheasant & Haslegrave (2016) also make a general statement that products designed by strong individuals might lead to unsolvable difficulties for individuals that are weaker or smaller. Additionally, one more important fallacy is mentioned by Porter & Porter (1998, p. 391);

"Designing from 5th percentile female to 95th percentile male dimensions will accommodate 95% of people."

The authors explains the fallacy by making the example that a male who is ruled out because of his body length might not be at the highest five percent in other measures such as arm length, waist size and so on.

In a study performed by Broberg (1997), product designers and engineering designers were asked what kind of frustrations were related with implementing ergonomics to product design. The three major problems according to the participants were that customers do not desire ergonomically designed products, the designers had inadequate knowledge of ergonomics and that ergonomics implementation took up too much time in the project.

2.5.2 Anthropometrics

Measurements of weight, size and proportions of the human body is called anthropometry, which is commonly used in the design process to increase comfort and usability according to Hanson, Sperling, Gard, Ipsen & Vergara (2009).

The relevant anthropometric measurements to this design project is the data related to the upper body such as waist circumference and waist-shoulder length for 5-95 percentile men as shown in figure 7. The waist circumference is from a data collection by Bigaard et al. (2003). Waist to shoulder data was found on theergonomicscenter.com (n.d.).

![Figure 7: Anthropometric measurements from 5-95 percentile male.](image)

Sanders & McCormick (1998) mention three approaches to anthropometric application in design: Design for extreme individuals, Design for adjustable range and Design for the average. This project is focused on designing for adjustable range to enable adaptability for the intended users. According to Sanders & McCormick (1998), design for adjustable range is commonly focused on being adjustable for a certain range of users such as the 5th percentile female to the 95th percentile male. They claim that the reason for not covering the entire spectra of body measurements is that the extreme measurements could lead to technical difficulties within the design.
2.5.3 sEMG as an ergonomic analysis method

In the study and analysis of human movement, Stegeman, Blok, Hermens & Roeleveld (2000) claim that a commonly used tool for analysing is surface electromyography (sEMG). This is a non-invasive method of measuring electrical impulses from working muscles (Day, 2002). Day states that when muscles create force, the fibers in the active muscles produce tiny currents of electricity. The small currents create a signal that can be measured using either conductive elements or electrodes on the skin (Figure 8).

Surface electromyography has, according to Criswell (2010), many possible uses and gives the user actual information about the function of the muscles in contrast to just making qualified guesses. Criswell mentions that one of the areas where sEMG can be used is in ergonomics research and design.

2.5.4 Reach and working height

When designing equipment for humans, the designer should take into consideration the zones of convenient reach as well as working height. Pheasant (2003) says that the general idea is to place the heaviest or most used equipment in positions that are convenient and easy to reach, which is also supported by Sanders & McCormick (1998). According to Arbetsmiljöverket (2012), convenient reach can be divided into zones where regularly used tools should be close to the body. These zones described by Arbetsmiljöverket are visualised in figure 9.

According to a study performed by Nielsen, Andersen & Jørgensen (1998), lifting weight at around shoulder height resulted in twice as high muscular load on the shoulder muscles as the same weight lifted at around waist height. The muscular load showed a linear relationship with increased repetitions per minute for all tested working heights.

Chengalur, Rodgers & Bernard (2004) discuss appropriate range of motion for some common movements in the upper extremities. Chengalur et al. make a general statement that working near the extreme areas of range for each motion increases stress on the working joints and muscles. Furthermore the authors claim that performing work while flexing or extending the extremities near the extreme ranges of motion might lead to a decrease in strength compared to doing the same work in the appropriate range of motion close to the neutral position of the extremities. A visualisation of the range of motion for upper extremities based on Chengalur et al. (2004) can be seen in figure 10.
2.5.5 Repetitive work

When performing manual reforesting, a common problem is the presence of repetitive work. Since the same motions are repeated several times a minute throughout the whole workday, the planters are facing some strain-related risks. According to the guidelines of Arbetsmiljöverket (2012), repeating motions lead to a constant undiversified stress which could lead to a successive appearing of serious long-lasting injuries in muscles, tendons and joints. Common areas of repetitive strain injuries is, according to Van Tulder, Mal-mivaara & Koes (2007), hands, wrists, shoulders, arms and neck.

To prevent strain-related injuries, Arbetsmiljöverket (2012) present possible counteractions. First of all, the rate of repeating a strenuous motion should be lowered by reforming how the work is performed. One way of doing so is job rotation, which Arbetsmiljöverket (2012) defines as a change of work task to diversify strain.

2.5.6 Design of hand tools

A product that is improperly designed to its purpose might yield undesirable consequences for the intended users. Sanders & McCormick (1998) mentions that improper tool design could lead to injuries or accidents related to use. The guidelines from Arbetsmiljöverket (2012) with the purpose of reducing risk of discomfort regarding hand-held tools, such as planting tubes, claim that the tool must have a suitable and conformed grip with high friction and evenly spread pressure. The grip should suit various users’ hand sizes, both men and female, and according to Chengalur et al. (2004) have a recommended length of 13 cm to avoid small areas of high pressure. The tool should also be possible to use both with the right and with the left hand as stated by Norman (2002) and Sanders & McCormick (1998).

An important design aspect to keep in mind is where to place triggers or buttons on handheld tools. Sanders & McCormick (1998) claim that controls or triggers that are used with high frequency should be designed for thumb usage rather than index finger usage to avoid a syndrome called trigger finger and because the thumb is a stronger, more versatile finger. However, hyper-extension in the thumb, as seen in figure 11, must be avoided to minimise the risk of inflammation (Sanders & McCormick, 1998).
Additionally, Pheasant (2003) emphasises the importance to remove all kinds of pressure points, such as sharp edges, pinch points between parts and so on. Furthermore the most comfortable handles should have a radius of around 15-25 millimetres with a circular cross section, since the possibility of pressure points will be minimal (Pheasant, 2003).

Norman (2012) argues that designers of handheld products with the purpose of being used by a general population should remember to think of left-handed users. In cases where left-handed products are not made the only solution is to create a product that is in itself ambidextrous, i.e. usable with both hands (Norman, 2012). A product designed only to be used with the right hand would leave out a large portion of the potential user base since 10-15 % of people are left-handed (Spiegler & Yeni-Komshian, 1983). Norman (2012) adds that aiming for ambidextrous use should be made even if it makes the product lose a small amount of efficiency for the average user.

2.5.7 Load and how it affects gait and posture

It is shown that there are different factors affecting performance while carrying load, such as the placement, magnitude of the load and even factors like terrain type according to Soule & Goldman (1969) and Browning et al. (2007). A popular ergonomic test is the double backpack test of the sort that Datta & Ramanathan (1971) or Lloyd & Cooke (2000) performed (Figure 12), which shows that well-distributed loads using a harness could reduce physiological responses during walking for longer periods of time.

While carrying load the risk of losing balance and falling is increased according to Rugelj & Sevšek (2011). They recommend to carry loads close to the body’s centre of mass to prevent falls. Physical strenuous work such as load carriage is associated with the risk of obtaining musculoskeletal disorders in upper limbs relative to walking without load according to Miranda et al. (2001). Abe, Yanagawa & Nihita (2004) show that energy cost of walking increased significantly when carrying load on the legs. Negrini & Negrini (2007) show an increase in asymmetry between the shoulders when they carry load in an asymmetrical manner, compared to carrying the load symmetrically.

2.5.8 Reforesting related discomfort and strain

Sullman & Byers (2000) indicate that manual planting is a highly strenuous work. In their study, discomfort when planting on pasture was experienced almost 50% of the time spent on planting. An overview of the observed discomforts can be found in figure 13. The major discomfort zones were mainly the right elbow followed by the lumbar area. Sullman & Byers (2000) argues that the reasons might be due to rugged soil and heavily weighing plant containers on the hips.

Perceived strain can depend on which part of the body carrying a mass. According to Holewun & Lotens (1992) there are differences in perceived muscle strain when carrying a weight with the hips compared with carrying using the shoulders. Their research indicate that carrying a weight solely using shoulders results in increased muscle strain in the shoulder- and lumbar areas compared to carrying the same weight including using the waist.

The study performed by Sullman & Byers (2000) showed that planters spend the vast majority of their working time doing the actual planting task while the rest of the time mostly was spent on getting new seedling trays and walking.

Figure 12: Even weight distribution resulting in even gait.
2.6 DESIGNING FUNCTIONAL WORK WEAR

In difference to fashionable clothing, which is mostly a construction based on the creativity of the designer, as Gupta (2011) explains that functional work wear is designed using a process similar to an engineering design process. The process is based on the user needs depending on the environment of the intended field of application. According to Gupta (2011), functional clothing must satisfy common needs for the intended users. These needs are divided into four sub-categories, supported by Gupta (2011) and McCann, Hurford & Martin (2005) using various phrasing. These four sub-categories are; Physiological, Biomechanical, Ergonomic and Psychological aspects which are described the way Gupta (2011) sees them:

**Physiological aspects:** These requirements are connected to the human physiology. An important factor of functional wear is making the user feel comfortable when using the garment. Usability and resistance to wearing are important aspects. Material should be chosen thinking of intended field of application - the garment should be waterproof if used outside etcetera.

**Biomechanical aspects:** Functional wear should fit the user’s body. Pressure exerted on the body should be distributed evenly. If pressure is applied while avoiding sensitive pressure points, the user will experience less fatigue and increase performance. Applying too much pressure to sensitive areas could lead to perceived discomfort, inhibited movement, skin abrasion and annoying rubbing.

**Ergonomic aspects:** Functional work wear should account for gait, movement and use. The work wear should be conformed for the user. An apparel that is too large might be in the way while working and a garment that is too tight could be perceived as uncomfortable. Additionally, Rosenblad-Wallin (1985) mentions that the load placement of the work wear combined with the centre of gravity is important when designing functional work wear.

**Psychological aspects:** Beyond aspects related to the body and movement of the user, aesthetics is an important factor when designing apparel. A product could have a perfect fit and function but look “wrong” according to the users and might therefore be rejected. Aesthetics is not as important when designing work wear as fashion apparel, but nevertheless an appealing look is important according to Rosenblad-Wallin (1985).
2.6.1 Material properties

When deciding what fabrics to use in work wear design there are some aspects to think of. Gupta (2011) stresses the matter that choosing the perfect fabric can be an extremely difficult task. Ljungberg (2007) mentions that apparel made using synthetic fabrics can be easier to keep clean than natural materials. Furthermore Gupta (2011) claims that an important addition to functional work wear is stretch fabrics. Using stretch fabrics can yield numerous advantages such as improved comfort, mobility and muscle support.

To fulfill the needed properties of a work wear, most of the times designers of functional work wear adopt a principle where materials with different properties are layered together (Figure 14) to form a system with the materials’ combined properties (McCann, Hurford & Martin, 2005). McCann, Hurford & Martin (2005) continue to claim that such layering systems often consists of a wear-resistant protective outer layer which often is waterproof. The inside then consists of an appropriate amount of dampening insulation layers depending on field of application.

2.7 MANUFACTURING

A simple description of manufacturing methods related to this project is described in the paragraphs in upcoming sections (Figure 15). The methods included are those meant to be used by BCC in the process of manufacturing the final product, since BCC do not manufacture things such as cloth components themselves.

2.7.1 Bending

According to Björklund, Hågeryd & Lenner (2002), when bending pipes the radius of the die should be adjusted to the diameter of the pipe for the pipe not to lose its roundness. When bending pipes, Björklund, Hågeryd & Lenner explain that it should be done with simultaneous drawing. At the bend there will be a compressive stress on the outer zone and tensile stress on the inner zone. The material’s elastic resilience of the bending process is what causes the stress which almost always occur. They mention that a possible compensation for the elastic resilience is by over-bending the material to a smaller radius to achieve the correct angle from the bending. Bending is commonly done by pressing machines, mechanical or hydraulic, designed for plastic deformation (Altan & Tekkaya, 2012).

2.7.2 Welding

When defining welding Radaj (2012) quotes the German Standard DIN 1910 [341]:

“Welding is the non-detachable joining or coating of components or base materials under the (mostly local) application of heat or pressure, with or without the use of filler material”

Radaj (2012) states that when the welding zone is in its plastically deformed or liquid state is when joining is preferably performed. Deformations and residual stresses might occur in the material due to the sharp heat input in a small very local area with the aid of rapid or too narrow cooling.
2.7.3 Reducing corrosion by coating

The manufactured metal parts will come in contact with certain media in the work environment such as weathering, and fouling which might result in undesired corrosion. ISO 8044:2015: Corrosion of metals and alloys -- Basic terms and definitions defines corrosion as a:

“physiochemical interaction between a metal and its environment that results in changes in the properties of the metal, and which may lead to significant impairment of the function of the metal, the environment, or the technical system, of which these form a part”

Maaß (2011) suggests a passive procedure for corrosion protection by isolating the material and applying protective layers. Corrosion is decelerated or prevented by coatings of paint or lacquer that are pore-free, firmly adhered to the base material, possess a certain ductility, resistant to corrosion and external mechanical stress.

Figure 14: Layering materials for combined properties

Figure 15: Relevant manufacturing methods.
3 METHOD
3 METHOD

This chapter describes the methods used in this project, from planning to final product - and the theoretical foundation on which these approaches were based. Most of this work was performed in Timrå at Norrplant with continuous feedback from the supervisor.

3.1 PROCESS

This project process is based on an iterative empirical cycle mentioned by De Groot (1961). Roozenburg & Ekels (1995) interpretate De Groot’s cycle and apply a design process approach to the empirical cycle which they call The basic design cycle. Their interpretation contains stages from the initial analysis to the final solution. Furthermore Roozenburg & Ekels believe the design cycle to be a trial-and-error kind of process where knowledge of the problem continually improves to push the project forward.

This way of performing product design is supported by Pahl, Beitz, Feldhusen & Grote (1997/2007). Bohgard et al. (2010) as well as Pahl et al. (1997/2007) stress the importance of the design process to include users and be iterative with repeating steps in a loop similar to a circle. When using such methods, the iteration loop should be kept simple in order to make the design process efficient. Pahl et al. (1997/2007) give a warning example where the loop would cover the entire design process leading to the designers having to start over entirely from the beginning.

An interpretation Roozenburg & Ekels (1995) basic design process and of which this project is based on was made by the design team and can be seen in (Figure 16) The loop is kept simple, yet covers the important stages of the design process to keep the project moving forward. The process is also depicted as a circle rather than a straight line, to emphasise the iterative approach.

To decide the aims for the different stages of the design process, a stage-gate methodology was also applied to the design process cycle. According to Cooper (1990), Stage-Gate is a technique of structuring a process by dividing it into different phases depending on work area. Between each phase there is a “gate” consisting of aspects that must be fulfilled before continuing with the next phase, so in the very end of every stage the results of the given stage is compared to the criterions in the gate.

![Figure 16: A visual interpretation of this master thesis project's design process.](image-url)
3.1.1 Stages of the design cycle

Various methodologies have been used which are connected to specific parts of the design cycle. These methodologies are described more thoroughly throughout this chapter. The stages of the cycle used in this project (Figure 16) can be summarised as the following:

**Analysis:** Performing a context analysis using a competition analysis and searching for user needs through various methods. The gate for this stage is the creation of a design specification.

**Concept:** Creating various ideas and concepts with the aim of satisfying the design specification. The probability of each idea or concept being a functioning design is then discussed to screen which ideas should follow through to the next phase. To move forward, some concepts that the authors believe to be suitting solutions must be formed.

**Prototyping:** The designs from the concept phase are tested either by computer 3D modelling or by the creation of testable prototypes. In order to move forward, the designs must be evaluable in some way, either by actual testing or reflection.

**Evaluation:** Prototypes or designs are evaluated by either the designers or potential users. Moving forward require information about the functionality of the tested parameters.

**Decision:** A decision is then being made based on the evaluation, whether the design is suitable for the final solution or if more research must be performed and other designs should be tested instead.

3.2 PROJECT PLANNING

A project plan was created in which the various intended stages of the design process essentially was created, with a general idea of which different stages and gates would be needed to complete the task at hand. These stages were implemented in a Gantt-chart (APPENDIX A).

The basics of a Gantt-chart is, according to Wilson (2003), a two-dimensional diagram where the vertical axle describes the different activities of a process while the horizontal axe defines which point in time where the activities starts and ends. The activities is positioned as a lying histogram in the diagram which then gives a clear picture of important dates in the project.

Wilson (2003) mentions the main idea of a Gantt-chart being that every single phase in the project is taken into consideration, where the process is created from the given phases. Furthermore the use of Gantt-charts for project management is a strong tool to, in an illustrative way, show important information in order to help the users define potential problems in the process and to create clear goals through the course of the project.

3.3 CONTEXT & ANALYSIS

Since this master’s thesis is performed by an already experienced user and a novice, the experienced user already had some opinions on current equipment regarding usability prior to the information gathering even started. To avoid potential influencing bias on the other designer, none of those opinions were mentioned until the end stages of this process phase. A lot of information has been gathered continuously to more precisely guide the end result.
3.3.1 Interviews

Short semi-structured interviews with a lot of people working at SCA who had experience of reforestation were performed to receive more understanding of reforestation in the middle area of the country. Interviews were also held with reputable entrepreneurs such as Jonas Lantz from Lantz Skogsvård who, according to the supervisor at SCA, once was Sweden’s largest forestry entrepreneur, to get professional opinions and thoughts.

Drevers (1995) describes the usage of semi-structured interviews as a very flexible tool suitable for examinations on smaller scale. He states that there are better alternatives for examinations or studies of larger groups of people. Drevers (1995) describes the way of performing semi-structured interviews is for the interviewer to set up some basic questions beforehand. These questions will be the basis for the interview, and during the interview it will become more structured which makes the interviewed person able to talk and express themselves freely.

A biologist working at NorrPlant named Niklas was often consulted throughout the project with questions regarding reforestation. He was an experienced reforestation worker interested in this project, and of the younger generation of employees at NorrPlant who possessed very relevant insight.

3.3.2 Survey

A simple survey was created to share on social medias to reach people who might have worked in some way with reforestation during their life (APPENDIX B). The survey was used to collect quantitative data quickly and get a quick overview of how different reforestation equipment is used. The survey contained mostly multiple choice questions but also ones where the individual had the option to answer with their own opinions. These opinions could vary from pinpointing specific details about the equipment or providing new ideas to explore.

Wiersma (2011) explains that the use of surveys has developed from home meetings and telephone interviews to also including internet based surveys. Internet based surveys are generally speaking cheaper, faster and more convenient to perform - both for the interviewer as well as the approached subjects.

Despite the positive aspects of internet-based surveys, there are times where other methods of information gathering is preferred. Wiersma (2011) mentions that the most substantial problem with internet-based surveys is the low participation rate since people who ignore the survey tend to have different opinions compared to the ones expressing their thoughts and opinions through the survey.

One important question which the design team wanted to get hard numbers for were how planters switched active seedling tray. This question was based on observed differences from previous experience by the experienced designer.

3.3.3 Think-aloud protocol

For a better understanding of what people think while concurrently using the reforesting equipment, the method think-aloud protocol was used. Subjects with previous experience of reforestation as well as people with no previous experience were handed the currently existing products in the Pottiputki-line and were asked to set a number of plants. They then had to describe what they did in every phase and verbalise every thought that crossed their mind during the planting process (Figure 17).

According to Hanington & Martin (2012), think-aloud protocol is one of the most common evaluation methods for usability testing. They describe the method as a way of explicitly asking the subjects what they do, think and feel while performing a, by the researcher, predetermined task. The main focus should be on what is going on rather than why.
While the think-aloud protocol is a commonly used tool, Jääskeläinen (2010) mentions an important consideration to keep in mind while studying the subjects. The studied people will only be able to verbalise information that is controlled by the working memory. This means that any instinctive task will not be registered by the user and therefore won’t be accessible for the researcher.

3.3.4 Fly-on-the-wall observation

A fly-on-the-wall observation of a planting team working for Lantz Skogsvård, based in the middle of Sweden, took place during half a day (Figure 18). The whole team consisted of younger men from Poland which spoke neither Swedish nor English except for the supervisor Oleg, who had been working as a planter for over 20 years in Sweden, who could understand basic Swedish. The design team and planting team met up in the morning for a long drive up in the mountains to the clear-cut that was to be reforested where the observations would ensue. No interviews or questions took place during the study, strictly observations of the team was performed. All observations were made at a distance using pen and paper to see how the planters used the planting equipment and what kind of obstacles they could face during their work – either environmental or equipment-related.

The observations were done to get insight in how the entrepreneurs use the planting equipment, and to confirm that the previous contextual analysis methods provided similar information regarding observed difficulties.

According to Hanington & Martin (2012) the fly-on-the-wall observation method is a technique specified to remove potential bias by removing the researcher from direct involvement or behavioural influences. The fly-on-the-wall method is prominent when people might change their natural actions to better suit or worsen the results of the observer.
3.3.5 Hierarchical task analysis
While observing the users in the fly-on-the-wall observation, a Hierarchical task analysis (HTA) was simultaneously performed. Every step the users did was written down and afterwards categorised into different tasks and subtasks. The HTA was used with the purpose of getting clear visuals of every step in the reforesting process and to pinpoint possible areas of improvement.

Annett (2003) describes that the purpose of using HTA is to break up a complex task into smaller subtasks where the one performing the HTA decides the level of detail on each subtask. The major point of using a HTA is, according to Annett (2003), to discover any tasks that may lead to performance loss in the system.

3.3.6 Competition analysis
A thorough research through the internet, old papers, theses and magazines of all reforestation products that could be found was performed. Furthermore, other markets with similar equipment such as land clearance equipment (Figure 19) and hiking equipment were scanned.

Pahl et al. (1997/2007) stress that a designer must use various information gathering techniques during the design process. Besides searching for relevant literature, they also consider assessing the products made by competitors as a valuable source for relevant information. Furthermore, to get a well-founded understanding of a market, Otto & Wood (2001) recommends that analysing products and systems from competitors can be a valuable tool in identifying important market innovations.

The competition analysis was made with the intention of widening the knowledge of functionality in existing reforesting products and to look for innovative ergonomic solutions from any design area that might be applicable to this project.

Companies that have the ability to identify competitors’ strengths and weaknesses can use the gathered knowledge to obtain a strong position on the market (Shetty, 1993). When striving towards developing an industry, a way of incorporating new innovations is, according to Shetty to search for technologies and practices in other industries that might be applicable to the aforementioned industry, but not yet recognised.

Figure 18: The subjects walking towards the clear-cut.

Figure 19: One of the designers testing land clearance equipment.
3.3.7 Competitive usability testing

By performing competitive usability testing, design teams can acquire valuable information which can be used to improve their own product. Hanington & Marting (2012) describes competitive testing as an opportunity to analyse other companies’ products from the user’s perspective.

In excess of internet searches, during the context analysis phase BCC sent a pallet with a set containing every model of their newest range of products up to the design office at Norrplant. Furthermore, Norrplant also had some old reforestation equipment. All these products served the purpose of analysis, testing and to be used however the design team saw fit. The testing of the product range was at first performed at a nearby slope next to the office in different types of weather conditions (Figure 20). The initial analysing was aimed purely on why the products were designed the way they were and how the varying functions could be improved to potentially increase usability.

Later on a test at a clear-cut was carried out, where the products were tested while actually setting plants to simulate field usage. The intention with testing the existing products was to pinpoint different problem areas and needs which then, together with the rest of the context analysis, would act as a foundation for the design specification.

Dumas & Redish (1999) explain that competitive testing can reveal strengths and weaknesses in competitors’ products. By realising what makes a competitor’s product coveted, the designer can use this information to create a product that is superior to satisfying users’ needs compared to the competition (Dumas & Redish, 1999).

3.3.8 Design specification

From the gathered opinions and observations throughout the context analysis, a design specification with measurable criterions was created. The design specification aimed to take into consideration the needs required through user feedback as well as additional goals and objectives observed by the authors. Since the design process was an iterative procedure, the design specification was continuously reviewed and changed whenever new knowledge affecting the specification was gathered.
In the end of the context analysis, the step before continuing with idea development is, according to Otto & Wood (2001) to create a design specification. They claim that the specification contains criterions of which the product’s design should be based on. Pugh (1991) recommends that the design criterions should be established early on in the design process and act as a reference for future development. Pugh stresses the matter that a design specification should not be considered static and if there is reason for changing the specification later on, then it should be done. An interpretation of Pugh’s (1991) Design Core with relevant specification areas for this project is visualised in figure 21.

Otto & Wood (2001) state that each criteria should either be testable or verifiable, otherwise it isn’t a specification. Furthermore, Otto & Wood mention that a specification is based on the designer’s interpretation of user needs and checklists. Users might not think of producibility and such topics, therefore Otto & Wood recommend to use checklists as a way of thinking of a wider customer base, containing a number of stakeholders ranging from manufacturers to distributors.

3.4 LITERATURE REVIEW

All information gathered regarding techniques and theories that’s been used throughout the project has mainly been collected from peer-reviewed sources in order to ensure a solid basis on which the project could proceed. During the first weeks of the project there was a phase where information regarding relevant areas for this thesis such as reforestation, the engineering design process, carrying harnesses, belts and ergonomics studies was collected. Additionally, information was continuously collected throughout the project when new ideas and questions that required new information surfaced.

The articles and information were partly found using internet search engines such as Google Scholar, databases available from the library search engine Primo and later on EBSCOhost. Common search words were Design, Engineering, Ergonomics, Product Development and various combinations of these. Course literature and books loaned from the university library was also read to find applicable information for this thesis.
3.5 IDEA AND CONCEPT DEVELOPMENT

The idea- and concept development phase was initially focused on creating a wide variety of ideas and designs for planting tubes and harnesses to meet the stated user needs. These ideas were then tested and evaluated to explore which ideas would lead to the final concept. To achieve the final concept, an iterative process was used where phases were repeated or revisited several times throughout the process when new findings or ideas had to be tested or conceptualised.

3.5.1 Mood board

The idea development phase launched by the creation of various boards filled with inspiration for the design process (Figure 22). The first board created was a mood board. The mood board contained abstract pictures and watchwords the authors wanted to mediate through their design and had the intention of describing which direction the design process would strive towards.

A mood board is, according to McDonagh & Denton (2005) a collection of images or other abstract content with the purpose of expressing feelings or moods related to the desired ambience of the product design process. A mood board is therefore a reflection of what type of feelings the designers want to communicate with their design.

Garner & McDonagh-Philp (2001) believe that the use of mood boards is potentially one of the most important tools to facilitate the progress of a product design process. They claim that a mood board can navigate a designer throughout the process and by its implementation embrace design thinking through problem solving.

3.5.2 Corporate identity boards

To fill up the gap between what the designers want to communicate with their design and what the employers want to communicate with their products, two other boards were made. Firstly, a style board with pictures showing characteristic features from the existing product line was compiled. The other identity board created was a style board. A style board is a kind of mood board that McDonagh & Storer (2004) describe as having the purpose of presenting a style or form that is desirable for the final design of a product design process to obtain. In this perspective, a style board is not as abstract as a usual mood board, but instead it contains images that displays the desired attributes.

Additionally, a board describing the company’s core values in words together with pictures that are in some way related to each word was created. The visual representations had the intention of establishing a more coherent understanding of the corporate identity.

Figure 22: A glimpse of the created inspirational boards.
A corporate’s identity isn’t just displayed through the functionality of their products. Pieczka (2006) claims that a corporate’s identity also depends on the corporate personality, which is a way of including such areas as corporate aims and core values into the corporate identity.

3.5.3 The catalogue method

While the project progressed through stages such as literature reviews competitive- and context analyses, some ideas had been growing in the design team’s minds. While the ideas might not have been generated intentionally, they still existed. Therefore, to not forget these ideas, they were quickly written down and later discussed when the idea generation phase had begun. By using this approach, which Johannesson, Persson & Pettersson (2013) calls the catalogue method, the discussions led to more ideas surfacing. This method was used to get these ideas out of the way for the other idea generating methods that were to come. Since the ideas were all fresh the method was also used to kickstart the upcoming brainstorming phase to generate new ideas while also sketching them for visual aid which can be read in the coming paragraphs.

Johannesson et al. (2013) describe the catalogue method as a simple and commonly used method suitable for tasks in need of problem solving. They explain the procedure as searching for information and cataloguing it to see how certain specific or related problems might have been solved by others. Another way to use this method, but in a more unstructured way is to look at new ideas for design through what is in style, such as fashion trends, art or anything that might relate to solutions of current problems (Johannesson et al, 2013).

3.5.4 Brainstorming

An initial methodical process focused on generating ideas called brainstorming was used since this was a method that was familiar to the design team from earlier experiences. The process was performed as a combination of brainwriting and brainsketching where some ideas were drawn on papers and some were written down on a list and thereafter discussed (Figure 23).

When generating ideas, brainstorming is according to Kudrowitz & Wallace (2012), an often occurring method used by product designers. Brainstorming is described by Kudrowitz & Wallace as a type of freely formed method for idea generation that should be performed during the early stages of a design process. They note that freely formed idea generating methods are not suitable for use during later stages of the design process. After the generating process the ideas from this method and the catalogue method would be evaluated to weed out impossible or unrealistic ideas. Sutton & Hargadon (1996) mentions that brainstorming is used to generate a large quantity of ideas.

Pahl et al. (1997/2007) claim that brainstorming is heavily dependent on participants triggering ideas in other participants through their own ideas, like a chain reaction. Brainstorming could then be a tool to explore ideas that perhaps never had been considered in the context of the project.

![Figure 23: Ideas generated from brainstorming hanging on the office wall.](image-url)
3.5.5 Sketching

Sketches were used throughout the whole design process with various levels of detail. When starting with the simplest sketching, a couple of simple templates of a man and woman were printed out to reduce the time that would have been consumed if these were drawn separately for every sketch. These templates showed vector sketches of a man and woman from the front, side and back. This method was used to quickly produce some ideas and concepts on whole harnesses to get some simple shapes that would follow the human form. When the templates were all filled out, sketches of specific functions and larger drawings with a higher level of detail were performed on blank paper.

During a major course of the design process additional ideas of varying complexity were generated and added (Figure 24). These were also added to the rest of the sketches and discussed in comparison to all previously drawn images. Including sketches for visual presentation throughout the process ensured a simple way of relaying the information amongst each other in the design team and to others involved.

According to Rodgers, Green & McGown (2000), a product design sketch can have five levels of complexity depending on when in the design phase they are performed. They believe that the grading system can help keeping track of design progression. From their study, Rodgers, Green & McGown (2000) decided the following five complexity levels:

**Complexity level 1:** Monochromatic drawing without shading or colour. Only one line thickness is used throughout the sketch.

**Complexity level 2:** Same definition as level 1 except line thickness is varying. The sketch may also include notes.

**Complexity level 3:** Monochromatic sketch that is roughly shaded. May also include notes.

**Complexity level 4:** Sketch made with higher accuracy. Varying line thickness with shading and may also include colour and graduation.

**Complexity level 5:** High level of detail. A coloured illustration to indicate the product’s final looks and form.

Figure 24: Sketching ideas for the planting tube.

Figure 25: Illustration of complexity levels.
3.5.6 Random word association

Literature about reforestation and other forestry related practices was used to randomly generate 10 arbitrary words used to generate new ideas related with a product. The selecting of words was performed by simply closing eyes, taking a random page and putting a finger down on the page and selecting the closest word. When a word was selected the focus promptly became to create a concept using the word in a brainstorming session. When using this method a lot of new ideas that might never would have been thought of surfaced, since some words were so arbitrary that they probably would never have come up in other idea generating methods.

This creative method is described by Johanneson, Persson & Pettersson (2013) as making a list of randomly generated words of which to associate individually with the current problem to be solved in the project. They note that it is important to write down the first and most spontaneous associations that surfaces, and not to ponder too deeply into more complex solutions. The use of associating a problem to random words can, according to Li, Li & Zhao (2007) help designers to think of a problem from different angles. By forcing an association between the words and the problem, designers might see a solution that otherwise wouldn’t be recognised.

3.6 PROTOTYPING AND CONCEPT EVALUATION

During the project, a wide range of different prototypes were built with different types of fidelity. Prototypes were tested amongst the design team, ordinary people, clients, private users and professional end-users. Through the process of prototyping and testing, a continuous evaluation of the developed concepts were made. Every major design decision was made with a user-centred design approach in mind.

Prototypes is the creation of design artefacts in physical form with different levels of fidelity for essential testing by the designer, client and users (Hanington & Martin, 2012). Hanington & Martin quickly covers the basics for the prototyping methods used for this project and are explained in the following paragraphs.

3.6.1 Parallel prototyping

Since so many prototypes were built during the project the term parallel prototyping is used to describe the creation of all physical designs. This method made explanations of complex ideas much easier compared to pointing on screens or sketches, but the key thing about the prototypes was that they could all be tested for evaluation. Some prototypes were sent to users as described further on in the other prototyping methods while some had slightly different end goals than being sent to end-users for testing.

Hanington & Martin (2012) discuss the importance of not getting stuck in a particular design and exploring other opportunities. They describe the method of parallel prototyping as a way to avoid fixating on a less superior design by creating a range of low-fidelity prototypes to be tested by end users. The end goal is not to find the best design but to reflect about the individual design elements of the prototype and receive constructive criticism to aid in solutions of problems and to more easily evaluate the designs.

Plattner, Meinel & Leifer (2012) when researching parallel prototyping had three hypotheses which were all supported according to experiments they performed and the results leads to the following quote being factual.

“Parallel Prototyping Leads to Better Design Results, More Divergence, and Increased Self-efficacy” (p. 127)
Designers may become too attached to a single design too early in the design process according to Cross (2004). This might make them reluctant to abandoning them when they might not be fully satisfactory solutions Cross argues. He writes that while some designers manage to create successful concepts right away, other designers manage to modify their concepts rather easily when difficulties with the design are encountered. Either way, if a prototype of a solution is created, it could be tested to verify if the solution is a good one or insufficient thus preventing such confined thinking as described by Cross (2004).

3.6.2 Mock-ups and early virtual prototyping

Following the objectives and aims of this thesis, focusing on improving ergonomics is a vital part of the work. Some of the most basic low-fi prototypes for industrial design are, according to Hainington & Martin (2012), those made in paper as well as quick 3D mock-ups on a computer to perhaps give a better sense of aspects such as form and scale (Figure 26). Furthermore, Rivero et al (2010) mentions that mock-ups are a “quick and dirty” way of testing and analysing ideas.

Therefore, mock-ups were made out of paper and soft foam to serve as several types of ergonomic belt and shoulder strap prototypes. Some shapes were based on designs from other papers and works found in the context analysis regarding belts and straps. While these belts and straps could be very different in shape they all still claimed to be ergonomic.

A surface modelling software, Alias Autostudio, was used to create early 3D-models of tray holders and the tube to give more life to sketches that were hard to understand and to validate functions of the design more easily. The 3D-models showed functions and could give an affirmation that proceeding with creating larger prototypes with higher fidelity, which is very time consuming, would probably not be a waste of time. These methods were later used to solve smaller problems and to totally remake some of the prototype designs that had to be re-iterated for various reasons.

Figure 26: Early mock-ups and an early virtual prototype.
3.6.3 RITE

RITE is according to Hanington & Martin (2012) an acronym for Rapid Iterative Testing and Evaluation, which is a method with a rapid test-fix-test-fix approach. RITE could help design teams identify major problems with a design before more costly prototypes are created. As soon as a prototype is created a RITE can be scheduled and these prototypes are changed as soon as a problem is reported (Hanington & Martin, 2012).

RITE was used to develop tray holders for easy placement and removal of the trays without the help of a rubber band and hook (Figure 27). Co-workers in the office were always available for testing of all the prototypes when needed. When in need of a field test the SCA supervisor could provide a private unbiased end user whom was available for testing. The first version of the tray holders were welded together with 6 mm steel rods which then were bent in the desired shape. The prototype was then rapidly tested around the office before being sent to a private end user for a day of field testing. The strengths and weaknesses of the concept were relayed back to the design team the very next day. After analysing the results from the testing, the weaknesses were fixed and a new version of the design was constructed for additional testing. This was an iterative process where new prototypes were tested, evaluated, re-designed several times to reach a satisfying final concept.

Furthermore a prototype for a fully automatic closing mechanism for the planting tube was created using a spring dampener from an RC car attached to the jaw lever (Figure 28). The functionality was tested in a slope outside the office to evaluate the function. Also a concept for carrying two more trays on the back with acceptable reach was constructed with the same method and materials used for the tray holder.
3.6.4 Desirability testing

Within seconds of being handed a product people make snap judgements about it based on how design elements make them feel, and first impressions really do matter according to Hanington & Martin (2012). While there are many efficient tools for evaluating if a design makes a user able to carry out an intended task, there is unfortunately less methods for evaluating how a product makes a user feel according to Benedek & Miner (2002). Benedek & Miner also write about new methods of measuring desirability, essentially to evaluate products based on feelings, such as enjoyment or stability.

Desirability testing was the testing phase for prototypes created to evaluate their shape and essentially their fit on a human body. This was performed on non-users and users within the anthropometric intervalls for this project to let them have opinions about the shapes and comfort of the belts and straps. The test subjects would say what they felt and were thinking when testing, and some of the tested designs were as expected more liked than others. This could steer the designs in directions to improve some of the more appreciated ones to be even more liked and would ultimately end up as a part of the end result. The desirability testing ensured that not only the design team had a say in what was experienced as comfort and visually appealing.

Five belts were created based on the first belt mock-ups by hand-sewing cloth together and using foam as filling to make the prototypes similar to a mass-produced belt. Additionally, five shoulder straps with a better foam material than the first mock-ups were also made. One prototype in each set was a hand-sewn copy of the existing models from Pottiputki. A desirability testing with 18 participants took place.

The test subjects weren’t told that the existing designs were a part of the test. The existing designs were in the test to verify that a new design would be beneficial if the existing ones got low scores. If the new designs are perceived as better fitting and more comfortable than the existing ones, there is a chance the end product will be more comfortable and possibly more ergonomic than the currently existing products.

While the methods for grading the desirability that Benedek & Miner (2002) writes about didn’t feel entirely suitable, a simple way of rating the models compared to each other was devised, though the subjects still had to express the feelings caused by the prototypes (Figure 29). The way to grade the most desirable prototype was by placing each belt in the order they favoured them, simply comparing them one to one. The most favoured prototype would receive the score 5, the second most would receive a 4 and so on. The prototype with the highest average score would be the most desirable version according to the subjects. For a prototype to be the final concept brought into the detail design without further ado, the prototype would need considerably more points than the other models when the testing was over.

Figure 29: Test subject feeling how the belt distributes pressure.
Sanders & McCormick (1998) discuss appropriate sample size when doing experimental research and mention that the danger of basing design decisions on the experience of too few subjects is that incorrect conclusions might be drawn that doesn’t satisfy a majority of the intended users. Further, Simon (1976) claims that the typical experimental ergonomics research has a sample size of nine subjects but can contain up to thousands depending on the performed research.

3.6.5 Experience Prototyping

Hanington & Martin (2012) writes about experience prototyping as a means of actively testing a design to get a live experience for exploring, understanding and communicating the design ideas. They claim that experience prototyping can be used by the design team internally as a means to get a sense of potential user experiences. The low cost, depending on fidelity of the prototype, also makes the method advantageous for persuading key audiences since it can be performed with users and clients (Hanington & Martin, 2012).

Medium-fidelity prototypes of harnesses and an ambidextrous, symmetrical planting tube were created by the design team to be tested by end-users in the field over the course of the summer weeks (Figure 30). These prototypes were not the final design and went through the same process of evaluation as the low-fi prototypes previously mentioned in RITE. The feedback from the testing users was reviewed to search for flaws or strengths in the design.

Figure 30: Prototypes sent for experience testing. Left concept focusing on ease of use, right focuses on increased carrying capacity.
There were two concepts for harness prototypes sent for longer field-testing; one more focused on improving comfort and ease of use while the other strived to test if increased amount of seedling trays would lead to increased efficiency. The concept created to increase comfort utilised tray holders developed from the RITE method with a sliding function fastened on a waist belt. The sliding function, made by break wires for bicycles, afforded the harness to sit straight along the sagittal plane, while the trays could be independently crooked. The other harness was built using the existing Pottiputki harness but with dual tray holders. This made it possible to carry two trays by each side of the hips.

Since some users wanted to be able to carry more trays with them, an optional addition to the sliding harness was also created for testing (Figure 31). It was a pad with a tray holder (a single or dual) that would be carried high up on the back and fastened at the front of each shoulder strap. Similar ideas had been worked on and scrapped several times throughout the project due to difficulties of creating a concept with convenient reach according to the theoretical framework.

But while creating the previously mentioned prototypes a simple way to create these was found using Pottiputki’s leg pads as padding and therefore they were also brought for field testing.

Only one prototype for the planting tube was sent for testing which was designed to be ambidextrous, with two triggers for use with both the right and left hand (Figure 32). It also had the closing mechanism and jaw centred to make the tube identical for both hands. The added material resulted in the tube weighing just a few grams more than an original Pottiputki version with no depth indicator plate.

The field tests were performed by a forest entrepreneur around the area of Timrå with a total of 12 testing employees. Initially a meeting was held with the team where they were informed about the designs and what to consider when using the prototypes before they were handed the prototypes. The information was to not think about the weight of the prototypes themselves since the prototypes still were at a pretty early stage of development.
After the summer weeks, the entrepreneur handed a compilation with statements and opinions from all users regarding every tested prototype. When the result of the testing came in, the negatives were quickly revised, just as in 3.6.3 RITE, to try and fix before building a prototype similar to what would become the final design. These final prototypes (harness and tube) were to be tested out in a clear-cut by the design team and the supervisor from SCA, Thomas, to get a precise feeling and quick evaluation of how the final design might be.

3.7 CONCEPT SELECTION

The concept selection phase for the final design was done by a lot of user- and developer testing of the different components and concepts which are deeper described in the sections regarding prototyping. Different parts of the concepts had different methods of selection. Function specific solutions were selected from user opinions while factors such as comfort were selected in combination with a majority rule voting.

Selecting the functions for the final concepts was based on results from the experience testing and RITE phases. The chosen functions for the planting tube, also from Rite and experience prototyping, led to the final design of the tube. Furthermore, selecting the shape of the harness was based entirely on the desirability testing phase in combination with what the designers considered being a valid design. The validity of the design was based on the theoretical framework, ergonomic assessments and the design specification. Validity is the assessment of the quality of a design proposal by examining the appropriateness of the design’s objective based on theoretical grounds, which is the design’s most desirable property (Roozenburg & Eekels, 1995).

3.8 DETAIL DESIGN

This chapter contains the methods used for finalising the design, starting by selecting materials and sketching a detailed visualisation to be used as a foundation for CAD and CAID using the programs Siemens NX10, Autodesk Maya and Keyshot 5 (Figure 33). Components from the existing products in the Pottiputki-line that wouldn’t affect the features of the final design in a bad way were implemented in the final design to keep the cost and effort of implementing the design as low as possible.

3.8.1 Material Selection

The materials in the existing equipment were seen as fitting for use in newer designs, since BCC wanted to keep the manufacturing process of the final design reasonably close to their existing products. The addition of new functions to the final design compared to existing equipment resulted in some extra components. These components are supposed to be bought and not be produced and therefore will not result in any additional manufacturing related tasks for BCC.

3.8.2 Modelling in Autodesk Maya

After sketching a suggestion for a final design in the highest complexity level according to the theoretical framework for sketching, a 3D model of the harness based on the sketch was modelled. The 3D model was created in Autodesk Maya to show the various elements of the final design more clearly and with a more realistic feel. Maya was chosen because it is a fast and easy way to create complex shapes (www.autodesk.com) such as clothing compared to for example Alias, and the fact that the model did not need to be used as a basis for construction. A human male mannequin was downloaded from grabcad.com to aid in the modelling to ensure correct proportions.
3.8.3 Modelling in Siemens NX
While the tube has more straight and rigid features compared to the harness, it was modelled in Siemens NX for it to be done quickly and accurate. NX is a 3D program for creating convergent solid models (www.plm.automation.siemens.com), making the models highly stable and easy to regulate. This CAD model also didn’t serve the purpose of being a basis for construction, it was merely created to show the concept in more thorough detail.

3.8.4 Rendering in Keyshot
The finished models were imported to Keyshot which is a very user friendly and fast rendering software capable of producing high quality renderings (www.keyshot.com). Using Keyshot results in a very lifelike feel to materials with minimal effort and provides an easy way to test different colour schemes.

Keyshot was used because the design team had previous knowledge of the software and consider it to be superior for rendering models quickly. The renderings had the purpose of showing detailed design features and creating a selling presentation.

3.9 RELIABILITY AND VALIDITY
To ensure reliability and validity from information gathered, several methods with different medias were used. Gathering information from local users by interviewing, trying to reach the rest of the country by an online survey, also field trips to entrepreneurs and other seedling producers. Information gathering about ergonomics relatable to the project has been searched for through a great number of articles and books. Since one of the authors has worked with reforestation during several summers with different methods, pinpointing the core problems with existing designs and how the work is performed, while also observing planting teams during the project should yield in accurately performed research.

Figure 33: Creating the 3D-models.
3.9.1 Testing the validity of the final prototypes using sEMG

As mentioned previously, validity is the assessment of the quality of a design proposal by examining the appropriateness of the design’s objective based on theoretical grounds (Roozenburg & Eekels, 1995). Therefore an attempt to analyse the validity of the final prototypes in comparison to existing equipment was carried out at LTU, using equipment for measuring sEMG.

Firstly, the design team decided together with Ulrik Röijezon, a lector with knowledge regarding ergonomics evaluation with the responsibility of handling the sEMG laboratory, which functions to be tested during the study. When the motorical functions to be evaluated were selected, the team had to decide which muscles’ activities were to be measured and analysed. The decision was made with advices from Röijezon as well as palpating which muscles were perceived to be active when performing the different tasks.

When all parties had come to an agreement which functions to test and which muscles to analyse, the test was carried out. By using recommendations from SENIAM (www.seniam.org), the authors learned how to perform an, according to SENIAM, accurate test. The available electrodes provided by Röijezon were standard pre-gelled electrodes according to the recommendations from SENIAM.

When deciding where to place the electrodes on the skin, SENIAM (2016) had recommendations for most of the selected muscles. Since smaller muscles without placement recommendations also were of interest, the location of these muscles were palpated to give a rough estimation on where to place the electrodes. To achieve a stable contact between skin and electrodes, the skin had to be prepared by first shaving the area where the electrodes were to be attached.

Thereafter any excessive dead skin cells had to be removed by scrubbing the shaved areas using alcohol and paper tissues. The electrodes and their linked sensors were then attached to the muscles of interest in two different tests (Figure 34).

The first test was focused on examining and comparing the muscular activity in nine different muscles of the lower body when using the jaw lever to open the existing pipe and the prototype pipe made by the authors. Before starting the test, a calibration of the resting muscular activity had to be done to eliminate any misleading noise. Thereafter the test subject performed the motion of tramping on the jaw lever to open the pipe a total of five repetitions for each of the two pipes starting with the prototype.

The second test was instead focused on comparing muscular activity in the forearm and hand needed when closing the different pipes using the left hand for the trigger mechanism. Since SENIAM did not have any recommendations for the muscles of interest, these had to be palpated in order to locate where to attach the electrodes. No muscles on the inside of the hand were studied since the electrodes would be in the way when gripping a tube handle. The resting muscular activity was once again measured, this time for five different areas on the forearm and back of the hand. When the calibration was done, the user closed each pipe five times using the left hand first with the prototype and then with Pottiputki’s pipe.

The process was recorded using a video camera and a data receiver called Noraxon TeleMyo DTS Desk Receiver with a software called Noraxon MR3 3.9.45. The data obtained from the electrodes was then displayed as graphs for each muscle tested. To get clear visuals of the energy required to do one repetition, a mean value were calculated for each of the ten repetitions for both tests.
The initial plan was to perform further analysis to search for any differences in muscular activity when wearing the different harnesses, but Ulrik mentioned that the sensors were sensitive to metal and pressure. For that reason, any plans on performing additional testing for the harnesses were abandoned and the focus had to be placed on analysing the differences in both previously described tests.

3.9.2 Testing the validity of the final prototypes using kinematics analysis

Additionally, Röijezon recommended using an equipment called MyoMotion for measuring kinematics to find out whether there were any positional differences for the lower limbs when doing the first test for the lower body. The equipment consisted of sensors, measuring angle and position, which were placed using straps on four areas of the lower body. These areas were selected based on advices from Röijezon and can be seen in the front view of figure 34.

Before performing the tests, this equipment also had to be calibrated by standing perfectly straight for a short amount of time. Thereafter, while doing the task mentioned in 3.9.1, data was recorded to try and find any kinematic differences. This data was also displayed in the Noraxon software through graphs describing every motion recorded from each sensor (Figure 35). Furthermore, a visual presentation of the data was also displayed by the software as a 3D skeleton showing how the lower body moved throughout each repetition. Like the sEMG measurements, a mean value for each repetition was calculated and further studied to search for anomalies.

3.9.3 Usability- and performance test of tray holders

As a final test to ensure that the new seedling tray design is actually better than the existing Potti-putki design, a usability test combined with a performance test was performed. The test subjects were four men and two females with no previous experience of manual reforestation in order to investigate whether the new or the old design were more user friendly for new users. A designer together with the first test subject went into a private room where two Powerpots laid on the floor. The person then had to wear the existing Potti-putki harness and figure out how to mount the powerpots in the holders without any advices from the designer.
Meanwhile figuring out how to attach the seedling tray, the user also performed a think-aloud exercise and described any thoughts that surfaced. When the subject was satisfied with the chosen way of mounting the trays, the user then had to change harness to the newly designed harness and perform the same task once again. Not until the subject had decided the preferred way of mounting trays for both the old and new design, the designer explained the intended way of attaching trays for both the old and the new design.

When both holder designs were thoroughly tested and discussed, a final performance test split in two separate tasks was performed to simulate actual field usage. Firstly, the user had to wear the old Pottiputki harness and try to mount two seedling trays in the holders as fast as possible while wearing appropriate gloves meanwhile the designer timed the exercise. Both trays had a starting position on the ground as they would have been out in the field. When both trays were securely attached, the timer stopped and the result was documented.

The second task was to swap both mounted trays with new trays laying on the floor. Once again the exercise was timed, starting from neutral position with both arms along the sides, and stopped when both trays were replaced and the new ones were securely attached in both holders. The results were once again documented meanwhile the user changed to the new belt and holders. Thereafter the both performance tests were performed again using the new design.

When the first subject had performed all tests and had a final reflection on both designs, the next subject were brought into the room while the first left. Instead of starting the usability test on the Pottiputki holders, this time the new design was first to be tested. This way of alternating which design the user first had to evaluate was performed throughout all remaining subjects.
3.10 PROCESS AND METHOD DISCUSSION

All our methods for analysing the kontext were based on the needfinding process. For finding the needs of the user, we have gone through each of the four stages of needfinding. This was done by setting goals for the project, observing and interviewing current- and have been-reforestation workers while analysing the information gathered. This information has been gathered by acting as the needfinder but also as the needer which ensured usability in the way Dumas & Redish described.

To ensure usability, we have included users throughout the design process, mainly by prototype testing, where the test subject’s opinion is weighing in heavily as a deciding factor for different designs. While examining the usability of prototypes was easy, efficient, and satisfactory, the product that may end up being manufactured might need slight alterations and therefore need to be further examined. These alterations might affect the usability in some way, maybe even for the better but there is always a risk for the opposite.

By involving entrepreneurs, workers and sending out surveys, we have been trying to make accurate predictions of what the user might want. We have had users participate in a lot of the different phases to try and react to ideas by field tests and such methods, all in hopes of achieving a good user-centred design. Since the interviews and observations were performed in the middle region of Sweden, the data corresponded to Victor’s previous experience but might not be as applicable for all areas of the country. Therefore we should probably have conducted interviews with users from a wider variety of places.

The relevant ergonomics research found in the beginning of the project provided a great foundation for concept creation and confirmation. The research mostly showed aspects of certain situations that was not ergonomical (such as inconvenient reach, carrying weight on the legs and so on), which might not have given solutions to the problem. This information gave us a clear indication on what aspects our design should avoid in order to strive toward improved ergonomic properties. The fallacies stated in the theoretical framework were always in the back of our heads which lead us to not making premature decisions based on our own thoughts and experiences. From the several different tests carried out in this project we have come to a conclusion that defining the “average” user is a very difficult task since people think differently. Therefore there will most likely be people having differing opinions about the designs which is something we will have to accept.

When doing the context analysis we were very fortunate that NorrPlant had saved old various planting equipment from all kinds of manufacturers for us to use as we pleased. Since BCC sent us all the newest Pottiputki equipment we could examine and compare these to all the available equipment thus providing us with a good understanding of the evolution of reforestation equipment. Every time we wanted to check something specific to the equipment, instead of scheduling user tests, we always had the opportunity to test for ourselves and on others around the offices. To have this equipment at hand eased the competition analysis by a great deal since finding information on the internet and other sources regarding reforestation equipment proved to be very difficult. Even finding general information regarding reforestation was difficult.
The iterative approach for our design process has been very suitable. It would have been very hard to achieve a successful result from just accepting the first solution that was presented without doing further testing and evaluation. Combining this iterative approach with the stage-gate model was a great way of ensuring that the project would be kept on the right track at all times using clear objectives to strive towards. Since our project approach consisted of a great number of iterations, the boundaries of some phases became a bit indistinct but we did not consider it to be a problem.

Since there are a few different ways to plant, it was useful to hear the observed people’s thoughts and explanations for different operations. While some of the context analysis from observations was not carried out in an actual clear-cut, we found it difficult to get engaged subjects to test the equipment in an optimal environment for us. The fly-on-the-wall observation could probably be performed as an ordinary observation including asking questions about the equipment because we believe that the planters would not change their planting pattern, as long as the questions come after some observation.

The use of inspirational boards was a quick and easy way to get an indication of what the final design should convey. When hanging on the office walls they also managed to provide motivation for the design team in creating something that would fulfill the design specification and core values of the company. We talked to our supervisor from BCC about the Pottiputki slogan “Finnish design since 1970” and what the slogan meant for them. This was a concern especially when Pottiputki has been manufactured by a Swedish company for over 10 years but BCC had no substantial answer to the question other than the buy-out contract stated that the slogan had to remain.

It was a good idea to write down all ideas that had been unintentionally generated during the first stages of the project so that great ideas would not be forgotten. The logical thing to do was to start with this method since most of the gathering of information was already completed from context analysis and data collection. Before discussing the quality of the ideas the team decided to carry on with a brainstorming phase to not undermine any ideas yet. A bad idea could still ignite a spark that would generate even more innovative and great ideas. The brainstorming phase was really a brain-sketching phase with blank papers and templates. This was a really good way to get ideas growing, especially when using human templates since it gave a good perspective of scales and which features could fit where on a human body.

Sketches was one of the more important methods throughout this thesis and we would recommend utilising the tool as much as possible in any type of engineering design projects. Furthermore the random word association method was very well fitting in the idea generation phase since it forced different thinking which could be a good thing. A method called Osborne’s Idea Spurs was considered to be used at first, but we realised that most of the spurs had been considered during the brainstorming phase without us specifically thinking about it. We would recommend to use random word association or at least test it as a later used method for many idea generation phases. Exploring new designs with mock-ups and in a 3D environment was really handy since it was so quick to create them and to verify simple mechanics that could not be visualised on paper.
The use of RITE was a great success, since if it had not been performed some designs might have been in their first version which compared to the final iteration would have been really Underwhelming. Since the project involved diverse components it was good to start with RITE as soon as a design that might come to use was created. This gave the design team more time to work on newer iterations if needed, which should ultimately lead to a better design.

When performing the desirability tests we probably had too many female participants compared to the ratio of women working with reforestation according to the survey results. The opinions between the two sexes did not seem to differ which made us consider the results to be representable for planters in general. Since the tests were carried out in groups with the participants they might have influenced each other, it might have been best to perform each test with each participant individually. An important lesson learned from the experience prototyping when sending the prototypes for a longer field test over the summer was to always underestimate the user’s ability to understand and follow directions without active guidance.

Throughout our education we have always performed a distinct concept selection phase using methods such as concept selection matrices. In previous conceptual design projects we have often not had the opportunity to test and evaluate the design during the development. This makes it tremendously important to make the right choice in selecting what will become the final concept.

In this master’s thesis project we had the possibility to continuously test and evaluate concepts which led to an ongoing concept selection throughout the whole development phase. It was still important for us to make the right decision, but we had the room to make changes in the design based on the ongoing evaluation in contrast to previous design projects in which we have been involved.

The mannequin we used while modeling the final design had some peculiar proportions and unnatural posture. This provided some difficulties in scaling the final design proportional to the mannequin. Although this was a free template of a mannequin to use as we pleased, in further projects for companies, designers could invest in better models or scan humans in desired positions for a more realistic and meticulous design.

When the validity and reliability testing was about to take place we decided not to do a Rapid Upper Limb Assessment since we thought the EMG results would be sufficient to ensure the validity of all our designs. Because the analysis took place very late in the project we chose to rely on user opinions and the results we managed to acquire from the EMG. The EMG tests could have been performed outside with more realistic conditions for a more optimal analysis, although we consider the acquired results to be representable. We could also have carried out the performance tests with experienced planters to ensure an improved efficiency for this user group as well.
4 RESULTS
RESULTS

This chapter contains the results acquired from the different methods of data collection, analysis, idea generation, concept development, prototyping, testing and concept selection.

4.1 RESULTS OF DATA COLLECTION AND ANALYSIS

The following paragraphs contain the results of the data collection and analysis divided in the methods used. Results gathered from this section acted as a foundation for the upcoming results.

4.1.1 Interview

Many of the reforestation workers couldn’t be interviewed since most planters in the local area are from the Baltics, Russia or Poland. While they possessed little to no Swedish or English language capabilities, their supervisors did. Some of the supervisors had never actually worked as a planter, so they weren’t able to provide much useful information either. Older people in the area who had worked with reforestation had mostly used older methods with a small pickaxe and shovel which weren’t relevant for this thesis. The interview held with Jonas Lantz resulted in mostly in a conversation where Lantz agreed that the existing equipment had to be improved. He was very helpful and invited the design team for a visit and living arrangements at his office in Torpshammar for a short period to study their equipment and planting teams.

Commonly the interviews resulted mostly in negative comments regarding different design features of the existing products, such as the rubber band and hook for securing the seedling trays, the weight of the tube and that full body harnesses weren’t used much. Users often stated variations of the following quote made by the first interviewee when asked to describe the current equipment:

“The equipment is heavy, uncomfortable and clunky” (interviewee A, spring 2016)

Those who had planted with pickaxe and shovel stated that when the Pottiputki tube came to the market it had been like striking gold, in comparison to the old equipment.

4.1.2 Online survey

A total of 89 respondents answered the online survey. The gender distribution from the survey between males and females who had worked with manual reforestation were roughly two thirds males and one third females. The ages 15-20 and 20-25 were the dominant age-groups when asked at what age the individual worked with reforestation which led to an understanding of the approximate target user-group.

Planting with frozen plants packed in cartons dominated with 53.1% while the cassette method was used in 40.7% of the cases. When asked what kind of carrying equipment was used, a hip-belt was the most common harness type used by the surveyed. Other common carrying solutions were hip-belt with shoulder support and a carrying harness called “banana” which was mentioned in the introduction. This information indicated a need to find a solution which could be used both for seedling trays and plant cartons in order to be compatible with most of the common plant-storage systems.

When asked which the most valuable trait a new type of reforestation equipment could bring, the participants had widespread opinions. About half of the subjects wanted to be able to plant more per day or need fewer walks for new seedling trays, i.e. efficiency related wishes, by reducing the time being spent on doing other tasks than planting.
The other half of the participants were more interested in increasing comfort, safety and/or conformability, summarised as ergonomic aspects. A vast majority of the participants had experienced discomfort and strain while planting and considered improved equipment to be of importance.

When the participants had to answer what they did when the first cassette was empty, a clear difference in the use of equipment was seen. More than 40% of the users spun the belt around 180 degrees while just under 30% loosened the trays and swapped places, and no more than one in ten started to use the planting tube with the other hand. Additional data collected from the survey can be found in APPENDIX C.

4.1.3 Think Aloud Protocols

The main information achieved from this method to aid in the design of the end result was the way some operations in the planting process were experienced by the users. The most outstanding problematic area of operation mentioned by a majority of the subjects was firstly regarding the process of swapping trays. The hooks that fastens the tray in the holder were troublesome to latch on to the tray and the users sometimes had to use two hands to get it in place while sometimes also having to remove gloves to be able to grip the hook. While performing the task, one user specifically said:

“The belt could be improved and especially the mechanism for attaching trays” (interviewee B, spring 2016)

Additional potentially problematic areas observed by the design team are pin-pointed in figure 36. All observed planters wore the harness in a crooked way in order to get the arm carrying the planting tube free from any obstacles. Since the tube only has a closing trigger for right hand use, none of the observed subjects chose to carry the planting tube using the left hand. By excessive use of the right hand, the planters had uneven posture which could potentially lead to strain-related discomfort in the future. Lastly the stiff leg pads worked as a fulcrum when the subjects walked in rough terrain which resulted in unwanted pressure on the abdominal area.
4.1.4 Hierarchical task analysis

The operations mapped in the HTA covered a cycle of planting two full seedling trays and led to a clear visual display of the various steps through the process of planting (Figure 37). The observed potential areas in need of improvement are encircled in Figure 37. Results from the HTA corresponded to answers received from the online survey that there are various ways of using the equipment. Mainly, the switch from the first empty tray to the other full tray was performed in a variety of ways, thus being identified as an area in need of improvement.

Furthermore, the steps for switching out two used trays to new full ones were many, and the authors also identified these phases as areas with potential of being improved or reduced in numbers.
4.1.5 Fly on the wall observation

The first observation occurred already before driving out in the woods. All Pottiputki tubes in the entrepreneur’s storage had the depth indicator plate removed (Figure 38), and some even had the welded on pin removed. The explanation for doing so was that the workers rather pushed the tube as far as they could down in the soil using sheer arm strength, and then if needed using the tube’s jaw-lever to budge the tube a little further into the ground.

By removing the plate and welded pin, the tube’s weight was lowered a total of 120 grams corresponding to around five percent of the total weight. An approximation made during the observations concluded that the average planter planted around 3000-3500 plants during a full workday. By removing the depth indicator, the total weight lifted per day would then be lowered by a total of 360-420 kg.

During the observations, two ways of organising the reforestation process was recognised which are displayed in (Figure 39). The first method was described with the words “Solo-planting” by the authors where each planter received the responsibility to reforest a specific area of the clear-cut. The planter then placed the transporting harness filled with seedling trays in the middle of that area and started planting in a pattern that looked like sunrays starting from the centre of the area.

The other observed way of organising the process was named “Social-planting” by the design team. Instead of having a dedicated area, the planters together were responsible for the whole clear-cut. They placed the transporting harnesses full with seedling trays in a corner of the clear-cut and then started walking side-by-side in a line while conversing. This method made the way back to the transporting harnesses longer since more ground in its vicinity was covered according to figure 38.

All workers during the fly-on-the-wall observations used a no-name carrying harness that the design team named “Reds”. These harnesses are further described in the competitive usability testing results. The carrying harness was placed in a twisted position on all workers, to get the arm carrying the tube free from obstacles. The general way of swapping trays was to spin the belt around 180 degrees.
The only exception who didn’t apply this technique was the most experienced in the team, Oleg, with more than 30 years of working as a planter. Instead of spinning the belt, Oleg switched the tube from the right hand to the left when the first tray was empty, adjusted the belt for planting with the left hand and carried on planting until both trays were empty. By doing so, his left thumb had to be in an awkward position every time he opened the tube (Figure 40).

Oleg knew some basic Swedish and when asked why he switched hands instead of doing like the rest, he declared he had realised years ago that he would most likely suffer complications such as damage in his right hand and arm if he would continue using the tube with the right hand only. Despite being the smallest and thinnest of the workers, Oleg was way faster than the others. He also seemed to have more energy than the others at all times during the day. His answer to this observation was that he believed in working the entire upper body instead of just one side to avoid fatigue.

When pressing down on the jaw-lever which is placed on the right hand side of the tube, most of the time the planter’s knee would be on the left side of the tube while the foot pressed down on the right. The knee and foot was only on the same side while pressing down when the terrain was really steep and the act of planting that single seedling could not be done quickly. This problem is further explained in the results for validity testing (chapter 4.5).

The observed planting teams did not use a machine to haul masses of seedling trays out on the clear-cut. They had to individually carry all seedling trays with a harnesses made only for transportation to the clear-cut. The planters had made some modifications to their personal equipment, like adding pads to the lumbar region with the purpose of improving comfort.

The time for planting 10 Jackpot trays was around 1 hour and 30 minutes, which makes 50 trays around 7 hours and 30 minutes work. This means only a 30 minute break for the average amount of 3000-3500 plants to be set per day. It would demand a lot of hard work for this clear-cut to be set in a decent frame of time since it was far away from the truck and on top of a mountain.

4.1.6 Competition analysis

The competition analysis resulted in a clear view of the most popular manual reforestation products currently in production. There are three different popular competing harnesses - Pottiputki’s current harness, a harness from Skogma and a design which was mentioned previously as the “Reds”, made by an unknown company. These designs are all analysed more thoroughly in the competitive usability testing chapter.

Resellers of reforestation equipment in Sweden almost exclusively sell the Pottiputki planting tube. According to the Human Resources contact on BCC, the pipe has overall looked pretty much the same since the first model came out in the 70’s with small adjustments made every now and then to optimise the functionality. The only other discovered manufacturer is located in Finland and called Finputki. These appear to be almost identical in design besides the fact that Finputki is coloured blue and has a spiked lever for more grip when opening the jaw. While talking with older people who used to plant in the 80’s, some mentioned the existence of a tube that was partially plastic, which was very light but could easily break. The design team however did not find any information regarding the mentioned tube anywhere.
Since there are few variations in the designs of products made for reforestation, design features were sought after in modern backpack designs and deforestation equipment. Modern backpacks were found much more conformable than the current reforestation harnesses due to the possibility of making swift adjustments with minimum effort. Specifically a technology called Etro System, found on many new backpacks’ chest strap, was identified as a potentially integrable feature for this project (Figure 41). This system enables quick and easy positional adjustments for the sternum strap by utilising a sliding mechanism.

Many backpacks also had elastic bands sewn on the chest strap to allow some flexing without manually adjusting the strap (Figure 42).

Deforestation harnesses were observed too for handling similar loads to the reforestation equipment, but had a wider variety of shapes and designs. Most belts had lumbar support and had a bent shape for a more conformed fit to a human body, instead of being completely straight like the reforestation belts (Figure 43).

4.1.7 Competitive usability testing
The harness made by Pottiputki stood out from the rest since it had compatible attachments for all common kinds of plant storing solutions. The main model divided and spread the load between the shoulder straps and pads at the hips, which forced the wearer to use the shoulder straps constantly or else the pads would fall down due to the friction around the waist not being enough to keep the harness up. While moving in heavy terrain, the pads pressed in towards the side abdominals in an uncomfortable way, as mentioned in 4.1.3.

The shoulder straps had to be worn skewed in order to reach all the plants in the active seedling tray. The pad design distributed the load between hips and shoulders more evenly than competitors according to the design team. Pottiputki also has other models, but not adaptable for seedling trays.
A cross-section of the Pottiputki shoulder straps showed all included materials - a strong woven fabric covering the inside from wear, a softer edge seam, a thin plastic sheet used for rain proofing the inside, a thin foam to give structure and a thick, soft foam for padding (Figure 44). The structure gave a wear-proof impression although both designers experienced that the plastic cover in the shoulder straps felt a little wide/sharp at the edges.

The harness has cassette holders that utilises a rubber band and hook to fasten the seedling tray in place. These holders were manufactured before SCA started producing seeds in the Powerpot, resulting in a poor fit for it due to a pin on the holder that is too long (Figure 45). In rough terrain both the Powerpot and the Jackpot tray risk to accidentally fall out of the holders. As described in the think-aloud process, the shoulder straps has to be worn in a crooked way to reach some plants and to keep the holders out of the way for the planting tube arm. This results in a skewed pressure on the shoulders.

The unknown company had a design which is referred to as “Reds” because their tray holders have very distinct red rain covers around thick foam pieces (Figure 46). They are fastened on a belt without padding, very un-ergonomic and uncomfortable. The mechanism for fastening seedling trays is basically the same one as Pottiputki uses but it’s just not in a framework. This is the version the entrepreneurs whom was visited were using, probably because of the light weight and an estimated lower price. The retailer also sells shoulder straps separately to be used with these “Reds” if a buyer wishes.

Skogma’s belt was the last found competitor, who seems to make their own version of the Reds, coloured orange and with less foam. They have a little bit thinner leg padding, but further research showed it had been used in older versions of the Reds. The Skogma belt is a newer design than the Reds but older than Pottiputki’s and has an older belt with padding around the waist part (Figure 47), and utilises the same framework for the cassette hangers that Pottiputki uses.
Due to the angle described in figure 46, the tray holders are also at an angle making this type of belt unstable. Despite the thin padding, the authors conclude that it is sufficient to feel comfortable over longer periods of use.

The testing of the Pottiputki tube showed they were durable steel tubes, and while weighing around 2.8 kg it still takes its toll on the user while carrying it weeks on end. The most common diameter, 45mm, comes in a right handed only design, while some pipes with larger diameter have the option to add another handle to make it possible to press down in the soil more easily with two hands. While talking to the supervisor from BCC he said that they’d formerly been considering making a kit to sell for conversion to left handedness but they didn’t think it was necessary at the time. The tubes are painted in clear red and can easily be seen out in the forest.

4.1.8 Requirement specification
The requirements were mapped and based on the results from the context analysis. The requirements were divided to specify those aimed for the harness and tube separately, it also contains some wishes and demand which could be good for the final design but might not be practically implementable. The requirements listed formed the requirement specification which the final design should aim to fulfil (APPENDIX D).

4.2 RESULTS OF IDEA- AND CONCEPT DEVELOPMENT
This chapter contains the results of the idea and concept development, thoroughly described in what results each different method yielded.

4.2.1 Moodboard
The moodboard provided a target to steer the end result toward through helpful and inspiring pictures & words (APPENDIX E). The moodboard was entirely based on information gathered during the context analysis with much focus on the needs mentioned by users throughout the phase.

4.2.2 Corporate identity boards
The corporate style-board highlighted some features and characteristics in the Pottiputki product range, such as colour schemes, which the design team aimed to incorporate in the final design (APPENDIX E). BCC shared their graphical profile for Pottiputki which couldn’t be disclosed to the public. Therefore the other board was created to interpret the brand’s core values which then was approved by BCC to be used in the thesis (APPENDIX E).

4.2.3 The catalogue method
The initial ideas that were discussed this phase led to the development of more ideas when discussing them within the design team. The method successfully generated over 20 ideas which were written down on a list (APPENDIX F).

4.2.3 Brainstorming
The ideas from the brainstorming phase were partly new and some were based on ideas from the catalogue method. An overview of these ideas can be found in the results for sketching since the brainstorming mostly went straight from idea to sketch in a brain-sketching manner. As the method generated so many ideas together with the previous ideas from the cataloguing method the time had come to discuss the quality of the ideas. By discussing, sorting and dismissing bad ideas, this left a quantity of realistic ideas to bring further along the development process.

4.2.4 Sketches
Sketches was a fast and simple way to convey the ideas from the brainstorming and catalogue methods (Figure 48). More detailed sketches were also drawn in connection to the brainstorming phase where different colours and additional design ideas were tested. The sketches created related to brainstorming were on a complexity level from one to three on the aforementioned scale.
Figure 48: Sketches of varying complexity level.
4.2.5 Random word association

*Transport, Mobility, Climate, Opportunities, Constant, Parts, Upgrade, Lines, Accessories, Placement and Cleaning*

These were the words randomly selected to be used with the method of random word association. The method was only used after all ideas that came easily ran out to try and trigger new ways of thinking. The results from this method were structured separately depending on which equipment they were related to (APPENDIX G).

4.3 RESULTS OF PROTOTYPING AND CONCEPT EVALUATION

This chapter describes all results acquired through different methods of prototyping and concept evaluation. One of the most influential methods used throughout this process was parallel prototyping. Since this method is permeated in all prototyping and evaluation methods, the results from each subchapter are partly results for parallel prototyping as well.

4.3.1 Mock-ups and virtual prototyping

Virtual prototyping resulted in simple 3D models for verification of functions and features for the seedling tray holders. The virtual prototypes made in Alias during this phase were mainly two different designs for these holders. The first design was supposed to be worn as the existing holders and can be seen in figure 49. The second design explored the possibility of storing seedling trays on the back to be able to carry more trays at a time (Figure 26). These 3D-models also worked as blueprints when proceeding to weld the first prototypes.

Some early mock-ups were created by thin cardboard sheets and provided a great way to quickly get a good feeling of size, shape and simple functions of designs for tray holders, belts and shoulder pads. This method led to the creation of a simple cardboard prototype that would through iterations with more rigid materials end up as the final design. Some designs were own creations and some were copies of existing belts from various producers to test the feeling when wearing them. The tested shapes can be seen in figure 50.
4.3.2 RITE

The availability to quickly do some field tests lead to some designs being perceived as great ideas while some didn’t feel durable enough just yet. The first tray holder version was made using steel rod and welding (Figure 51).

The unbiased planter who tested the first version of the seedling tray holder-prototype commented the following after a day of testing:

“Great idea for placing and fastening the trays since the holders were more stable and it was easier to switch trays when accustomed to the new equipment. The pins for holding the tray in place sometimes got on the wrong side of the tray” (planter A, spring 2016)

This led to quick assessments of the design, solutions were quickly invented and implemented which resulted in a new design (Figure 52). The new design was partly made out of sheet metal which made the function of attaching and detaching a seedling tray flawless. The downside was that it weighed about three times as much as the first prototype which weighed around 500 grams (the same weight as those currently on the market). With another iteration of the design the weight could be reduced to about two times that of the initial design (Figure 53).

One of the prototypes generated from an iteration of the brainstorming method later in the project was a self-closing hydraulic solution for the planting tube. The jaw would have a small hydraulic damper close to its hinges that would slowly close itself. The hydraulic tube was tested outside the office but due to the RC damper being regulated entirely using a spring the design team found no way of slowing down the closing mechanism enough for plants to pass through the jaw.

The more a design got refined in the search for a higher quality product the producibility of the design would always be the first thing to be assured. Since designing with producibility in mind makes for a better product as Boothroyd (1994), Chen, Miller & Sevenler (1995) states which is described in 2.1.1.
4.3.3 Desirability testing

All testing of any prototypes, low to high fidelity, always resulted in new viewpoints and thus was used as many times as possible throughout the design process. The various tests were performed by experienced users and non-users, and this could be utilized as a quick way to weed out terrible designs.

Since one of the prototypes in both the belt and shoulder strap range was a copy of the existing the tests gave a clear indication of how the users reacted to the existing design compared to the designs made by the designers (Orange belts in figure 50). Most test subjects would take time to feel the newer versions but was almost always really quick to discard the existing models and give them a low score. Only two persons of the 20 participants liked the existing shoulder straps while nobody liked the existing belt. When told that the existing belt were a part of the evaluation one subject responded:

“Oh, the straight one. If it is supposed to be completely follow the body, there will be a gap in the back. So when keeping the load even over the whole belt you need to wear it skewed.” (Test participant A, Summer 2016)

Several other participants also agreed to this statement and claimed that the waist adaptation, or the lack thereof, was the main reason why that belt received low scores.

One of the belts, called NorrPro2 (Figure 50), did get considerably higher score than the others (TABLE 1), while the subjects had more widespread taste in shoulder strap design (TABLE 2). Two shoulder straps stood out from the rest, numbered 2 and 3. These models were very similar in shape, the difference being that number three was a bit wider overall.

![Evaluated shoulder strap designs.](image)

### Table 1: Desirability scores for the tested belts.

<table>
<thead>
<tr>
<th>Belt</th>
<th>Total</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norrpro 2</td>
<td>80</td>
<td>4.44</td>
</tr>
<tr>
<td>NorrProMod</td>
<td>70</td>
<td>3.89</td>
</tr>
<tr>
<td>Rockan</td>
<td>53</td>
<td>2.94</td>
</tr>
<tr>
<td>Norrpro</td>
<td>45</td>
<td>2.5</td>
</tr>
<tr>
<td>Standard</td>
<td>22</td>
<td>1.2</td>
</tr>
</tbody>
</table>

### Table 2: Desirability scores for the tested shoulder straps.

<table>
<thead>
<tr>
<th>Shoulder strap</th>
<th>Total</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>69</td>
<td>3.83</td>
</tr>
<tr>
<td>3</td>
<td>62</td>
<td>3.44</td>
</tr>
<tr>
<td>4</td>
<td>54</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>52</td>
<td>2.88</td>
</tr>
<tr>
<td>5(Standard)</td>
<td>33</td>
<td>1.83</td>
</tr>
</tbody>
</table>
4.3.4 Experience prototyping

When the design team tested the prototypes the sliding prototype worked very well, and especially with the ambidextrous pipe. A concern was that the tray holders were dangling a little too much because of slack in the wire that kept the holders in place. The main concern was that the tray holders could not go the full way to the front of the belt because of how the wire was fastened. While fitting perfectly on the members of the design team, it was clear that the tray holders would end up too far back on people with a wider waist. The harness on the back for extra seedling trays wasn’t exactly comfortable, according to the designers, and it was understood that carrying it would become extra weight. This meant it would also be one more thing to carry when everything is carried to the clear cut.

Although information about the downsides of heavier, imperfect fit and some functions might not working 100% as intended was relayed to the planters, almost no one remembered these statements when they had evaluated the tested prototypes. A lot of the statements were based on how heavy each prototype was compared to the existing equipment. Results from the experience prototyping are found in (APPENDIX H). Some comments were also collected from phone calls and are not found in the appendix.

The harness on the back for extra seedling trays wasn’t exactly comfortable according to the designers, and it was understood that carrying it would become extra weight. This meant it would also be one more thing to carry when everything is carried to the clear-cut. This concepts was not well received by the test subjects and apparently only one of the 12 planters would want to use the feature with one extra tray in the future.

The ambidextrous pipe was well received, the centred foot pedal was liked since most people step on it in an awkward angle which now had been reduced. Since all entrepreneurs visited during the project had all removed the plate used to adjust hole-depth, the test group thought it was a good riddance since they didn’t use it anyway. The changing of hands was appreciated (Figure 55). The main downside regarding the tube design that had to be reworked was that sometimes the opposing trigger hit the user’s knuckles when the tube was thrust with high force into the ground.

The harness that carried four trays at the hip was perceived by all planters to be too heavy even with change in materials. The weight from the four seedling trays was simply too much, this resulted in the idea being scrapped.

The sliding harness was more appreciated, most commented that it was heavy and the tray holders ended up too far towards the back for test subjects with wider waists, but some liked the idea of sliding the trays together with the ambidextrous pipe. Out of the two different harness concepts, this idea was the one to move forward towards the detail design with rapid iterations to remove the troublesome factors experienced by the users.

The more appreciated concepts became the only ones left and also the ones seen fit to keep on developing towards an end result. While also using the RITE method on these prototypes by quickly changing disliked portions of the designs to something that would work. The changes were:
• Assuring that the position of the triggers on the tube would not hit the knuckles when using the tube simply by shortening them a bit.
• Reducing the weight of the tray holders which were changed into a lighter framework design, sort of a combination of newer and older ones, but this time the design became lightweight and durable (Figure 56).

When asked what he thought about the harness concept he said:

“The idea with keeping the harness in a fixed, straight position is excellent and the fact that you can remove the shoulder straps is great, which is something I would like to try out more. The tray holders work excellent and is something I believe would be manufactured regardless if the rest of the concept wouldn’t become a real product” (Thomas Vestman, summer 2016)

4.4 RESULTS OF DETAIL DESIGN

This chapter contains the detail design of included materials and product sketch of what became the final design.

The harness uses a durable and protective material that reminds of a soft and thin nylon webbing as an outer layer. On the inside there is soft foam used for making the parts more comfortable against the body. The shoulder straps contain two extra layers, one of which is an elastomeric/plastic that is placed just under the outermost layer to ensure protection of the foam from heavy rain. This layer is reduced a bit towards the inner edge compared to the existing design since the edge can be felt through the harness and give a sharp cutting feeling towards the neck for some users. The other layer is a thinner more rigid foam placed in between the soft foam and rain-cover which serves as structure and extra padding. It is noted that there are different types of glue on each side of the material, it might be that no glue is fit to use for both the rain-cover and thicker foam together. A soft red cloth is covering and protecting the seams on the sharp edges and also gives some colour to the harness. The emblem is an embroidered cloth patch and the logotype is embroidered directly on the shoulder straps outer layer.

Both the belt and the shoulder straps are kept similar in length and size to the existing Pottiputki gear since these seemed to satisfy the anthropometric demands in the design specification based on the desirability testing.
The leg pads on the new design will use the same materials as the belt, with an addition of a thin plastic strip at the top to keep it a bit stiffer. The stiffness aims to add a more fluent shape and motion of the pads. The straps and belt are made from nylon webbing which is durable from damage and weathering. The buckles and strap keepers are made from nylon which makes them strong and durable. The additional features for the harness’ new design uses standardised parts and materials which can be bought from suppliers and sewed on.

The seedling holders use the same materials as the old ones, steel rods with a diameter of 5-6 mm. The fastening for these holders reuses the same hangers from existing models which utilised a universal fastening mount for Pottiputki’s equipment.

The product sketches of which the harness renderings are based on can be seen in figure 57. The new design for the tube require no new materials. The chosen design paths are further described in the upcoming chapter *Final design.*
4.5 RESULTS OF VALIDITY TESTING

As mentioned previously, the leg and jaw-lever is often at opposing sides when planting at a quick pace observed from end users and tests. This results in an awkward angle for the knee when using the planting tube, shown in the left frame of figure 58. The ambidextrous planting tube concept enables a motion with less twisting and is more easily accessible as seen in the right frame of figure 58.

4.5.1 Testing the validity of the final prototypes using sEMG

The design team wanted to verify the solution of reducing this awkward angle and see if there was an increase in ergonomic properties by the sEMG data collection. The first sEMG recording for the lower body gave a clear indication of lowered activity in Gluteus Medius by up to three times the activity of the old planting tube.

When testing the muscular activity for using the new tube with the left hand compared to a right handed tube, the test showed significant reduction in activity of smaller muscles in the hand (APPENDIX I). The activity had shifted from the small muscles in the hand to the larger ones in the forearm which according to Röijezon was to be desired because the smaller muscles in the hand are intended for fine motoric motions rather than performing the same motion thousands of times each day. When the test had been carried out the designer that was the test subject for this second test expressed high physical discomfort in the base of the thumb. This express of discomfort also verified the need of tubes for users who work with the left hand since the subject did 40-50 motions of the thumb, compared to a user that has to do it over 3000 times per day if only using the left hand.

Figure 58: Angular difference in lower extremities between the two tubes, old pipe to the left.
4.5.2 Testing the validity of the final prototypes using kinematics

The kinematics analysis confirmed a reduction in angles by the ankle compared to the existing Pottiputki tube. The total mean reduction in the angular movement for a repetition was a halving of the angular movement for the Pottiputki tube. All data from the sEMG and kinematics of the test for the lower body can be found in APPENDIX I.

4.5.2 Usability and performance test of tray holders

When testing the usability of the tray holders, not a single one of the six test subjects managed to figure out the correct way to attach a seedling tray to the existing Pottiputki tray holders. All test subjects tested a wide variety of ways to mount the seedling tray and nobody noticed or used the rubber band and hook. Every test subject considered the Pottiputki holders to be the opposite of user friendly. When they were told how to attach the seedling trays and were given some attempts to try it out, one of the test subjects stated that

“I think the hook is a bad way of attaching the trays since my fingers are almost too weak to attach the hook. Furthermore my fingers got pinched between the hook and seedling tray which hurt” (Test subject A, Autumn 2016)

When testing the new tray holder design, five out of six participants managed to within seconds figure out how to mount the seedling trays. The last subject had trouble due to being unsure which way the trays were supposed to be while planting but claimed that if that information was told before testing the holders, the way of mounting would have made sense.

The general opinion from all participants was that the new design was much easier to understand, much faster to use and with much lower risk of mounting the trays in an incorrect way. One user claimed that

“Well, it is at least a hundred times better than that circus (refering to the old tray holders), the equipment should be simple and useful which I think you have managed to achieve” (Test subject F, Autumn 2016)

The performance test indicated a clear reduction on time spent trying to attach the seedling trays for all participating subjects. On average, every test subject had at least a threefold reduction in time needed to perform the task of picking up two trays from the gound and attaching them(test 1), while the subjects on average lowered the time by almost five times on the second test of demounting two trays followed by mounting two new ones directly after. A mean value for all participants in the tests is shown in table 3.

<table>
<thead>
<tr>
<th></th>
<th>Test 1 (s)</th>
<th>Test 2 (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NorrPro</td>
<td>5,7</td>
<td>7,3</td>
</tr>
<tr>
<td>Pottiputki</td>
<td>19,7</td>
<td>33,7</td>
</tr>
</tbody>
</table>

Table 3: Time difference between the both designs.
5 FINAL RESULT
5 FINAL DESIGN

This chapter presents the final result of this master thesis, with chapters separating the harness and planting tube. The final result strives toward making manual reforestation ambidextrous work or the very least fit for left-handed users as well. The chapter presents and describes all included components of the new design which makes this a possibility.

5.1 HARNESS

The final result for the harness is a concept that has been developed to increase comfort, ergonomics and eliminate bothersome tasks (Figure 59). The harness is optimized for its ability to be fixed and sit straight along the sagittal plane, achieved by functions which makes the tray holders able to slide independently along the length of the belt. This allows for a more comfortable shape of the belt. The sliding of the seedling tray holders allow for quick adjustment of their placement if the user wishes to use the planting tube with both hands. The harness utilises a new type of tray holders that removes the need for a rubber strap and hook and also heavily reduces the need for using two hands while placing or removing the trays. Since this is now such an easy task the switching of trays is performed quick and with ease. The intention of this design is to reduce the urge of spinning the belt which is not possible when utilising shoulder straps.

The harness will contain the same basic materials as existing models from Pottiputki and is called NorrPro, based on the name of the belt concept. These materials are light, durable and water resistant to a satisfying degree. Only four new materials are required for the new features on the harness but these are standardised parts which can be bought from suppliers such as Duraflex.

Figure 59: Rendering of the NorrPro harness.
5.1.1 The Belt

It was decided to use a padded belt to support the seedling trays (Figure 60). The belt design was chosen because it fit the main concept of sliding the trays, and positioning them as preferred - independently from the rest of the harness to a certain degree. The belt also gives the user the opportunity to use only the belt without shoulder straps by being modular - while using a full body harness should distribute the weight more evenly, it might still be the will of the user to only use a belt. It also allows removal or addition of upper body clothing by not having to take off and lay down the whole harness since the belt could still be kept in place.

"I want the equipment to be easy and efficient. The equipment should be self explanatory”

(Usability tester C, Autumn 2016)
Since the purpose of the belt is to sit straight on the body it has now been given a more comfortable and fitting shape (Figure 61). Possible high pressure points are at the sides where the hip bones can be felt through the skin which might result in chafing. To try to avoid chafing, the belt has a modest upward curve to it, to make it more horizontally aligned when in use and spread the pressure more evenly across the hips. The design chosen in desirability testing, NorrPro2, has additional lumbar support compared to the existing belt. The shape also provides more protection for the back if used when carrying the seedling transport harness which might lower high pressure on the lower back resulting in less back-related problems of the kind that Sullman & Byers found.

"I definitely prefer a belt with lumbar support instead of just a straight belt"

(Desirability test subject C, Summer 2016)
New features/functions on the belt are the addition of seams with an enclosed 3-6 mm rope (Figure 62). This was added to act as a rail for the Etro style system to slide along the width of the belt. At the back there is an addition of cloth which makes the webbed belt and Etro system disappear under it, mostly for the sake of aesthetics and a more modern design. This was also designed to be a surface for placing a Pottiputki emblem to display the brand (Figure 62), since the old way of displaying the brand with embroidered repeating text on the webbing-belt felt outdated.

The new and improved seedling tray holders are light and easy to use (Figure 63). The trays simply slides down in the frame to be put in place, and are lifted up for removal. This is easily done with one hand, and the trays stay in place even while jumping or taking a fall. Even though these tray holders are a bit larger than the older design, there is only a small need for adding a bit of material due to an optimised design with similar manufacturing techniques.

The holders are fastened with the same universal mounting for Pottiputki equipment placed on a thin padding for more comfort against the leg. From the results gathered in competitive usability testing, not a lot of padding is needed between the leg and tray holder to feel comfortable. Therefore these pads are thinner than the existing Pottiputki pads but are still perceived as comfortable from the last experience prototyping test. On the top of the padding there is a joint using the same Etro system, as previously mentioned. The Etro style clips are sewn on the leg padding and when connected to the “rail” on the belt they offer the possibility to slide the tray holders in desired positions. Since the Etro style clips act as a joint there will not be a need for applying extra force to bend the pads when walking. The clips are made in plastic which makes them cheap to replace if one breaks.
"The idea with keeping a straight harness is excellent and the new tray holders work great"

(Thomas Vestman, Autumn 2016)
When the active seedling tray is brought as far forward as possible, the user has a convenient reach to all the seedlings (Figure 64). The user has full freedom to adjust the trays however they find suiting. Due to how the pads are attached to the belt, the etro clips work as a joint which prevents the pads from applying pressure to the planter’s abdominal area when walking in heavy terrain.

Figure 64: Rotated seedling tray holders.
5.1.2 The shoulder straps

The new shoulder straps are reshaped into what is perceived to be a more comfortable shape, based on desirability testing, with the major changes in the front. In comparison to previous designs, the front is no longer flaring outwards from its centreline, instead it flares a bit inward to align it more with the straps connecting it to the belt, which run straight downward (Figure 65). Additionally, a small rubber strap has been added to the front shoulder strap based on wishes from users to be used for strapping a small water bottle, mobile phone or any other things the planter would like to keep easy accessible.

The sternum straps which run between the front parts has been changed to Etro style sternum strap which most modern and more luxurious backpacks use. This is the function demanding new materials for the shoulder straps, but no major change in aesthetic design was seen as needed.

Figure 65: Front side of the shoulder straps.
The connecting webbing straps between the shoulder straps and belt will utilise a rubber band effect that can be found on many modern backpacks which provides an elastic effect (Figure 66). This function will be applied to possibly reduce the feeling of only the belt or the shoulder straps are carrying all of the weight. In other words, they are added to distribute the weight evenly between the hip and shoulders.

"The new design is well thought-out and I do not feel pain in my shoulders as I did with the old design"

(Usability tester B, Autumn 2016)
The back of the shoulder straps is kept very close to the old Pottiputki design because the design is simple but still functional (Figure 67). The small difference done was to make the shape a bit more in line with the rest of the design by creating the shield-like form in the lower part of the pad. The Pottiputki label is clean and was reused from the old design since it was a practical way of displaying the Pottiputki brand.

"I want a planting harness where the seedling trays are fast to attach while avoiding too high loads on the shoulders."

(Survey participant A, Spring 2016)
5.2 PLANTING TUBE

The new planting tube is designed for use with both or either hand to make the user experience as comfortable and fair as possible. The dual triggers are two mirrored triggers with an extension on one of them to bridge them so that both move when one is pressed to open the same mechanism (Figure 68). By adding an additional trigger, the closing mechanism was then centred partially to avoid the risk of kicking the long steel rod while walking but mostly to get the mechanism centred between the both triggers for equal function. The triggers are placed a bit forward from the grip in a position to not hit the knuckles of the user. The handle has a length of 13 cm which coincides with the theoretical framework for hand-held tools (Figure 69).
The opening jaw lever is centred directly under the handle (Figure 70). This was made with the intention to reduce the awkward angle in the lower extremities that occurs when most users press it with their right leg. While using the left leg it will be pressed in the same manner, which is fair and gives more free space for the left foot when walking. The end result is very close to being completely symmetrical (Figure 71).
5.3 MANUFACTURING METHODS

Deciding which manufacturing methods to use for all components were based on information from BCC of what kind of equipment they could provide. The shoulder straps, waist belt and leg pads are created by cutting the desired shapes from materials, placed in layers of a desired order. The edges are covered by a protective soft cloth and then sewn together. The strap buckles and strap keepers are fastened by sewing on their respective webbing before they are sewn to the belt or shoulder straps. The new sternum straps can be sewn on, and covered by sewing the webbing belt over and covering their seams, or the soft cloth edge can also serve that purpose. The logotype is embroidered before the shoulder straps are sewn together and so is the emblem patch. The sewn components and all kinds of plastic are intended to be bought from suppliers. A product image of the full harness can be seen in figure 74.

The tray holders are created from steel rods which are cut, bent and welded together to form the framework design according to the schematic layout before they are coated (Figure 73). The mounting for the trays are made in the same way but from slabs, and they are fastened in the leg pads by rivets and plastic bushings.

The new jaw-lever for the planting tube is the same as the existing versions - a cut steel slab which is welded on and coated but with the addition of a bending operation to centre it. The extra trigger is a mirrored replica of the existing one with the additional section with a hole for the closing mechanism and a hole to join it together with the old trigger. The old trigger has its mechanism hole removed and an added length to also have a hole to fasten the triggers together using a rivet. These are also cut from slabs, welded with a simple bearing before they are coated. They are then placed on pins on the tube which are held together by themselves and the closing rod.
Figure 74: Product illustration of the final design.
6 DISCUSSION
6 DISCUSSION

This chapter will discuss the acquired results relative to the theoretical framework. Additionally, the designers’ thought of future work and what this project hopes to have achieved are discussed.

6.1 PLACING THE RESULTS

Initially when starting the project we had our minds set on creating a revolutionary design completely different from existing designs. While the project progressed the testing of the more revolutionary designs indicated that people wanted to keep the design pretty close to the existing products. Therefore we decided to make a solution based on incremental design with smaller radical changes suitable to ensure an increase in working environment. According to Verganti this sort of approach would lead to a successful project and from our experience we agree to this statement.

Initially we thought a lot of our design choices relating to ergonomics would concern the application of anthropometric measurements. Pretty soon we discovered that relevant anthropometric data was very hard to find for our specific needs. The sources we did find were for people outside the Scandinavian area and although data from outside of Scandinavia might differ a bit, we found it better to use than nothing at all. Based on the problems of finding suitable anthropometric data, most of our choices of size for the products are based on our observations from the evaluation. Most measurements are similar to the existing designs but the shapes are more adapted to fit the human body, male or female.

The results from the online survey were as we had anticipated, older full time workers are more rare since the work takes a great toll on the body while it is a popular summer job for younger people. The hip belts were also dominant, which was expected when they are cheaper and using shoulder straps hinders the most popular technique of switching active seedling tray by spinning of the belt. Some of the answers in the survey could be highly dependant on which method of carrying plants and way of planting (social- or solo planting) that the subject were used to, and would possibly yield another result if they were differentiated by methods used. The general results from all context analysis methods coincided with each other and gave very clear problematic areas that needed to be redesigned.

While performing the think-aloud protocol method we had the statement made by Jääskeläinen regarding instinctive performance in mind. By keeping this in mind we noted that the participants were also doing some minor instinctive adjustments together with the equipment which they did not mention.

The lower body is constantly engaged by walking and carrying weight while getting tired at the end of the day. This got us thinking that the arguments Oleg made about ambidextrous work should also apply for the legs. Since one leg lifts the active cassette a little, a more even load distribution between the legs would be preferable which we hope would reduce strain-related injuries and reduce fatigue in the long run.

We considered the final design to fulfill the design specification to a whole, apart from some wishes that we realised did not coincide with the needs found, such as increasing the amount of trays that are carried at the same time. Many of the elements in the specification came naturally during the design process which relieved us from having to constantly revisit the specification and to instead trust our instincts.
20 ideas was quite a lot to have before even starting the actual idea generating phase. It was important to quickly write these down to not forget about these later on. Some of the ideas might have been a bit far fetched but it was a great way to kick-start the idea generation phase. When performing the random word association the random words selected were not truly random. We chose words randomly generated with a bit of context to them instead of words like horse, the, I, beach and so on. The results we acquired from the idea generation phase coincided with the expectations we had for the phase - Ideas that we could test and evaluate.

We saved a great deal of time by creating the mock-ups. Due to the complex nature of some designs in combination with being created by hand they were not perfectly symmetrical, but this did not seem to bother any of the test subjects. It was very practical to have so much material available at the office where some had very similar properties to the materials in existing equipment. Furthermore it gave a confidence boost to receive positive feedback from the early RITE phase. We are also satisfied with not proceeding with user testing for some prototypes that would not amount to anything and thus be wasting our time, such as the hydraulic tube.

From the desirability testing we got valuable confirmation that coincided with our belief that the existing Pottiputki designs was indeed in dire need of change. We think that it was a great way to incorporate a test of the existing design by not disclosing it to the participants. If we would have been clear with our intentions they might have altered their opinions to satisfy our design to a greater extent, for better or worse.

During the experience prototyping the test subjects seemed to be more focused on finding small negative attributes of the designs rather than evaluating the concepts as a whole. It was very uninspiring to mostly receive negative comments which the majority of were previously known. When trying to gather more detailed opinions of the respective functions we felt almost unwelcome and were met with a lot of negativity from the entrepreneur. The information we did gather was that carrying more load seemed to reduce ergonomic factors in such a way it would result in a reduced efficiency.

Since repetitive work is related to strain, and the suggestions for fixes are lowering the rate of repetition, by reforming how the work is performed. Suggestions like job rotation, and the observations lead to the final concepts for both the harness and tube to be optimised for alternating hands while working. This reduces the rate of which planting is performed by only a few sets of muscle groups, and rotates the work load which reduces the work done by that specific muscle group by half. A downside might be since a lot of discomfort is reported in the elbow the chance to feel discomfort in both elbows increase. While the grip on newer planting tubes are completely circular, making it symmetrical it might be a bit short according to literature, which is the reason why we stretched it out a bit in the new design. Since it is symmetrical the grip itself is good for use with both hands, the tricky part is the position of the triggers with the perspective of reach since they have to be moved out from the grip to avoid being hit by the user’s knuckles.
As mentioned manual reforestation is a very strenuous work, where discomfort have been experienced by the lumbar area makes the development of a more ergonomic or comfortable belt a good idea. Since some users feel that a full body harness either have all the load on the shoulders, or all load on the hips rendering the shoulder straps useless. Strain increased in the shoulders compared to the hips according to Holewun & Lotens (1992), so there is a need for a way to distribute the load a bit. We’ve come up with the rubber band solution for the connecting straps which should absorb and distribute some of the load, also coinciding with the theory for designing functional work wear.

We believe the results from the sEMG testing to be valid and show factual improvement of the working environment that the end users will experience. The test for the jaw-lever improvement show reduction of the needed activity in specific muscles, while the test for the new trigger was less clear. Since there are so many small muscles in the forearm, Röijezon’s recommendation was to perform emg testing with the use of needles, because the surface electrodes are difficult to pinpoint on deeper muscles. Due to not having this sort of equipment, we had to settle with using the sEMG method for this test as well. The test did however show a transfer of muscle activity from the smaller muscles in the hand to the larger ones up along the forearm. Even if we cannot pin-point the exact muscles precisely this should make little difference since these muscles are the ones supposed to do the heavier repeating work.

The usability tests were performed on non-users with no previous experience of manual reforestation, the reason being that no nearby end-users were available, but also that we wanted to check if the usability aspects in the theoretical framework were fulfilled to a higher grade than the Pottiputki design. We did unofficially perform these tests on ourselves as well and also saw significant necessary task- and time reduction. Even if we are not end users ourselves, this project has made us very used to handling the equipment and we doubt an end-user will need to use it in other ways, or do the tasks faster compared to us.

6.2 RELEVANCE
While the world seems to be waiting for machines to take over tedious and strenuous work, such as reforestation, there has not been much development or research performed for the manual side. If the concept should be manufactured and implemented, we believe a reform of the classical way of planting with seedling trays might take place. Advantages that could be seen if the results are implemented might be:

- An increasing use of harnesses utilising shoulder straps.
- Reduction of discomfort and strain related injuries for reforestation.
- Left handed users can use their dominant arm with the same conditions.
- Strengthening the recessive arm by alternating working arm.
- More efficient handling of the reforestation equipment.

Economically speaking the harness and tube will probably not be cheaper than former models. Since Pottiputki aims to be the high end brand for reforestation equipment, we believe the design should reflect its price.
With the equipment being designed specifically to be more comfortable and to have higher ergonomics to increase long term efficiency, we believe it achieves a real high end-quality status. The economy of the reforestation business could see a slight increase if work capacity is increased on account of a better work environment for the planters.

6.3 REFLECTION

While planning for the project we believed a distinct concept selection phase was going to take place, with methods such as concept weighing. Since we had never built and tested this many prototypes before we did not really know how effective the method would be for choosing concepts. This we believe to be positive, and since the selections were done during different stages of the project we did not have loads of second tier concepts to choose from in the end. In our earlier projects it has been common to say that 3 concepts will be chosen and one of them is to be selected as final result, such as we had decided in the planning phase. This has been done in a lot of our projects before, and by experience some designs might just be created to fill the quota of expected concepts to choose from, which sometimes has felt tedious and unnecessary.

The collecting of testing results and description of what we wanted to get out of the prototype test over the summer could have been carried out in a better way. People who are not designers probably do not evaluate product functions like a designer, especially the ones designing the product. We might have been caught in the saying “designers are not typical users” from the theoretical framework. We believed it would be easy to understand what to evaluate, especially since we explained what we wanted the test subjects not to evaluate. By explaining what not to evaluate it is possible that we unintentionally made the users focus on exactly these things while testing.

6.4 RECOMMENDATIONS

Further recommendations for implementation is testing a high end prototype to see how the product would work in a finalised state and if any last minute changes is needed to be done. Test subjects could try planting with two hands with the current existing equipment for a while, and then trying the new equipment to see if they actually can perceive the new design as an improvement. This could be tested for a while to also see if muscles would become less strained by the work while using the new equipment and both hands compared to only one. Big companies such as SCA, who’s got a guidebook on how their land should be reforested, could (highly) suggest planting with both hands.

For future development work about manual reforestation using seedling trays as carrying method, we believe that the trays themselves need to be rework. These trays are designed solely for growing seeds in a compact and transportable way, for maximising volume and not designed for being carried out in the field at all. This might demand a sacrifice of volume for the seedling producers, but if a way is invented that is really efficient and preferred, more people might want their products in the end and increase sales.
CONCLUSIONS

This chapter answers the research questions stated in the beginning of this thesis, and describes the relation to the final result with the set objectives and aims.

RESEARCH QUESTION 1

“How can currently existing equipment for reforestation be reformed to ensure improved working environment, ergonomics and efficiency for the user?”

With our final result, the shape of the waist belt and shoulder straps should improve comfort. The flexing straps that connect the belt- and shoulder-parts of the harness could help to evenly distribute the load between the waist and shoulders. The new tray holders lower the need for two hands to be used when placing and removing each tray. They also reduce the time needed to swap placement of the trays. The holders also reduces the wanting to spin the belt around to swap tray position which also motivates the use of shoulder straps. The ability to adjust the position of the tray holders while still maintaining a stable position for the harness makes it perfect for not only regular use, but use when alternating hands while planting.

The sliding ability of the tray reduces the chance of having to adjust the harness so that it becomes crooked on the user’s body, it also provides more personal conformability. This last point crumbles if the user’s waist diameter is too large, although our design will still be less crooked and more conformable than existing products.

The Etro style sternum strap is also more conformable for different body types, and this is a tested method which can be found on almost all new backpacks. The leg pads are jointed and will not by themselves apply resistance towards the legs if they are in line with the walking direction. This will likely reduce the effort needed for just walking compared to stiff leg pads.

If the shoulder straps for some reason are unwanted the belt will still work on its own, so the shoulder straps will be removable. The main thing about this is to make sure the user still knows that using shoulder straps theoretically would be better than not using them. Also making sure the user knows that the harness as a whole is designed to function with shoulder straps without any problems.

The ambidextrous tube improves working environment for both left and right handed users by making it almost fully symmetrical. This is done by having a trigger on either side for use of either hand and centering the opening lever to reduce weird angles for the lower extremities. The centering of the lever makes it fair and equal for both left- and right handed users. The dual trigger makes it equal for both left and right handers, and these functions also makes it perfect for alternating hands while planting. The added weight of the extra trigger is about 20 grams, at least on our prototype, but removal of the plate that regulates the hole depth reduces the weight by even more. The little bit of added weight if the depth plate would still be in place might be a little bit less efficient for each person (mainly right handed users).

All these functions have been designed to improve the working environment, ergonomics and efficiency for the users. The least clear objective of the design to validate is the efficiency. The logical clearly affected areas are the swapping of seedling trays which reduces time for the activity. The main thing we have to argue for long term improvement in efficiency is improvement of the ergonomics which in itself increases efficiency. The efficiency increase should be achieved by increasing pace of work, reducing strenuous activities of single muscle groups and fatigue in the end of the day.
RESEARCH QUESTION 2

“How can we verify that the results of the project will have the desired effect?”

We performed sEMG tests for the ambidextrous planting tube and the results were positive. There is a significant muscular activity reduction in gluteus medius and tibialis anterior because of the reduced leg angle needed when opening the jaw lever. This result could probably have been even greater if tested with harness and a full seedling tray since it would also mean lifting a weight. The left oriented trigger shows significant reduction in the muscles on the top side of the hand compared to using a standard tube with the left hand which requires an awkward movement of the thumb. This awkward movement was performed a couple of times to find the right muscles for applying the electrodes and the actual test was 10 movements. This is important to note, because the test subject started to feel physical agony in the thumb only after these few movements. Since the average planter sets about 3000-4000 seedlings per day, a left handed user could be spared weeks of agony that might occur before the user could get used to the pain.

We cannot argue that the shape of the harness is ergonomic, since the sEMG test couldn’t allow testing of it. The shape of the belt and shoulder straps are perceived as comfortable from the results of desirability testing, but this is not guaranteed to be synonymous with the design being ergonomic. Nevertheless it is an increase in the working environment, although there are other functions of the harness that simple logic can dictate if they are improving the ergonomics. These functions are for example the leg pads which are not being pressed hard into the user’s abdominals when taking steps, the harness can sit straight along the centerline of the body, the tray holders can be put in whichever way feels the most comfortable (within reasonable limits).

The tray holders are definitely an improvement in working environment since these motivate and encourage the use of a full body harness with the ease of switching trays and their sliding capabilities.

The most we can argue for increased efficiency in a radical way is the reduction of time needed for placing/swapping trays. This is only a small portion of the time, since the majority of time is spent actually putting seedlings in the ground. The incremental change for better efficiency through improved ergonomics and working environment would have to be tested with a time study of sorts. Since there are few veteran reforestation workers, the one we found had come to the conclusion of reducing the highly strenuous work by dividing it with the corresponding muscle group on the other side of the body.

The hardest parts to verify is the functionality of the sliding etro clips, on account of the fact that there was no tests made or found to verify how well the sliding capability would perform with higher weight compared to the light usage on backpacks. Also the flexing webbing straps that connects the shoulder straps to the belt were hard to verify since the idea was born very late in the project and there was no time to test it in full scale. We are both sure to have seen this applied for other products but have not been able to find applicable information other than it is used in sternum straps and recommended to be used by the theory for functional work wear.
**RESEARCH QUESTION 3**

“Is development of a whole new product or technique required to deliver the desired effect or are current methods sufficient?”

The planting tubes only need some rework by bending the opening lever, centring the closing mechanism and adding the dual trigger. It is basically an updated version of the regular tube. It is a new product that provides the opportunity to perform a technique with alternate use of hands while planting. Pottiputki has had versions of the trigger which was pulled upwards from under the grip resembling a trigger for a gun which one may perceive as a great solution. This solution has long since been discarded for reasons unknown, but we trust that the engineers at the company knew what they were doing since they reverted to the triggers that are still used today. So the development of the dual triggers we believe will have to be completely new.

The harness has to basically be completely new save the materials to achieve all desired effects since the sliding mechanisms are previously unseen, and the shapes are designed to sit still on the body to be more comfortable and ergonomic. Creation of the new tray holders could be made to fit older models of harnesses and be sold separately. We believe these would become more popular than the existing ones even without the rest of the new harness.

While materials remain the same, the new materials that would be needed for the sliding mechanism and the flexing material for the connecting straps. These are as previously mentioned standardised parts which can be bought from suppliers.

---

**RESEARCH QUESTION 4**

“Is the final result compatible with existing equipment and techniques or is additional change needed?”

Yes, if it’s wished upon the harness can be used as a completely regular harness by removing the shoulder straps and using only the belt. The sliding mechanism can be locked in different primitive ways and the new tray holders could be swapped for old ones. The new tray holders could further motivate the sales of Pottiputki’s current (shoulder strap utilising) harnesses by just replacing the old tray holders. This ensures that no one has to change their ways unless they want to when buying a new harness. The ambidextrous pipe in no way forces the user to alternate hands while planting, it is only an option. By adding the universal mounting for Pottiputki equipment the harness can be used with other seedling holders, such as a bucket. It is then important to keep in mind that the final result is specifically designed for being optimally used with seedling trays.
CONCLUSIONS

PROJECT OBJECTIVES AND AIMS

“The objective of this thesis project was to improve the way manual reforestation with the usage of seedling trays is performed, with focus on improving the user’s work environment through improved ergonomics and efficiency. In this context, efficiency was considered as increased planting rate and less time handling the equipment while planting.”

The process has been going smoothly and we’ve done everything we set out to do, while encountering minor bumps we still feel like we’ve achieved a satisfying end result.

SCA’s aims for this master’s thesis:

• The end result should be focused around implementation with the method of reforestation with seedling trays.

Check, as it is recently stated: By adding the universal mounting for Pottiputki equipment the harness can be used with other seedling holders, such as a bucket. It is then important to keep in mind that the final result is specifically designed for being optimally used with seedling trays.

• The end result should result in a change for the better in the industrial standard for reforestation.

If workers use techniques that is afforded by the end result it probably will. Since theory suggests improved efficiency and ergonomics the design should provide an increase in quality of the working environment

• The main focus should lie with the improvement of the users carrying equipment mainly by improving ergonomics. But the other equipment are also of interest.

We feel that we’ve improved the harness significantly and improvement of the planting tube for people which are left handed and who use both hands when planting.

• The end result must be economically viable.

We believe it is, since no material changes are in place, only addition of a small components the cost might increase if new machines or techniques are needed for bending the tray holders as well as reshaping the belt might add some cost to the product.

• To have a prototype(s) created to be tested during the summer months of 2016

Testing of different kinds have been performed, positive and negative critique of the designs have been received which has helped the design reach a qualitative state. Although the feedback from the largest test wasn’t what we’d hoped for, it was still feedback and could be used. The mistake is on our part for not following through with a day of testing together with the subjects to educate which aspects of the design we were most interested in evaluating.

Additional aims added by the design team:

• The carrying equipment should fit the most commonly used seedling trays. Since other companies uses mostly the same dimensions, this should be possible in order to ensure and ease the sale of products for the manufacturer.

The new tray holders fit the JackPot and PowerPot perfectly which was desired. They also fit the third most commonly used tray, StarPot, if it’s not to bent which many of them can be.

• An increase in efficiency for the user which leads directly to an increase in efficiency for the employer.

More clear-cuts should be finished faster resulting in that more clear-cuts can be reforested in one day, time-schedules might be kept more easily, more work could be done in a season or workers might be able to go home earlier and be more refreshed for the coming workday.
• *An improvement in user experience, with focus on ergonomics and comfort.*

Since the early efforts of drastically improving efficiency couldn’t amount to any good results the focus shifted. The new focus was to increase the ergonomics and comfort as much as possible, which should lead to incremental improvement of efficiency for an improved user experience.

• *Conformability of the carrying equipment to fit for various body types to a certain degree.*

The conformability isn’t changed significantly compared to current models, but the parts are reshaped to fit body types in what is perceived as a generally more comfortable way. A significant notation is that the current Pottiputki harness will fit people with a large waist circumference better than compared to a belt. People who are bluntly put, fat, will have such a gap at the front of the belt that they probably will claim that the current model is better for them. Luckily there seem to be hardly any fat people working with reforestation full time since the work itself burns a high amount of calories every day.


McDonagh, D., & Denton, H. (2005). Exploring the degree to which individual students share a common perception of specific mood boards: observations relating to teaching, learning and team-based design. *Design Studies, 26*(1), (pp. 35-53).


REFERENCES


Tovey, M. (1997). Styling and design: intuition and analysis in industrialDesign. *Design Studies, 18*(1), (pp. 5-31).


APPENDICES
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Skogsplanteringsutrustning

Vi är två studenter som utvecklar en ny typ av manuell skogsplanteringsutrustning. Denna enkät är avsedd att vara ett underlag för oss i vår utvecklingsprocess för att ta fram en ny standard för skogsplanteringsredskap.


Har du planterat skogsplanter tidigare?

☐ Nej

☐ Ja, jag har sommarjobbat med det

☐ Ja, jag har gjort det ideellt

☐ Ja, jag har planterat privat

☐ Ja, jag har planterat åt en entreprenör

Kön

☐ Man

☐ Kvinna

☐ Other:

Ålder vid senaste skogsplantering (om du planterat tidigare)

☐ <15

☐ 15-20

☐ 20-25

☐ 25-35

☐ 35-50

☐ >50

Vilken planttyp användes mest?

☐ Plantor i kasserter

☐ Plantor i kartong

☐ Barrotsplantor

☐ Other: ___________________________
Vilket verktyg användes oftast för att sätta plantorna i marken?

- Planteringsröra
- Planteringsspade
- Other: ________________________________

Vilken typ av kroppssele användes oftast?

- Midjebälte
- Midjebälte med axelstöd
- Axelhängd "banan"
- Ingen sele
- Other: ________________________________

För de som planterat med kassett - Vad gjorde du när du var färdig med den första kassetten?

- Började använda planteringsröret med andra handen
- Snurrade midjebället så den fulla kassetten hamnade där den tomma var
- Lossade kassetterna och bytte plats på dem
- Du gjorde ingen förändring utan sträckte dig för att plocka ut plant med den fria handen på motsatt sida
- Other: ________________________________

Bar du oftast ut plantorna själv till hygget?

- Ja, jag bar dem för hand
- Ja, jag använde en bärmes
- Nej, plantbasen gjorde det
- Olika från gång till gång
- Other: ________________________________
Bar du oftast ut plantorna själv till hygget?

☐ Ja, jag bar dem för hand
☐ Ja, jag använde en bärmes
☐ Nej, plantbasen gjorde det
☐ Olika från gång till gång
☐ Other: ____________________________

Har du några förslag på förbättringar?
Your answer

Vad tycker du var bra med den planteringsutrustning du använde?
Your answer

Tyckte du någon del av utrustningen var bättre än övriga delar? Varför?
Your answer

Vad anser du vore den mest värdefulla egenskapen för en ny typ av planteringsutrustning?

☐ Bekvämare
☐ Lättare att ställa in för din kroppstyp
☐ Kunna plantera fler plantor på en dag
☐ Minskad risk för skador och/eller skavsår
☐ Färre promenader för att fylla på med plantor
Har du planerat skogsplanter tidigare? (89 responses)

- Nej: 5 (5.6%)
- Ja, jag har satt: 52 (58.4%)
- Ja, jag har gjort: 17 (19.1%)
- Ja, jag har planerat: 41 (46.1%)
- Ja, jag har planerat: 22 (24.7%)

Kön (89 responses)

- Man: 64%
- Kvinnan: 34.8%
- Other: 1.2%

Ålder vid senaste skogsplantering (om du planerat tidigare) (84 responses)

- <15: 21.4%
- 15-20: 13.1%
- 20-25: 13.1%
- 25-30: 13.1%
- 35-50: 47.6%
- >50: 1.2%

Vilken planttyp användes mest? (84 responses)

- Plantor i kassetter: 53.6%
- Plantor i kartong: 39.3%
- Barrotsplanter: 1.2%
- Other: 6%

Vilket verktyg användes oftast för att sätta plantorna i marken? (83 responses)

- Planteringsrör: 91.6%
- Planteringsspace: 6%
- Other: 1.2%
Vilken typ av kroppssele användes oftast? (84 responses)

- Midjebälte: 27.4%
- Midjebälte med axelbälte: 27.4%
- Axelhängt "banan": 6%
- Ingen sele: 36.8%
- Other: 0%

För de som planterat med kassett - Vad gjorde du när du var färdig med den första kassetten? (49 responses)

- Började använda planteringsröret med andra handen: 42.9%
- Snurrade midjebältet så den fulla kassetten hamnade där den tomma var: 12.2%
- Lösgav kassettorna och bytte plats på dem: 10.2%
- Du gjorde ingen förändring utan sträckte dig för att plötsa ut plantar ur dem: 9.8%
- Other: 0%

Bar du oftast ut plantorna själv till hygget? (83 responses)

- Ja, jag bar dem själv till hygget: 28 (27.7%)
- Ja, jag använder planteringstvätt: 20 (24.1%)
- Nej, planterna är byggda in: 22 (26.6%)
- Olika från gång till gång: 25 (30.1%)
- Other: 6 (7.2%)

Vad anser du vore den mest värdefulla egenskapen för en ny typ av planteringsutrustning? (84 responses)

- Bekvämare: 21.4%
- Lättare att ställa in för din kroppstyp: 28.6%
- Kunna plantera fler plantor på en gång: 14.3%
- Minskad risk för skador och/eller skavsnar: 11.9%
- Fårre promenader för att fylla på med plantor: 18%
- Other: 0%
## Appendix D

### Requirement Specification

<table>
<thead>
<tr>
<th>Demands/Wishes</th>
<th>Harness</th>
<th>Tube</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Competition</strong></td>
<td>Something that is completely new to the market.</td>
<td>Something that is not used by competitors.</td>
</tr>
<tr>
<td></td>
<td>Something that could lead the market.</td>
<td>Something that could lead the market.</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>Not heavier than current harnesses.</td>
<td>Not heavier than current tubes.</td>
</tr>
<tr>
<td></td>
<td>Weight should be kept as low as the design can afford.</td>
<td>Weight should be kept as low as the design can afford.</td>
</tr>
<tr>
<td><strong>Company Constraints</strong></td>
<td>Too complex components that are difficult to manufacture.</td>
<td>No too complex components that are difficult to manufacture.</td>
</tr>
<tr>
<td></td>
<td>Standardised parts should, if possible, be used.</td>
<td>Standardised parts should, if possible, be used.</td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>About the same size as current models, not too big so it becomes a nuisance.</td>
<td>About the same size as current models.</td>
</tr>
<tr>
<td></td>
<td>Keep the harness from becoming clumpy, should be easy to carry to the clean-cut.</td>
<td>Increase grip length.</td>
</tr>
<tr>
<td><strong>Process</strong></td>
<td>Streamlined operations, e.g. no hook or rubber band.</td>
<td>Reduced exertions.</td>
</tr>
<tr>
<td></td>
<td>Quick and easy to use for novice users.</td>
<td>For both right- and left handed users.</td>
</tr>
<tr>
<td><strong>Patents</strong></td>
<td>Patents checked for no similarities.</td>
<td>Patents checked for no similarities.</td>
</tr>
<tr>
<td><strong>Customer</strong></td>
<td>Easy to put on and remove. Removable shoulder straps.</td>
<td>Easy to use. At least as comfortable as current models.</td>
</tr>
<tr>
<td></td>
<td>At least as comfortable as current model. Easy to use buckles.</td>
<td>Afford fair left handed use.</td>
</tr>
<tr>
<td></td>
<td>Bring pride to the customer. Affordable.</td>
<td>Bring pride to the customer. Affordable.</td>
</tr>
<tr>
<td></td>
<td>Able to use with different planting techniques.</td>
<td>Left handed use. Reduced leg angles.</td>
</tr>
<tr>
<td><strong>Ergonomics</strong></td>
<td>Padded. No weight directly on the legs.</td>
<td>Suit the method of planting with different hands.</td>
</tr>
<tr>
<td></td>
<td>Affords partial weight to be carried on shoulders.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Harness should always be kept straight.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lumbar support. Able to use with both hands.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Anthropometrically adapted for 5-95% male.</td>
<td></td>
</tr>
<tr>
<td><strong>Testing</strong></td>
<td>Prototypes should be built.</td>
<td>Prototypes should be built.</td>
</tr>
<tr>
<td></td>
<td>Easy and low cost prototypes. Assure quality improvement.</td>
<td>Easy and low cost prototypes.</td>
</tr>
<tr>
<td><strong>Safety</strong></td>
<td>No sharp edges. No abundance of metals (conductivity).</td>
<td>No sharp edges.</td>
</tr>
<tr>
<td></td>
<td>No chafing.</td>
<td>Incremental use of other hand to reduce risk of injury.</td>
</tr>
<tr>
<td><strong>Legal</strong></td>
<td>No weight over 20% BW.</td>
<td></td>
</tr>
<tr>
<td><strong>Product Cost</strong></td>
<td>Affordable.</td>
<td>Affordable.</td>
</tr>
<tr>
<td><strong>Quality</strong></td>
<td>Kept similar to current models.</td>
<td>Kept similar to current models.</td>
</tr>
<tr>
<td></td>
<td>Durable, should reflect price.</td>
<td>Durable, should reflect price.</td>
</tr>
<tr>
<td></td>
<td>Be perceived as very qualitative.</td>
<td>Be perceived as very qualitative.</td>
</tr>
<tr>
<td></td>
<td>Extra functions, such as bottle holders.</td>
<td></td>
</tr>
<tr>
<td><strong>Materials</strong></td>
<td>Kept similar to older models. Kept dark to obscure dirt.</td>
<td>Kept similar to older models. Kept dark to obscure dirt.</td>
</tr>
<tr>
<td></td>
<td>New materials needed should be easy to acquire.</td>
<td>New materials needed should be easy to acquire.</td>
</tr>
<tr>
<td><strong>Environment</strong></td>
<td>Should handle the Swedish environment.</td>
<td>Should handle the Swedish environment.</td>
</tr>
<tr>
<td><strong>Aesthetics</strong></td>
<td>Designed to reflect price.</td>
<td>Designed to reflect price.</td>
</tr>
<tr>
<td></td>
<td>Aesthetically pleasing. Reflect a modern design.</td>
<td>Aesthetically pleasing. Reflect a modern design.</td>
</tr>
<tr>
<td><strong>Performance</strong></td>
<td>Improves working environment, increases efficiency.</td>
<td>Improves working environment, increases efficiency.</td>
</tr>
<tr>
<td></td>
<td>Radical improvement of working environment and ergonomics.</td>
<td>Radical improvement of working environment and ergonomics.</td>
</tr>
<tr>
<td></td>
<td>Incremental increase in efficiency.</td>
<td>Incremental increase in efficiency.</td>
</tr>
<tr>
<td><strong>Quality Reliability</strong></td>
<td>Fit the most commonly used seeding trays.</td>
<td>High price should reflect high quality.</td>
</tr>
<tr>
<td></td>
<td>High price should reflect high quality. Moving parts kept low.</td>
<td>Should handle rough use. Moving parts kept low.</td>
</tr>
</tbody>
</table>
CONFORMABLE DESIGN FOR ALL

DURABLE

INNOVATIVE

SAFE LIGHT

COMFORTABLE
SUSTAINABILITY

PLANT THE PLANET

QUALITY

COMMITMENT
• “Hiking trolleys” För att transportera kassetter. Fästas i selen. Handtag för medhjälpare
• “Magasinet” - ryggsmonterad sele
• “Ledat bälte” med axelremmar
• “Hållare i skenor”
• “Stum trampspak”
• Bättre handtag
• “Slangröret”
• “Skruvröret”
• “Ta bort ett hål i kassetten” (powerpot)
• “Bättre att hänga extra kassetter”
• “Vända på axelstödet”
• “Ironman-sele” (stöd under armar)
• Flexande axelremmar
• Fira ner bärmesen
• Teflon i käften på röret
• Klicka fast bärmes i sele för att få midjebelastning
• Fästen på bökbara skenor
• “Magasinröret”
• Mindre storlek kassetter
• Förminska regnskyddet i axeldelen
Transporteras
- Något kan minimeras
- Stapla saker i varandra
- Fästa utrustning i varandra
- Transportera annat på selen
- Transportera tomkassetter

Rörlighet
- Rörelsefrihet
- Selar ska ej röra på sig, vara stabila
- Inte ha stora och hindrande lårvaddar
- Inget ska vara i vägen
- Inte behöva sträcka sig för att använda
- Få ner tyngdpunkten

Klimat
- Tunnare regnskydd
- Återanvändbara material
- Material som påverkar naturen minimalt
- Ska klara klimatet den används i

Möjligheter
- Använda utrustningen till annat
- Användas av vänster- och högerhänta
- Avlasta plantröret på hjul
- Möjlighet att hänga upp för torkning
- Att kunna vila utan att måsta ta av sig allt
- Markera och namnge utrustningen
- Förvara små föremål på selarna
- Plantera utan tröja

Konstant
- Jämn belastning mellan axlar och midja
- Kunna jobba längre utan avbrott
- Spännena ska inte kunna släppa
- Inga gummitänder som kan lossna

Beståndsdelar
- Skydd
- Axelstöd
- Midjestöd
- Svankstöd
- Ställbara fästen
- Sele med seamless mellan axel & midja
- Kan vara uppdelad mellan midja - axel
- Kan vara modulär

Uppgradera
- Standardiserade delar
- Fästa lite vad man vill
- Fungera med andra enheter

Ledningar
- Underlätta hjälp man kan få
- Stabila fästen mellan delarna
- Kan vara mer glidbar insida i röret
- Minskade ledtider (mer plant/timme)

Tillbehör
- Vattenflaskhållare
- Planträknare
- Kassetträknare
- Sladdhållare för musik
- Camelback

Placering
- Allt ska vara placerat nära kroppen
- Helst ur vägen för planteringsarmen

Rengöring
- Vadering kan tas ut
- Allt ska gå att spola av med vattenslang
- Material och färger ska ej dra åt sig skit
- Vadning gjord för att klara av tvätt
- Metall ska ej rosta
### Test av utrustning veckorna 24 och 25

<table>
<thead>
<tr>
<th>Testperson</th>
<th>Längd</th>
<th>Vikt</th>
<th>Kön</th>
<th>Erfarenhet /år</th>
<th>Sele/Dubbel</th>
<th>Sele/Rygg</th>
<th>Sele/Slides</th>
<th>Rör</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 L</td>
<td>M</td>
<td>Man</td>
<td>5+</td>
<td>Tungt för axlar, rygg och knän</td>
<td>För tungt</td>
<td>Funkar bra, stabil och stadig</td>
<td>Handsken fastnar i knappen, tung</td>
<td></td>
</tr>
<tr>
<td>2 M</td>
<td>XL</td>
<td>Man</td>
<td>10+</td>
<td>Ergonomisk smidig, men för tungt, svårt att skiftra lädor</td>
<td>För tungt</td>
<td>Lådor kommer för långt bak</td>
<td>Tung</td>
<td></td>
</tr>
<tr>
<td>3 L</td>
<td>L</td>
<td>Man</td>
<td>15+</td>
<td>Tungt</td>
<td>Varför</td>
<td>Lådorna kommer lit till långt bak, svårt att nå planten, kasseterna känns vara i obalans och dinglar när man rör sig. Tung. Gillar inte sele överlag i regn och svett...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 S</td>
<td>M</td>
<td>Kvinna</td>
<td>5+</td>
<td>Tungt</td>
<td>Orimligt</td>
<td>Obalans</td>
<td>Avtryckarn längt från tummen, när ej fram</td>
<td></td>
</tr>
<tr>
<td>5 M</td>
<td>L</td>
<td>Man</td>
<td>1</td>
<td>Bekväm men tung</td>
<td>För mycket</td>
<td>Bekväm men tung</td>
<td>Avtryckarn smäler på handen</td>
<td></td>
</tr>
<tr>
<td>6 M</td>
<td>M</td>
<td>Man</td>
<td>1</td>
<td>Gillar axlar, bekväm men tung. Svårt att byta lädor</td>
<td>Tung</td>
<td>Tung</td>
<td>Obalans</td>
<td></td>
</tr>
<tr>
<td>7 L</td>
<td>L</td>
<td>Man</td>
<td>3</td>
<td>Bekväm hade varit bra med annat material, fördelat att kunna gå lång</td>
<td>Obalans</td>
<td>Bekväm bra med annat material</td>
<td>Bra att kunna byta hand</td>
<td></td>
</tr>
<tr>
<td>8 M</td>
<td>L</td>
<td>Man</td>
<td>2</td>
<td>Bra men tung</td>
<td>Obalans, svårt att hålla</td>
<td>Bra men tung</td>
<td>Avtryckarn träffar handen</td>
<td></td>
</tr>
<tr>
<td>9 M</td>
<td>L</td>
<td>Man</td>
<td>2</td>
<td>Tung</td>
<td>Tung</td>
<td>Tung</td>
<td>OK för vänster hånta</td>
<td></td>
</tr>
<tr>
<td>10 M</td>
<td>M</td>
<td>Man</td>
<td>10+</td>
<td>Tung, gillar det gamla systemet bättre</td>
<td>Nej</td>
<td>Tung, gillar det gamla systemet bättre</td>
<td>Avtryckarn smäler på handen</td>
<td></td>
</tr>
<tr>
<td>11 M</td>
<td>M</td>
<td>Man</td>
<td>3</td>
<td>Gillar sele, bra om den var lättare</td>
<td>Nej</td>
<td>Nej</td>
<td>Avtryckarn smäler på handen</td>
<td></td>
</tr>
<tr>
<td>12 S</td>
<td>S</td>
<td>Man</td>
<td>5+</td>
<td>Bra men tung, bra inga snoddar som går sönder, bra för axlar, bra med mer lädor varje gång</td>
<td>Inte nödvändig</td>
<td>Som dubbel sele</td>
<td>Bra att pedal är centrerad, dåligt att avtryckar gör ont</td>
<td></td>
</tr>
</tbody>
</table>
Noraxon Standard EMG Analysis

Subject: Victor Andersson
Date of birth

Record:
Name EMG plantsättning arm hand 5ch
Date Measured 2016-09-28 11:06
Number of periods 10

Analyzed Signals / Periods

Subject Comments
Noraxon Standard EMG Analysis

Subject
First Name: Victor
Last Name: Andersson
Date of Birth:

Record
Name: EMG plantsättning arm hand 5ch
Date Measured: 2016-09-28 11:06
Number of periods: 10

Mean of Each Period
- EXT.CARP.RAD. LT, µV
- FLEX.CAPR.U LT, µV
- ABD.POL LT, µV
- EXT.POL LT, µV
- ADD.POL. LT, µV

Maximum of Each Period
- EXT.CARP.RAD. LT, µV
- FLEX.CAPR.U LT, µV
- ABD.POL LT, µV
- EXT.POL LT, µV
- ADD.POL. LT, µV

Averaged Mean Amplitude of All Periods
Averaged Max of All Periods

Record Comments
Noraxon Standard EMG Analysis

First Name: Dennis  
Last Name: Bröms  
Date of birth:  

Subject: Name EMG Kinematics plantsättning - s...
Date Measured: 2016-09-28 10:29
Number of periods: 10

Record:
Analyzed Signals / Periods

- Hip Flexion LT, deg
- Hip Flexion RT, deg
- Hip Abduction LT, deg
- Hip Abduction RT, deg
- Hip Rotation - out LT, deg
- Hip Rotation - out RT, deg
- Knee Flexion LT, deg
- Knee Flexion RT, deg
- Ankle Dorsiflexion LT, deg
- Ankle Dorsiflexion RT, deg
- Ankle Inversion LT, deg
- Ankle Inversion RT, deg

Subject Comments
Noraxon Standard EMG Analysis

Subject:
First Name Dennis
Last Name Bröms
Date of birth

Record:
Name EMG Kinematics plantsättning - s...
Date Measured 2016-09-28 10:29
Number of periods 10

Analyzed Signals / Periods

- Ankle Abduction LT, deg
- Ankle Abduction RT, deg
- LUMBAR ES LT, uV
- LUMBAR ES RT, uV
- GLUT. MED. RT, uV
- GLUT. MAX. RT, uV
- SEMITEND. RT, uV
- BICEPS FEM. RT, uV
- VMO RT, uV
- VLO RT, uV
- TIB.ANT. RT, uV

Subject Comments
Noraxon Standard EMG Analysis

**Subject**
- First Name: Dennis
- Last Name: Bröms
- Date of birth: 

**Record**
- Name: EMG Kinematics plantsättning ...
- Date Measured: 2016-09-28 10:29
- Number of periods: 10

---

### Mean of Each Period

- **Hip Flexion LT**, deg: 17.3 ± 1.57
- **Hip Flexion RT**, deg: 20.1 ± 2.04
- **Hip Abduction LT**, deg: -1.15 ± 1.74
- **Hip Abduction RT**, deg: -4.0 ± 1.9
- **Hip Rotation - out LT**, deg: 10.9 ± 9.1
- **Hip Rotation - out RT**, deg: 3.2 ± 3.9
- **Knee Flexion LT**, deg: 17.5 ± 1.9
- **Knee Flexion RT**, deg: 8.1 ± 1.9
- **Ankle Dorsiflexion LT**, deg: -9.8 ± 2.1
- **Ankle Dorsiflexion RT**, deg: -9.6 ± 2.1

### Maximum of Each Period

- **Hip Flexion LT**, deg: 24.2 ± 1.9
- **Hip Flexion RT**, deg: 72.4 ± 8.9
- **Hip Abduction LT**, deg: -6.0 ± 4.0
- **Hip Abduction RT**, deg: -10.9 ± 11.9
- **Hip Rotation - out LT**, deg: 17.5 ± 1.9
- **Hip Rotation - out RT**, deg: 23 ± 4.3
- **Knee Flexion LT**, deg: 92 ± 9.6
- **Knee Flexion RT**, deg: 89.6 ± 9.8
- **Ankle Dorsiflexion LT**, deg: 3.4 ± 4.5
- **Ankle Dorsiflexion RT**, deg: 1.2 ± 4.6

---

### Averaged Mean Amplitude of All Periods

<table>
<thead>
<tr>
<th>Channel</th>
<th>Mean, Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip Flexion LT, deg</td>
<td>17.4 ± 1.9</td>
</tr>
<tr>
<td>Hip Flexion RT</td>
<td>20.1 ± 2.04</td>
</tr>
<tr>
<td>Hip Abduction LT</td>
<td>-1.15 ± 1.7</td>
</tr>
<tr>
<td>Hip Abduction RT</td>
<td>-4.0 ± 1.9</td>
</tr>
<tr>
<td>Hip Rotation - out LT</td>
<td>10.9 ± 9.1</td>
</tr>
<tr>
<td>Hip Rotation - out RT</td>
<td>3.2 ± 3.9</td>
</tr>
<tr>
<td>Knee Flexion LT</td>
<td>17.5 ± 1.9</td>
</tr>
<tr>
<td>Knee Flexion RT</td>
<td>8.1 ± 1.9</td>
</tr>
<tr>
<td>Ankle Dorsiflexion LT</td>
<td>-9.8 ± 2.1</td>
</tr>
<tr>
<td>Ankle Dorsiflexion RT</td>
<td>-9.6 ± 2.1</td>
</tr>
</tbody>
</table>

---

### Averaged Max of All Periods

<table>
<thead>
<tr>
<th>Channel</th>
<th>Mean, Units</th>
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<tbody>
<tr>
<td>Hip Flexion LT, deg</td>
<td>24.2 ± 1.9</td>
</tr>
<tr>
<td>Hip Flexion RT</td>
<td>72.4 ± 8.9</td>
</tr>
<tr>
<td>Hip Abduction LT</td>
<td>-6.0 ± 4.0</td>
</tr>
<tr>
<td>Hip Abduction RT</td>
<td>-10.9 ± 11.9</td>
</tr>
<tr>
<td>Hip Rotation - out LT</td>
<td>17.5 ± 1.9</td>
</tr>
<tr>
<td>Hip Rotation - out RT</td>
<td>23 ± 4.3</td>
</tr>
<tr>
<td>Knee Flexion LT</td>
<td>92 ± 9.6</td>
</tr>
<tr>
<td>Knee Flexion RT</td>
<td>89.6 ± 9.8</td>
</tr>
<tr>
<td>Ankle Dorsiflexion LT</td>
<td>3.4 ± 4.5</td>
</tr>
<tr>
<td>Ankle Dorsiflexion RT</td>
<td>1.2 ± 4.6</td>
</tr>
</tbody>
</table>

---

**Record Comments**
Noraxon Standard EMG Analysis

Subject

Record

Mean of Each Period

- Ankle Inversion LT, deg
- Ankle Inversion RT, deg
  -10.3 -14.1 -14.5 -15.4 -17.9 -20.7 -24.6 -25.1 -25.9
- Ankle Abduction LT, deg
  -9.33 -8 -5.69 -9.84 11.8 14.2 11.9 11.7 12.4 17.7
- Ankle Abduction RT, deg
  -10.9 -14.1 -14.5 -15.4 -17.9 -20.7 -24.6 -25.1 -25.9
- LUMBAR ES LT, uV
  33.9 37.9 26.5 24.7 25.6 20.9 19.6 26.1 18.5 15.1
- LUMBAR ES RT, uV
  43.9 41.8 37.5 43.2 45.8 48.3 49.5 45.9 42.5 35.4
- GLUT. MED. RT, uV
  30.1 17.1 18.9 20.6 22.3 27.2 19.9 18.2 18.8 20.5
- SEMITEND. RT, uV
  28.2 22.5 24.7 24.1 28.3 31.4 25.7 19.1 20.7

Maximum of Each Period

- Ankle Inversion LT, deg
- Ankle Inversion RT, deg
  1.68 -1.07 -3.5 -1.07 1.1 0.99 2.03 3.57 -0.571
- Ankle Abduction LT, deg
  -4.57 -1.68 3.24 12.4 15.7 19.9 15.6 13.8 17.4 22.1
- Ankle Abduction RT, deg
  -4.53 -12.1 -12.1 -9.42 -14.7 -12.3 -13.2 -18.6 -17.3 -16.3
- LUMBAR ES LT, uV
  78.3 88.9 59.9 86 64.8 54.3 46.7 76.6 44.2 33.1
- LUMBAR ES RT, uV
  93.4 72.2 73.4 112 83.6 105 92.5 101 75.4 76.8

Channel Mean, Units

- Ankle Abduction LT 7.28±8.72
- Ankle Abduction RT 11.4±8.71
- LUMBAR ES LT, uV 24.9±6.59
- LUMBAR ES RT, uV 63.3±17.9
- GLUT. MED. RT, uV 57.9±22.7
- GLUT. MAX. RT, uV 5.77±0.649
- SEMITEND. RT, uV 5.58±1.71
- BICEPS FEM. RT, uV 44.2±12.8

Averaged Mean Amplitude of All Periods

VMO RT, uV 14.3±4.5
VLO RT, uV 14.3±4.5
106±22

Averaged Max of All Periods

- Ankle Abduction LT -12.9±3.99
- LUMBAR ES LT, uV 53.3±17.5
- LUMBAR ES RT, uV 89.4±13.5
- GLUT. MED. RT, uV 172±69.6
- GLUT. MAX. RT, uV 5.77±0.649
- SEMITEND. RT, uV 66.1±25
- BICEPS FEM. RT, uV 66.1±25
- VLO RT, uV 24.2±6.7
- TIB. ANT. RT, uV 11.1±1.7
- TIB. ANT. RT, uV 106±22

Record Comments

APPENDIX I (6/8) sEMG ANALYSIS
## Noraxon Standard EMG Analysis

### Mean of Each Period

<table>
<thead>
<tr>
<th>Periods</th>
<th>VMO RT, μV</th>
<th>VLO RT, μV</th>
<th>TIB.ANT. RT, μV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.3</td>
<td>10.7</td>
<td>114</td>
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<td>2</td>
<td>10.2</td>
<td>9.31</td>
<td>79.8</td>
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<td>3</td>
<td>11.2</td>
<td>9.9</td>
<td>84.2</td>
</tr>
<tr>
<td>4</td>
<td>12.3</td>
<td>10.2</td>
<td>88.2</td>
</tr>
<tr>
<td>5</td>
<td>12.1</td>
<td>9.92</td>
<td>154</td>
</tr>
<tr>
<td>6</td>
<td>14.8</td>
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<td>106</td>
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<td>7</td>
<td>12.5</td>
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<td>127</td>
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<td>8</td>
<td>9.63</td>
<td>8.64</td>
<td>120</td>
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<td>9</td>
<td>9.06</td>
<td>7.54</td>
<td>93.8</td>
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<tr>
<td>10</td>
<td>9.12</td>
<td>8.1</td>
<td>90.9</td>
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</tbody>
</table>

### Maximum of Each Period

<table>
<thead>
<tr>
<th>Periods</th>
<th>VMO RT, μV</th>
<th>VLO RT, μV</th>
<th>TIB.ANT. RT, μV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25.3</td>
<td>39.4</td>
<td>585</td>
</tr>
<tr>
<td>2</td>
<td>22.9</td>
<td>32.5</td>
<td>374</td>
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<tr>
<td>3</td>
<td>24.5</td>
<td>31.6</td>
<td>319</td>
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<td>4</td>
<td>33.1</td>
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<td>39.6</td>
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<td>304</td>
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<td>6</td>
<td>75.3</td>
<td>75.1</td>
<td>539</td>
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<td>27.6</td>
<td>30.3</td>
<td>339</td>
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<tr>
<td>10</td>
<td>28.7</td>
<td>38.2</td>
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</tbody>
</table>

The data represents the mean and maximum EMG activity (in μV) for different periods, illustrating the muscle activity levels for VMO, VLO, and TIB.ANT. RT.
Marker at 3.5 sec
Microsoft LifeCam Cinema

Parameter
Mean EMG, uV

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXT.CARP.RAD. LT</td>
<td>78.62</td>
</tr>
<tr>
<td>FLEX.CAPR.U LT</td>
<td>65.00</td>
</tr>
<tr>
<td>ABD.POL LT</td>
<td>141.56</td>
</tr>
<tr>
<td>EXT.POL LT</td>
<td>61.46</td>
</tr>
<tr>
<td>ADD.POL. LT</td>
<td>48.50</td>
</tr>
</tbody>
</table>

Marker at 26.6 sec
Microsoft LifeCam Cinema

Parameter
Mean EMG, uV

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXT.CARP.RAD. LT</td>
<td>112.56</td>
</tr>
<tr>
<td>FLEX.CAPR.U LT</td>
<td>99.83</td>
</tr>
<tr>
<td>ABD.POL LT</td>
<td>83.91</td>
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<tr>
<td>EXT.POL LT</td>
<td>63.27</td>
</tr>
<tr>
<td>ADD.POL. LT</td>
<td>79.22</td>
</tr>
</tbody>
</table>

Marker at 2.1 sec
Microsoft LifeCam Cinema

Parameter
Mean values for 1 sec around time point of picture Angle, deg

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip Rotation - out LT</td>
<td>8.30</td>
</tr>
<tr>
<td>Hip Rotation - out RT</td>
<td>17.00</td>
</tr>
</tbody>
</table>

Marker at 26.4 sec
Microsoft LifeCam Cinema

Parameter
Mean values for 1 sec around time point of picture Angle, deg

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip Rotation - out LT</td>
<td>-4.46</td>
</tr>
<tr>
<td>Hip Rotation - out RT</td>
<td>0.00</td>
</tr>
</tbody>
</table>

APPENDIX I (8/8)
sEMG ANALYSIS