A shin guard to boost my confidence and protect your legs

Positive design for child amputees' sports performance

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Master Thesis Report

Msc Integrated Product Design

Delft University of Technology

ÖSSUR

TU Delft

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ÖSSUR TU Delft

“Any technology could do anything but add itself on to what we already are”

- Marshall McLuhan

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Abstract

Children living with lower limb differences can utilize prostheses for mobility and conformity. However, children's prostheses is a small market where development happens slowly, with a very small selection of products.

Products in the children's prosthetics market prioritize providing mobility and tackling mechanical challenges, but amputee children are found to suffer socially as well. (Michielsen, Wijk, Ketelaar 2010) Due to their bodily differences, they can feel stigmatized, which leads to stress, anxiety and lowered self esteem. (Vaes, 2014) Stigma and lowered participation can especially impact preteens, a subset of children 8-12 years old who have increased social awareness and strong motivation to fit in with their peers.

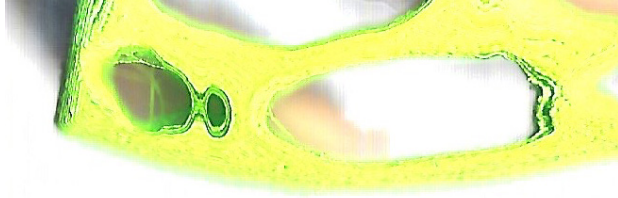
In the research phase of this graduation project, I aimed to construct a design methodology to understand the concerns of amputee children and utilize this to design a product that prioritizes the emotional wellbeing of its user. I employed positive design research to understand the sources of unmet or unvoiced needs, priorities and preferences children could have. As children differ from adults in their cognitive, emotional and language skills, I leveraged principles of designing for children as well as psychological research into children's development to develop my own methodology, a collection of exercises to uncover the motive hierarchies of preteens. Through in-depth evaluation of the exercises with a child participant, in combination with information from other stakeholders, I found moments in an amputee child's life a design could provide value.

The collection of product ideas that stem from the research were narrowed down using a lens of feasibility in the scope of this project and desirability for the end user. The final idea selected is a shin cover designed to boost the amputee preteens' self-confidence when playing soccer, through facilitating a mental shift from daily to exercise use.

Amputee preteens can feel insecure on the football field, as they perceive their prosthetic legs not appropriate for exercise, even though they functionally are. Although sports prostheses exist, they are difficult to finance, offer no additional benefits in contact sports, and amplify the bodily difference between children and their peers. Moreover, children wearing prostheses are barred from playing soccer starting at 14 years old as the prosthesis can harm the players of the opposing team upon impact.

When donned on, as if plate armor, the prosthesis cover visually transforms the prosthesis. The auditory feedback of the snapping cover and buckle provides confidence that the cover is attached properly. 3D printing technology is explored as an enabler of the lightweight, compliant mid-layer which dampens oncoming impact.

This concept, rooted in the concerns of one child who was an amputee, was evaluated with preteens from a football school using a prototype. Children were quickly able to identify the prototype as a shin guard and approached it with curiosity.



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Introduction

Between the ages of 8-12, children fall into the category of “preteens”. Sitting in between childhood and adolescence, preteens are starting to investigate who they are, where they can fit in and define what it takes to get along in the world. In an effort to be more adult-like, they push away their childhood interests, attach themselves to role models and mimic their behavior. Preteens are heavily concerned with their peers’ opinions, they tend to value what their friends might think of them above all else. (Acuff & Reiher, 1997)

Figure 1, Children with lower limb differences wearing prostheses to play.

An estimated 230 children in the Netherlands experience this tumultuous period with a limb difference. (Rjinders et. al, 2001) These children usually navigate their day-to-day lives with the assistance of a prosthesis. As this project is conducted in collaboration with Össur, a company that predominantly focuses on lower limb mobility solutions, the context of this project was selected as children, specifically preteens, with lower limb differences.

Lower limb prostheses, as in legs and feet, assist children in mobility, but come with increased work and concerns children must navigate. Different prosthetic feet are designed for different activities, with only select ones allowing for running and jumping. Children also are responsible for cleaning and taking care of this device, they must deal with added concerns of breaking their prosthesis or exposing it to bad weather, water or dust.

Lower limb prosthetics look quite different from the bone and flesh feet their peers have, so children with lower limb differences must think of how well an outfit or a shoe can work with their prosthesis, and be equipped to handle the reactions of others in public settings. Socially, children with disabilities suffer as they are more restricted in participation in day-to-day life situations. (Michielsen, Wijk, Ketelaar 2010) In addition to these hardships, children are cognitively and verbally developing, so they often cannot verbalize their complaints or at times understand their own needs.

01
Assignment

1.1 How design can help

A leg prosthesis is a product that children with limb differences use almost every day for long periods of time. In doing so, they form close, complex and changing relationships with the product. Specifically for children, this relationship is also affected by the opinions of their peers, parents and people they encounter in public settings. Their experiences in relation to these groups of people color how they might feel towards their prosthetic limb.

Considering the design of a foot prosthesis poses significant mechanical challenges and the market for pediatric prosthesis is relatively small, manufacturers have prioritized making structurally sound and reliable products for children. The products in this market focus on minimizing pain and discomfort, rather than enabling independence and increasing quality of life. When compared to the advances in the adult prostheses, pediatric solutions fall short. (Langley et al, 2020) The complex emotional reactions the wearer experiences throughout the day and attachment between the product and its wearer present a new opportunity in designing children's prostheses. As it is previously uninvestigated, solutions stemming in this field can provide a significant increase in quality of life for the wearer.

1.2 Project Aim

In order to serve the emotional needs of the wearer, technological innovations in the current Junior prosthetics need to be bridged with the priorities and values of the target group. Informing the design processes with the motives, values and expectations of the wearer would enable Össur to meet the psychological needs alongside physical ones. This project focuses on approaching the design of prosthetic feet for children from an emotional and psychological wellbeing perspective. It aims to construct research tools to interview children themselves to understand the complex relationship children construct with these objects and utilize the insights gained to design a lower limb prosthesis for preteens to answer the central question;

How can children's prosthetics facilitate confidence and serve the emotional wellbeing of their wearers?

Additional questions are explored in connection to this central inquiry;

- What is the relationship between a child and their prosthesis currently like?
- How does the hierarchy of concerns preteens have change depending on the context they are in?
- Can a physical product rooted in a small group of children's concerns offer scalable solutions to a larger group?

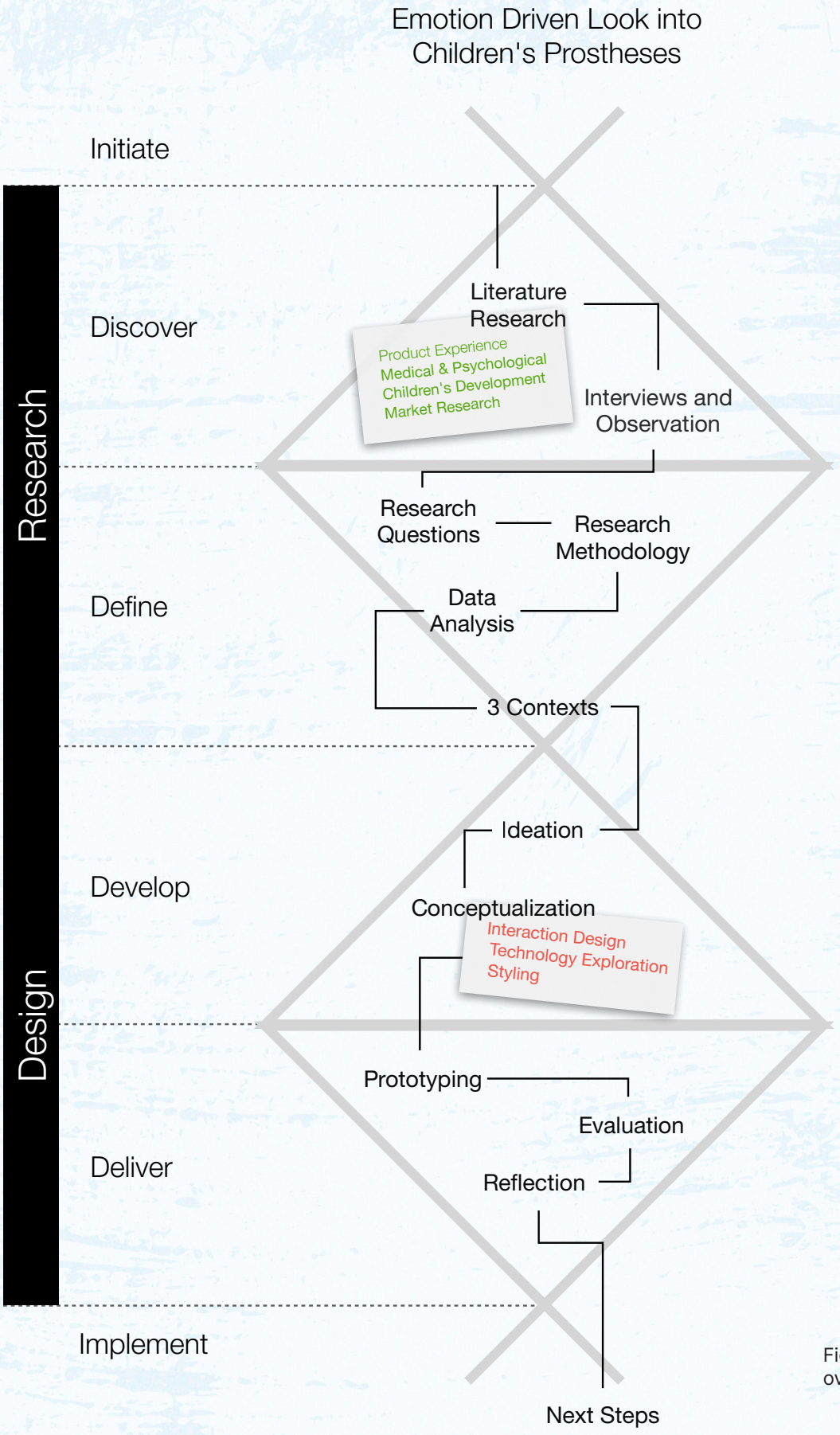


Figure 2: Project overview.

1.3 Structure

This graduation project consists of two sections, research and design. In the research phase, research methodology is developed for communicating with children regarding their day to day life, and information is collected regarding this target group. Utilizing insights gained in the research portion, a product is designed for children with lower limb differences.

Chapter 2 reports on the literature review conducted to gather **Background Information** regarding children living with limb differences, basics of lower limb prosthetics, provides an overview of solutions currently on the market, orientates preteens in child development and describes the impact emotion driven design methods could have in conducting this research.

Chapter 3 describes the **Methodology** research conducted into methods of emotion driven design, co-designing with and interviewing children, and presents the resulting hybrid methodology used in this project.

Chapter 4 presents the **Results** of qualitative studies conducted with a child participant as well as information shared by experts and other stakeholders.

Chapter 5 outlines the **Design** process in terms of ideation, technology exploration and styling.

Chapter 6 presents the **Final Product** designed.

Chapter 7 provides the **Evaluation** of the design and offers **Recommendations** on how the design can be improved.

Chapter 8 reports the **Conclusion** of the project in terms of feasibility, viability and desirability and **Reflection** on the project as a whole and elaborates on the limitations of the project.

02
Background

This chapter presents a literature review of concepts relating to limb difference, basics of lower limb prosthetics, and provides an overview of solutions currently on the market. It also provides research on child development to establish a theoretical understanding of children's psychological development and interests.

Figure 3: Overview of the literature review

2.1 Pediatric Limb Difference

A limb difference can be defined as the partial or complete absence, or malformation of limbs. (University of Illinois, 2021) In the United States, it is estimated that 25000 children live with limb loss. This makes about 1.6% of all people living with limb differences. (Hall et. al, 2021) About 70% of these children have a congenital deficiency, meaning a partial or total absence of skeletal elements of limbs at birth, and the rest have undergone amputations. The reasons for amputations vary from malignancies (37%), trauma (29%), infections or other pathology. (Rjinders et. al, 2001) Children with these kinds of significant limb differences can wear prostheses to participate in daily activities like walking, running and playing.

In order to find the correct solution for the child, they must undergo pediatric rehabilitation, which encompasses the selection and fitting of the suitable prosthetic device and the following treatment. A multidisciplinary team is instrumental in this process, including physical therapists, device makers, technicians and teachers. The social environment of the child like parents, siblings and friends can play an important role as well. (De Hoogstraat)

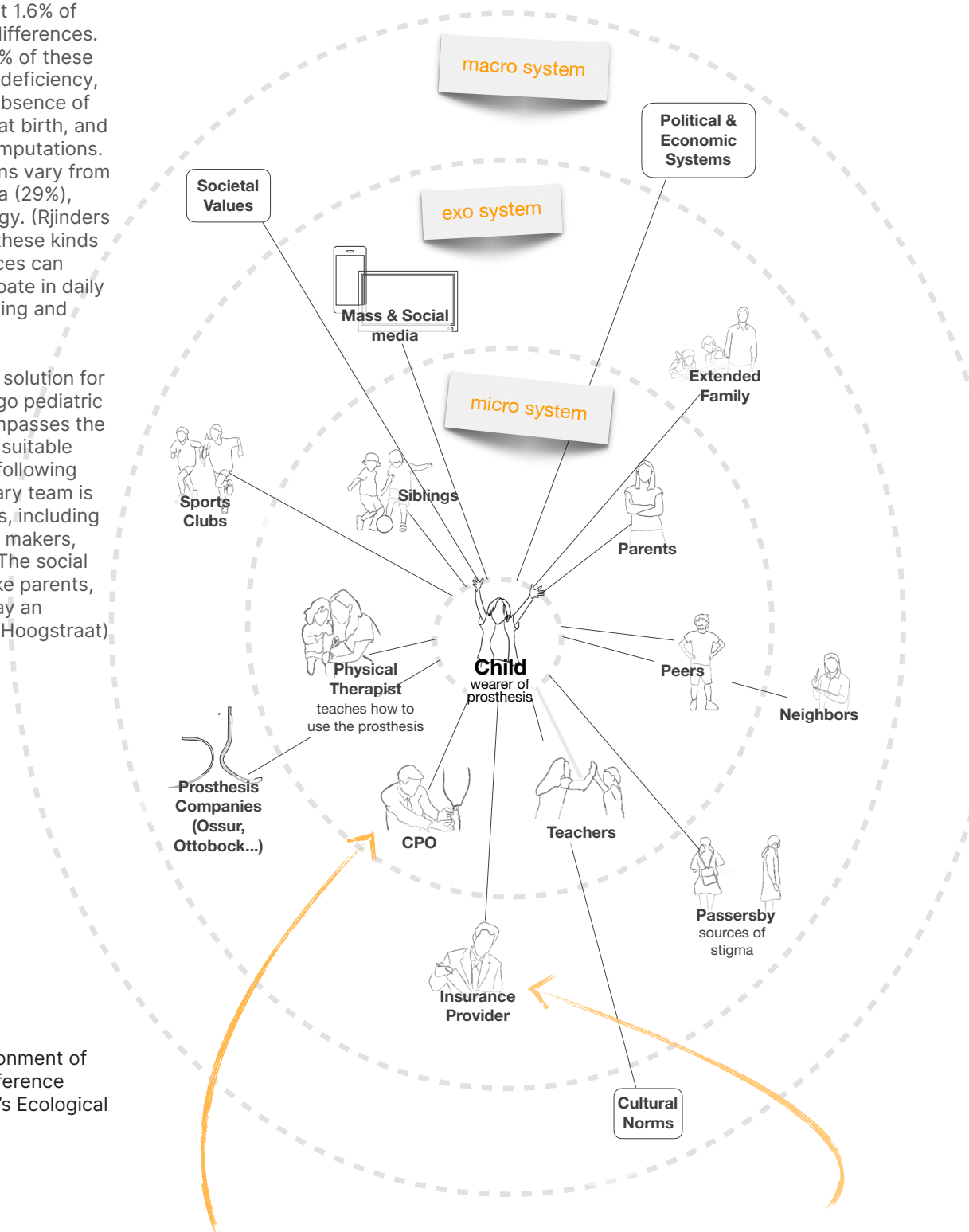


Figure 4: The social environment of a child living with limb difference based on Bronfenbrenner's Ecological Systems Theory (2007)

2.2 Prosthetic Lower Limbs

Prosthetic devices are artificial body parts people with limb differences can use to restore mobility, alter the look of their residual limbs and enhance functionality of their bodies. For lower limbs, the most common prostheses are transtibial, or below the knee, and transfemoral, above the knee. What kind of prosthesis a person will receive depends on the makeup of their residual limb, commonly referred to as the "stump", as well as their lifestyle and mobility goals. (De Hoogstraat; Hall et. al, 2020) The activities the person would like to be able to do and cosmetic preferences of the children and parents are the two main demands the medical team must consider in selecting a mobility solution for a child.

A prosthesis is made up of different components to ensure the fit and to find the right solution for its wearer. The most common components are liner, socket, a support structure and level-specific components like feet and knees. (Hall et. al, 2020)

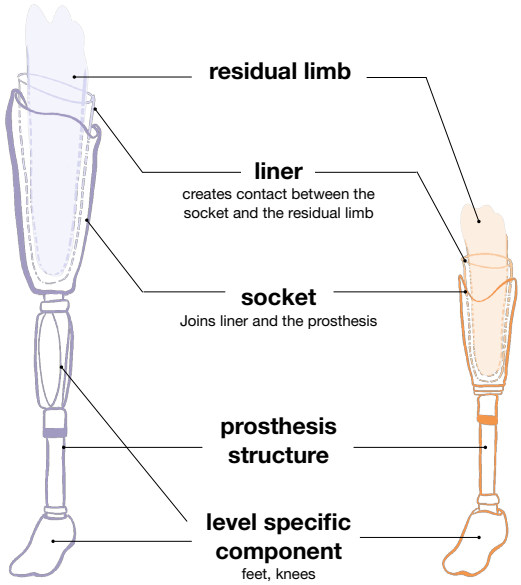


Figure 5: Components of prostheses

The socket must be custom-made for each patient to ensure a proper fit. For this, the residual limb is 3D scanned or molded, and a test socket is made. The test socket is fine-tuned on the body of the person and remade. Follow-up appointments are necessary to ensure comfort and proper fit, which is especially important for vacuum-attached sockets. This process is repeated for every prosthesis the person is to receive. While adults will need a new prosthesis every 3-5 years, as children are growing, they will require a new prosthesis every 12-24 months. (Hall et al., 2020)

It is very important for the liner to fit the stump to create the largest contact area possible. Otherwise, force concentrations and improper fit of the prosthesis will cause blisters on the stump, which can prevent the person from wearing their prosthesis. As liners are in direct contact with the body, it is recommended for them to be cleaned weekly. (Ottobock US, 2020a)

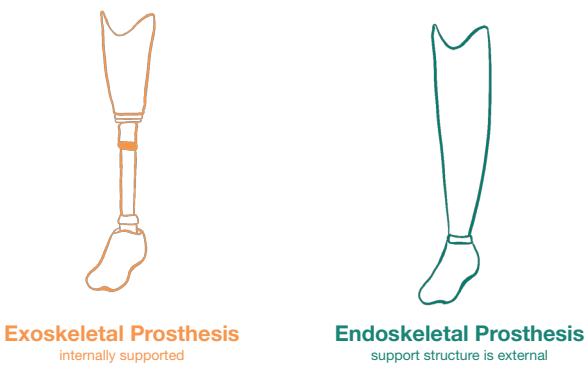


Figure 6: Types of lower limb prostheses

2.3 Requirements of Lower Limb Prostheses Design

All prosthetic feet must be strong, compact and durable. While all prostheses must support the weight of the body while standing and walking, select prostheses must be even stronger to carry larger forces encountered in high impact activities like running or jumping. People traverse different kinds of terrains from asphalt to soil, in different weather conditions, so a prosthetic foot must be durable in these conditions. For people to walk comfortably, the weight of the prosthesis should be comparable to the limb it is made to replace, and provide reasonable stability in gait. Most people prefer wearing a shoe over their prosthetic feet, so the foot should be compact enough to fit in a shoe as well. (Ottobock US, 2020b) This combination of weight, size and strength requirements make the design of a prosthesis challenging.

Figure 7: People can lead active lifestyles wearing prosthetic feet.

Different prosthetic feet are made for different activities. SACH feet, the simplest and most affordable feet, are primarily cosmetic and are not recommended even for daily wear. For daily, or low impact activities, daily feet with a small amount of energy storage are preferred. These prostheses are made from stronger materials, like metal or composites, and go in a cosmetic shell that imitates an anatomical foot. These feet usually have a high level of articulation at the ankle to allow for the wearer to comfortably move their forefoot to adapt to uneven ground.

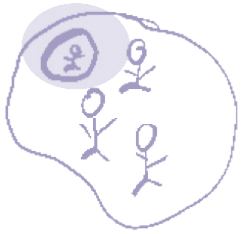
Foot prostheses designed for high impact, athletic activities are also called sports blades. These prostheses are made from carbon fiber, and store lots of energy in their spring structure. Much like an anatomical foot, the prosthetic structure compresses under high load, and releases this energy to push the foot forwards, making them ideal for running and jumping.

Figure 9: Energy storage in muscles versus in a prosthesis. Much like an able bodied runner's muscles, The prosthesis stores energy and absorbs impact that would have caused harsh reaction forces at various points on the amputee's body. (Ossur, 2021)

Figure 8: SACH foot on a baby (left), an Össur daily foot on a child (right), teenager doing a track activity on an Össur blade. (middle)

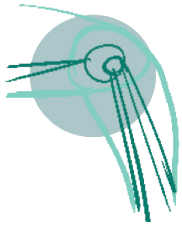
2.4 Roadblocks in Children's Protheses

The design of lower limb prostheses is governed by demanding requirements, and the field of children's prosthetics comes with additional challenges. Due to the added complexity of these products, only a few companies produce prostheses for children, and the range of designs they carry are limited compared to their adult ranges.



Statistically, children make up less than 2% of all persons living with limb difference. The market for children's prostheses is much smaller (Hall et. al, 2021), so the investment made into research and development is limited. As each unique model of prosthesis will come with its own production costs, the demand for each product must be able to offset these costs and be profitable for the company.

Children grow quickly and grow out of their prosthetics. They require new prosthetics much faster than adults, or for prosthetics to be adaptable to their growth. Hall et. al, 2020; Langley 2020)



Children require smaller prostheses with shorter build heights. Minimizing technologies to fit into this smaller form factor is challenging. For example, microprocessor-powered knees improve stability and safety, but it is very difficult to produce smaller versions of these. (Hall et. al, 2021)

Children are unpredictable and demanding in their activity needs. They are considered "extreme users" who require their prosthetics to be stronger, more durable and more flexible, which puts them in "Activity level 4", the same category as active adults and athletes. (Guðrún Sveinbjörnsdóttir, 2022; Ottobock US, 2020a)

Activity Level

Activity level, or K level, is a categorization of the activeness of a person's lifestyle. It indicates the rehabilitation potential of a person, and is a driving factor in prosthesis prescription. (Amputee Coalition, 2013)

Figure 10: Children posing with prostheses they have grown out of.

Figure 11: Child foot compared to adult foot.

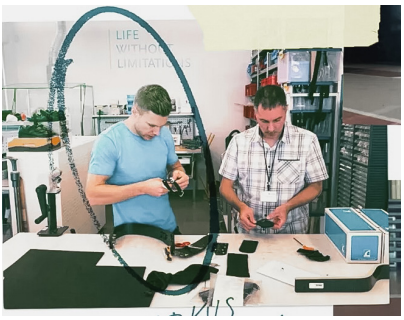
Figure 12: Children playing at the Ossur Running Clinic in Italy

Considering the added mechanical challenges and the small market size, it becomes difficult for companies to invest in needs beyond the functional in designing children's prostheses.

2.5 Össur

Össur provides the leading technological solutions for prosthetics, bracing and supports. (Össur) Prosthetics such as feet are made from silicone and carbon fiber for lightweight construction and shock absorption. Most of their offerings are designed for high and extreme impact, suitable for walking and jogging as well as sprinting and long-distance running. While Össur's product range is extensive, their focus is on providing functionality and technological innovation. Their motto "life without limitations" displays their commitment to enabling their users to participate in a wide range of activities. They collaborate with athletes to enhance their performance in their preferred sports, and use insights gained in this to improve solutions available for a larger group of prosthesis wearers.

Figure 13: Össur products & athletes



2.5.1 Össur Junior

With the motto “keeping childhood fun” Össur is looking to empower children to take part in distinctly childhood activities like play and explore the world around them. Össur’s Junior line is suitable for children between the ages 5 and 12, and focuses on movements specific to children and their anatomy. (Össur, 2021) The Junior line is unisex and comes in four sizes. They currently offer two models of liners, one knee and five feet products for juniors. Össur presents the most diverse set of prosthetic solutions across any brand. But even their solutions for children are less varied than those for adults due to limitations mentioned before.

Figure 15: Children using Össur junior solutions

Figure 13: Overview of Össur adult versus Junior solutions

2.6 Market Overview

2.6.1 Methods

In order to approach the products on the market from a wellbeing lens, it is important to establish product criteria that are rooted in the fundamental psychological needs of children. (Chapter 2.11.2)
As needs manifest differently for people of different ages (Desmet & Fokkinga, 2020), the most relevant needs for children of this age group were selected to be studied based on literature on children's development by Bee & Boyd (2010), Sharman (1995) and Acuff & Reiher. (1997) Different products and different features can help address these needs. Looking at the current portfolio of children's prosthetics and their features, toys and other children's products as well as solutions available for adults living with limb difference, I identified ways in which fundamental psychological needs in question could be embodied through products in the context of children's prostheses. From this smaller list of core needs and examples of embodiment, I specified a list of features that meet, contribute to, or answer to these needs.

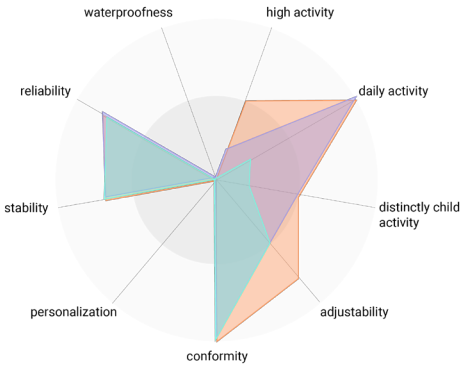
need	Significance to preteens	Can it meet this need?	Physical embodiment of how the product can answer to a need	
autonomy	y (preteens)	y	**physical abilities** (active and daily), freedom to choose **(time)**	opportunity is a cool one, individuality, self reliance
beauty	n	y	forms and colors, fairings, accessories	communal understanding of beauty
comfort	y (all kids)	y	comfort in socket, gait, **adjustability**	already addressed, mechanical problem
community	y (preteens)	y	**mimic natural look** or be represented in social groups (role models)	about conforming
competence	y (5+)	y	physical abilities (active and daily), **waterproof**, environment-proof	play spontaneity is a challenge
fitness	n	y	physical ability (active), social participation in play(recognition)	already addressed by ossur
impact	n	n	-	has not been identified as a priority for children
morality	y (preteens)	n	eco-friendliness	out of scope
purpose	y (preteens)	n	-	out of scope (too large)
recognition	y (preteens)	y	**identity:** reflecting preferences & interests of child in colors, characters, forms, accessories...	expressing identity and being accepted for it
relatedness	y (all kids)	n	-	out of scope. important for the child, but not through a product
security	y (all kids)	y	**reliability** of product and **stability** of movement it provides	already addressed, mechanical problem
stimulation	y (all kids)	y	indirectly, through enabling participation (physical, social)	allow for play

Table 1: Process of selecting a set of criteria to examine childrens' lower limb prostheses

While "Activity Level " speaks to the lifestyle of a person, "Impact Level" describes the most force the lower limb prosthesis is predicted to encounter. For example, a truck driver with a sedentary lifestyle can be categorized as Activity Level 2, for the 2-3 times they might jump out of a moving vehicle in a year qualifies them for a higher Impact Level foot. (Peter Slijkhuis, 2022) While all children are considered Activity Level 4, their ages, hobbies and goals can make different feet suitable for them. Children's products can be categorized into three groups that speak to the Impact Level of the product.

2.6.2 Market Overview Results

Low/Moderate Impact



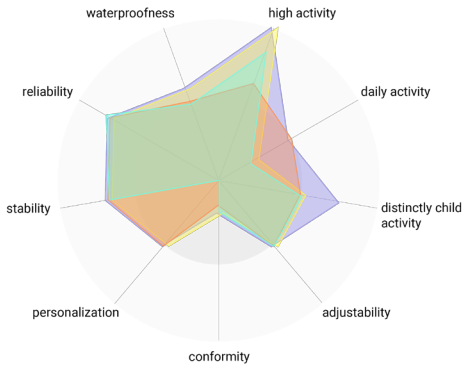
The most common and affordable option is the solid ankle cushion heel (SACH) foot, which is usually made of wood or plastic with a soft foot cover to absorb impact when walking. Made for light walking at home, these feet are preferred for younger children with low mobility and for parents who prefer a cosmetic look. (Ottobock, 2020)

Figure 16: Young child wearing SACH foot (left), SACH Feet examples (right)

For daily walking activities indoors and outdoors, dynamic feet are preferred. These feet are made from metal or carbon fiber, and can provide a small amount of energy return to allow wearers to walk with ease. (Ottobock, 2020) Some feet in this category have increased articulation at the ankle to allow for traversing uneven terrains. They come with a cosmetic cover that looks like an anatomical foot, and can be worn with shoes.

Figure 17: Ottobock dynamic foot(right), child running with a dynamic foot

High/Extreme Impact



High activity pertains to sports enjoyed recreationally that include fast-paced walking and jogging. These feet most commonly make use of carbon fiber components to store energy more effectively. The carbon fiber blade acts as a spring, and stores energy when the wearer steps on them. When they raise their feet, the blade releases this energy, giving the user an extra push. Feet designed for extreme activities can be used for running, sprinting and jumping. These feet usually cannot be worn with shoes, but must be worn with soles to increase traction and protect the composite material from impact. (Ossur, 2021)

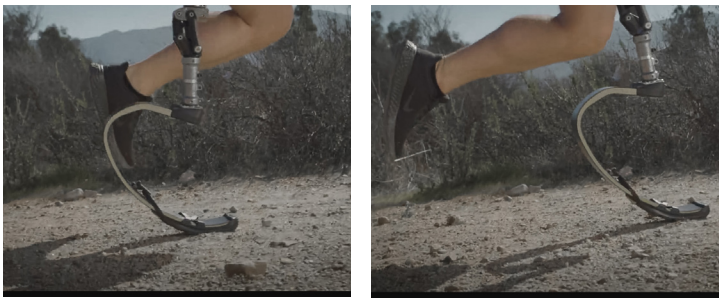
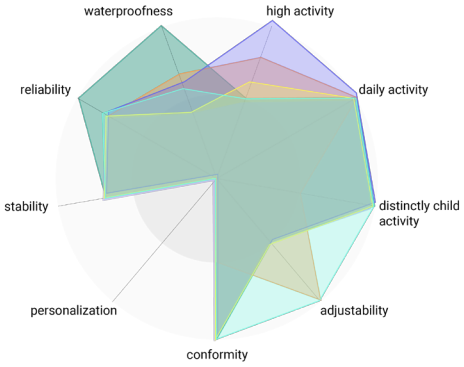


Figure 18: Ossur Running Blade in action

Figure 19: A children's sports blade from Ossur (left), a child wearing the same running foot (right)

Moderate and High Impact



These feet are a combination of daily and sports feet. They have some carbon fiber or other flexible elements to allow for comfortable running, but they also can fit into a cosmetic foot cover.

Figure 20: Ossur Flex Foot Jr

The RUSH kid foot stands out in this category due to its increased robustness. It is saltwater and dust resistant, which can allow children to play without being concerned about damaging the foot. It is important to note that these specifications from the manufacturers might not reflect the experiences of the users themselves. In a later interview, it was found that CPOs encourage children to go into water regardless of manufacturer recommendation, as they almost always grow out of the prosthesis before any adverse effects of water can be seen.

Another foot that diverges from the rest of the products is the Blatchford Mini Blade XT. With patterns and two color options, this is the only product in the children's market that allows wearers to make a cosmetic preference.

Figure 21: Blatchford Mini Blade XT in two colors

2.7 Market Insights

Division of daily/play scenarios

Even though medium impact feet exist, no foot allows for both extreme impact that would be encountered in a play scenario for children as well as comfortable daily walking. The functional requirements of the two use cases call for different kinds of mechanical builds. So no foot can allow children to continue daily activities and play football at recess, if children own two feet, they must decide which one to wear prior to the activity, before they leave their home.

Enabling Play

Play activities of children differ from exercise, as they are spontaneous with high bursts of energy. When children's play is considered, resistance to elements and combined fit for both daily and high impact activities make a prostheses a good for play.

Figure 22: Children with prostheses playing

Communicating a personal identity

As only a small number of products are available for children, there are no avenues of self expression for the wearer. For adult prostheses, third party companies offer covers for prosthetic feet called fairings that have a wide range of colors and designs available. Sockets are not mass-produced, but made for the person by a prosthesis maker, so it is possible for them to add an artwork of the wearer's preference. So for children, some amount of personalization is possible at socket level.

Figure 23: UNYQ and Cekoon as popular third party brands to produce fairings for prosthetic feet

Figure 24: Color and design options in children's sockets

2.8 Understanding Children

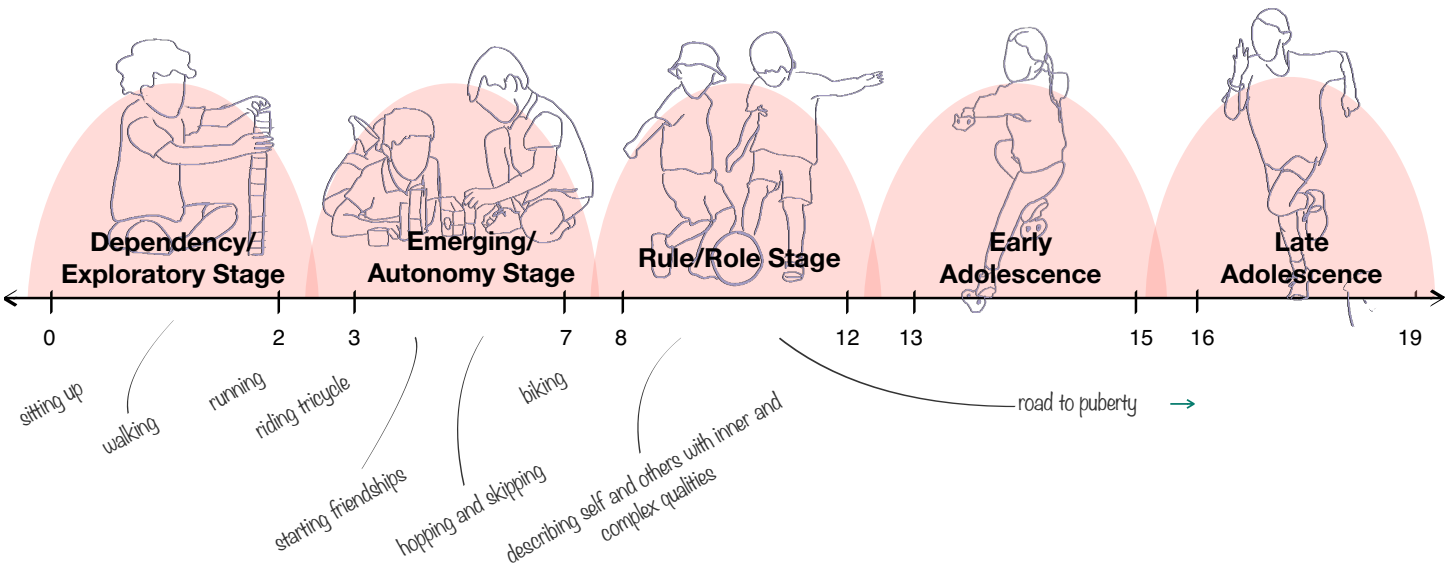
"A child who has an amputation, or is born with a limb deficiency, is on an unlimited forward trajectory. We can't define how disabled they will or will not be. They're focused on growing, getting better, more functional, and feeling more powerful."

- Andrew Pedtke, MD, orthopedic surgeon

2.8.1 Developmental Milestones

The majority of prostheses are designed for the elderly. This is a group who is well set in the way they live, certain of what their capabilities are and in activity levels. In this sense, children as prosthesis wearers are very different. They are continuously learning about their capabilities, mastering new skills and discovering their interests. By the time children reach 8, they have mastered most basic mobility skills such as walking, running and jumping, and are constructing close relationships with their peers and playing in complex and diverse ways.

Figure 25: Overview of developmental milestones of children. (Bee & Boyd. 2010; Sharman et al., 1995)



2.8.2 Rule/Role Stage

Ages 8-12 are referred to as the Rule/Role stage: children in this age group are curious about how the world around them functions and where their place in it will be. One manifestation of this is strong attachment to role models. Adults around them such as parents and teachers, as well as celebrities and other figures in popular culture pose as examples of how they can think, socialize and dress.They adapt their behavior to emulate their role models. (Acuff & Reiher, 1997)

Acceptance amongst peers is also important for children. Between the ages of 8-12, children display peer-oriented thinking: they look to form and display their interests, and to gain recognition from their peers for it. All thoughts and decisions go through a "conformity filter": What are the social rules around them? Do they belong with their peers? This need manifests itself in how children partake in group activities like clubs, team sports and social play. In these environments they wish to display their newly-constructed identities. In this sense they are egotistical, they love personal and customized products that will give them a sense of self worth. (Acuff & Reiher, 1997)

Preteen ages lie in-between early childhood and adolescence. Children at these ages look to position themselves as grown-ups as they push away concepts they deem to childish, at least outside of home. Acuff calls this the "billboard effect": clothes and products they bring outside of home are viewed as manifestations of their identities, so they start to become mindful of what can be worn or displayed publicly.

In contemporary societies, independence is increasingly valued where we are directed to look internally for self-worth and shut out external comparisons. From this perspective, preteens' needs of fitting in, following trends and brands and looking outwards for a sense of identity can be interpreted as superficial and shameful.

8-12 years old is a formative period regarding a person's identity, conclusions people make about themselves and where they fit at this age will most likely reach adulthood. (Acuff & Reiher, 1997) The worries and motives children have in this period are appropriate for their age and necessary in finding their identities and how they perceive they will fit into the world. Validating, enabling and facilitating these fascinations and interests can serve the psychological wellbeing of a child.

Play is a natural process and is essential for all children. (Canning, 2007 ; Ginsburg, 2007) The benefits of play extend into all areas of child development, from cognitive to physical and psychological. Through play, children can practice and master physical skills, digest the world around them, and practice social skills necessary in adulthood. (Poitras, 2016)

2.8.3 Role of Play in Children's Lives

As children grow up, their play patterns change. While younger children play primarily solitarily, their need for increased complexity and social interaction push older children to play more with peers, and within groups of the same gender. They seek increased detail in toys, and are drawn to richer complexity in audio and visuals. They enjoy collecting things like cards or action figures and displaying their collections. (Acuff & Reiher, 1997)

Play between the ages of 8-12

Examples of toys that successfully meet the concerns of the children and present them with engaging play scenarios at this age are video games and dolls. Dolls, specifically Barbie, have remained a popular toy for preteen girls, and rightfully so. With a wide range of professions, Barbie serves as a role model for any child. The level of detail of the Barbie dolls, as well as the clothes, accessories, animals and props are very high. This extended range of products also enable a wide variety of play. Children can play by themselves, or with friends. They can dress up the dolls, enact fantasy play scenarios, role play and collect and display their collection. Video games on the other hand, are able to present rich audio and visual experiences and challenge the motor skills of their players. The complex storylines push children to think logically and with the wide selection of options, it is possible to find games that speak to the interests of any child. (Acuff & Reiher, 1997)

Children's increased attention to detail manifests itself in crafts skills and toys as well. These products, like knitting, painting and jewelry making sets empower children to express themselves visually, allow them to adorn customized clothes and accessories and express their individuality.

Figure 26: Video games are vibrant and high in action, whereas Barbie presents a wide selection of highly detailed figurines and accessories to be collected

Impact on prosthesis design

Play occupies a monumental role in children's development and wellbeing. While we all could benefit from more playful designs, products designed for this target group must address desired play scenarios of children. Not only will this result in products more relevant to the target group, but potentially benefit their long term wellbeing.

When children are put into the same category as professional athletes in Activity Level, we are making the assumption that the activity profiles of these two groups are similar. While both groups display high activity and have the most demanding physical activity needs, training for athletes is scheduled and their activities are unvaried. Play for children, on the other hand, is complex and diverse, with bursts of unpredictable high energy movements. Founder of RUSH Prosthetics J. Blount Swain states how current exercise prostheses are challenged by children: "There's a presumption that a lot of children want to run—but they're not running the 100-meter dash a lot— they're out being more creative than that" (Otto, 2016) As children do not plan for play, an ideal prosthesis must be ready to face anything a child might throw at it. It must allow for a combination of daily movements and high impact activity and be resistant to the elements children might encounter day to day like water, sand, dirt. An exploratory questionnaire on play behavior of children with lower extremity prosthesis confirms that play behavior must be considered when designing prostheses for children: "Hopping, skipping, jumping, and other distinctly childhood fundamental movement skills deserve their own attention and child-specific solutions" (Kerfeld et al., 2018)

2.9 Meaning of Prostheses

“The choice to wear it [a prosthesis] (or not) is not morally neutral: it is an expression of the person one wants to be, the life one wants to lead, and the values one wants to endorse. (Medard Hilhorst, 2004)

Products obtain and convey meaning with respect to the identity of their users, and prostheses are no different. Wearing a prosthesis is sometimes preferred, as it signals competence and conventionality and not wearing one and using an alternative support like crutches can be viewed as asking for help. One prosthesis wearer recounts that even within a scuba-diving club he is a part of where all members know he has one leg, people will try to clear the way and help him when he comes in with crutches, but will not offer similar accommodations when he wears a prosthetic leg. (Murray, 2005)

Wearing prosthetics can help mitigate reactions of outsiders by looking more conventional. (de Jong et al, 2012) One prosthesis wearer states that their brother ”cannot stand to see me without a limb on” so she chooses to wear one even when she does believe she needs to. (Murray, 2005)

Similarly, anatomically conventional prostheses are preferred when the wearer wants to blend in, and more colorful prostheses with more distinct forms are preferred by people who embrace their body as it is, and do not hesitate to communicate their difference to outsiders. (Hilhorst, 2004) Specialty prostheses, like a running or jumping blade can convey the competence of its wearer as they require a certain amount of skill and interest in the sport to be prescribed. These considerations allow people with limb differences to align themselves with groups they want to belong to, and distinguish themselves from ones they do not relate with. (Hilhorst, 2004)

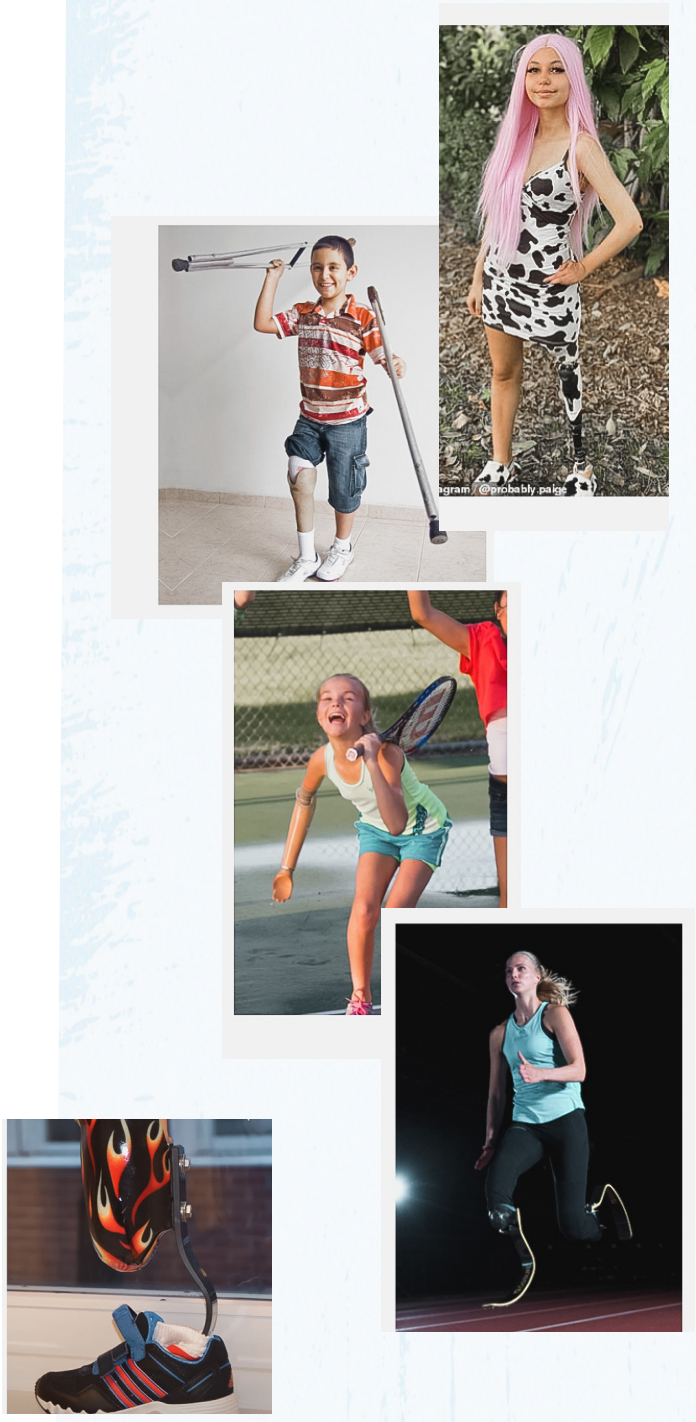


Figure 27: Prostheses convey messages regarding their wearers

2.9.1 Prostheses and Identity

Body Image

Wijk reports that for forearm amputees, the relationship between a prosthesis and person is complex, and the prosthesis is expressed as a part of the person's identity, rather than their body. Wijk et al, 2015) Its extent of impact also depends on the wearer's sense of agency. For example, one participant reports that their prosthesis' impact on their body image is a very automatic feeling. "When I take it off, my arm ends where it really ends, but when I have the prosthesis on it ends where the prosthesis ends" (2015) Some people experience their prostheses as not a part of their bodies but as a foreign part like a tool or a fake hand. They described their prosthesis as "being like a part of their clothes or shoes, just something they naturally put on when leaving home" one recounted that "Being without the prosthesis felt like being undressed, and was described as like being without make-up or a bra" (2015)

The foot prosthesis exists in close proximity to the body for long stretches of time, and unlike a hand prosthesis, its wearer must rely on it for mobility in those periods. How the prosthesis itself and the wearer's sense of agency impacts their body image should then be an important consideration in understanding the relationship between a person with limb difference and their prosthesis.

Display of Identity

Hilhorst writes that a prosthesis is a more permanent display of identity than clothes. (2004) While we can change out of clothes and phase out garments we no longer relate to, a prosthesis is there for a child to wear every day for months at a time. For preteens, here we can recall the "Billboard effect", that preteens view their garments as a way to display their identities to their peers. The prosthesis can allow its wearer to make a stronger statement about their identity, like a tattoo, and facilitate the process of acceptance and recognition. This is an opportunity only children with prostheses have. If the child grows out of an interest before they do of the prosthesis itself, or if the prosthesis was a mismatch with their identity in the first place, then the consequences can be more dire as well, comparable to wearing an embarrassing shirt to school every day.

Function and Meaning

The meaning of a prosthesis is not only related to its visual attributes, but can come from its functions as well. In "What Can a Body Do?" Sara Hendren writes about Cindy, a quadruple amputee, who has had many complex prosthetic hands, but the one she appreciates the most is a "pen cap". This prosthetic was made especially for her by her prosthetist team to enable her to write thank you notes in her own handwriting. Cindy has made the pen cap prosthesis a display of a trait she is proud of, a display of her identity. (Hendren, 2020)

Figure 28: Cindy and her pen cap

2.9.2 Meaning by and for others

Product Stigmacity

Meaning of the prosthesis is not only constructed by its wearer, but is also shaped by the context, the people the prosthesis and its wearer are surrounded by. According to the WHO, disability is an interaction between features of a person and the overall context in which the person lives. (WHO) As meaning occurs in relation to reactions from others, people who interact with the child and the product also take part in the meaning-giving process.

In a study on product stigmacity, Kristof Vaes conducted an experiment on how bystanders perceive people who wear mouth masks. He found that when people wore masks that were colorful and playful, they were considered more approachable and likable compared to wearing more neutral-looking medical masks. They conclude that stigma around disability is a response from the bystanders, and does not emerge from the user. (Vaes, 2014)

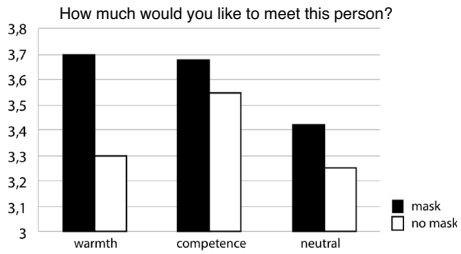


Figure 29: Vaes study on stigmacity of dust masks with different designs

Reactions to Prostheses

Wijk found that some amputees chose to wear prostheses in social situations to not attract any unwanted attention, they wanted to blend in and feel “normal”:

“It is very important if you think about how I am looked on in relation to other people around”

“I’d feel naked somehow, that something is missing, for it is after all, a part that should be there.” (Wijk et al, 2015)

Negative emotions towards one’s own prosthesis often arise in social settings, and in relation to other people. Children and adolescents with forearm deficiencies report experiencing shame, being different from peers, being fed up with their limb deficiency and wishing to be more like everybody else. (de Jong et al., 2012) This can be harmful to children as Vaes finds that responses to stigma include stress, anxiety, increased vigilance and working memory load, which leads to long-term outcomes of lowered self-esteem and reduced social interaction (Vaes, 2014)

Reactions of others can have a positive effect as well. In a study on upper limb differences in pediatric patients, de Jong et al. reports that “positive feelings towards deficiency are also from the way the environment reacts to the child’s deficiency” (de Jong et al., 2012)

The wearer’s attitude towards their prosthesis and their sense of body image does not only change with the reactions of bystanders, but it evolves as one grows as well. Especially for children with upper limb differences, younger children often do not feel the need for a prosthesis, (de Jong et al., 2012) and some children do not consider themselves different from their peers. (Hilhorst, 2004) In teenage years as children become more aware of themselves and others, it becomes more important for them to blend in, thus the need for a prosthesis increases. (de Jong et al., 2012)

2.10 Confidence and Participation

Negative interactions children experience when they are in public, as well as their perception of their own physical abilities can lead to an avoidance of public and social interactions. Socially, children with disabilities suffer as they are more restricted in participation in day-to-day life situations. (Michielsen, Wijk, Ketelaar 2010) The underlying causes are found to be primarily physical and social. Physically, these relate to children's functional abilities and social causes vary from attitudes of community members and family or the social competence of the child. (Michielsen, Wijk, Ketelaar 2010) Disability then is not a static condition, but it changes with respect to the individual children, the situations they are in and reactions they encounter from others.

2.10.1 Participation and the Social model of disability

The social model of disability takes into account the contextual factors a health condition is encountered in, and how these affect the body function & structure, activity and participation to reach a more particular definition of disability. (WHO ICF)

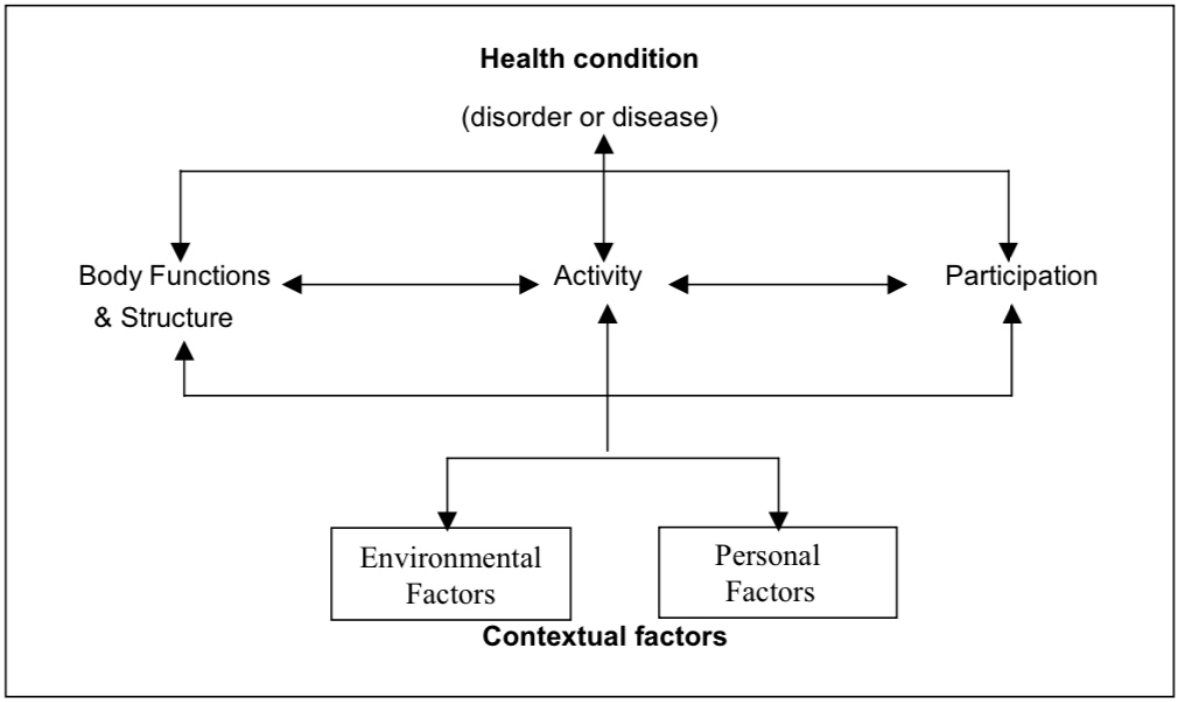


Figure 30: Social Model of Disability (WHO)

According to this model, a health condition can create disability at three levels. How it changes body structure or functions, how and to what extent one can take part in different activities, and the overall participation of the person. For preteens, for whom socializing with peers and understanding their place in the world through exploration is a point of focus, decreased participation can pose a barrier for their development.

Participation

Participation is defined as one's involvement in life events. This can be in a game during recess, or important events like one's graduation

Competency in each activity people encounter, other personal factors, as well as environmental factors will create a shifting understanding of one's disability and confidence, which will inform their next action, participation or avoidance. A comprehensive understanding of disability takes into consideration the context of the person in terms of the activities they take part in and people they are surrounded by.

Self esteem is a primary factor that affects participation. Poulsen et al., reports that lower self confidence and perceived peer rejection in children with and without disabilities contributes to a general decrease in physical activities. (Poulsen et al., 2006) Confidence can help facilitate increased participation. Understanding what makes up confidence and how it affects preteens could help designers facilitate it.

Confidence, or having faith in oneself is then a twofold occurrence, one must both believe in their competence, their physical ability and skill set to conduct an activity, and feel recognition that they have the respect and appreciation of the people surrounding them.

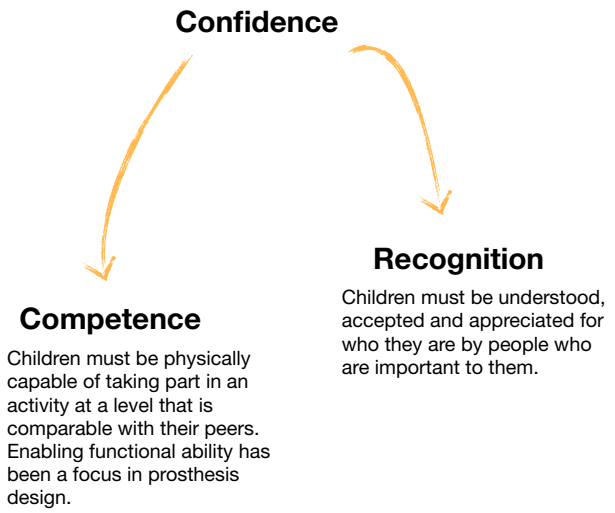


Figure 31: Components of confidence

From a social development perspective, the primary focus of preteens is their peers. Recognition from peers is important for preteens.

"Higher perceived social support, especially classmate support is correlated with higher self esteem in children with congenital limb deficiencies"
(Hilhorst, 2004; Michielsen, Wijk, Ketelaar 2010)

Even though peers are found to be the most impactful people in preteens' lives, children's primary caretakers are also impactful in forming their sense of acceptance. How they view the physical capabilities of their children affects what they will encourage them to do, and if they will hold them back due to concerns of physical safety or fear of rejection.

Let us examine the accounts of two parents on their children wearing leg prosthesis:

"He will sometimes do activities that are too dangerous for him, or he cannot do, because everyone else is doing it" (Kerfeld et al., 2018)

This parent views their child to be deficient for this condition, and is more likely to hold them back from testing their physical boundaries to ensure their safety.

"You should never assume their ability, let them discover their limits" (Ashby-Coventry, 2020)

Meanwhile, this parent is likely to allow their child to discover their own boundaries, expose them to more opportunities and let them take more agency in their lives.

The interactions children have with parents are not limited to social settings, parents often serve as the translator between their children and others, and are the decision makers when it comes to their children's treatment, and prosthesis selection. Parents then not only affect how the child perceives themselves but also have agency in how the child and their prosthesis interact.

For example, parents are found to prefer natural prosthesis for their children, as they fear their children would not be socially accepted and they prefer their children to blend in with their peers, "for it is difficult for them to accept that their child is visibly different", which is at odds with their children's preferences, who were found to prefer more colorful and playful designs. (Hilhorst, 2004) In the "meaning" section we uncovered that an unapologetic prosthesis can convey a message of confidence to bystanders, that the wearer is not trying to hide their assistive device.

Impact on prostheses

The prosthesis the child wears can contribute to the wearer's self esteem through enabling physical competence, facilitating recognition and allowing them to increase their control over the various environments and situations they encounter.

Ideally, prostheses should enable their wearers to be equally as competent as their peers physically. In addition to offering physical support and mobility, prostheses designed for children of all ages must allow for spontaneous bursts of high activity that define play. The expectations of children who have a congenital difference versus an amputation can differ in terms of what physical goals they have. While any prosthesis that increases the mobility of children with congenital differences is likely to impact their confidence positively, as it helps them do things they could not do before, like walk for the first time, amputees who have had experiences living with two legs from birth and are adapting to a new situation following a trauma, most likely compare its functionality to a past experience. Their prosthesis is likely to not match their expectations in terms of mobility.

To increase their sense of recognition, children must have avenues of building and communicating their identity. Prostheses can allow for children to display their preferences and identity. Children consider any garment or gear they display publicly as a reflection of their identity. As an object the child prefers to wear when they are outside, the prosthesis has the opportunity to assist children in displaying groups, communities and traits they would like to be aligned closer with. As preteens are susceptible to peer-oriented thinking, a prosthesis that clashes with their perception of their identity can lead to decreased confidence.
In addition to positive peer, bystander and parental reaction, agency, a person's control over their disability, be it physically or in image, is found to increase self-esteem. (Dunn, 1996) Whether this entails an ability to cosmetically conform to the expectations of people around, physically perform up to their expectations, or something else altogether, depending on the context the person exists in. As the social model of disability demands a changing set of needs and expectations, then a prosthesis that allows for a child to adapt to shifting environments throughout the day will give them the most control over their disability.

2.11 Product Experience

From an industrial design perspective, experiences of users with a product occur on three levels: aesthetic gratification, the extent to which a product is pleasing, meanings we attribute to the product and the emotions the product elicits. (Desmet & Hekkert, 2007) Emotions are a part of our everyday lives, and this includes experiences with products we use as well. Morris Holbrook, a researcher in consumer behavior, considers emotions an important component of our consumption behavior and a key understanding in product experience. (Holbrook, 1982) For example, we might feel excited to wear a new pair of running shoes, or the sight of an iPod can leave us in admiration or a remote with many buttons in hesitation.

Emotions serve the wellbeing of the person. Don Norman reports that positive emotions are critical to learning, curiosity and creative thought. We tend to approach problems with more creative, out of the box solutions when we are in a happy mood. (Norman, 2004) Being able to systematically approach and unpack product emotions can allow us to understand the experience of the user in relation to a product, and its impact on the wellbeing of the user. This section introduces various theories that relate to emotions experienced in relation to products, and put them in context of the user.

2.11.1 Appraisal Model of Emotion

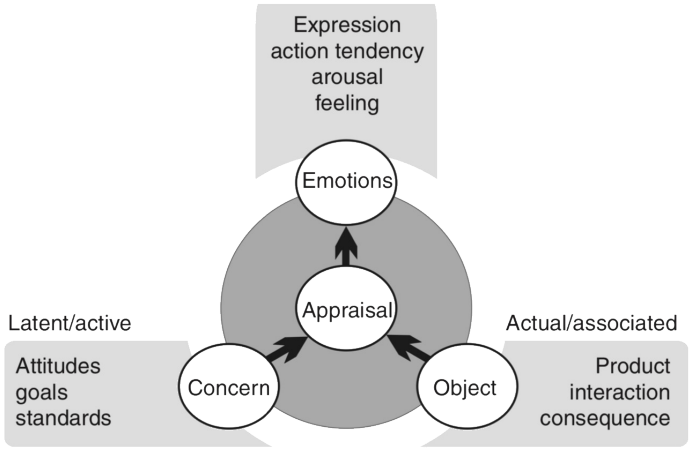


Figure 32: Basic Model of product emotions (adapted from Desmet 2002)

Emotions are reported to have functional benefits. They establish our position with respect to our environment and encourage us to move towards positive, safe or good experiences and avoid negative, bad or dangerous ones. (Arnold, 1960) This process of evaluation, assessment and assignment of value judgment is the foundation of the basic model of product emotion. (Desmet, 2008) The internal assessment of a situation with respect to its impact on our wellbeing is called appraisal. Desmet elaborates that this framework, which explains the process that elicits emotions is primarily universal. (Desmet 2008)

In this framework, emotions are directed towards a stimulus which can be a product, its usage or a resulting consequence. Emotions stem from a concern, which can be an attitude, a goal or a standard that is attributed to a product by the person. Based on this combination of a product stimulus and our internal value system we appraise a situation and experience an emotion in response to it.

Motives are manifestations of our values in specific situations. The concerns we experience regarding a product, needs we have, expectations we place on the product and ourselves, or goals we set in relation to it make up our “motives”. (Desmet, 2021) Desmet and Hekkert illustrate how this framework functions through numerous examples: “ We can experience joy in response to a mobile phone that we appraise as matching with our concern of being in touch with our friends, desire towards a new car model that we appraise as matching with our concern of mobility, frustration in response to a chair that we appraise as mismatching with the concern for comfort” (Desmet & Hekkert, 2007) Emotions can then tell us about concerns, needs and expectations people have regarding products.

Emotions and appraisals are context dependent. Desmet states that it is essential to investigate the users’ concerns given the context in which the product appears in. (Desmet, 2008) If our expectations are different, our emotional responses will be different as well. Let’s take waking up in the morning as an example, a person who is to meet a dearly missed friend will welcome the morning alarm, as it indicates the beginning of the day, but someone who has an exam might find the same alarm irritating and experience fear in hearing it ring.

2.11.2 Fundamental Psychological Needs

Even though people and lived experiences are rich and complex, several researchers were able to identify trends in motives people share. The Fundamental Psychological Needs Framework is the most extensive and recent of these and has been compiled with a design context in mind, which is why it has been selected to be used in this project. The research identifies 13 fundamental psychological needs people have, and states that fulfilling these will contribute to one's well being. Adopting this framework to investigate user experience will give us a comprehensive overview of a product's ability to aid its user, and help designers understand why a product elicits a positive reaction or identify or predict causes of potential dissatisfaction. For example, a garden gate that does not lock will fail to meet our need for safety, whereas we might prefer an open office as it increases our sense of closeness to our coworkers, addressing one's need for connectedness. (Desmet and Fokkinga, 2020)

In the case of children's prostheses, a sports blade will contribute to the competence of its wearer and enable them to fulfill their need for fitness as it will allow them to keep up with their peers in running and jumping. A lifelike cosmetic hand prosthesis on the other hand could be welcomed for its sense of beauty over a simple hook prosthesis.

Leveraging this information on how emotions emerge, what they relate to and what needs serve our wellbeing, we can design products that better fit the end users. Emotion driven design is the practice of designing with this kind of intention to encourage predefined targeted emotions. (Desmet, 2016) The design process prioritizes understanding the current relationship users have with products to use it as a starting point to minimize negative affect and boost positive moments of interactions.

2.11.3 Types of Knowledge

User insights are often welcomed in design. In asking someone about their opinions, we can get information on what they are currently thinking. These kinds of insights the user is aware of and can share when asked are called explicit or observable knowledge. But in using a product every day, we form complex relationships full of expectations and emotions, full of habits that speak to needs we might not be aware of or voice explicitly. These kinds of information only seems to exist in the context and duration of the interaction, but inform our experience with a product as much as opinions we share with others. (Sanders & Stappers, 2012) This can be knowing that a door that only locks when pulled tightly, or that a certain plate makes a lot of noise when placed on the coffee table, or that the handle of a particular mug gets too hot to hold, so one must hold the cup on its rim.

Motives fall into this implicit knowledge category. As emotions stem from these motives, it can be possible to uncover them through emotion-driven approaches. Desmet views emotions as "gateways to what people really care for". "All the positive and negative emotions that are experienced in the context of using a product are viable entry points to understand what people really want, need, and expect in that situation" (Desmet, 2016)

Laddering

Emotions are difficult to realize and challenging to verbalize for most people at varying degrees. Emotion-driven research focuses on capturing emotions in the moment and recording the eliciting conditions. These can later be processed with the person to uncover their underlying motives, or mapped to get a general picture of the overall user-product interaction.

One technique to uncover motive hierarchies is laddering. Laddering is an in-depth interviewing technique in which product attributes and personal reactions to these attributes are linked to personal values. (Desmet, 2021) Based on Jonathan Gutman's Means-End theory, it studies "How consumers translate the attributes of products into meaningful associations with respect to self-defining attitudes and values" (Reynolds & Gutman, 2001) With a personal motive derived from an experienced emotion as a starting point, the ladder reveals how motives link to more general goal, values and needs of the person. (Desmet, 2021)

2.11.4 Emotion Driven Design and Children

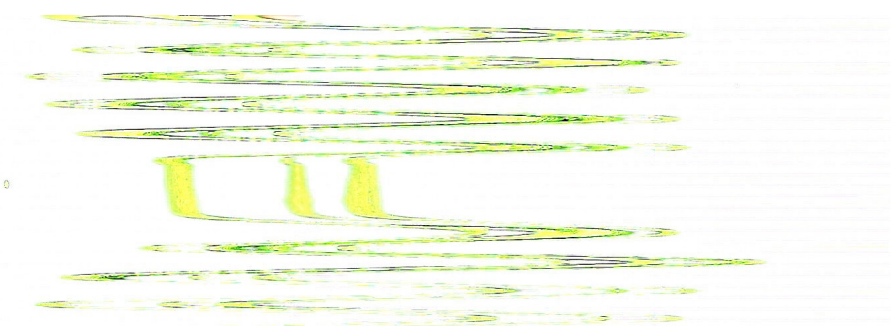
Emotion driven design approach can be a powerful tool in conducting this project on user-centered redesign of children's prostheses for its emphasis on unvoiced and unmet needs, its ability to unpack complex and shifting product experiences and its resultant insights are robust and rooted and rich as they are rooted in lived experience.
Children differ from adults in their cognitive and language skills. They are learning and growing. Interview methods designed with an adult perspective in mind need to be adjusted for their attention and interest. For example, children cannot think in abstract ways, so it would be challenging for 8-12 year olds to voice dissatisfaction regarding a product when asked in an interview setting. They need to be engaged in the context of the product interaction, and be asked their experiences and opinions in concrete scenarios. Preteens for instance have only recently gained an understanding of self at the age of 6 (Bee & Boyd, 2010) so their understanding of their needs and awareness of the impact of everyday experiences is newly developing. They lack granularity in emotional vocabulary, and cognitive refinement as they think in black and white. (Acuff & Reiher, 1997)

Designers can benefit from an emotion driven and human centered approach in obtaining insights into children's lives and in evaluating the fit of a product as they focus on the context. They collect information through stories that can be later abstracted away to reveal trends. Emotion driven design can be a powerful tool in uncovering their needs and designing products that are rooted in their concerns, which can in turn elevate their day to day experiences and contribute to their wellbeing.

The experiences of disability and assistive devices are not stagnant, but change depending on activities one is participating in, people they are surrounded by and the emotional climate of the person, Medard Hilhorst, a professor of Medical Ethics in Erasmus University Medical Center states that we cannot approach a limb difference as a purely physical situation, the observation that a limb is missing. The understanding, or the judgment of the situation is not restricted to a matter of taste or subjective preference with respect to one's bodily looks. He states that the "value judgment", or how the prosthesis impacts one is "rooted in the everyday experiences one has when dealing with the device" (Hilhorst, 2004)

The experience of wearing a prosthesis changes in relation to the daily situations the wearer experiences. Thus, he concludes that the "prosthetic fit", the assessment of what kind of prosthesis one might need is not only a medical one but a personal and social issue. (Hilhorst, 2004)
Emotions give us an understanding of the needs, values and expectations of the prosthesis wearer through a shifting and contextual lens. Through uncovering hierarchies of needs of the wearer, we can gain a better understanding of their values and motives. We can understand them not as patients but as people. Hilhorst states that this is what we must aim to understand to uncover a prosthetic fit: " by reflecting on a person's life history, we can understand the idea of 'prosthetic fit' as normative, in that it is grounded in a person's fundamental convictions with regard to his personal identity. It is linked to an idea about what it is to be a person and shape one's future; it refers to ideals, aspirations, expectations, etc." (Hilhorst, 2004)

Emotion driven design methodology focuses on studying the experiences of singular individuals. It aims to collect stories, observations and concrete manifestations of product experience. The resulting learnings then are rich and in depth, especially when compared to surveys or conventional interview settings. The experiences of one can be used to investigate the convictions of a larger market segment. Upon validating findings with a larger representative group, and placing the needs of the individual in the context of the market, niche insights that scale up to a larger dataset provide true value for the designer. (Seemann, 2012) They pose new opportunities, as they stem from latent needs that are unreachable in quantitative approaches, and can result in human centered solutions that can scale.



Children are “extreme users” of their prostheses, with high activity levels and potential to improve athletically.

Preeteens want to be recognized and accepted for who they are by their peers and parents

A prosthesis conveys a message regarding its wearer’s identity to the outside world

Confident children have increased participation in life events which increases their social activity and wellbeing

Control over their disability in how it is presented can increase the person’s confidence

Figure 33: Takeaways from literature research

03 Methods

Children differ from adults in anatomy, activities they partake in, and their view of themselves, and children with limb differences are no exception. Using the recent work in human-centered design and co-design with children, it is possible to obtain an in-depth understanding of the complex relationship children with limb differences construct with their prostheses. The insights in this line of research is rooted in the children's behavior, psychological needs and emotional responses in daily scenarios. These insights provide tangible ground for design decisions that prioritize children's emotional wellbeing.

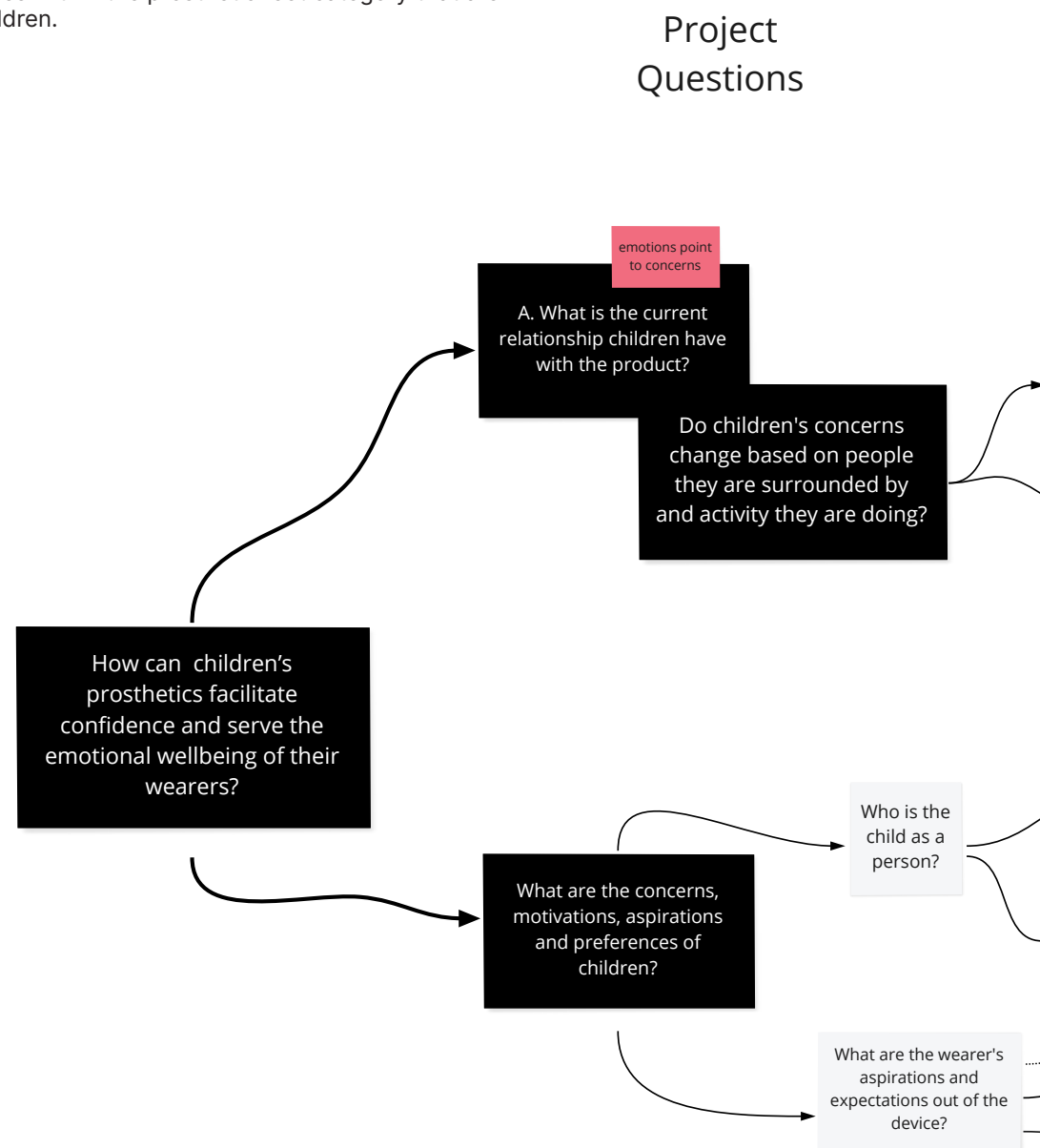
3.1 Developing Research Methodology

The aim of this project is to develop a methodology to make use of children's latent and tacit knowledge regarding their prosthesis and to demonstrate the method through the redesign of a product within the Junior line. The research phase of this project explores how children living with lower limb differences view their prosthetic devices, and how their expectations change in different daily scenarios. By getting a better understanding of the product-user relationship, we can identify how the prosthetic feet made for children must change to better serve the emotional wellbeing of the wearers. This section details the research questions formed in the scope of the project and outlines how they inform the sessions conducted with participants.

3.2 Research Questions

The research questions that guide the interview sessions relate to these personal motives and uncovering motive hierarchies children construct. Once we are able to get a sense of the child's identity and values, we can probe how their concerns change based on changing contexts they are surrounded by, such as the people around them at the time and the activity they are doing.

By answering these questions, I hope to gain an understanding of what children within the age group value and track the dynamic changes the product must adapt to and study to what extent it is currently able to fulfill the wishes and needs. This way, I can identify product opportunities within the prosthetic feet category that are rooted in the needs and wishes of children.



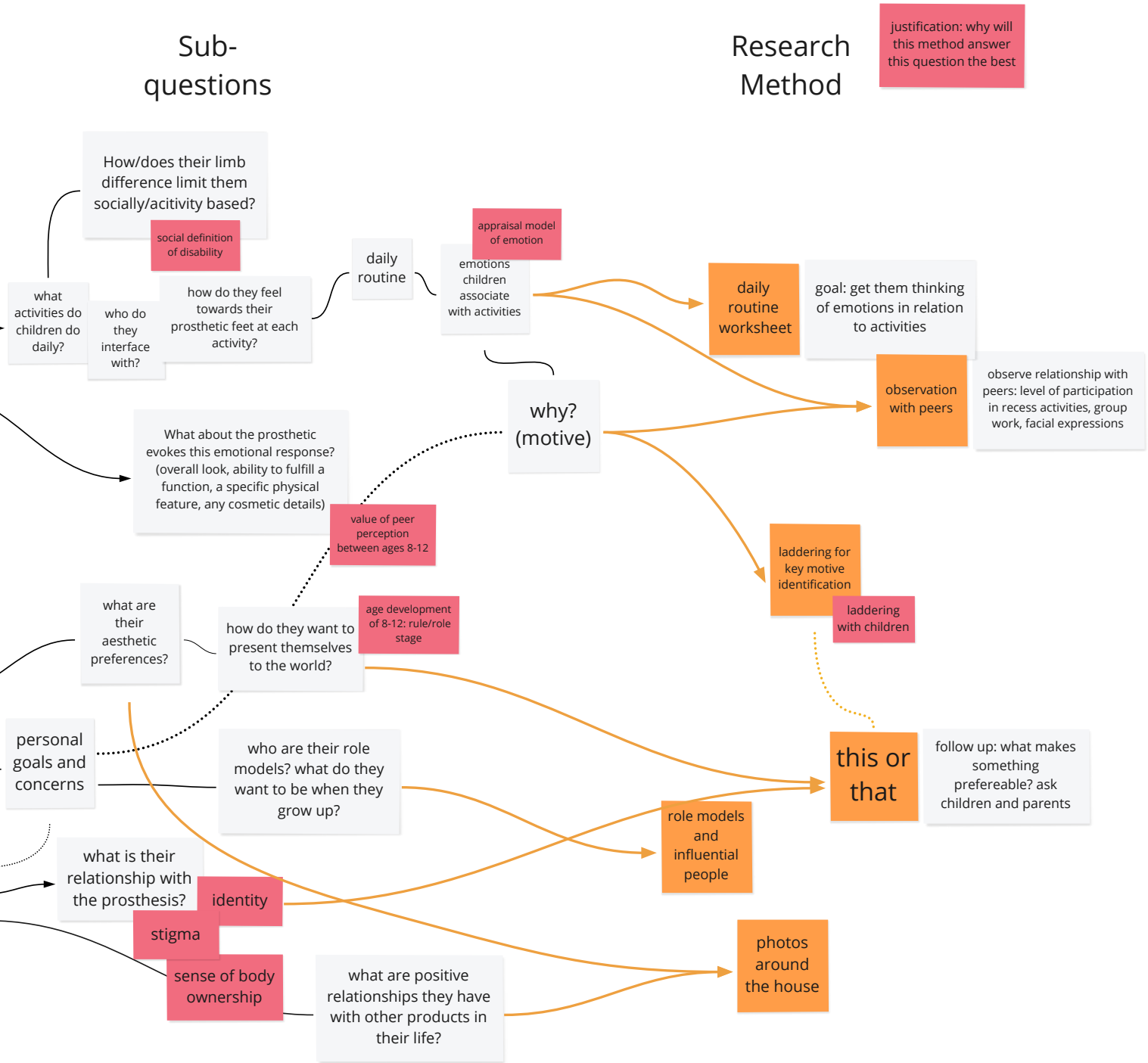


Figure 34: Overview of research questions exercises that can provide answers, and research the exercises are inspired by

3.3 Interviewing Children

Research into the emotional, social and cognitive development target age group as well as co-creation methods and interviewing children was conducted for takeaways to be adapted in the interview sessions. This section outlines the findings of this research as they relate to interview methodology.

Most intuitively, the interviews must be kept within the attention span of the children by making them short and engaging. The questions and materials presented should fit their interests.

1. Tailor conversations to children's interests

As the target age group is between young childhood and teenage years, their interests lie in between as well. Material presented to them should not be too childish, but also not too boring. Acuff states that as children "aggressively push away childish concepts" to distinguish themselves from younger children, it becomes especially important to ensure the material presented to them speaks to their new-found tastes. (Acuff & Reiher, 1997)

A visit to the children's library revealed a popular visual style amongst the current top fiction books for the preteen ages. This hand-drawn art style was adapted in all materials prepared for the interview sessions.

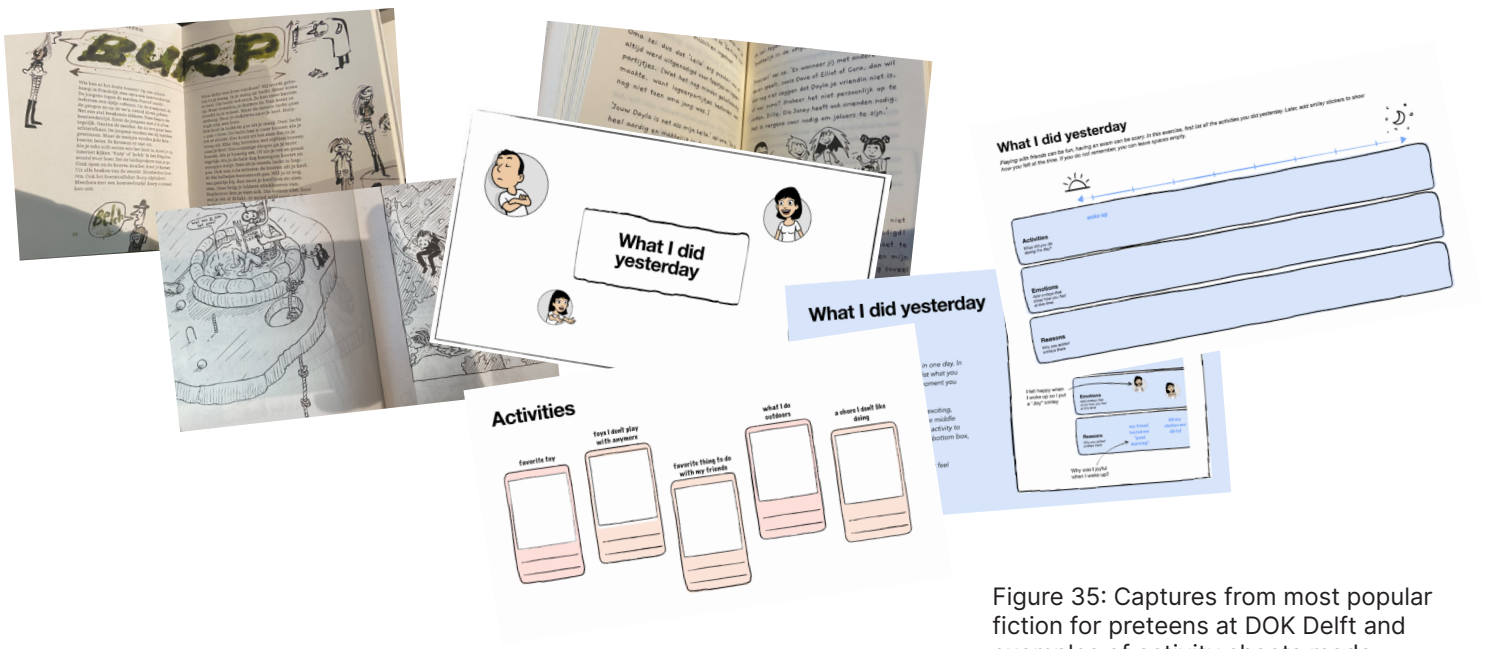


Figure 35: Captures from most popular fiction for preteens at DOK Delft and examples of activity sheets made

2. Assign roles

Multiple accounts state the impact of "assigning roles" for increasing children's attention and interest. Gielen (2013) notes that the sense of being on a mission, for example being handed a camera as a reporter, intensifies the attention of children to the activity at hand. Similarly, Paula Koolmess, a child psychologist states that assigning roles, for example making them the specialist, would increase their enjoyment in sharing personal stories and emotions. (2022)

3. Keep questions concrete

As for communicating emotions, Gielen reports that children are able to handle abstract topics if they are presented through concrete examples that relate to their lives. (Gielen, 2013) This finding is repeated by Freeman and Mathison in their book Researching Children's Experiences. In interviewing children, they advise staying away from abstract thinking and formulating questions into concrete cases they can place themselves in. (2009) Another manifestation of this principle is asking for justification of choices children make. Zaman & Abeele recommend that rather than asking about a standalone concept, asking children to compare it so something they consider superior or inferior can help the interviewer follow the values of the child through their decision-making process. Utilizing laddering technique to uncover the means-end hierarchies in the context of comparison is recommended. They have found the "think aloud" method in which the participant is asked to vocalize their thinking to be burdensome for children. Laddering on the other hand was able to work with the cognitive differences of children as it is gated and incremental in questioning. (Zaman & Abeele, 2010)

4. Keep it in context and allow children to experience first

According to Jean Piaget, children learn through experience. (Ackermann, 2001) Children find it easier to talk about something after experiencing the interaction or having the product in question be physically present. (Zaman & Abeele, 2010) In creative sessions with children, Gielen reports that the value is in the direct reaction children have to what they encounter. The researchers must pay attention to the direct encounters the children have with the context being studied. For example, for a project regarding outdoor recreations, being in nature, and having to justify their reasons to capture images of outdoors, children shared insights regarding what nature means to them and what they enjoy doing outdoors more concretely than when in a traditional classroom setting. (Gielen, 2013)
This also means that the interviews will be more fruitful, and the cognitive burden on children will be reduced if sessions are conducted in the context being studied. Research at home or school is preferable over a laboratory setting. Attention should be paid into where the children would encounter the product or subject in question. (Zaman & Abeele, 2010)

5. Shift away from a right or wrong mindset

As children generally encounter adults in positions of authority, they come to assume this relationship with any adult they meet. This relationship can be challenging for a creative interview session, as children think in terms of right or wrong in answering questions. (Gielen, 2013) To shift the tone of the session to one of sharing, where every contribution is appreciated, icebreakers are recommended. (Gielen, 2013; Freeman et al., 2009) Icebreakers between children and researchers are open ended activities that build on the input without a value judgment. These allow for the researcher to show that all input is valuable and appreciated.

6. Diversify expression opportunities

Contextmapping focuses on creation of artifacts by the user and sharing of ideas captured in these objects. It aims to present a varied set of tasks and materials that the user can express themselves and their emotions through. While it was not developed with children in mind, Gielen (2013) finds that the "Make and say principle, together with the diversity of tasks and materials, helps reach deeper reflection, beyond explicit knowledge into the domain of tacit and latent knowledge" with child participants as well.

In summary, interviews with children should be shaped as open-ended activities that are varied, tailored to their interests and focused on facilitating children to incrementally verbalize their decision making process. They must be presented with concrete options or subjects that relate to their daily lives. This way, the children will be more engaged in the process and be more likely to share their input.

3.4 Session Plans

Human-centered design research requires a comprehensive approach in which people surrounding the child participant are also interviewed to get a better understanding of the context of the product-user interaction. The plan for user research then includes parents, peers, teachers, medical professionals. This section details the goals and methods of sessions planned with all stakeholders. Four sessions are planned with the child wearing a lower limb prosthesis and form the core of the design research. Interviews with other stakeholders are conducted in relation to these core sessions.

These are the plans for sessions for children wearing prostheses. Prior to each session, children are asked to complete short exercises and their answers are used to start a discussion during the session. The activities question their preferences, values and allow for discussions on their decision making processes. Refer to Appendix B for the full session plans and interview materials shared with the child participants.

Session 1

Goals

- Establish a friendly relation without viewing the interviewer as an authority figure
- Get base information regarding activities, places, characteristics to build on with the parent & in later activities
- Direct their attention to their relationship with the prosthesis and their emotional responses towards various stimuli

The introduction is a conversation with the child to get basic information they offer and give them an opportunity to ask questions to the interviewer. This is followed by an icebreaker game and a discussion of their daily routine using the “My Day Yesterday“ worksheet

Icebreaker

The icebreaker shifts the tone of the session to a friendly, creative and conversational one. Here it is important to continuously show that the interviewer appreciates any input the child has and that there are no right or wrong answers in these sessions.

The icebreaker selected is the Winnicott squiggle game. On a piece of paper, one person draws a squiggle. The other person turns the squiggle into something by drawing on it. The two people take turns squiggling and drawing on top of it. The goal is to make the squiggle into something meaningful. (Winnicott et al., 2010)

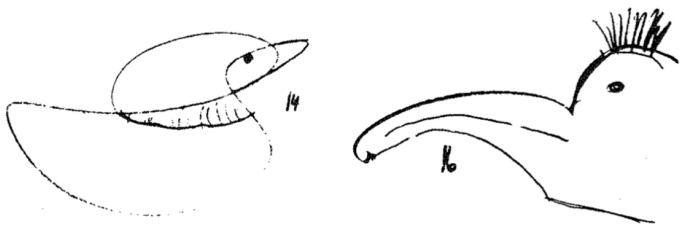


Figure 36: Examples results of the squiggle game

- *Emotions can be an entry point into concerns*
- *Shift away from a right or wrong mindset*
- *Keep questions concrete*

Session 2

Goals

- Explore the product language child is familiar with and prefers in terms of aesthetics and interaction
- Gain a broad understanding of the participant in terms of their personality and preferences and how these color their concerns
- Build upon the knowledge on how the lower limb difference has been affecting their participation and social activities and the effect of the prosthesis in these

This or That

A discussion on the choices children have made. What makes something preferable? Ask questions about the qualities of the chosen item. If stuck, ask them to explain why their choice is better than another option in that category.

Why did you choose X for this question? What makes X the best in Y? How is it better than Z in Y?

Your mother/father told me you also might like Z, what do you think about it? Do their preferences change based on the situation?

Is this your favorite game for playing alone or with friends?

Do you like custom things or things that are similar to those your friends have?

- *Keep questions concrete by asking children to compare*
- *Laddering can help uncover motive hierarchies*
- *Diversify expression opportunities*

Session 3

Goals

- Get an idea of the personal qualities the participant is familiar with and find relations between these and their aspirations, goals. personality traits and motives
- Understand their motives and concerns at different situations, using the results of past activities as a starting point

Reporting

The reporting activity has a small booklet that has various prompts. Assuming the role of a reporter, the child must take photographs that reflect the prompts in the booklet. The interviewer and the child together follow prompts, brainstorms possible photos that can capture the statement and discuss their ideas. After the photo is taken it is glued to the booklet and a short caption is written to explain the reasoning.

The interviewer and the participant go over the photos and discuss the selection of scenes/items selected to depict statements, focusing on the justification process of the participant.

Role Models

This activity brings together all past findings and relates them to the personal preferences, motives and concerns of the participant. The first part of the discussion brings out the personal qualities the participant is familiar with. The following questions are used to discuss role models and their motives.

What would you want to be in the future? Can you tell me about this job? Who do they interact with, what responsibilities do they have? What do you like about this job?

Is there anyone you look up to? Tell me about them, what do you like about them? Do you think you are like this person? Why/why not? In X situation/activity, how do you think they would feel/act? IF you were more like them in terms of X, how would you behave?

What do you most like about your best friend? Can you tell me about a time you had a lot of fun with them?

These questions can be used to start conversations on personal values. If the result of a discussion is not fruitful, another one can be used. The goal is to get to statements of motives(needs, goals, impulses, values) that can be expanded on using the laddering technique to reach more generalized personal values of the participant through uncovering motive hierarchies.

- *Keep questions concrete*
- *Diversify expression opportunities*
- *Allow children to experience first*
- *Assign roles*

Session 4

Goals

- Conduct follow up discussions in any activity that needs room to expand on
- Confirm initial conclusions and understandings regarding research questions
- Inform direction on initial product ideas through discussion with the participant.

Sessions with other stakeholders

Parents

Following every session with the participating child, a conversation with a parent takes place. The goals of these sessions are:

Confirm/expand on results of sessions with the child (e.g. Identify the effect of peer perception through concealment of “childish” interests)

Their categorization of and their view on the prosthesis

Information the child does not have into the prosthesis selection, (e.g., lower limb difference or amputation rehabilitation process)

Medical Professionals

In the selection of the appropriate prosthesis and the following adaptation process, physical therapists and other medical professionals are instrumental.

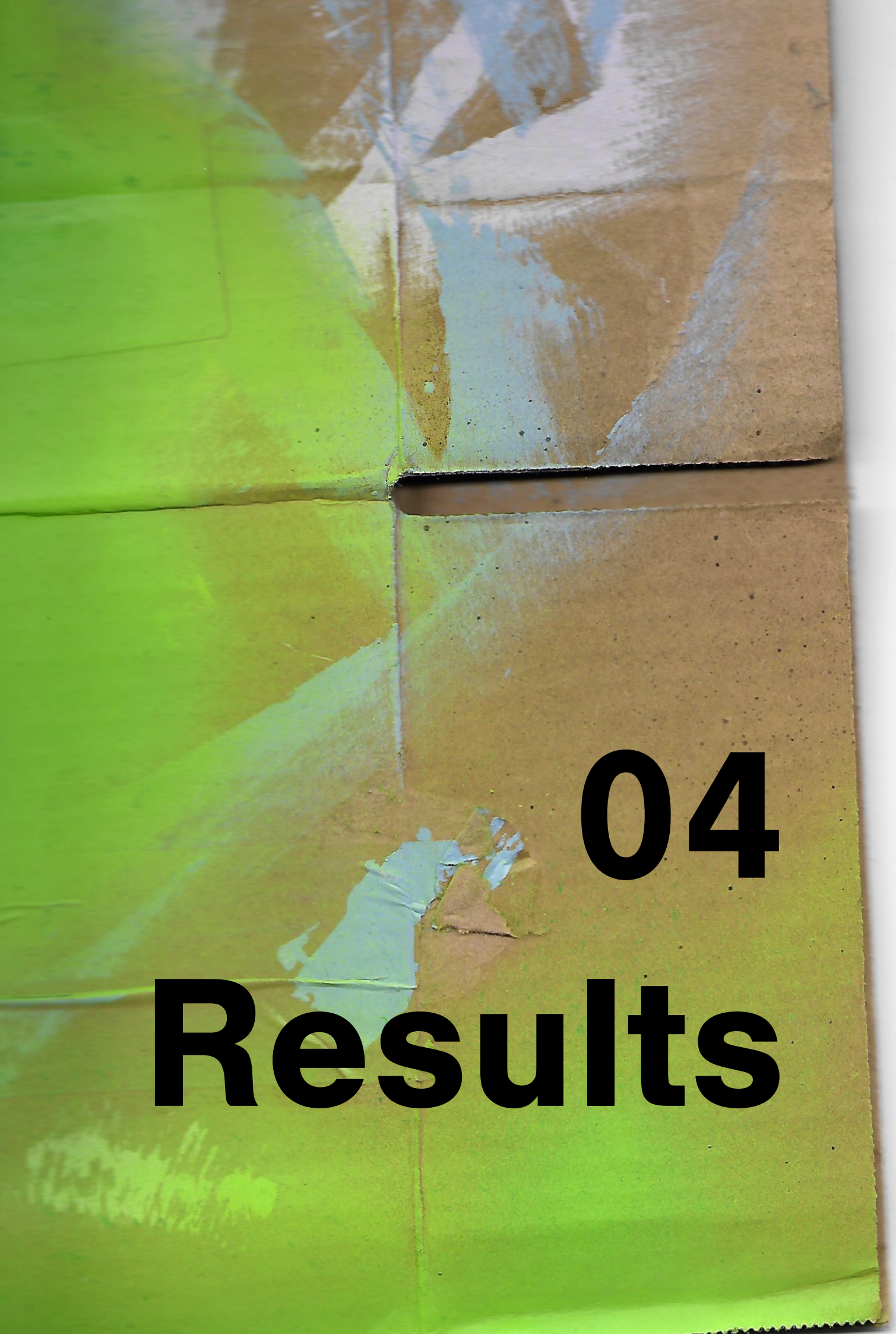
Prescriptive perspective on the prosthesis selection and rehabilitation process. Their priorities and concerns.

How familiar are they with the concerns/motives of the child, being in a decisionmaking position on their prosthesis & rehabilitation

Peers

Preteens are increasingly susceptible to their peers’ opinions, therefore it is possible to discover the interests of children in this age group through interviewing their classmates.

Which concerns/motives are shared amongst the friend group, which ones are particular to the student, which ones are due to lower limb difference?
Aesthetic preferences and trends of the demographic the participant belongs in.



04 Results

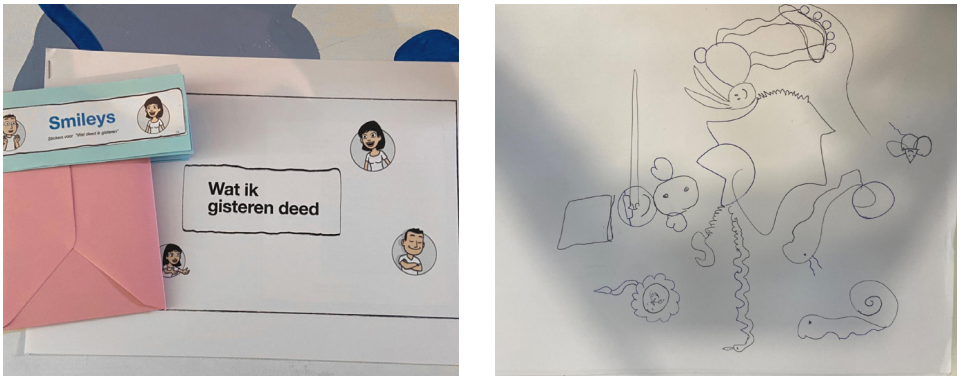


Figure 37: The activity packet sent to participant and the result of the icebreaker

In order to get a comprehensive look into the life of a child living with a limb difference, I had the opportunity to interview various stakeholders and experts. While some sessions were recorded and fully transcribed, in some I was only able to take notes. The summaries of these sessions can be found in Appendix C. This chapter presents a collection of insights which have informed the product design process and the list of requirements.

4.1 Session 1

The child participant was an 11 year old boy. The sessions were conducted in Dutch, with the help of a translator.

He was initially hesitant and answered questions asked in short, yes/no answers. However, he seemed to enjoy the icebreaker and opened up more afterwards. He is a very active boy who was born with a congenital difference. His leg was amputated less than a year ago to fit a foot prosthesis, but he quickly went back to his hobbies. He plays football in his school team, and practices three times a week. In addition to this, he bikes to school, enjoys learning tricks on his stunt scooter and has recently tried bowling for the first time.

> *C: When I have vacation, it takes too long because then I miss my friends.*
>
> *"I'm never nervous before the game, I'm always looking forward to the game. But when I have to shoot I get nervous because if I missed it, that's never fun"*

He is a fan of the local professional football club where he lives, and he owns many products with their logo on. He even picked their team crest as the design for his prosthesis cover.

> *"I will put the [local professional football team] logo on every prosthesis. And I think I'm going to do some more, I also want some credit for it. [lists two other local teams]."*

"What I did yesterday" was completed with very short statements and little information. As he showed no interest in it, it was difficult to facilitate a conversation around it. Instead, we chatted about him, his hobbies and with the help of his mother, he told us some of his experiences.

For example, when we asked "when was the last time you felt hope" and he said he did not remember it, his mother reminded him of his first goal with a prosthesis: "Outside 16 meters, over the keeper. The keeper accidentally shot the ball into my feet, but I shot... so no one was on target." His mother said that after the goal, he came up to her to say 'it finally worked'

He has a generally positive outlook and did not complain. He talked about his amputation surgery and the following recovery process in a very neutral, matter-of-fact way. He got more excited when he was talking about his physical activities which was visible in his facial expressions, length of his answers and the tone of his voice.

I: And what did they do then?
C: They amputated my foot.
I: And what about getting used to it, with scootering for example?
C:Yep, I've learned everything I could.

Out of the four emotion stickers he put on the "My Day Yesterday" Worksheet, three of them were "proud". He oriented our conversation around his accomplishments. For example, he would talk about what he was able to do in a negative situation rather than voicing a concern or negative emotion.

"Everybody in Spain, I was this tournament, I was 9 and they said I can't play football with 4 toes, But I scored with an overhead kick "

He did bring up that he did not like it when people look at his leg "in a strange way", he wants to have something to say to them back, not an explanation but a defense (eg. a shark bit it off)

'I was in Spain and there were some big slides, and they said "what do you have?" I said: "my leg has been eaten by a shark!" '

He views his prosthesis as a way to conform. When going on a week-long school trip, he was concerned about taking his leg off to sleep.

Mom: And you did try to sleep with your leg on right? At home last week?
C: Yeah, but it was no problem [that he took his prosthesis off to sleep was not a problem for the friends]
Mom: Yes because you thought maybe I should leave it on when sleeping at camp. We practiced it here at home, but then you took it off at 4:30?

There is unvoiced concern around stigma that is apparent in this interaction. He was worried enough about having to take his prosthesis off when sleeping around his friends, which started long before the sleepover, that he tried to sleep with it on before he went on the trip.

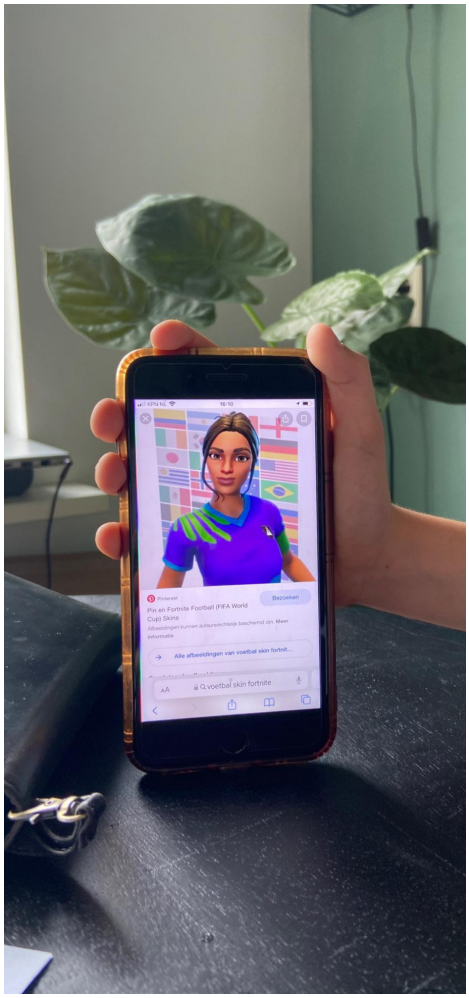


Figure 38: Participant showing his favorite Fortnite skins

4.2 Sessions 2 and 3

Upon the request of the child participant, sessions 2 and 3 were conducted on the same day. Session 2 centered around the “This or That” worksheet. The participant was excited to see us come in, and was eager to start explaining the selections he had made for the exercise. If he resonated with a question, he gave us a long-winded explanation but quickly brushed over the ones he was not interested in.

Figure 39: Excerpts from This ot That

He has a strong consideration for aesthetics. He prefers things that are cohesive in color or form.

C: Beautifully printed and because it is black.
C: Yes I think this [points at last option] doesn’t look very much like a bottle.
C: [smiles] Yes they all don’t fit me very much, so I just chose the most beautiful one, I think.

I: What makes this one the most beautiful?
C: In a special way, on a bend and then like this [follows the bend front part of the scooter with his finger]. But I prefer a stunt scooter.

He did not prefer the more basic sneaker. He said he liked the design of the other one, but the way he describes this one as “mediocre” speaks to the allure of having something unique/novel as a desirable quality in outfits.

Here in his shoe selection, he is detailing the aesthetic motivations he has towards having a preference. He is referring to the looks - the stripe shapes on the sole, the colors and how the colors of the whole shoe fit together in general to make it beautiful. Nothing about one looking more comfortable than the other.

C: Yes the bottom, those stripes, tiger stripes. And yes the color, it fits well together with those colors.

shoes I would like to have

Figure 40: Excerpt from photo reporter

In selecting shoes, popularity of the model amongst friends is most important. Then selecting a colorway that he likes, red.

C: Yes I would like Nike Airmax shoes, yes I may. But I don’t necessarily need it, but would be the shoes I would like the most. Preferably Jordan’s.
I: And why are those maybe even better than these [points at his shoes]?
C: Jordan’s? Jordan’s is just a good brand of shoes, and very expensive shoes. 300 euros.
I: And how do you think your class would react if you walked in with those?
C: Oh yes I know, very much, think that’s very cool.

His likes and preferences are contextual. He wants to be wearing the right garment for the right context. Especially wants/ loves room to express his appreciation of his favorite football team,

> *I: Which socks would you most like to wear during football?*
> *C: Yes Netherlands [points at third]. And I think Fortnite socks are a little weird.Then you have game socks when you're working out, that's a little weird.*

Collecting is also an interest, which parallels the research by Acuff.

> *C: That you can build your own team and then when you have to make the best team possible, and then you can get higher and higher. And that you can make your own character, with which you then have to make your own career. And that you then also have to get as high as possible.*
> *I: Does the fact that you have to make your own character make it fun that you then have to...?*
> *C: Yes!*

He also mentioned he was collecting Pokemon cards, but not so much anymore

> *C: Pokemon cards. I don't do much with them anymore, I used to save them.*
> *I: What did you first like about this?*
> *C: The saving of it because it was just a bit of a trend back then, now not many people do it anymore. "*

> *"Favorite toy? Game console! I also have a special reason for this because when I had surgery I got this from my class"*

Figure 42: Collecting

Figure 43: Style

Children are resilient no matter what the parents think. They don't mind falling or care about being cautious.

C: Yesterday I fell really hard, I wanted to go on a high one. And my foot went wrong so it went like this, and then I fell on my stomach but it didn't hurt that much.
I: Do you continue immediately afterwards?
C: Yes

C: Gaming! If one day I can't play games, I won't be happy. Then you have an angry me

C: What is fun for me? Soccer!
I: Who would you want to have dinner with?
C: I would not want to have dinner with someone who is famous because that is very uncomfortable.
I: What would you like to do though?
C: Play football with a professional football player.

He has a trusting relationship with his CPO.

I: Would you like Nike to design you a prosthesis?
C: No [explaining he wants Bert, cause he knows him for 11 years already. Nicer than Nike making it]

Reflection

This or that is a simple exercise to do when alone, and the justification process that results from the act of comparing and choosing gives rich results. Photo Reporter could be done alone, but we found it a good facilitator of conversation. Our participant was willing to move around the house, so we got to have conversations in the context of the product/experience every time, as we had to travel to it for our participant to take a photo. Being in the space, looking at the objects around sometimes helped as an inspiration. For example, looking in the closet to figure out which chore he does not like and seeing the vacuum, and sometimes helped him reflect in the moment and find a related topic to share.

This version of Photo Reporter is different from the intended one. Initially, I wanted to print the prompts out, and allow him to take photos and manually glue this to the sheet himself. As he was not engaged by the first exercise that was printed out, and considering his digital inclinations, I made this exercise into a simulated app. The prompts were put on individual vertically formatted slides, and he was able to take a photo without exiting the app, scale it, and write a caption. This was both more practical as it skipped laborious tasks of printing the pictures out, cutting and gluing them, and the participant was visibly excited to take part in a game over the phone more than a worksheet on paper.

Going to school and playing football is the primary way children socialize, but football serves as an identity and style beyond just exercise.

Preteens value appropriateness of looks of products to the context they are used in to mitigate stigma, but also desire a distinct, cool style to be perceived as cool.

Stigma from the outside world can make the prosthesis wearer feel “other”. Concern for the perception of their prosthesis/residual limb is a significant motivator in how children choose to act in social scenarios.

A prosthesis (or adjacent product) must be visually categorizable as a familiar product, but unique in its category to be perceived as cool.

A prosthesis must be desirable in shifting contexts

A prosthesis must give parents assurance and children confidence.

Figure 44: Takeaways from interviews

4.3 Shadowing CPOs Bert Voskuil and Koen from DeHoogstraat Pediatric Center

Figure 45: Child receiving a check up (image found online) and the sign for DeHoogstraat

Bert Voskuil is a CPO, or an “instrument maker” at DeHoogstraat. He has upwards of 30 years of experience making prostheses for children. He is the person who designs the whole prosthesis and orders the components needed from various companies, so he is in charge of what gets prescribed. He states that in the Netherlands child amputees get one prosthesis covered by the insurance, and while possible, it is often difficult to make an argument to get a sports blade in addition to it. Bert, or CPOs in general, have been working with the same children since their birth. They trust them to make them the best prosthesis available.

For children, the prosthesis solutions are highly varied. As congenital differences lead to different anatomies, solutions for each child tend to be more specialized. For amputee children, the cover-type prosthesis is preferred. This is an endoskeletal cover that has a prosthetic foot permanently attached. This eliminates the ankle joint, but as the foot already has some affordance in movement, this does not cause a considerable problem in Bert’s experience. While adults and older kids get foam covers, For younger children, including 12 year olds, hard covers are preferred for damage they will take in play.He has observed foam covers getting ripped apart in days at the hands of children.

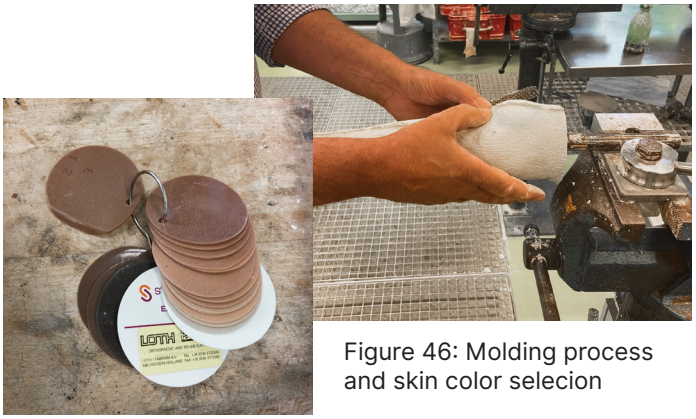


Figure 46: Molding process and skin color selecion

For younger children, the carbon blades are not a good option, they are too stiff. In his experience, Össur Pro Flex is the best foot for children, as it is the softest, but this is not a children’s foot. So only older children who reach the weight target can use these feet.

Bert underlined the difference in mindset amputee children have from children with congenital differences. Getting used to a prosthesis is a challenging process for all, but relearning how to walk for amputees is frustrating. He finds that children with congenital differences are more tolerant of the prosthesis as it gives them a skill they have not had before.

Prosthesis making is a precise, hands-on process. Bert must feel the overall shape of the residual limb is, where the bones are and where the scar tissue lies to accommodate for these in shaping the socket and the liner.

Here Bert is smoothing over the parting line and shaping the mold. He must feel the mold to match the stump better. The pattern and color is added to the cover as a sheet of fabric during the layup. There are many pattern options in the layup room, but children do not choose them often, they go for more natural designs, especially girls starting at 15-16 years old.

4.4 Interview with trainer Frank Dik

Frank is the resident exercise & running trainer at DeHoogstraat. He coaches children and adults who are learning to walk with a leg prosthesis for the first time as well as people who are learning to use a sports blade. With 25 years of experience coaching amputees in track and field and 8 years of experience as the national athletics coach for amputees for the Paralympic games, Frank has had a lot of experience assisting people in getting the best use out of their prosthesis.

"I am not looking as a physical therapist. For safety i am looking for what do i see and what do I have do to get a better result"

Frank believes that children must develop a feeling for their prosthesis to be able to use it to its limits, and making mistakes is a part of the process as "we start walking by falling". He states that the response of the parents in these situations is what colors the child's attitude.

"Fall down, stand up, walk again. Most of the parents are really scared. Because when parents are scared then the child doesn't develop"

He also thinks that sports blades truly can have an impact on older children who want to pursue track and field events seriously and want to train frequently. "I understand that giving young children the experience to run, but when you have a good socket and you have a good knee, for an above knee amputation, they can also run with a daily prosthetic" For events like running and jumping in a track and field setting, the sports blade is superior, but it does not offer any additional mechanical benefits for other kids of sports.

The spring response of the blade is what makes it beneficial for running. To get a "response", the child must be able to put a lot of force into their step. This is the case for the daily prostheses as well, but children must see them in this way, learn to use them in this new way to be able to get a similar response.

Two benefits he sees in sports blades over daily prosthetics is responsibility and signaling competency. Owning a high cost, specialized product for exercising makes children more likely to frequently exercise, which Frank finds desirable. He also marks the sports blade as a transition into getting "one" with the prosthetic leg. Daily prostheses look conventional, but a sports blade will always stand out. He finds that once children start exercising frequently with a sports blade, they become less worried about hiding their prosthesis.

Parents want what they know to be the best for their children, so they are the ones who insist on getting their child a sports blade. They might compare their child to the other children they see with prostheses, and put on expectations which oppose the trainers' or physical therapists' decision for best course of action.

Figure 47: Frank Dik and a running training

4.5 Össur Global Academy Director

Peter Slijkhuis is the Manager of the Össur Academy. With a background of physiotherapy and physiology himself, He is responsible for the educational material CPOs, distributors and internal Össur team receive on the Össur products. This means that the information CPOs receive on the Össur products outlining functionality, intended installation and adjustment guidelines and lifetimes comes from him.

The socket and liner must make as much contact -in terms of surface area- as possible to provide grip and comfort. A small contact area can cause blisters, which means the child cannot wear the prosthetic for a couple days. Which is why a “perfect fit” between the residual limb, liner and socket is crucial.

The children’s liners have a “lock and pin” system. This is a ratchet system that makes clicking sounds and snaps when it is locked. The “Nice, audible click” of the locking gives the user confidence, knowing it will not come off.

In terms of children starting to use a prosthesis, the short term goal is acceptance. If they are able to see the benefit of the prosthesis immediately, they are more encouraged to wear it. However the long term goal is to instill the healthy and preferable practices that will keep them painless for life.

Peter has observed 12 as a threshold age for using a sports prosthesis. Children younger than 12 have no problem with a non-cosmetic (natural looking) prosthesis. If they get used to a sports prosthesis before then, they will continue on with them, however it is much harder for a child older than 12 to switch to a sports prosthesis if they have had no experience with it before. They will prefer a natural looking prosthesis even over increased functionality. He hypothesizes that this could be specific to the Netherlands, because 12 years old is the threshold age between primary and secondary school. As older children in primary school have increased confidence, they are able to try new experiences that they later might find stigmatizing with less hesitance. Once they reach secondary school, surrounded with children up to 18 years old, they want to disappear rather than stand out.

4.6 Blog “Onze Daan”

I have learned a lot from an online blog, “Onze Daan”, in which a mother has chronicled the life and treatments of her son. I am very thankful for the mother for her openness and vulnerability and sorry for the challenging journey their family and friends have gone through.

Literature research revealed that parents believe that their child is strong in character, resilient and they do not complain. This is true for Daan as well, “he does not complain but keeps on going”.

“He is a child, plays and does his thing”

There are many mentions of taking off a prosthesis being a relaxing action. “Take off your prosthesis, put on sweatpants and do something for yourself” Wearing a prosthesis for him feels uncomfortable, but it is an action they view as a part of getting ready. “Daan upright was very different from flat on the couch. Now also gel in his hair and his prosthesis back on. What a different face. ”

Figure 48: Daan

experts

Daily prostheses can be used for most exercise and play as effectively as sports blades

Children are not afraid to get tough with each other in sports, wearing a prosthesis does not change that

A prosthesis can become an extension of one's body though practice

A prosthesis should encourage exercise & exploration and make children feel safe in doing so, especially between 10-12 years old.

literature

Children are "extreme users" of their prostheses, with high activity levels and potential to improve athletically.

Preeteens want to be recognized and accepted for who they are by their peers and parents

A prosthesis conveys a message regarding its wearer's identity to the outside world

Confident children have increased participation in life events which increases their social activity and wellbeing

Control over their disability in how it is presented can increase the person's confidence

user research

Going to school and playing football is the primary way children socialize, but football serves as an identity and style beyond just exercise.

Preteens value appropriateness of looks of products to the context they are used in to mitigate stigma, but also desire a distinct, cool style to be perceived as cool.

Stigma from the outside world can make the prosthesis wearer feel "other". Concern for the perception of their prosthesis/residual limb is a significant motivator in how children choose to act in social scenarios.

A prosthesis (or adjacent product) must be visually categorizable as a familiar product, but unique in its category to be perceived as cool.

A prosthesis must be desirable in shifting contexts

A prosthesis must give parents assurance and children confidence.

Figure 49: Overview of insights gained in all research activities

Understanding the potential user

attitudes

Membership: Football is a source of style and identity

Growth: With hard work and practice I can get better at any activity I would like

Identity: I can flourish when I feel accepted by my peers

needs (inborn requirements)

I need to be accepted by my peers (acceptance, recognition)

I need to be recognized by my parents for my capabilities (competence)

I need to feel comfortable when I am in a public setting

goals (aspirations and intentions

I want to get better at activities like football, stunt scooters and gaming

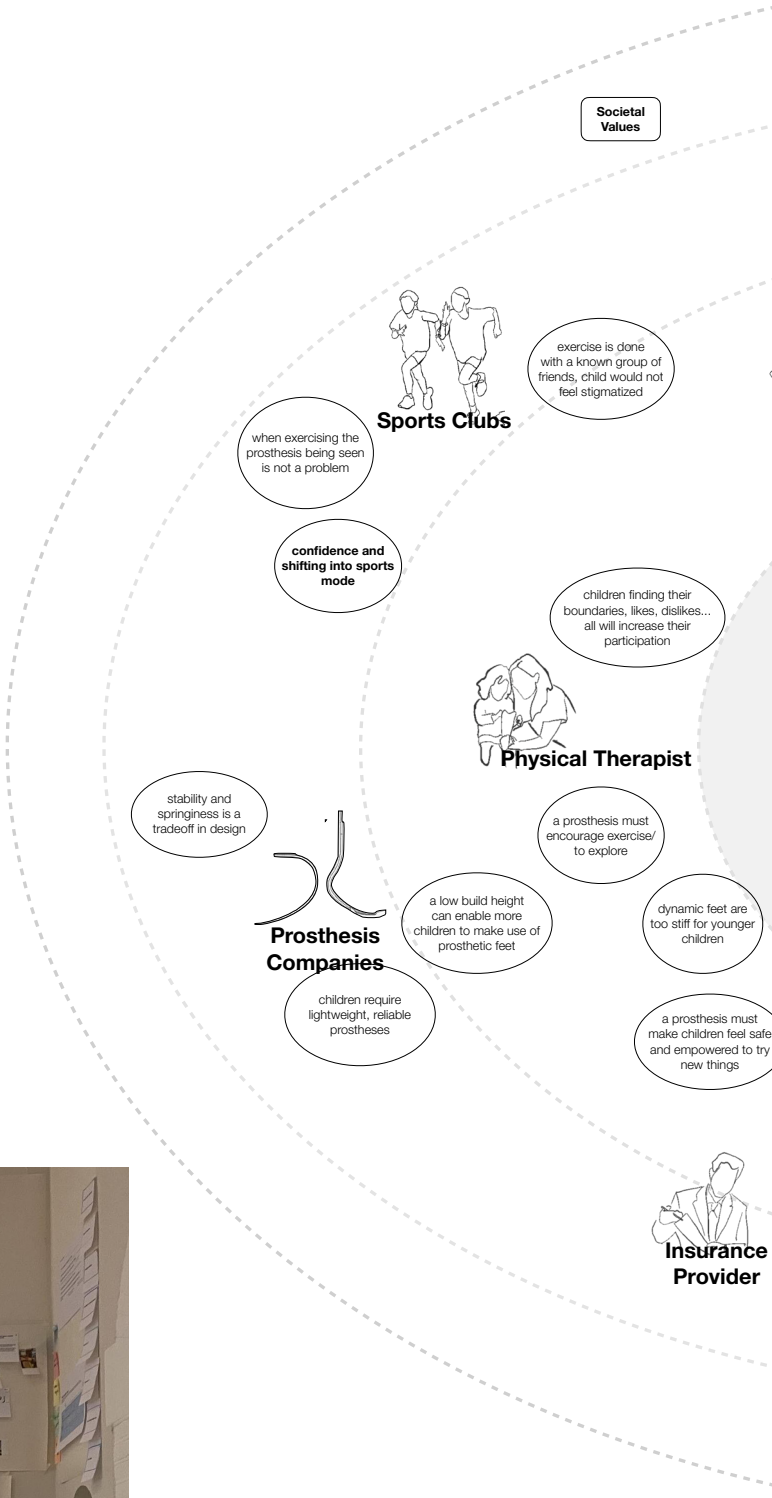
This is what keeps me motivated to stay active and social

Ultimately I want to be able to spend time with my friends doing activities I enjoy

Figure 50: Profile of a preteen wearing a lower limb prosthesis. This is primarily based on sessions with the child participant

4.7 Bringing insights together

From these sessions quotes were drawn out and paraphrased into short statements. These were made into cards as recommended in the Convivial Toolbox. (Sanders & Stappers, 2012) Full set of cards can be found in Appendix D. The cards were grouped by theme, and these themes were later titled. The themes that emerged were aesthetic preference, living with a prosthesis, personality of the wearer, stigma & others, children's attitude. Insights that connect different pieces of information were drawn, and when appropriate turned into statements regarding the role of the prosthesis in the situation.



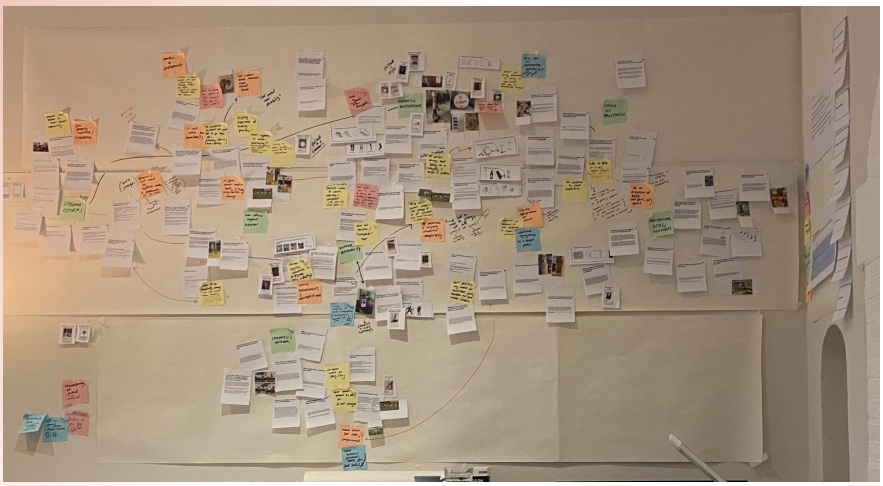


Figure 51: Manual first level data analysis process. The yellow notes are first level insights that connect information, orange ones are statements regarding the function of the prosthesis in terms of a "a prosthesis must..." statements, and blue ones design opportunities.

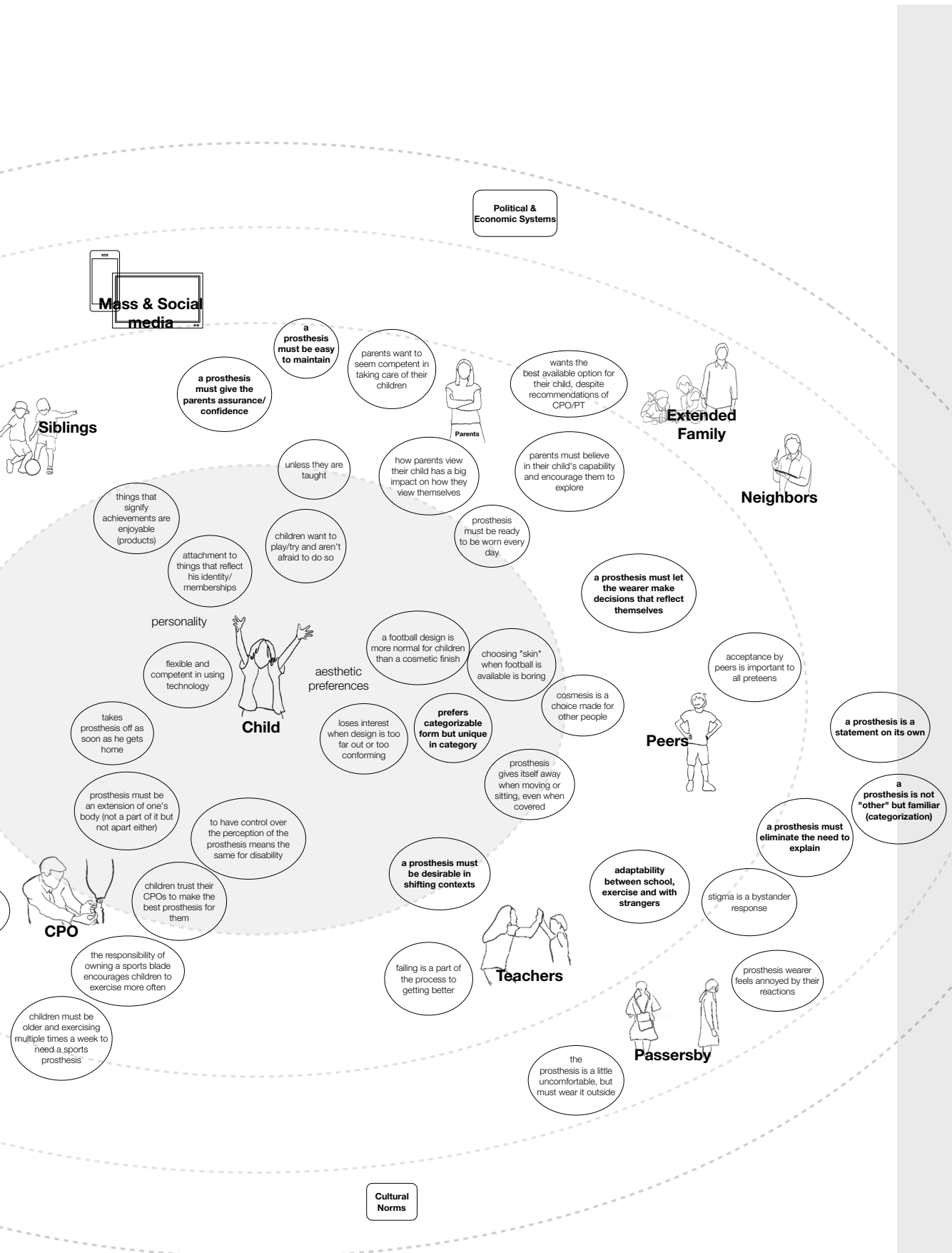


Figure 52: Overview of overarching insights from literature and field work used in brainstorming

05

Design

5.1 Ideation

5.1.1 3 Contexts

Building on these insights, I identified three moments in which a design intervention could have a positive impact. I constructed stories that are rooted in the experiences of the participant, enriched with data from the other mentioned sources. The stories are created around interactions and moments in which the participant has voiced concerns, or have been pointed out by an expert.

Story 1

Figure 53: Story 1

Insights Used

12 is a threshold age for sports prosthesis. If children have not tried it before this age, it is unlikely that they will be willing to try it later. 10-12 is usually the last time children really will experiment with their boundaries, try different sports and find what physical activities they like. The daily foot functions as well as a sports foot when the child knows to push hard to get the spring reaction. As children view their daily foot as a casual product, they fail to use it differently.

Current and Desired Interactions

The first context is out in the football field. Currently, a child who only has a daily prosthesis can feel discouraged to engage in the sport wholeheartedly, thinking a daily prosthesis is holding them back.

The child must see their prosthesis as a sports equipment. When the prosthesis transforms into a sporty object, the child can separate it mentally from a daily context. This way, they can construct a new relationship with the prosthesis in a sports setting, one which calls for a heavier use. In this exercise mindset, the child can be more confident in how they play football, motivated to join in on the action.

Story 2

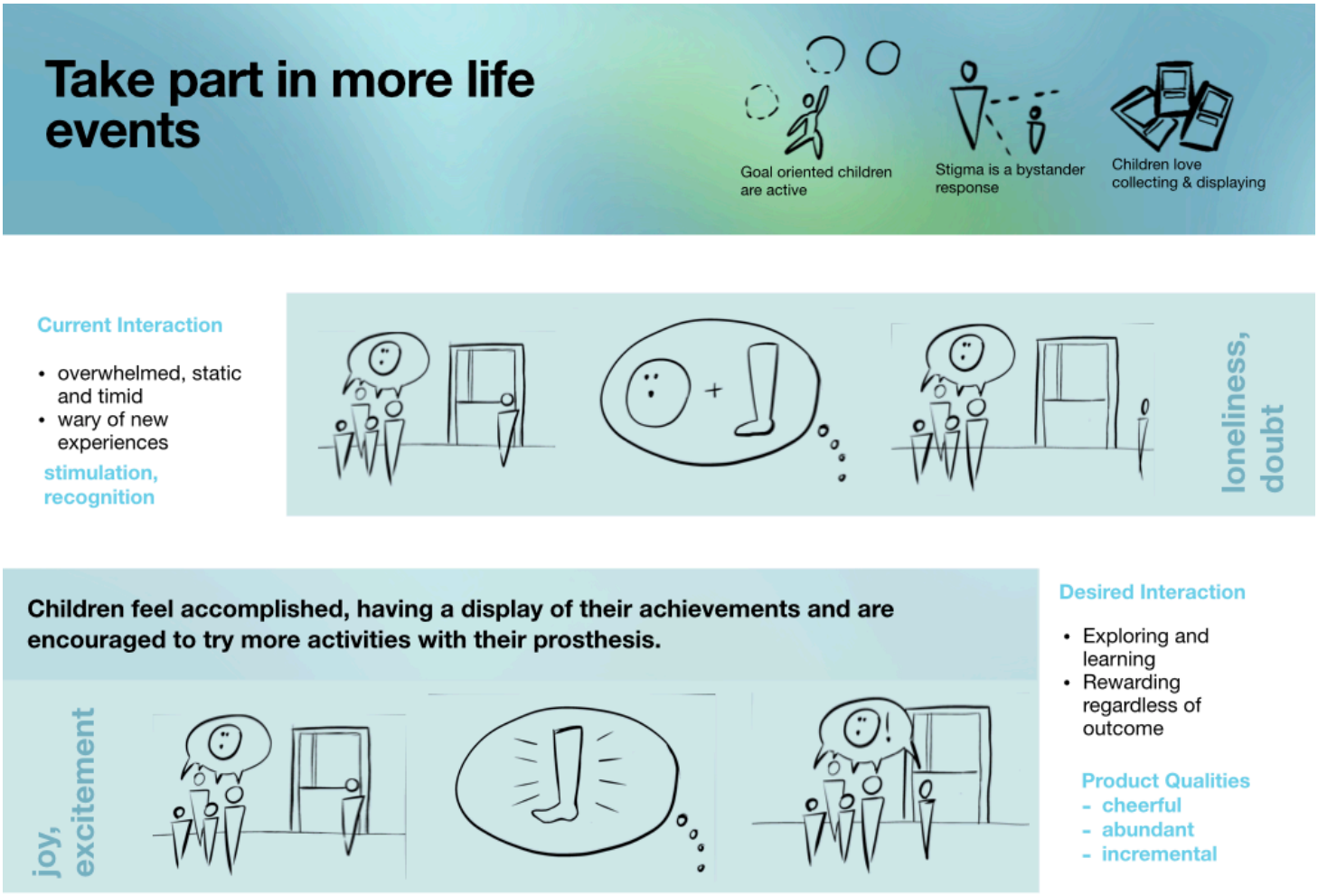


Figure 54: Story 2

Insights Used

For increased participation and mental wellbeing, it is important for children to try out different activities, or feel motivated to keep practicing something they like. Only by trying and figuring out their limits can they understand how a prosthesis can support them in different situations. By practice children can gain an intuitive understanding of where their prosthesis starts, where it ends and how they can move it.

Strangers often react to children's prostheses and can ask intrusive questions. This makes children feel stigmatized, leaving them frustrated and embarrassed. Preteens enjoy building collections of toys and displaying them to their peers.

Current and Desired Interactions

Right now, preteens are wary of new experiences, especially ones that can expose them to new people. With their prosthesis, children expect for physical activities to be more laborsome. Which is why when presented with an opportunity to try something new, children might be hesitant to join in, thinking of the burdensome learning experience that comes with mastering it.

Considering 12 a threshold age for new experiences, preteens should feel encouraged to try new activities. Trying something should be seen as exploring interests, as if collecting them. Their prosthesis can be a visual display of experience, showing how much it has been used. This way, children can see trying new things as a rewarding and exciting activity, regardless of their competence in it.

Story 3

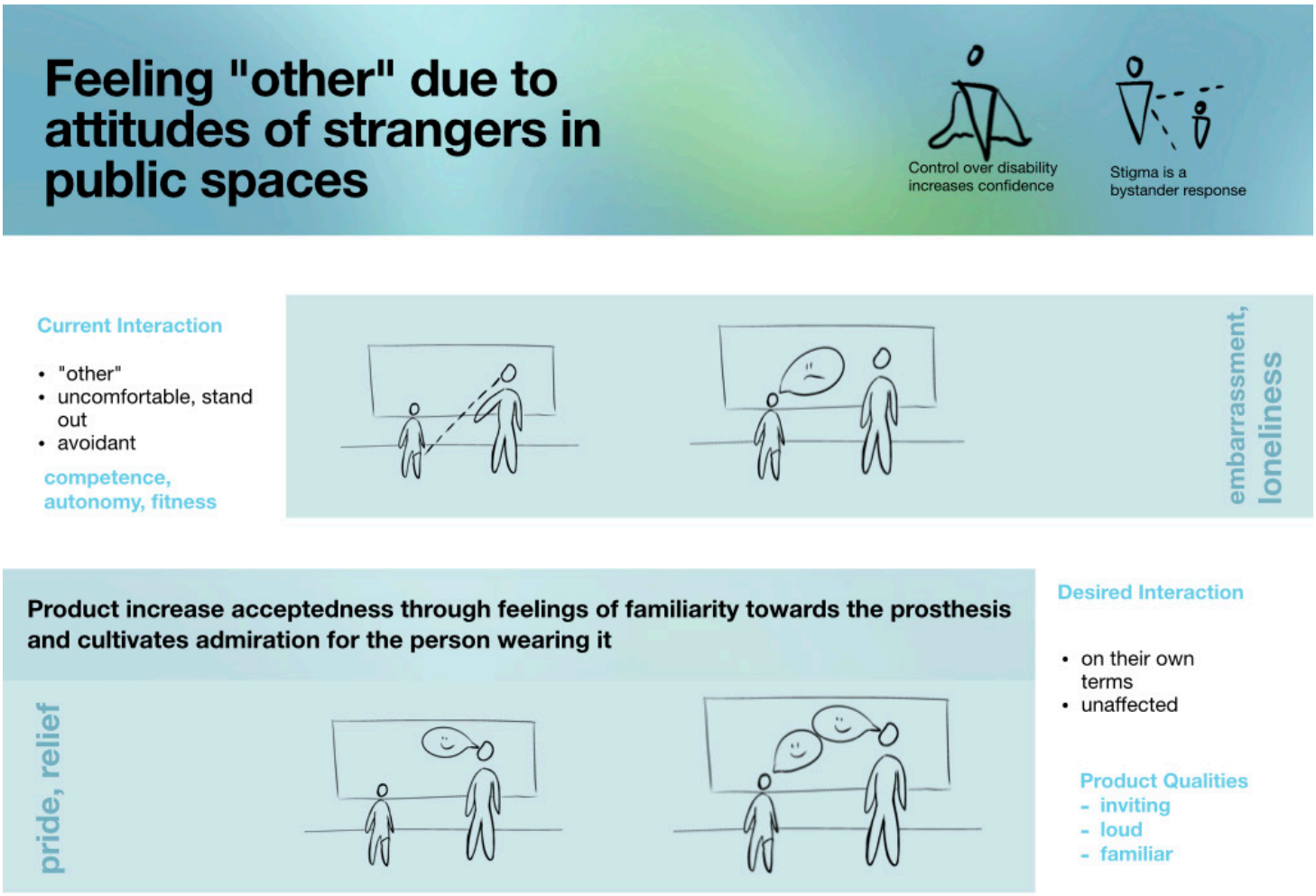


Figure 55: Story 3

Insights Used

Stigma is a bystander response that makes the stigmatized person feel inept in the interaction, and even not in control of how their disability affects them. When these interactions occur frequently, they can exaggerate feelings of being different from others.

Current and Desired Interactions

Strangers often react to children's prostheses and can ask intrusive questions. This makes children feel stigmatized, leaving them frustrated and embarrassed. This can make children hesitant to get out of their comfort zones such as school or home, and view even a vacation as a gloomy task.

Children feel proud and in charge of the interaction with a stranger when they are able to say something amusing. A prosthesis should be easily categorizable for a passerby, mitigating the shocked reaction. If the prosthesis has its own identity, this can decrease children's need to explain themselves, and instead be more confident with an increased sense of body ownership.

5.1.2 Brainstorming I

In order to kickstart the ideation process, a series of brainstorming sessions were conducted. The first two sessions were with TU Delft students within the Industrial Design Faculty, and the third one with the Össur Design Team. To be able to explore the solution space quickly, I conducted Brainwriting exercises with TU Delft students.

After the students were primed with insights from Chapters 2 and 4, the three stories were presented one by one, and the students and I silently ideated on each problem. This led to a very large collection of ideas, often out of scope and repeating. (Appendix E)

Figure 56: Brainstorming sessions

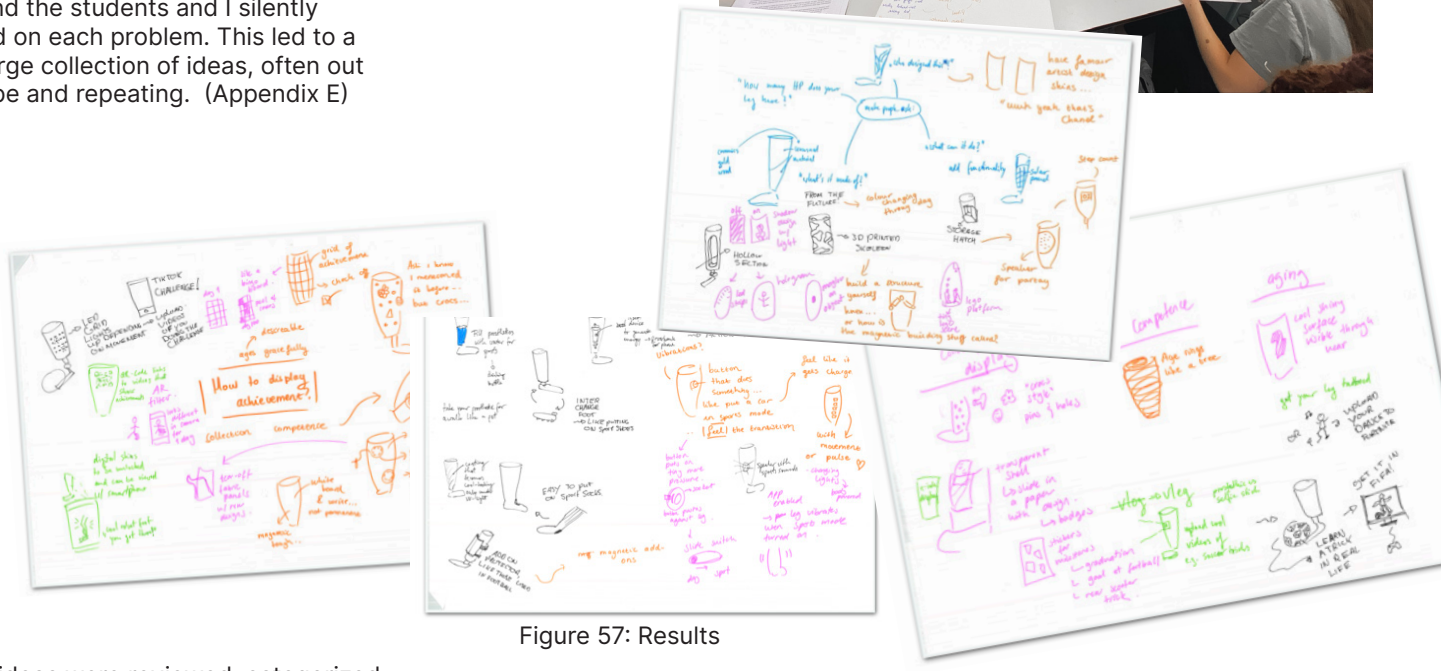


Figure 57: Results

These ideas were reviewed, categorized and selected through using a short set of criteria:

- Novelty
- Scope of intervention
- Extent to which it can address the problem

The ideas that were selected in this process were detailed and built on to reach a final list of 6.

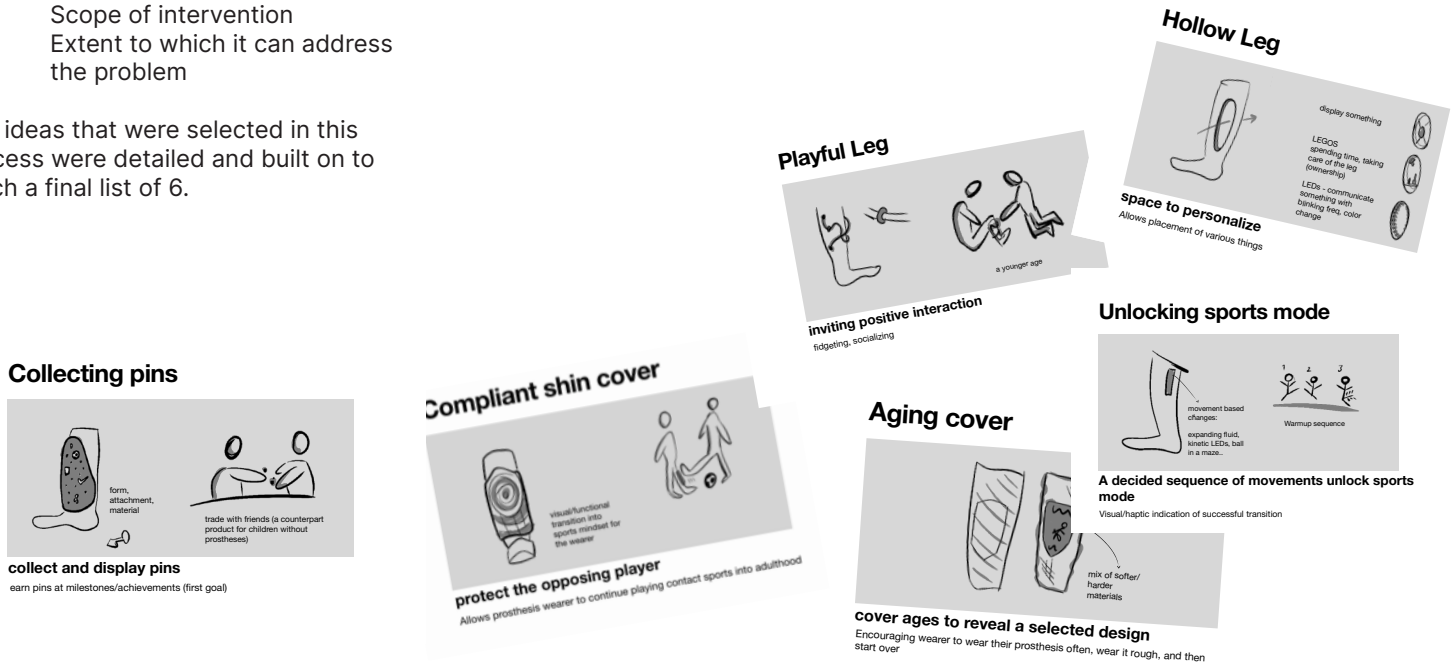


Figure 58: The 6 selected ideas

5.1.3 Brainstorming II

An online brainstorm session was conducted with 3 designers from Össur as well as the Director of R&D in the Design Center. For this session, a persona reflecting the child participant and relevant research, a selection of summative insights of the data analysis process were presented, the 3 contexts and the product ideas were presented. Later on, the designers asked questions and gave feedback on design ideas one by one using the sticky note feature on the online whiteboard. The session lasted for one hour. The complete documentation can be found in Appendix F.

The generated feedback and ideas were clustered and plotted on a graph with axes “Importance” and “Feasibility” in lieu of a Pugh Chart or Harris Profile, as the ideas addressed different problems for which a list of requirements suitable for all cannot be developed. This process put 2 idea directions in the highest ranking section of the graph, and these ideas were selected to be pursued further.

feasibility:

- product scale (physical size)
- product scope (level of intervention the final product requires is feasible to build on for Össur)
- ease of answering questions most important to the concept success (lowest fidelity prototype required)

importance:

- increases confidence and participation of target group (children ages 8-12)
- lifetime of the product +matches the prosthesis or the product should be independent of the prosthesis (do they get bored after a month?)
- competency of parents is not harmed (the product does not come with increased upkeep)
- fit in children’s behavior (eg. children lose things)
- safety (external moving parts, tugging on clothes, harming leg it is on, or other legs)
- Level of compliance with existing regulations in its field

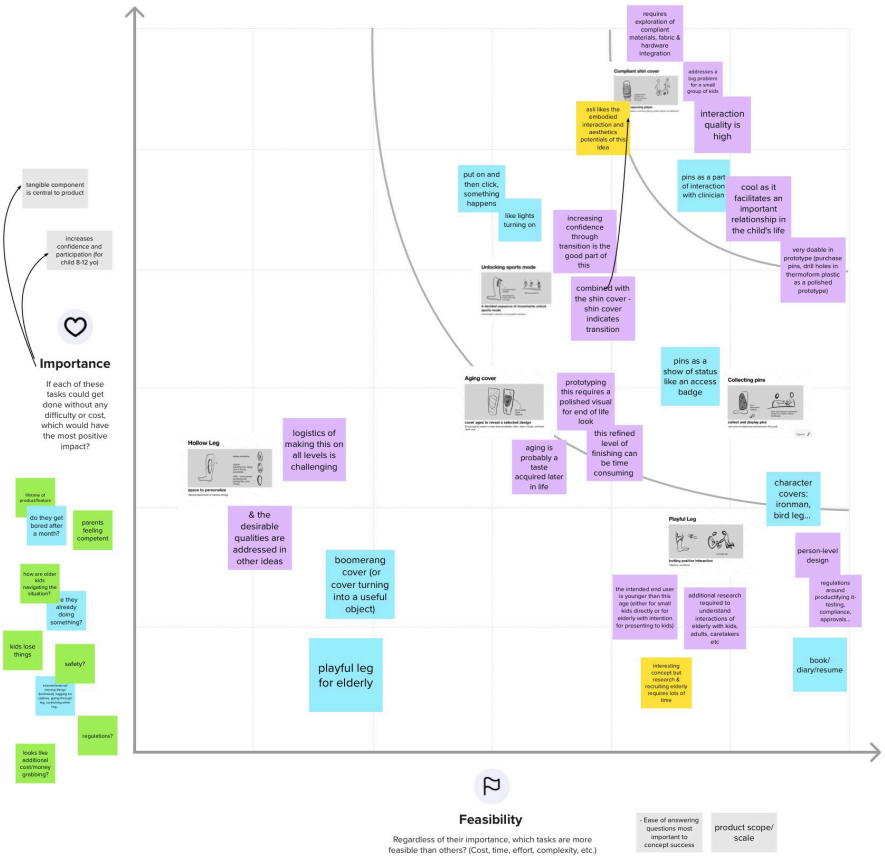


Figure 59: Ranking of concepts

Compliant Shin Cover For Football

Good

- Opportunity for embodied emotion in interaction
- Solves a very apparent and important and relevant problem

Bad

- Attachment to an existing prosthesis could be difficult, needing an invasive change on the prosthesis cover
- The target audience is very, very small (amputee children playing football)
- Regulatory board could simply reject the idea, no guarantee it can work

Collecting Pins

I was surprised this was compelling, as I thought maybe it is too childish. A team member mentioned it can be used as a way for a child to connect with the clinician. The clinician can be asking about where the child got a pin, or they could be the ones giving the pins to the children. Either way, it would give them something like a journal of the child's recent achievements.

Good

- Building relationship with cpo is important for children
- Simple in construction

Bad

- Unsure if this kind of collecting is desirable for the target group (preteens), more effective for younger children
- Relies on "being cool" to work, an elusive concept that is ever changing. The longevity of the solution is in question
- Collecting is desirable for its collectiveness, when peers can take place or look up to you. Displaying is a big part of it, and displaying relies on an audience
- Longer validation period is necessary, with a wider group of participants (inaccessible at the time)

Final Idea Selection

While the potential of the pin cover in facilitating a relationship between the child and their CPO is significant, the age group this idea would be most effective for is younger than the target group of this project.

The pin cover also requires an extensive "buy-in" from the side of the child. The children must want the pins, enjoy displaying them and be motivated by the prospect of acquiring one enough to facilitate action and conversations with their CPO. For it to be accepted by children in this way, the product needs to be perceived as cool. While cool also plays a role in the desirability of the protective shin cover, it is not it's only strength. The shin cover also provides an immediate functional benefit that can be easily defined and made to be achievable.

Contact with child participants who can directly benefit from one idea and provide feedback for its development is not to be overlooked. The child participant recruited in this project already has built a trusting relationship with his CPO. The difficulty of reaching people within the specific target groups cannot be undermined, and recruiting a new set of participants is not possible within the time constraints of the graduation project.

When all of these factors are considered, the elusiveness of "cool" the pin cover relies on, the background of the child participant who is able to give feedback, as well as the differing age groups suitable for the projects, the compliant shin cover for football was selected.

5.2 Conceptualization

5.2.1 Design goal

After selecting a product direction and context, I revised the design vision to reflect the updated design goals.

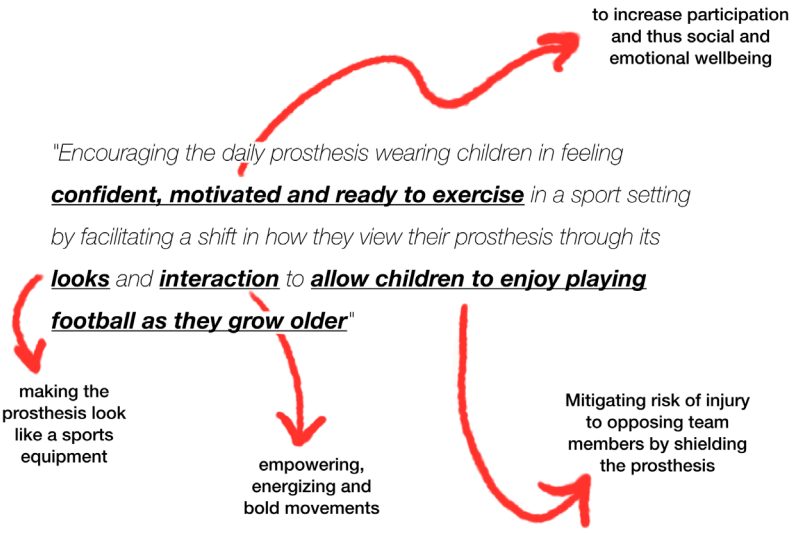


Figure 60: Design goal for the prosthesis cover for football

5.2.2 Requirements

In order to design a product that is feasible to manufacture, desirable to the target user as well as viable in the long term, products requirements were derived from insights gathered earlier on in Chapters 2 and 4.

Promote confidence

see chapter 5.1.3, 2.10.2 and 2.10.1

Confident children are more prone to participate in more life events. In addition to this, the daily prosthesis most children are prescribed can perform as well as a sports blade in playing football, but require children to step differently from how they usually walk. Ensuring the child that their prosthesis is now ready for football by providing a clear distinction from its previous state and a clear transition moment between the two can help them shift their mindset to use their prosthesis diff erently. This way, the child is able to get more out of their prosthesis, which can improve their performance and boost self esteem.

Assumptions

If the cover provides a stark diff erence from how the prosthesis looks like without one, the wearer could see it as two different “modes” of the prosthesis. A attachment method that feels bold and reactive can mark this transition period and indicate readiness for exercise.

Provide safety

see chapter 4.4

The product should able to protect opposing team members from impact. No part of the product should pose an additional safety risk when it is worn or while putting it on. The product should not have any component that can pinch, catch on or scratch any exposed skin.

Assumptions

A firm but compliant material or structure can absorb the kinetic energy of an oncoming kick and decrease the reaction force delivered to the leg. This way, the bones are less likely to fracture. Smooth surfaces will prevent catching or scratching. Limiting hard and moving parts where the person is likely to touch the product can limit skin pinching.

Respect sense of agency

see chapter 2.6.1 and 2.10.2

In order for children to feel confi dent, they need to feel competent. If the child requires the help of others when putting on the sports cover, it can send them the message that they are not ready to do things on their own. The product

should be easily put on by the child themselves to not disagree with their need for autonomy.

Assumptions

Putting the cover on and taking it off can be done by the wearer, and done so with ease comparable to conventional shin guards.

Be reliable

see chapter 2.10.2 and 4.5

The product performing in a predictable manner in line with the wearer's expectations, and doing so over and over again allows the child to build trust with the product. The product should give the confi dence that they do not need to worry about whether their shin guard will break. The product then must signal that it is worn correctly, be durable and should not be able to instantaneously fail suck as burst or fall off.

Assumptions

Making use of well-studied, well understood technologies in the design, as well as making it as simple as possible, can allow for the product itself to behave consistently.

Feasible in manufacturing and assembly

see chapter 4.3

The production of the product should be possible given the current prosthesis manufacturing and assembly methods. The design of the product should allow for it to be disposed of responsibly. This means that the components of the products that are made of dissimilar materials should not be adhered permanently to each other.

Assumptions

Using the current methods used to manufacture prosthesis covers can allow the design be produceable. The prosthesis-makers will have an open-minded attitude towards small changes made to the cover as long as they can be one so using the techniques they currently use.

Allow for expression of style

see chapter 2.8.2 and 4.2

Children at this age group have a strong desire to dress in a way that signals their personality and interests to the outside world. In order to be accepted as a product used in the football setting, it must fi t in with the rest of the accessories, and become a part of their uniform aesthetically and still allow children to choose a design that reflects their style.

Assumptions

The form of the product, color choices and hardware used can make it become a part of the football uniform seamlessly. Offering variations in colorways is a way to allow for choice practiced in most sports products. (eg. shoes, clothes)

Does not contribute to stigma

see chapter 2.9.2

Feeling stigmatized by others can make children feel anxious and insecure. The product should not not amplify their bodily diff erence from their peers. Visually, the product should be easily categorizable as a shin guard and how it is put on should fit into how children change into their uniform or be a part of their warmup sequence.

Assumptions

The looks of the shin guard and its similarity to conventional shin guard will mitigate looks bystanders might give and questions they might ask that the wearer perceives as intrusive.

Provide comfort

The product should be as lightweight as possible. This is the main factor that will curb the risk of injuries due to comorbidities.

Assumptions

Limiting the weight of the product to that of a shin guard found on the market will give a reliable upper bound for weight.

5.2.3 Concept Development with Key Technologies

5.2.3.1 Compliance and Desired Stiffness Range

Compliance can be described by how structures deform under load, or the opposite of stiffness. (Slocum, 2008) The main function of this shin guard is to absorb and dissipate the energy that is delivered to it when the prosthetic leg is kicked by an opponent. This can be calculated using conservation energy between the kinetic energy of the kick delivered to the cover and the amount of energy the shin cover is able to absorb through compression. This will determine the softest (the least stiff) the cover can be, which is the lower bound for K.

The leg that is kicking the cover will feel a reaction force. For soft surfaces, this force depends on the duration of the kick, or how much the soft cover moves inward. This can be calculated from impulse and conservation of momentum. This will determine the maximum stiffness the cover can be, which is the upper bound for K.
Carrying out these calculations, I was able to identify the ideal stiffness range to be 284000N/m and 530000N/m. (Appendix H)However, to be able to move through a wide range of material and geometry options quickly, it is important to gain an understanding of what these numbers correspond to in a way that is intuitive.
As stiffness is a measure of how much a structure deforms under a load, in the direction it is applied to, it means that I can predict how much a material should deform when pressed on by hand. If I were to compress a structure with a 10kg load, the materials should deform between 0.19 and 0.35mm.

A kick would deliver a lot of force, so materials that are really soft, as in deforms when I press with a light force, cannot be suitable. What I was looking for in a material at this stage is resistance, they should only really move when I press very hard with a couple fingers, and then still be able to return to their original shape, this shows me that they can absorb large forces. I used this simple test, in combination with feasibility considerations to determine a suitable compliant material.

5.2.3.2 Material Exploration

Following themes were identified as potential avenues of compliant materials and attachment methods. A full technology exploration map can be found in Appendix G.

Figure 61: Technology exploration

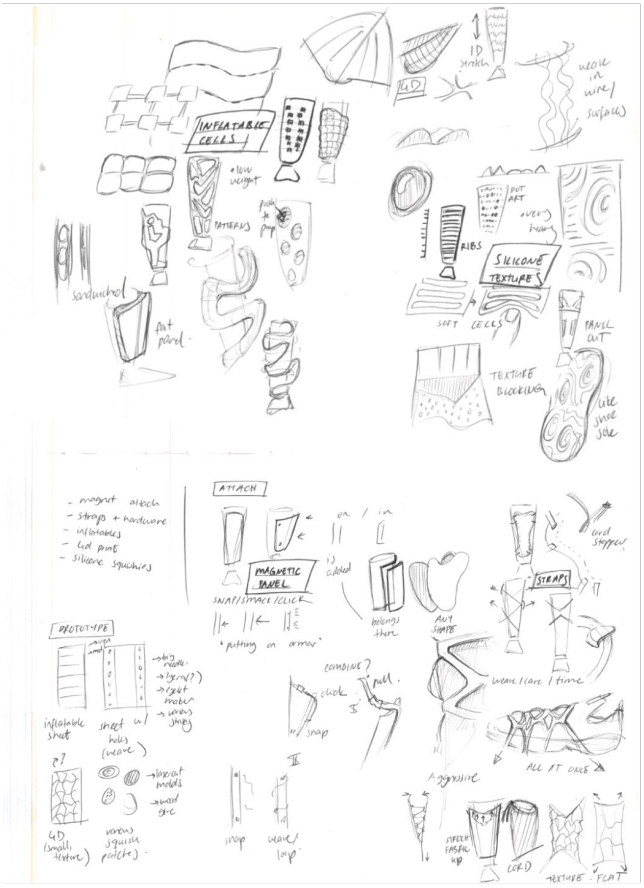


Figure 62: Ideation on applications of technologies into concept

Voronization

Voronization is one way in which geometry of a structure is computer generated. When these structures can be 3D printed using FDM, they are reported to behave like sponges. The stiffness of these airy structures can be tightly controlled by controlling the wall thickness as well as the hole size and density at specified locations. For example, in the sneaker sole concept Nervous System, the areas that show up darker in the middle of the soles are the denser areas that are less likely to deform under load. (Nervous System, 2015)

Inflatables

Inflatables are airtight structures that increase in size and change shape when filled with gas. They are desirable practically, as they can be very low profile when deflated, which marks a clear distinction between the two states. When inflated, depending on the properties of the material, they can be tough and flexible, and absorb loads with ease. A downside of such materials is that if they are under too much load, the internal pressure increases greatly, which can cause them to burst. They are not resistant to punctures either. If punctured, the air will quickly escape, causing the structure to deflate.

4D printing

4D printing refers to the use of traditional 3D printing techniques to make structures that morph and shape after being printed. One such method, explored here, is printing on stretched fabric. In this process, a 2D pattern is printed using FDM printing onto a layer of fabric pre-stretched onto the printer bed. When the printing is complete, the fabric is released. The relationship between the printed plastic and fabric assuming its neutral state causes three dimensional structures to form. (Gurberan, 2013)

5.2.3.3 Concept Development

Based on technology research and further ideation, I generated possible design opportunities that can answer to various aspects of the concept. Combining solutions for different parts of the design, I generated three concepts of varying complexities.

Morphological Chart

Concept detailing occurred in three main areas: defining user interaction in putting it on and taking it off, determining a suitable technology for the compliant part and devising a practical model for the construction of the product.

Figure 63:
Morphological chart

Basic

This design combines the lightest, simplest options. The inflated shin guard can slide into a pouch worn over the prosthesis like a sock, similar to how current shin guards are worn. No modification is necessary to the prosthesis itself. While this method of putting the shin guard is familiar to the wearer, it is not quick or can provide any auditory feedback.

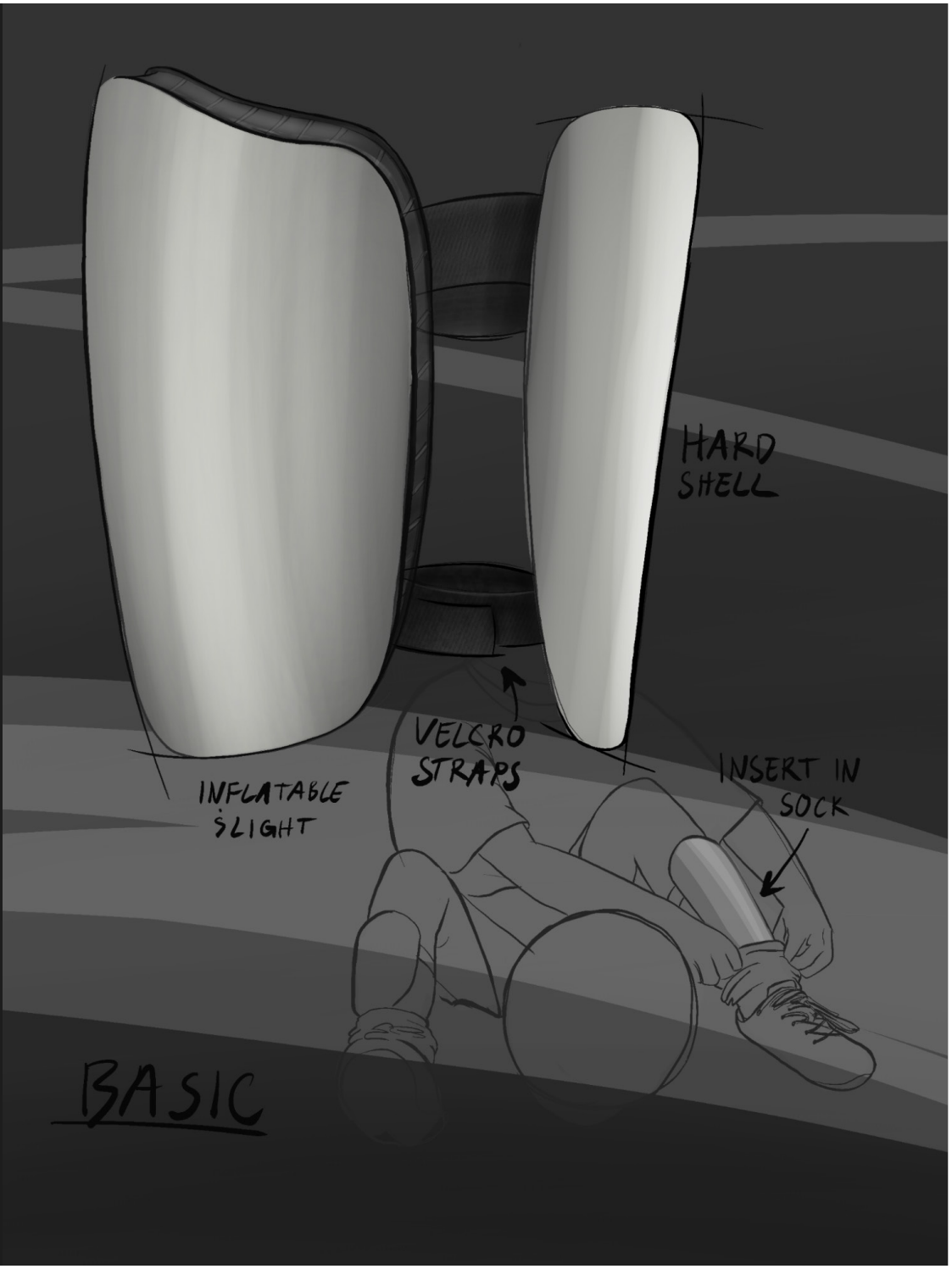


Figure 64:
Basic prosthesis protector

Tech Forward

This concept variation utilizes the newest technologies in manufacturing. Computer generated patterns of the print can be made denser, therefore harder or more sparse and soft. This way, the wearer can receive a design that works the best for their age, position on the football field, and likelihood of injury. As the backing, compliant layer and cover all are fabric, they can be sewn together.

The design features a quick release mechanism that secures the cover onto the prosthesis, which can be released at the press of a button. The sudden movement of putting the cover on, and the conforming click heard when the cover is correctly attached are considered rapid and strong movements that can energize the wearer. The grabbing and locking part of the quick release mechanism must be installed into the prosthesis itself.

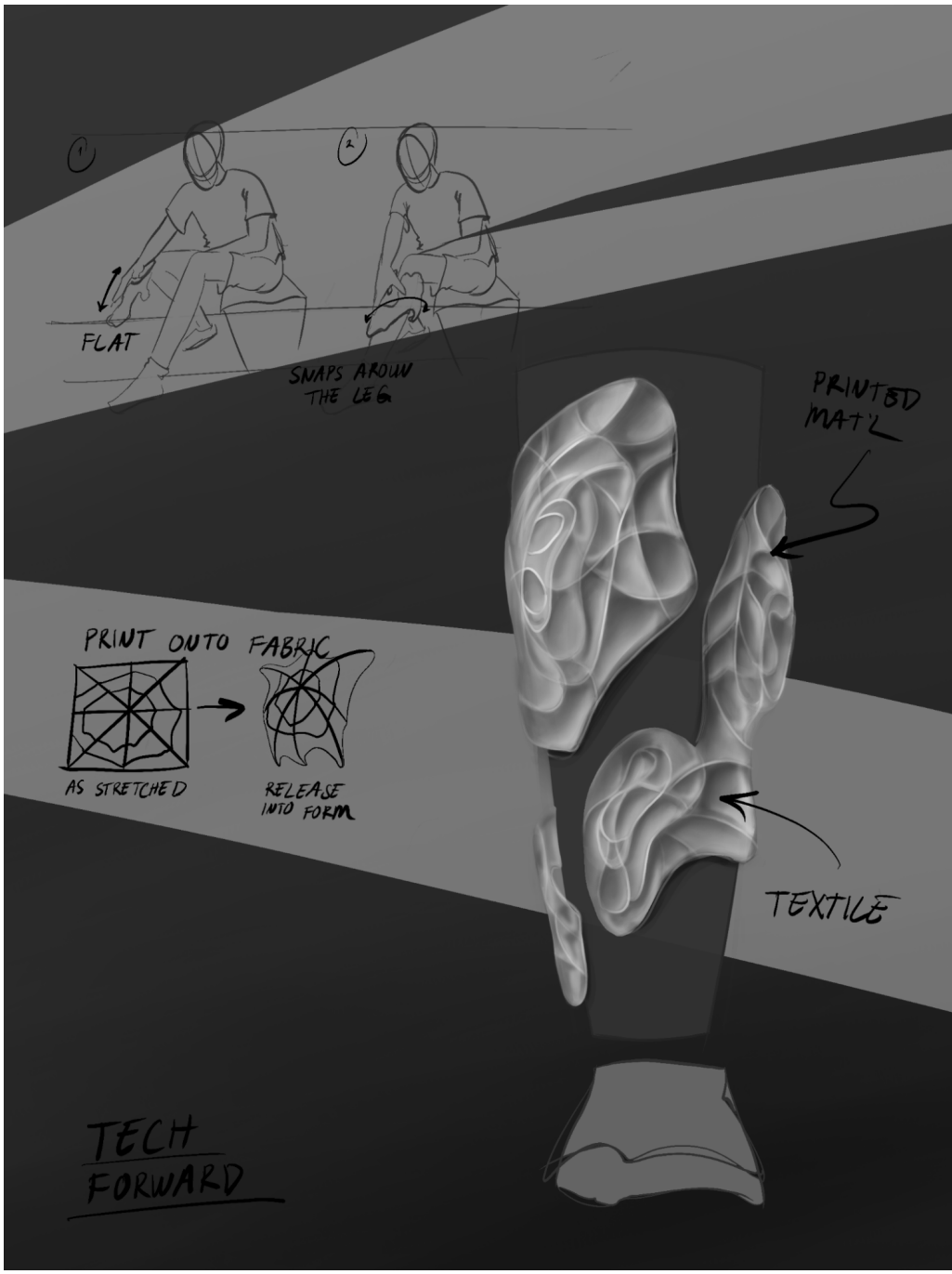


Figure 65: Tech forward prosthesis cover

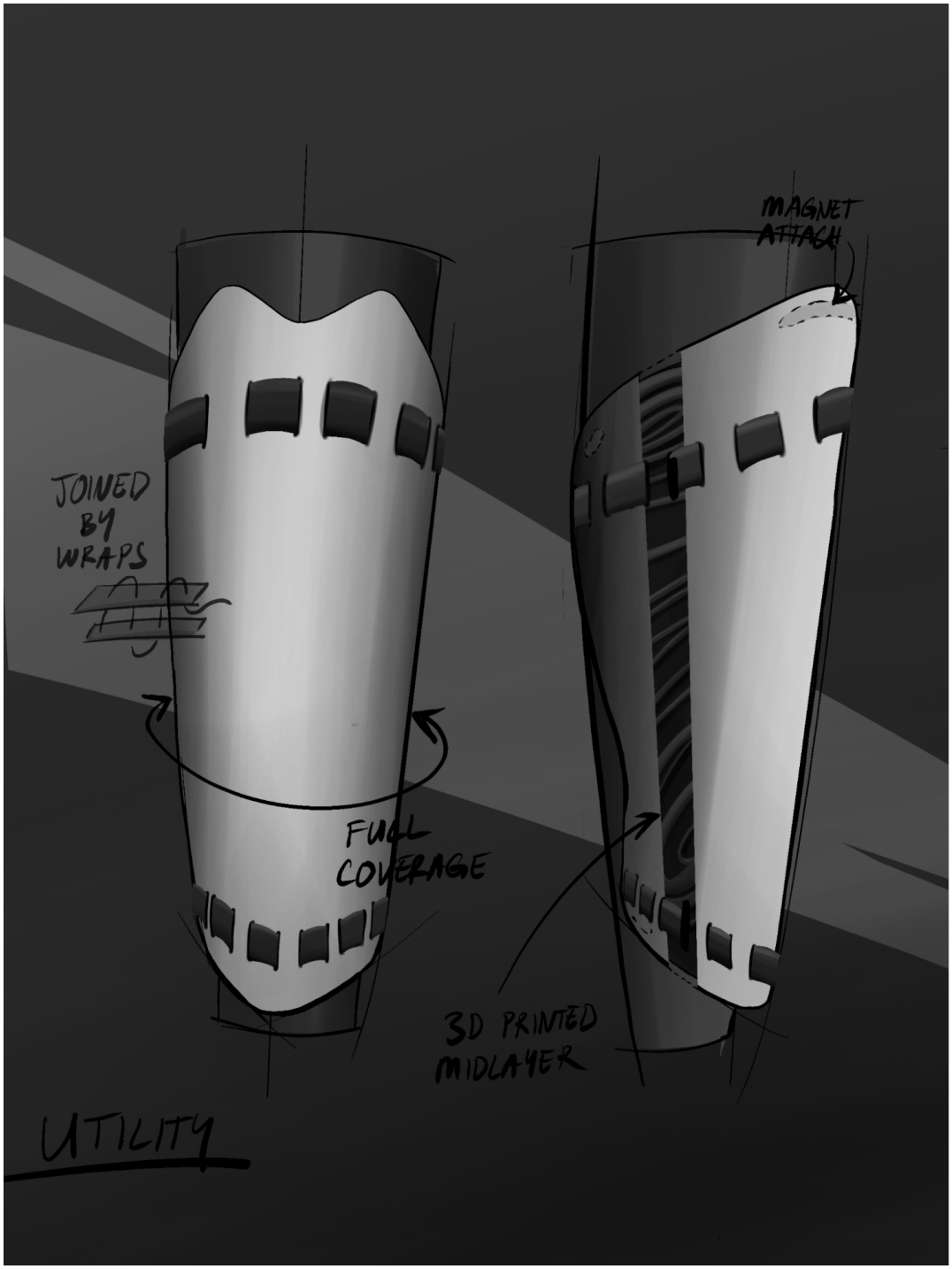


Figure 66: Utility style prosthesis cover

Utility

The utility concept is a combination of the most feasible technologies that satisfy the interaction requirements set for putting the cover on and taking it off. The magnetic attachment is quick, and provides auditory feedback in the form of a snap. Customization in colorways provides different options children can choose to match their shin cover to their uniform.

5.2.3.4 Concept Evaluation for Feasibility

Feasibility of implementing various technologies in the cover was assessed through prototyping.

Inflatables

- Purchased potential materials, any sheet plastic that had traces of being heat processed (crimp lines)
- Binding test. Apply heat to two layers of samples to bind them together.
- Make an airtight shape with internal topology and an air nozzle. Used a soldering iron for thinner crimp lines with a directed heat application

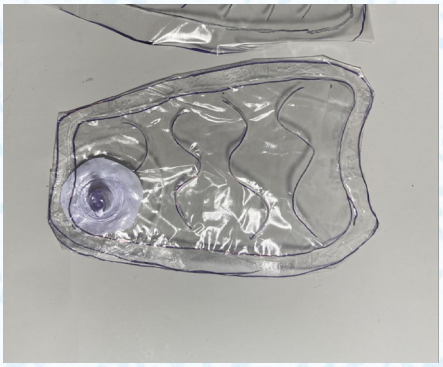


Figure 67: Inflatables

What worked

- Found a material that can be manipulated and structured with heat
- The internal structure takes shape easily

What didn't

- Difficult to bind a dissimilar plastics, e.g the air nozzle in an airtight way
- Inflating is not instantaneous, need considerations for a built in or external pump. In the football field, having an external pump can be isolating, as it is a unique action
- Puncture is a concern. While the Reebok Pump shoes demonstrate that it is possible to produce a puncture resistant, durable inflatable, extended research and testing is required.

There are a lot of practical considerations that make inflatables difficult to realize in this project, the main consideration is how the inflating and deflating interaction would affect the user. The desired interaction is quick and ideally with auditory or tactile feedback, to give the user the confidence it is set up quickly and mark a clear transition from the "daily" state. Inflatables on the other take a long time to prepare, and deflating all the way is laborsome, so this technology was not found to be appropriate.

4D Printing

Followed the process outlined by Naomi Atmopawairo in her graduation report.(Atmopawairo, 2019) Fixed fabric onto a Creality Ender 3 Pro printer and printed structures of varying thickness and height. Fabrics tried were elastane and polyester blends.

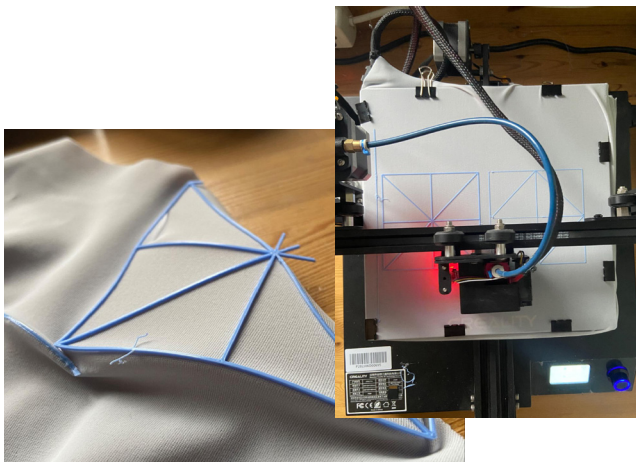


Figure 68: 3D printing on fabric

What worked

The print firmly attaches to elastane tulle

What didn't

- The tulle is too thin and flexible, so the print did not warp when the fabric was released
- The print did not attach reliably to thicker elastane and polyester blends
- In order to bend easily, the wall thickness of the printed plastic needs to be thin. (1.5x0.5mm) At this thickness, the plastic is not stiff enough to resist impact. The k factor is too low.

From these first level experiments, it is possible to see that 4D printing has potential to build compliant materials. These experiments also showed that doing so would require considerable effort in fine tuning and experimenting to find the right parameters for this application.

Silicone

Silicone is a widely used material for prototyping. What was investigated was the minimum wall thickness of molded structures possible, as well as the maximum depth of such walls. Some molds were lasercut out of wood to find out these parameters.

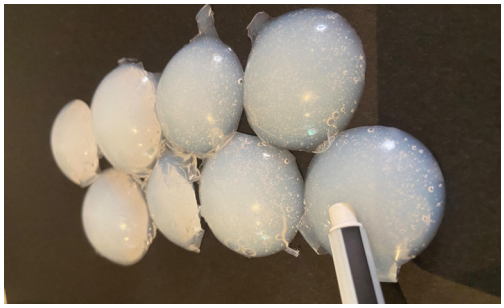


Figure 69: Silicone tests

What worked

Possible to go down to 1mm wall thickness, as long as there are no sharp changes in geometry of the walls. The corners tend to get stuck, so do the small pins

What didn't

Fully dense structures like the circular pattern are too heavy. The layer design needs to have ribs and spacing to create stiff but light shapes.

Figure 70: Silicone mold

With these learnings, a shape with 1cm depth and 1.5mm wall thickness was designed. The curves are rounded to be able to remove the pattern from the mold with ease. The mold was 3D printed for strength and a smoother finish.

The resulting shape came out of its mold with ease and no tears. In places where the walls are denser, the structure is more rigid and the sparse areas more compliant. However, the silicone utilized is fairly flexible with a too low spring constant.

3D Printing with Soft Polymers

3D printed compliant structures out of TPU, a more flexible filament than PLA.
Tried two different geometries, the voronated, sponge-like structure as well as the thin walled geometry that also was explored with silicone

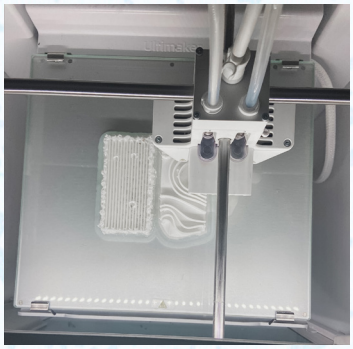


Figure 71: TPU printing

What worked

- Both structures were possible to print
- Passed the stiffness test

What didn't

The sponge-like shape required a lot of internal support that cannot be taken out with FDM. SLS is a more suitable additive manufacturing method for it, as the support material is not needed for designs with overhangs.

Final Concept Direction

Due to the feasibility of prototyping, the “utility” concept is taken as a basis for further design work. In terms of attachment/detachment interaction, the magnets provide a lower cost, lower complexity alternative to designing a quick-release mechanism. However, the various kinds of impact the shin cover will experience in the course of a match or training session, the low shear strength of magnets can cause them to detach. In order to increase the cover’s resistance to side loads, an additional method is required to secure the cover onto the prosthesis.

A buckle was chosen as the secondary securing method as it is low cost, mechanical, familiar in the context of sports equipment and quickly secured when compared to lacing methods.

The final product concept that emerged from the research and ideation is a shin cover designed to boost the amputee preteens’ self-confidence when playing football, through facilitating a mental shift from daily to exercise use. When donned on, as if plate armor, the shin cover visually transforms the prosthesis. The auditory feedback of the snapping cover and buckle provides confidence that the cover is attached properly. The 3D printed TPU structure provides a lightweight, compliant mid-layer to dampen oncoming impact.

The compliant layer, here pictured as a sponge-like texture, is sandwiched between a front-facing plastic panel and a tough but flexible backing.

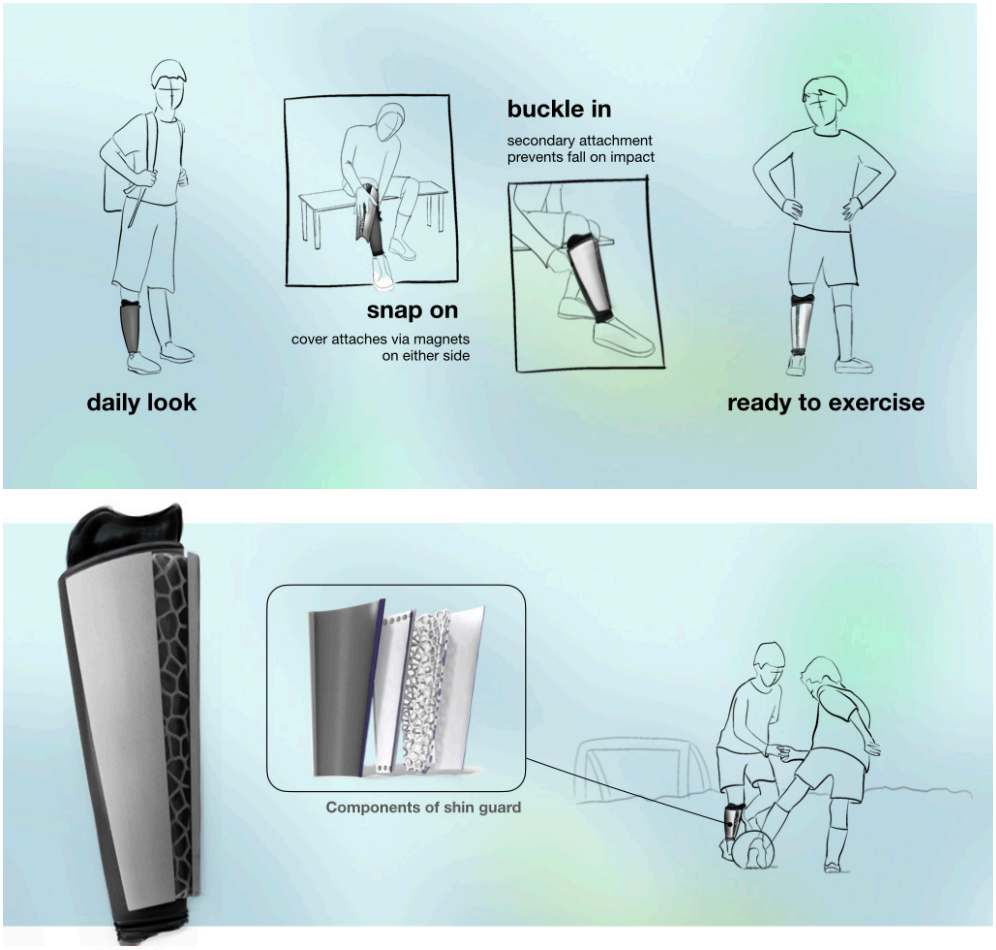


Figure 72: Prosthesis cover concept

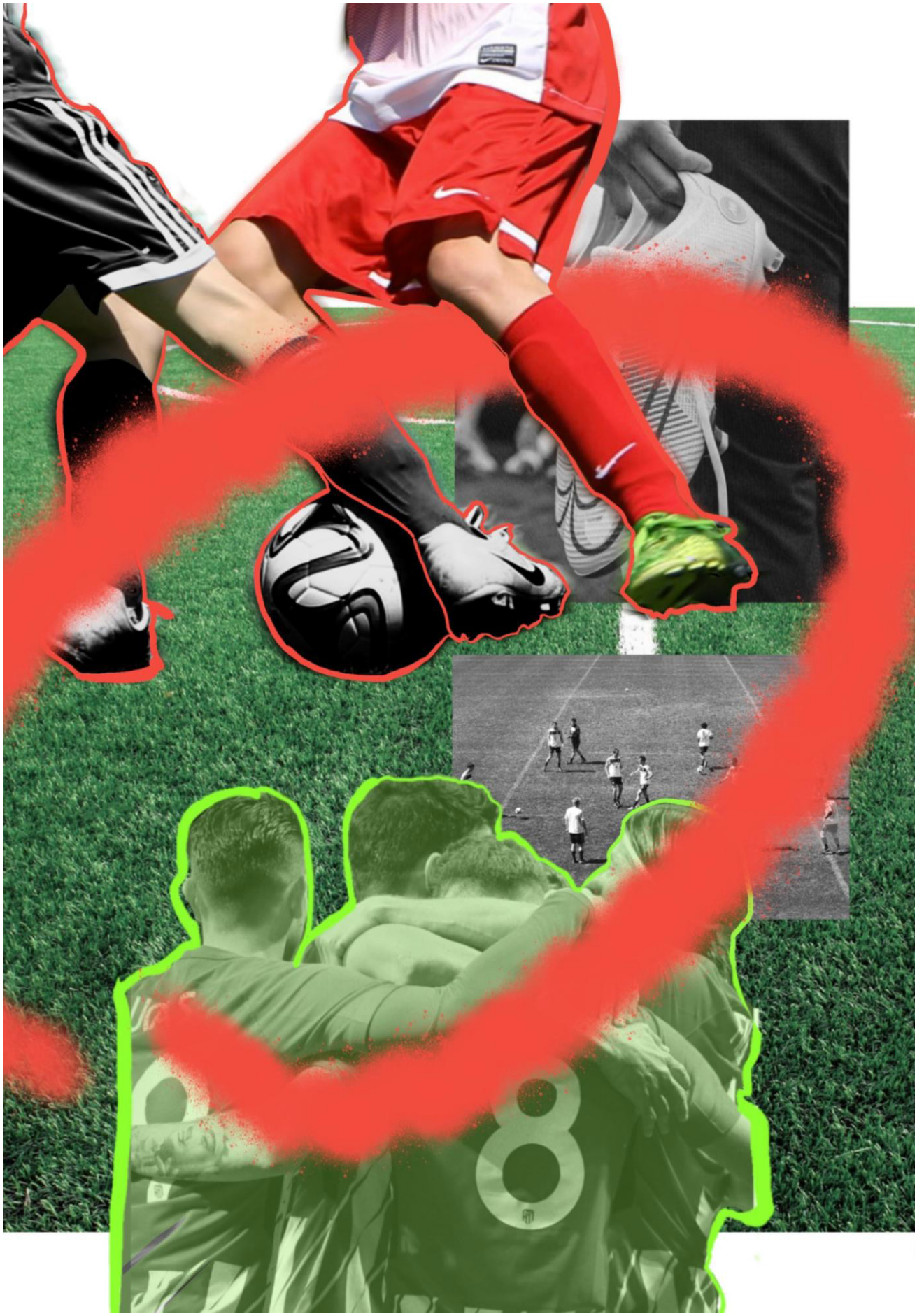


Figure 73: The cultural (target group/lifestyle) collage

5.2.4 Product Styling

Literature review into child development, as well as the accounts of the child participant strongly suggest that for the shin cover to be desirable for children, it must fit their style.
For styling the product, I made three collages that reflect the various visual aspects of the product, and ideated on the appearance of the shin cover using these as a reference. The final design decisions however were made by consulting children of the target age in an online survey.

The target user group is preteen children wearing prostheses, who play football frequently. First, I put together a visualization of the style of the wearer based on interviews with my child participant and research into current football uniforms and equipment. Football practice is a moment children get together with their friends and focus on the task at hand, so it also indicates a moment of separation from everything outside of the football field.

The shin cover indicates a similar transition from daily life to exercise. The desired product qualities defined in the Ideation Chapter for this product were energizing, bold and reactive. The product should make its wearer feel proud to own such a product and make them feel confident in their own abilities in football.

Figure 74: The emotive (feel/ambiance) collage

The lifestyle of the wearer and the intended product qualities dictate a sporty, bold look for the product. The materials used in the product and its final look should reflect these.

Figure 75:
The memetic (looks) collage

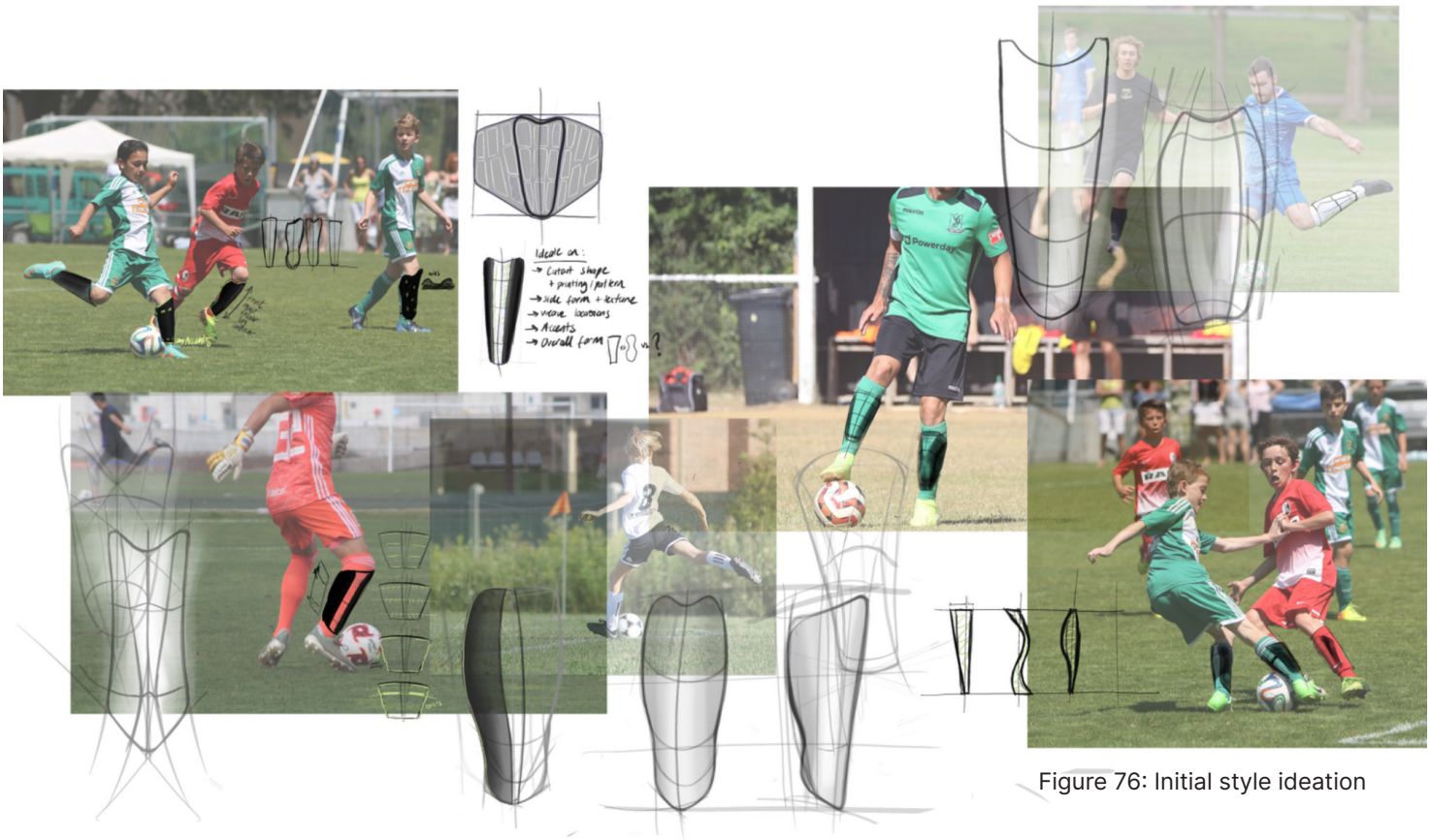


Figure 76: Initial style ideation

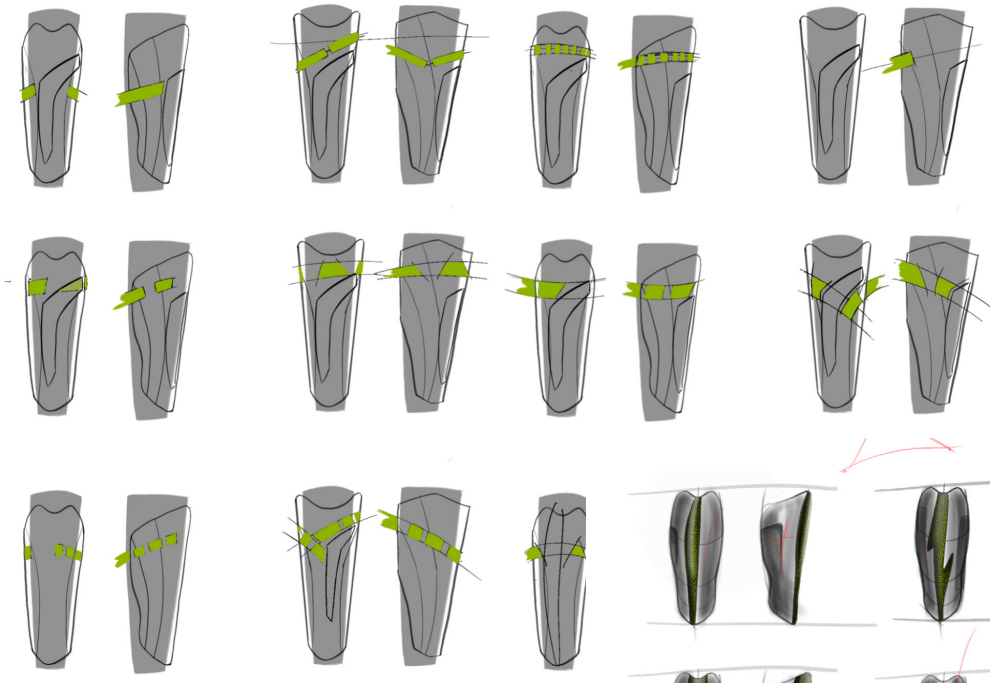


Figure 77: Strap weaving ideation

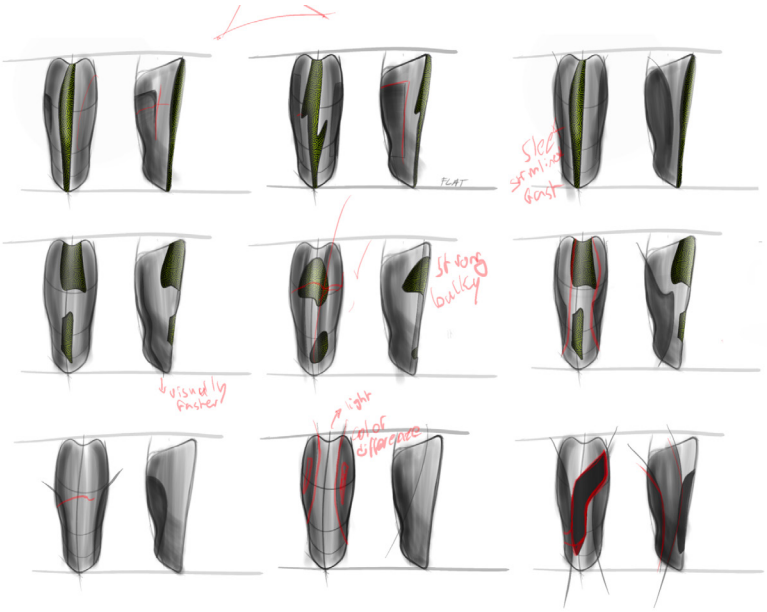


Figure 78: Form and contour ideation

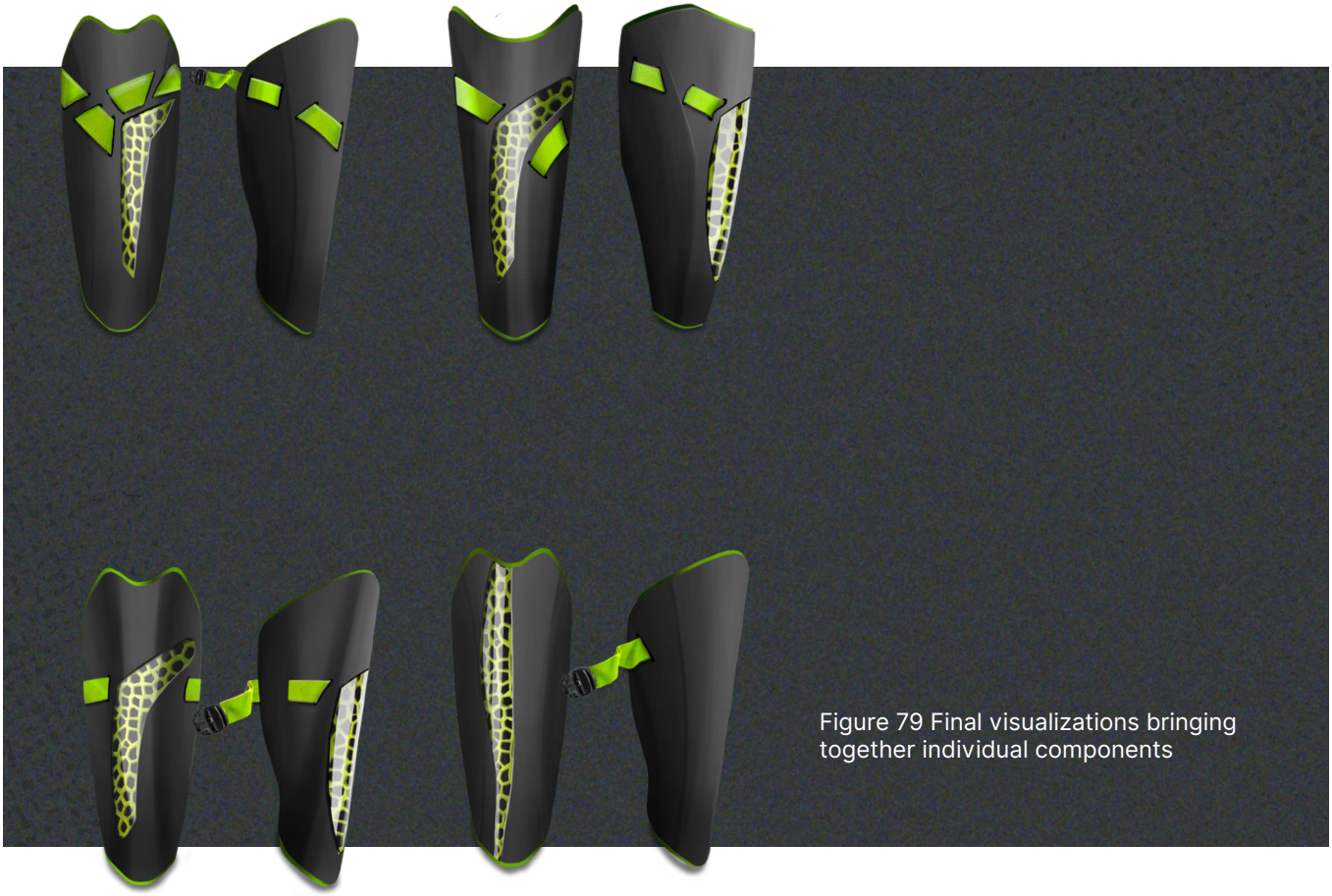


Figure 79 Final visualizations bringing together individual components

Children of the target age group were consulted in an online survey to inform final design decisions. (Appendix I) 5 of the 6 children who responded chose the third option in style, while some mentioned they liked the window shape (2) others mentioned the overall shape as their reason (2). However, with a small number of participants, in an online survey, it is difficult to get definitive results as other children chose these as parts of the design they did not like. Due to material constraints, color option 1 was chosen for prototyping.

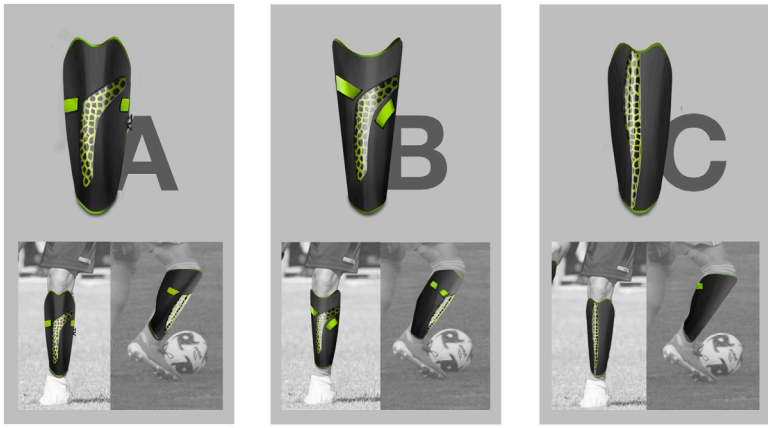
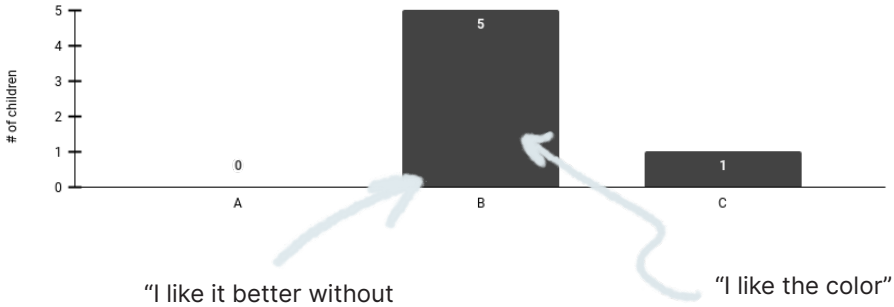


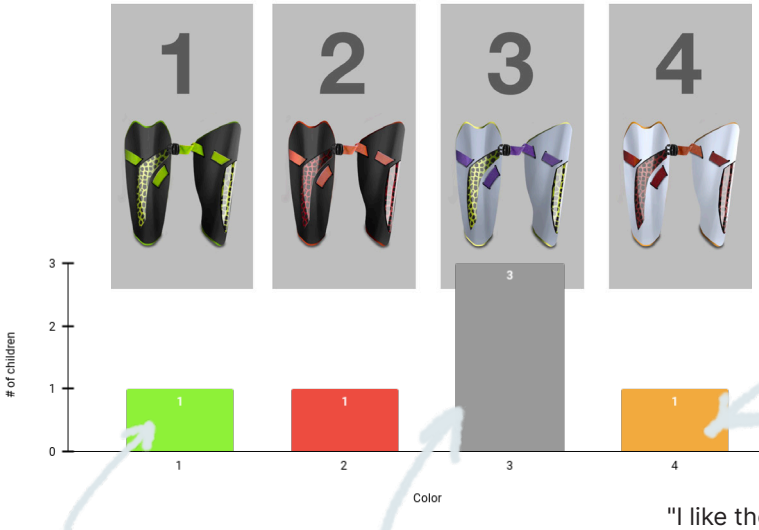
Figure 80: Responses of participants in the online style questionnaire in form



“I like it better without straps, just with socks”

“I like the color”

Figure 81: Colorway selection



"This is my favorite color!"

"pattern looks 👍👍 "

"I like the color because it's not too dark"

5.3 Prototyping

The final concept, with the selected style was prototyped in 1:1 scale. This both helped me understand the details of the manufacturing process for this product, and served as a sensitizing material in evaluative sessions. As the literature research suggested children need to fully experience the design and interaction steps (Chapter 3.3) to be able to envision using a product, it was important for a product representative of the looks, weight and size of the final concept to be made.

06
Final Design

The compliant shin guard is a daily prosthesis cover to be worn by an amputee when playing football. In the event of an accidental kick, the flexible midlayer dampens oncoming impact and mitigates serious injuries, like a bone fracture.

In addition to the physical protection it provides to all players in the field, it aims to encourage children to be more confident in the field. With the visual transformation and tactile feedback it signals its wearer to shift their mindset from a daily one to one of exercise. When donned on, as if plate armor, the shin cover visually transforms the prosthesis into a sports-worthy leg. The auditory feedback of the snapping cover and buckle provides confidence that the cover is attached properly.

6.1 Product Use

The product is meant to be used any time the prosthesis wearer wants to play football. When the cover is placed over the prostheses, it magneticaLly snaps into place by attaching to the set of magnets permanently adhered onto the prosthesis.

Following this, the wearer brings together the two stRaps on the cover and buckles them together in the back. As magnets can be knocked out of alignment in a forceful contact, the mechanical strap provides a resistance against the cover detaching completely.

1. snap on *2. buckle in* *3. ready to exercise*

Figure 82: Putting on the cover

Much like the conventional shin guards, the compliant shin cover is not resistant to getting dirty. The plastic exterior can be wiped clean with any soft cleaning agent. As it does not contact skin directly, any part of the cover is not likely to encounter sweat. In the case it does get wet, it can be left to dry overnight.

	> 8 years old	*8-12 years old*	*12-14 years old*	*semi professional/ professional*
Without Prosthesis Cover	play football without a shin cover	as the football skills of the players advance, the play gets rougher. The prosthesis starts posing a risk of injury to the players on the field		The child is no longer able to play football due to risk of injury to other players
With Prosthesis Cover	play football without a shin cover	As the play gets rougher, child starts using the shin cover to protect the opposing team members and get used to wearing it while playing *Feeling confident and empowered to play as they perceive their prosthesis as sports-worthy* *Get a new cover every year as they grow rapidly*	Continue wearing the shin cover as they are used to wearing it *Get a new cover every year as they grow rapidly*	Be able to pursue football professionally as the prosthesis no longer poses an injury risk *Get a new cover every other year as it deteriorates*

Figure 83: The intended timeline of wearing the compliant shin cover.

6.2 Construction

The shin cover is made up of three distinct layers. The front is made out of polycarbonate(PC), a plastic material that is impact resistant and commonly used in making helmets and other protective gear. The compliant midlayer is 3D printed from TPU, a softer plastic. The hole sizes, wall thickness and density of pattern dictate how stiff or compliant each section can be. The TPU components of the midlayer are sewn onto a Nylon backing, a water resistant fabric rain jackets are typically made from.

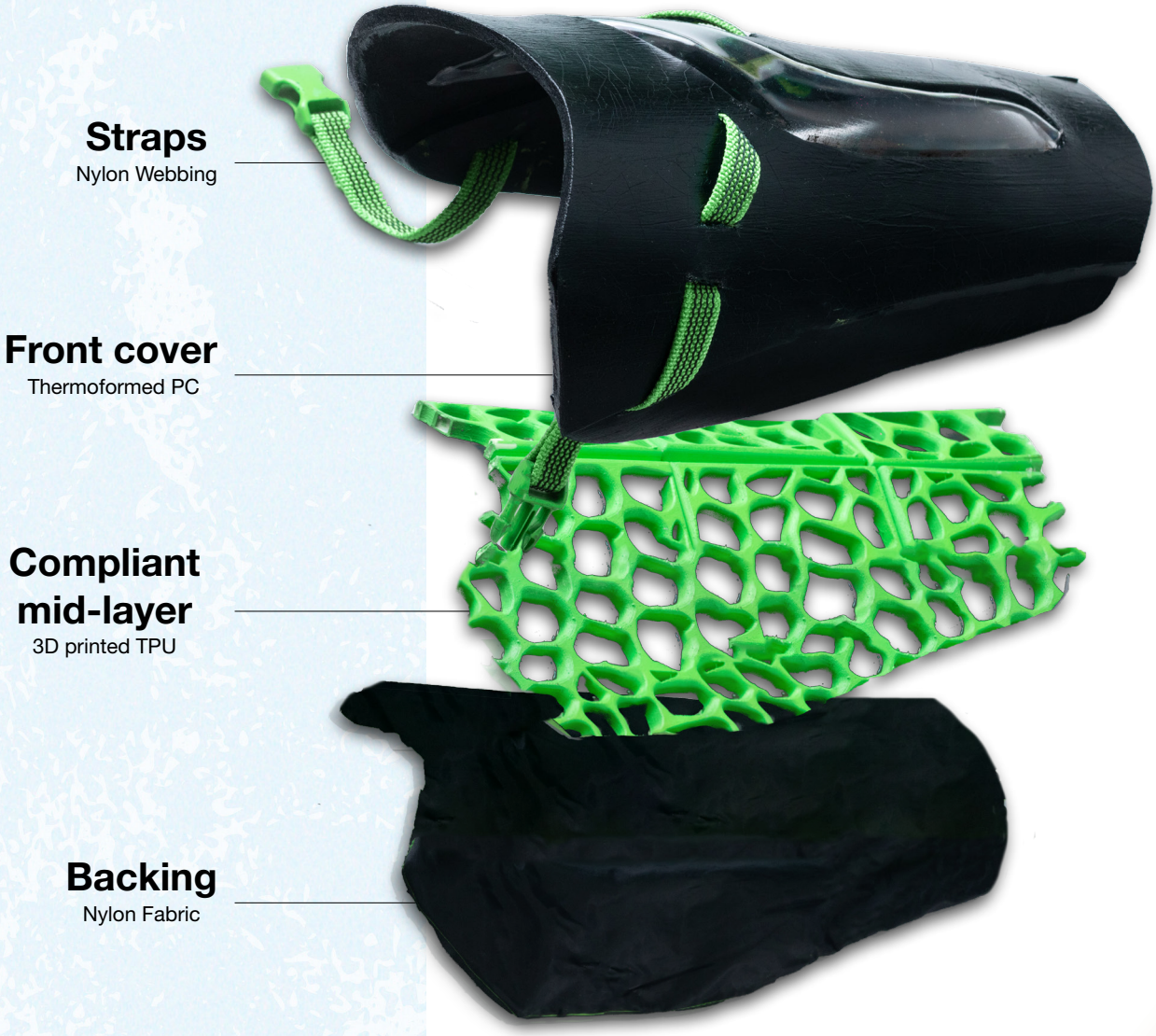


Figure 84: Components of Cover

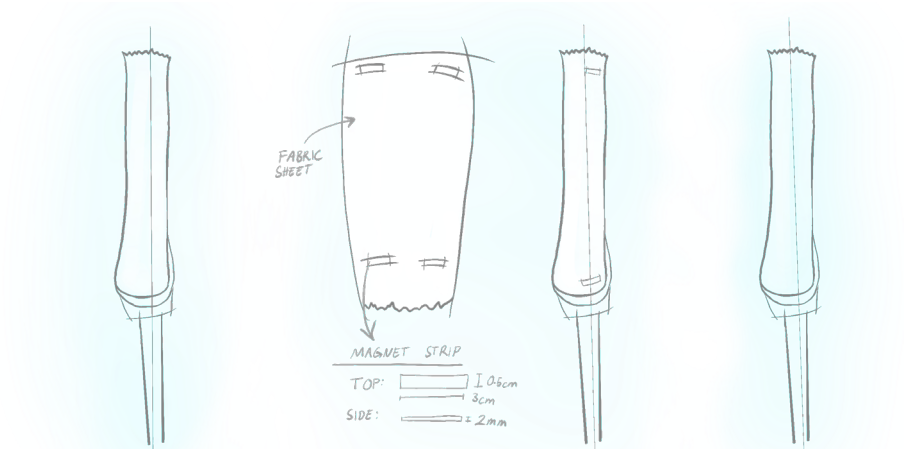
Envisioned Manufacturing and Assembly Processes

The two polycarbonate components, the colored part and the transparent window are individually thermoformed and cut to shape. The two parts are joined via ultrasonic welding, a manufacturing process that can join together similar plastics with no adhesive.

The midlayer components are sewn onto the nylon backing through the attachment holes. The front cover is sewn onto the backing via the previously made hole pattern around the edges. The Nylon webbing is sewn onto the nylon backing and threaded through all layers going outwards, then the buckle is attached and edges of the webbing sewn.

This design requires magnets to be installed on the prosthesis cover itself. The CPO who makes the prosthesis cover in the first place, can install the magnets during an appointment.

The cover comes with a paper cutout that can be taped onto the prosthesis, showing where the magnets must be adhered.



1. Laminate as usual until the final layer.

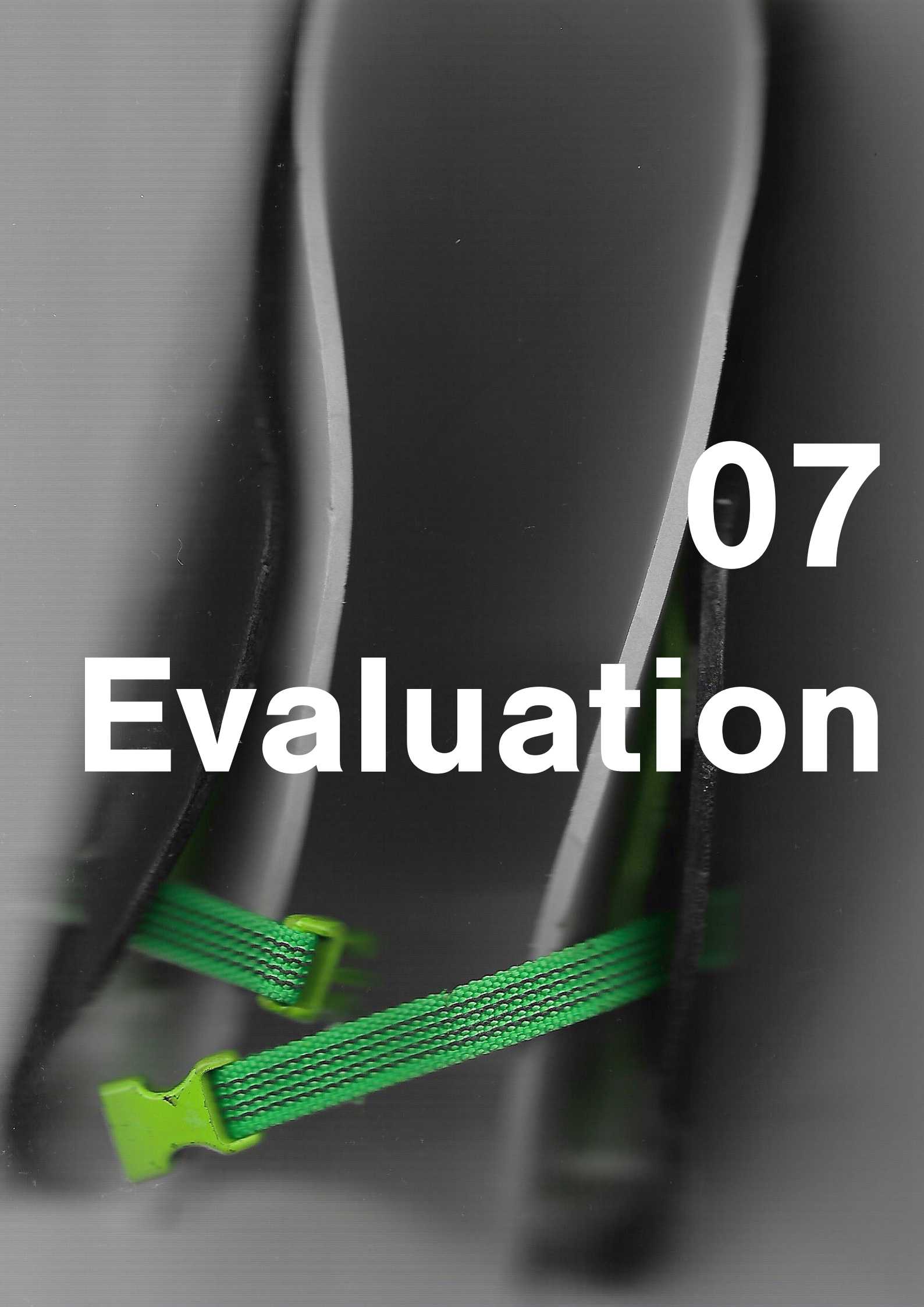
2. Apply the fabric sheet with embedded magnet strips and apply resin over it.

3. Put on final layer of fabric as usual.

Figure 85: Magnet gluing process at the CPO's office.

6.3 End of Life

On the cover itself, all dissimilar materials are joined together via reversible methods. The layers of the materials can be separated by cutting the threads between the materials and properly disposed of. The magnet inserts can be cut away from the nylon backing and be reused in another cover. Considering no adhesives are used in joining the PC sheets together, they can be disposed of and recycled as they are upon separating from the backing.



07 Evaluation

With Children

I conducted evaluative sessions with different stakeholders to understand whether the design met its initial goals and how it should evolve to better fit its intended environment. These sessions were conducted with:

- Children between the ages of 8-12 at a football club for understanding desirability of the product as a shin guard and ease of putting it on
- Physical therapists for feedback on the concept overall and movement, function and possible obstacles the concept can pose in these areas
- A CPO and a prosthesis maker on feasibility of manufacturing on the prosthesis-side
- Football regulatory bodies on acceptability of such a product, whether they would be open for a change on the regulatory side

Children who are not amputees reflect the peer opinion, which is critical for the prosthesis wearing preteens. At first, we handed them a prototype and had a conversation with them on the styling of the product as a shin guard. Later, we handed them a sheet with magnets attached to mimic the prosthesis, and asked them to slide this inside their football sock, as they do with conventional shin guards. This way, they were able to experience putting on the prosthesis cover.

All three had comments or reactions to the size of the prototype. Feels too large and bulky the way it is to be practical during the game and would not protect their leg as their shin guard would (feels too soft for that)

“it is a little large” - dragon

- As the prosthesis cover looks like a shin guard, the differences from the conventional shin guards stand out more.

All three children commented on the magnetic attachment as well. When asked to put the cover on and take it off, they mentioned it makes a satisfying sound.

“satisfying, nice sound” - dragon

The pattern of the green part is striking and the window evokes curiosity regarding what is inside.

“Looks beautiful... a little weird too” - dragon

“Can I have a go?!” - shark

“ I actually think it’s funny, especially these things [pointing at pattern behind window]” - shark

“I think it’s pretty, so I’d wear it on its own” [referring to without a prosthesis]” - shark

” I think green is nice for boys, for example I would also like purple or something.” - shark

The first thing Shark asked her friend who was trying it on was whether it was comfortable.

All three children we talked to were very cautious in aligning the magnets at their first try. They put on the cover slowly and watched each magnet click into place. This directly contradicted my intended interaction style, where the wearer slams on the cover onto their leg. However, as they fidgeted with the cover during our follow up discussions, I observed that they became less careful and quickler in doing this.

Yeah, it’s fitting nicely, I feel like playing football... with this shin guard’ - shark

“I put it on like this, then I’m ready to go” - shark

Slow and careful but they say it’s easy to get on and off

The children alluded to being in a more active or confident state when they put on the cover.

Marking a transition.

”if I had a prosthesis and I’m wearing this then I would feel ready to play football.” - shark

Owl mentions it is easy to set up, (excited premo) they girl offers, yeah you only have to close this thing [the buckle] and it’s ready

Feels nice, it feels... mighty - Owl

Medical Professionals

The two physical therapists from DeHoogstraat did not see the size as a potential obstacle for children who wear prostheses. As it is very light, especially when compared to the prosthesis which is much heavier it would not impact their movement or health in a negative way.
She did worry if the child would feel further stigmatized if the magnets were visible, or if they accidentally stuck to magnetic objects. However, the CPO was excited about the prospects of magnets in the prosthesis “This is a good idea, I did not think of this” offering children extended interaction possibilities

“Now, its 50-50, the soccer club asking them to cover it up, add padding, ask a lot of adjustments to be made for them to join, which makes the children feel resistance”

To Anka as long as it allows children to play without feeling unwanted by the football clubs, children would wear them.

Installation of magnets was not a problem as long as the distances were rigidly set. Initially, I thought to have magnets with adhesives on their backs, stuck on using a guide. The prosthesis maker mentioned their concern that the magnets will move with layers of resin spread over them during the layup and recommended there be a link between them, ensuring they would be at the same distance from each other. Upon feedback, I changed it to being adhered to a fabric layer, makes the installation truly become the same as the layup process and requires them to learn no new additional skills.

Regulations

Whether this prosthesis cover would be protective and accepted within the regulations of football were investigated by emailing football referees and various regulatory boards from different countries.

All of the people I reached out to confirmed that a product like this could be allowed as it falls under shin guards categorically, as long as it does not harm other players. Rene Mijderwijk, KVNB Senior policy officer, Referee cases professional football, defines too dangerous as sharp, pointy or rough.

“There are not a lot of conditions a shin cover must meet currently defined“ - Rene

The Chief Medical Officer of KVNB Edwin Godhart confirmed that he sees it as a significant risk to other players to have players with prostheses or braces on the field.

Jan, professional referee, mentioned soft, padded and lightweight as benchmarks he would consider in allowing someone to keep sports equipment during the game.

FA Iceland replies that “ The laws of the game say; shinguards – these must be made of a suitable material to provide reasonable protection and covered by the socks” This guard currently cannot be covered by the socks, so further research must be done to understand the regulations here, and maybe design a more flexible sock to go over it if needed, or make design changes to adapt this product for a professional league.

The main conclusion from the regulation side is that as long as it can protect the other players and does not pose other risks to the players it will be allowed and could allow for people with prostheses to play professionally.

08 Conclusion & Looking Forward

This graduation project set out to find methods to design for children living with limb differences, and demonstrate these through an example design. Overall, in doing this project I was able to see that the main challenges in the core prosthesis product are mechanical and known by their designers such as size, weight, and stability. However, children are diverse in interests and it is important to keep children with limb differences active and social, so the small number of core products offered to them cannot serve their fundamental psychological needs. Boosting the confidence of children through fulfilling their needs for competence and recognition from family and peers was found to be an important aspect of emotional wellbeing.
In this field, an ecosystem of simpler, complementary products can be of value in diversifying supported activities to facilitate socialization, mitigating stigma and addressing other concerns of children with limb differences.

8.1 Key Contributions

A set of guidelines were developed to communicate with preteens regarding their concerns, preferences and priorities. The set of guidelines were adapted to a series of exercises a designer can use to understand these concerns of children. These exercises were used to have in-depth conversations with a child amputee which served as a starting point for ideation.

The prosthesis cover for football is a novel design that addresses a problem that was unknown to all but the people affected by it. Child amputees were not directly and knowingly barred from football, but the regulations in combination with the attitude of rulemakers have made it strenuous to play wearing a limb prosthesis. With its compliant structure, the prosthesis cover for football mitigates the risk of injury for other players in the field. It looks like shin guards commonly used in football to allow children to fit in with their peers and circumvent evoking unwanted attention and stigma.

When worn, the prosthesis cover visually transforms the daily prosthesis to a sports equipment. The magnetic attachment makes putting it on rapid and reactive, as if putting on a piece of armor. This way, it aids the child in seeing their daily prosthesis as a sports equipment, and makes them feel ready to exercise. The shift in mindset can make children feel more confident in football and this feeling of competency can boost their socialization and participation in life events, positively impacting their wellbeing. The prosthesis cover has a potential to be used in professional leagues as well , which would assist in its standardization amongst the football community in playing with prostheses.

To summarize, this graduation project offers:

- A review of children's prostheses from the perspective of how well they are able to address the fundamental psychological needs of preteens
- A set of exercises a designer can utilize to understand the concerns, preferences and priorities of preteens in a way that was difficult to achieve though traditional interview methods.
- A physical product that can boost preteens' confidence in the football field and allow them to enjoy playing football as they get older

8.2 Desirability

Understanding the concerns of children was the central concept in this project. I started out my research phase with the question “How can children’s prosthetics facilitate confidence and serve the emotional wellbeing of their wearers? ” This required me to investigate the relationship children construct with their prostheses, study the hierarchy of concerns preteens have, and if they change in different contexts. I explored this thorough in depth interview sessions with one amputee child, filled with activities tailored to preteens’ interests and attention span. This approach was somewhat unusual, the experiences and insights of this one child were used to identify moments in which design could have an impact.

Combined with literature and expert opinions, I set out to design a product with the following goal: “Encouraging the daily prosthesis wearing children in feeling confident, motivated and ready to exercise in a sport setting by facilitating a shift in how they view their prosthesis” The looks of the product and the moments they interacted with the product were identified as aspects of the design that could assist in fulfilling this goal.

Evaluating this concept with children showed that the styling of the product allowed at least some to feel more confident, as one described that he felt “mighty” and the other “ready to go” upon putting it on with ease.

Recognition versus novelty is a considerable tension in designing for children, especially preteens. Preteens want to fit in with their peers to be accepted, yet somehow stand out. The short evaluation sessions done with a small group of children showed that they can easily visually categorize the product as a shin guard when they encounter it in the context of football. Albeit larger, the form and scale of the product, as well as the straps mimic the shin covers they are used to wearing, so children had no problem putting it on, even when no directions were provided. As the prosthesis cover was perceived as a common shin guard, it is concluded that it is less likely for peers to make children feel stigmatized for wearing it. Even though the product was easily categorizable for them, it was not common or boring. The window allowed the cover to stand out as a shin cover as it evoked the children’s curiosity, inviting them to admire it, at which point they noticed the “funky” pattern behind it.

Meaning of being an amputee in the future

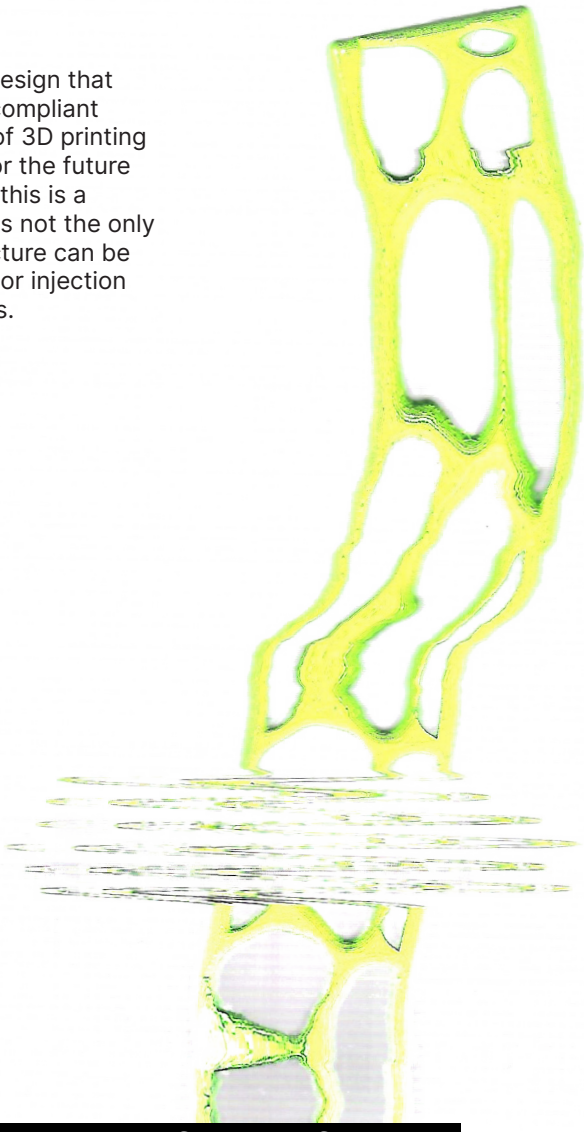
In the beginning of the project, I studied how a prosthesis can convey a meaning regarding its wearer. The shin cover concept was found to challenge the conventional view of being an amputee. As children with prosthetics were considered “too strong”, other children needed to be protected to play football together.

I believe that products like this can challenge the meaning of being an amputee athlete. If the product is adopted and used as intended, it can allow for more children with limb differences to play football for longer, increasing the likelihood of them making it to professional levels. A similar product can make their prostheses softer for the other players, and allow them to play in these leagues. This kind of visibility of people with limb differences in athletic settings is important because athletes, especially football players often serve as role models for children. With more people with limb differences becoming visible and adored in this field, it is possible that children feel less stigma about their own limb difference as they relate to the professional players.

8.3 Feasibility

Feasibility refers to the ease of manufacturing of a product given the current state of art in technologies in this field. In order to understand the full set of considerations that must go into producing the design, the prototype built was deliberate in its material selection. Each part of the prototype that must substitute a material was selected with thought into how the outcome would be replicated in a mass manufacturing setting. Product teardowns of conventional shin guards were done to understand how they were manufactured. Consideration of methods used in this field resulted in a product that is simple in its construction: plastic and fabric layers held together with thread, just like how conventional shin guards are made. Through this prototype and product teardowns, it can be concluded that with the technologies available today, the challenge at hand can be addressed. Considering the end of life of the product at a design stage made it possible to suggest assembly methods that can be undone quickly with the right tools, so that they could be responsibly disposed of.

One component of the design that can evoke doubt is the compliant layer, which makes use of 3D printing at a mass scale. While for the future flexibility of the product this is a desirable technology, it is not the only solution. The same structure can be made with die-cut foam or injection molded with soft plastics.



Serving as an example for the future of custom sportswear

3D printing was selected as the manufacturing method for the compliant layer for future flexibility. Limb differences of children are predominantly congenital, with each leg looking unique. The CPOs must consider the anatomy of each leg to come up with a solution special to the child. In addition, what types of accidents and injuries are common differ with respect to what position a football player plays in. 3D printing allows for each component to be different. It is possible to change the stiffness of each distinct section of the compliant layer through changing the wall thickness of the print, or the frequency and size of holes in the pattern. This way, a particular section of the cover can be made to be softer or offer more protection.

Moreover, the individualization and customization brought with 3D printing can serve as a pilot for other products. Currently, the use of 3D printing is piloted by some sportswear companies in shoe soles, but due to the repetitive strain the soles see, they delaminate easily. 3D printing becomes a more fitting technology in products that need to deform less frequently such as this one. Through piloting this technology at a smaller scale, the companies can understand the advantages and limitations of it without a hefty capital investment, while still producing a product that offers significant value to its wearer.

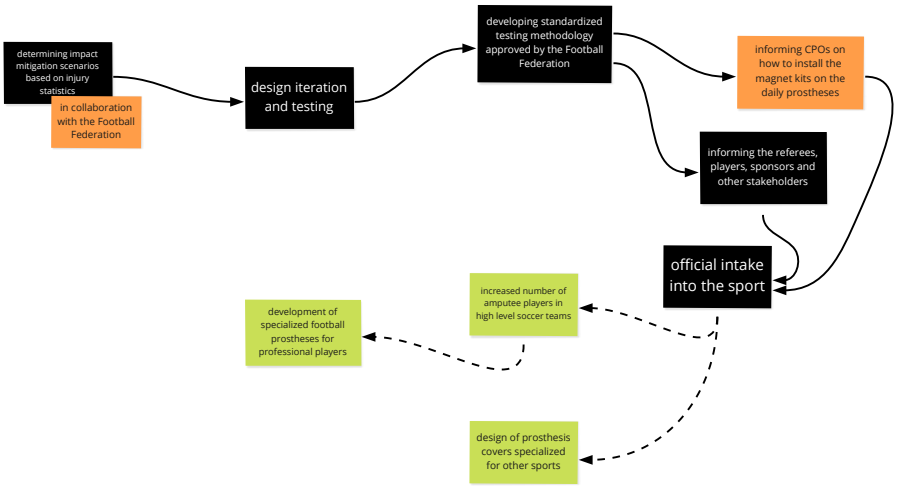
8.4 Viability

The long term success of this prosthesis cover depends on two aspects. First, it must be accepted in football clubs with interest from professional leagues and stay desirable for its target audience.

Regulations

Football is one of the fundamental ways preteen boys socialize and exercise. However, most times, amputee children feel resistance in being accepted in their local football clubs. The extent of questions they receive, and being asked to pad their prosthesis by hand every time they want to play is enough to discourage less confident children. This prosthesis cover can only offer a promising solution if it gives the football clubs the assurance that their players will remain safe and evoke less stigma, which is why the regulatory aspect is significant in its viability. Being a part of the accepted equipment in the “Laws of the Game” in the view of IFAB can make the product more accepted in all other leagues of football. Numerous experts from different leagues were consulted in the acceptability of this product. At first glance, they all considered it an approachable and acceptable solution as it can be categorized as a shin guard, so no resistance is expected in the field from the referees in the use of this product.

Most football experts consulted stated that for the product to be acceptable, it must pose no further risks for the players on the field. Standards must be put into place in terms of its weight, size and lifetime as well as how much force the shin cover should be able to dampen for players of different ages. These standards should be developed in collaboration with IFAB and be testable, producing replicable results under different load conditions.



Long Term Desirability

Trends amongst children change rapidly, in a way that baffles parents and designers alike. For preteens, wearing something that is outdated is a source of stigma. For the prosthesis cover to continue being a source of confidence, its styling must stay relevant for children as they age.

Most contact sports have a similar concern for the safety of their athletes, meaning similar products would be desirable for them as well. If the producer would like to ensure a growing demand for this product, they must consider how the product can be adapted to fit the safety needs of different contact sports.

8.2 Limitations

One of the main challenges of this project was finding participants. As children are a vulnerable group and there are so few children with limb differences in the Netherlands, each generative and evaluative session was conducted with a small number of participants. At this scale, the biases of one participant can impact the findings of the research greatly.

To ensure the desirability of the product for its target group, it is important to evaluate it with children with lower limb differences who play football, and with a larger group of participants. It can be fruitful to interview them together with their peers as children can communicate more comfortably with each other. In addition to this, it was observed that children answer their peers' questions regarding a product more truthfully than that of the designers, as they might feel an obligation to make the designer happy.

Due to constraints in time, only one prototype was brought to evaluative sessions with children. The guidelines suggest that even when children cannot verbalize their reasons, encouraging them to make choices can inform designers of their preferences. To get more targeted feedback and detailed justifications for preferences, the children should be provided with multiple different prototypes and be asked to choose between them under different conditions.

Next Steps

In order to be able to offer this product on the market, the design must be updated and further evaluated.

The low fidelity foam prototype was used to seek feedback. However, the size of the prototype was a considerable concern for children and experts alike in the evaluation sessions. In the next iteration of the design, the design should be made slimmer to address this point of apprehension.

In the evaluative session children were observed to be slow and careful in attaching the prosthesis cover. This can be because the magnets were placed at far ends of the product. The magnet locations should be updated, with attachment points placed at the axis of symmetry of the cover. This way, the magnets will always snap correctly. Another way to prevent children from worrying about the magnet match is by making them invisible to the children. In next iterations of the design, the magnets should be better integrated into the product, making them invisible to the wearer.

While calculations were carried out to estimate what materials could be used, these cannot take the place of rigorous testing. In order for the product to be accepted, it must prevent risk of injury by kicking. More extensive research should be conducted into statistics of injuries of football due to contact and the nature of these injuries to develop realistic test cases and standards. Based on these standards, the geometry of the compliant layer can be updated to reach the desired stiffness range. The viability of the product relies on its legal acceptance in amateur and professional football leagues. The standardization of the product requirements must be carried out in tandem with IFAB, and a strategy must be developed to make the product rules legal.

Lastly, while the CPO and prosthesis makers interviewed in this project consider magnet attachment to a cover-type prosthesis, how this is carried out should be detailed and evaluated with a larger group of prosthesis makers.

Reflection

This project allowed me to work for a unique group of people, children, and I thoroughly enjoyed learning from them. In larger projects like this, I am used to making rigid plans and executing them, but this thesis taught me to be open minded and flexible in my approach. Initially, I set out to find a framework in which children's products could be developed in the context of prostheses. The process of talking to children, parents and experts made me realize that the needs of children are highly contextual, complex and difficult to capture and study in a graduation project. They also change with time, trends, geopolitical location, and other factors that impact children's lives and living environment. Instead, I learned that to design for children, it is more important to study how to communicate with them, make them feel safe to answer (or refuse to answer) questions honestly and offer information. This is why I focused on bringing literature on psychology, play and design, along with real-time learning from the children to put together guidelines on talking with children, and create activities that allow children to express themselves and their concerns.

Throughout the project, my priority was to speak to children and their friends to directly listen to their concerns from them, and this proved to be one of the more difficult challenges in this project. I struggled in reaching out to the correct people in advance, and in explaining my research. Children living with limb differences are frequently approached by outsiders to talk about their life. Regardless of their intentions, questions can feel intrusive, leaving children weary and feeling like they are being studied. In doing this work, I learned to not take my work so seriously, to listen and be a friend first, and leave the analysis and research questions for later. I like to think in doing this project I not only learned a lot about design, but about being a more fulfilled person.

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