FAST-HIKING BACKPACK FOR WOMEN

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AN ANTHROPOMETRIC APPROACH TO THE DESIGN OF FAST-HIKING BACKPACKS FOR WOMEN

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SUMMARY

For this graduation thesis, the goal is to design a backpack that is suitable for fast hiking with women specific sizes, features, and accessories. The selection for the design of a backpack for female hikers was chosen because current backpacks on the market are designed with male bodies in mind therefore, female users experience more issues with misfit and discomfort. This project works closely with a company that is known as a producer of sporting equipment and sportswear who would like to expand their portfolio with products that aims to improve the fit and comfort of their customers.

Before entering the design phase, it is important to understand the aspects of backpack design, challenges with products on market, and gender differences of the upper body in order formulate design requirements. It was revealed from user research that female hiker faced high levels of discomfort on their neck/shoulders, chest area, and lower back due to the misfit of backpack size and unoptimized placement and shape of the shoulder/hip straps. With these identified issues, this was prioritized during the ideation and concept generation to explore solutions that reduced shoulder and chest discomfort while improve overall fit.

To create an appropriate fit of the backpack, anthropometric data was gathered from the DINED and ANSUR II database to formulate an anthropometric guideline. However, each database has its limitations such as data from DINED reflects students from the ages 17 - 27 and not all Dutch adults while data from ANSUR II reflects data of female soldiers and not civilian populations. The main design goals gathered from the research are to establish parameters that are relevant for backpack design asides from stature. Concluding dimensions of the backpack are based off the two databases and aims to fit women within the 5^{th} and 95^{th} percentile of the proposed body parameters.

After that, ideas and concepts were generated based on the identified issues, anthropometric research, and design requirements. Inspirations were drawn from existing products such as posture braces, women's body armor/ military vests, and baby swaddles/3D knitted shoes to create three concept directions.

The final concept design being a strapless system that replaces conventional shoulder straps with stiff, bendable shoulder hooks allowing for ultimate freedom of the shoulders, chest, and arms while pack load will be fully distributed onto the hips. Physical prototypes were made of the winning concept to validate the carrying system and tested with users regarding fit, comfort, and mobility.

From the testing results and observations, the strapless system proves to be a potential design that could improve the overall fit and comfort for women. As it allows for freedom of the upper body without the complications sternum and shoulder straps while maintaining the usability and functionality of a conventional hiking backpack. However, further development is needed to fully validate the design for a fast-hiking context. To do so, general recommendations are given to improve the next iteration.

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1 INTRODUCTION

This section serves as an introduction to the project while outlining the design context, assignment, and project approach.

1.1 PROJECT OVERVIEW

THE COMPANY

This graduation project is a collaboration between TU Delft and a company who will remain confidential. They will be referred as the Company or Client moving forward.

The Company is known as producer of high-end performance sporting equipment and sportswear with distribution within Europe, North America, Australia, and many other places. Their aim is to provide customers with the highest level of comfort and fit therefore, products are handcrafted and curated for the specific sport. Now, the Company hopes to provide more versatility by introducing a women specific fast-hiking backpack that embodies the highest level of fit and comfort for women.

THE ASSIGNMENT

The Company proposed the assignment of developing an optimized fast hiking backpack specifically for women to ensure comfort and fit for their customers. This includes an exploration on ergonomics, comfort, and user product experience to pinpoint current challenges.

As for optimizing fit, anthropometry is considered to determine which body measurements of women is relevant for backpack design. Essentially, redesign current fast-hiking backpacks and/or that would improve the fitting, comfort, and usability for women based on the research collected.

Figure 1. Example of terrain
Source:

WHAT IS FAST HIKING?

Fast hiking, also known as fast packing, is a relatively new sport where it combines aspects of backpacking and trail running. The goal is to pack minimally and move as efficiently as possible to cover large area and distances outdoors. The pace includes jogging the flats, power hike the inclines, and running the declines (Colyer, 2022). It is not limited for just elite athletes or fit runners but for anyone who has the desire to challenge themselves physically.

Trip durations are often multiday based on the user and dependent on the days, the backpack capacity one would take might differ. Minimalist packers might be satisfied with a 12L backpack while others who enjoys more luxury or comfort in their trip will use a 30L backpack. In that instance, they might compromise pack comfort and ease of mobility, but it is solely based on user's preference.

TARGET GROUP

As briefly mentioned, the target group for this project is adult women. It can be assumed that the women are able bodied of varying size and shape that can participate in this sport. There are no excluding factors such as user's fitness rating, physique type, age, or whether they do this competitively or recreationally. As this project explores the anthropometric approach, body measurements will be collected of European (EU) women as it is the largest market for the client. To narrow the target group, measurements Dutch women will be the foundation for the backpack design because there is more access to data based on Dutch women than other European women. Anthropometric differences based on population will be considered and detailed for the client's knowledge.

PROJECT APPROACH

This project aims to understand the problem and challenges concerning fast hiking backpacks, perform research on what factors or (gender) differences contribute to the challenge of ill-fitting backpacks for women, and based on the insights, present concepts and/or features that would best solve the matter. Additionally, to be able to provide insights and recommendations for the Company in terms of women specific backpack design.

The Double Diamond design process was adopted for this project for its structure and organization for creative thinking space. The two diamonds allow the ability for exploration (divergent thinking), acting (convergent thinking), and the ability to loop back and iterate at any stage of the process (Framework for Innovation, 2022). The process can be divided into four parts: discover, define, develop, and deliver as shown in figure 2.

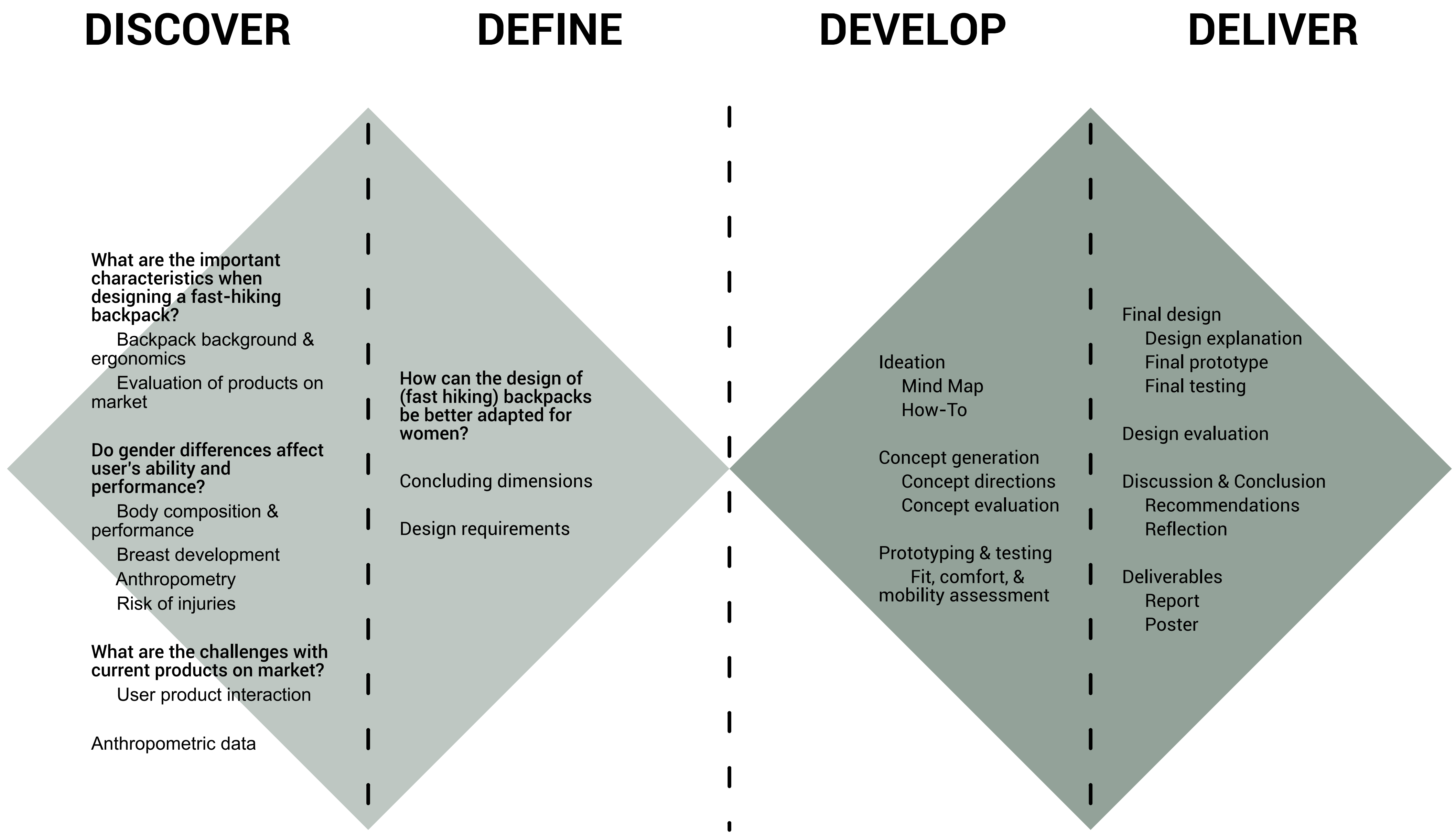

Figure 2: Double Diamond design approach

2 CONTEXT RESEARCH

In the research phase, it mainly consists of literature and desktop research regarding the design of hiking backpacks in regards to safety, ergonomics, and (dis)comfort. Followed by a dive in gender differences in terms of physical and anatomical differences that might affect user's ability and performance. The last section of research covers the evaluation of products on the market and user's inputs collected via surveys regarding user's hiking experiences, fit, comfort, and challenges with their backpacks.

2.1 RESEARCH PLAN

In this preliminary phase, the goal is to understand the context of fast-hiking, the equipment involved, and the user-product interaction. Various methods of research are conducted such as literature and desktop research, as well as qualitative research in forms of user interviews and surveys.

Collected information and data are used to formulate an anthropometric guideline that can be used as a foundation for women specific backpack design.

RESEARCH QUESTIONS

As stated in Project Approach, the project aims to understand the problems and challenges women face with current fast-hiking backpacks. As well as how anthropometric design can play a crucial role into the redesign of women fast-hiking backpacks. Therefore, the main research question is as followed,

How can the design of (fast-hiking) backpacks be better adapted for women?

Before the research question can be answered, the following knowledge is needed to have a firm understanding about the user-product interaction.

What are the important characteristics when designing a (fast-hiking) backpack? This question will help understand the approach companies take when it comes to backpack design and how women specific features are considered. Additionally, provide the necessary background to backpack safety in terms of ergonomics, (dis)comfort, and usability. This can be done through literature and desktop research in combination with user surveys.

Do gender differences affect user's ability and performance? The exploration of gender differences can provide the need and/or want to gender specific gear and backpacks and how it can improve user's performance and safety. This helps create a foundation that will aid in the design process to see what aspects can be redesign and improve. This can be done through literature and desktop research.

What are the challenges with current products on market? This can be answered through desktop research of existing products on the market and user survey to understand user's behaviors, needs, and challenges when it comes to their hiking backpack. Thus, providing insights on how future products can be improved to fit more female users.

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2.2 DESKTOP RESEARCH

BACKPACK BACKGROUND

Research question - What are the important characteristics when designing a (fast-hiking) backpack?

For recreational or non-recreational uses, backpacks are the most convenient forms of load carriages. Form and shape of the backpack might differ based on the usage context. Military personnel carry heavy loads filled with equipment, protective gear, and firepower while recreational hikers carry subsistence and comfort items (Knapik et al., 1996).

Backpacks are separated in multiple categories from trail running packs (~5L – 10L) to backpacking packs (50L+). Dependent on the scenario, certain backpacks might offer more attractive or useful features for the users. Figure 3 outlines the potential features in hiking backpacks.

For this project, the focus is on hiking backpacks, specifically the category of day packs as it aligns with the definition of fast hiking. However, the concept of fast hiking involves overnight stays whereas, day hiking normally lasts between 3-5 hours. Hence the need for overnight shelter and other equipment that might not be necessary for day hikes. Day packs are found between 15L-30L where it can store the necessities while being ultralight and can be used for either activity.

Figure 4 outlines the common equipment needed for a multiday (average 2-3 days) fast-hiking trip. Size and shape of equipment varies on user's preference as gear are becoming lighter and more compact where users might not utilize the full pack capacity for their trip.

On the market products are sized based on one's torso length with hip circumference in consideration. Women's backpacks can be found in one size fits all or multiple sizes, usually XS/S and S/M. For sizes that are larger, suppliers recommend unisex backpacks, but unisex sizes are designed with men in mind therefore, adjustability and features might not be accommodating for women. As many might argue there are little to no benefits with women specific sizes and design, the chances of incorrect backpack fit are lower and so are the risks of musculoskeletal injuries and back pain.

Figure 4: Packing list includes but not limted to: appropriate apparel (rainwear, gloves, change of clothes), trekking poles, easy to digest foods (energy bars, fruit), water, navigation system, first aid kit, shelter, and light source

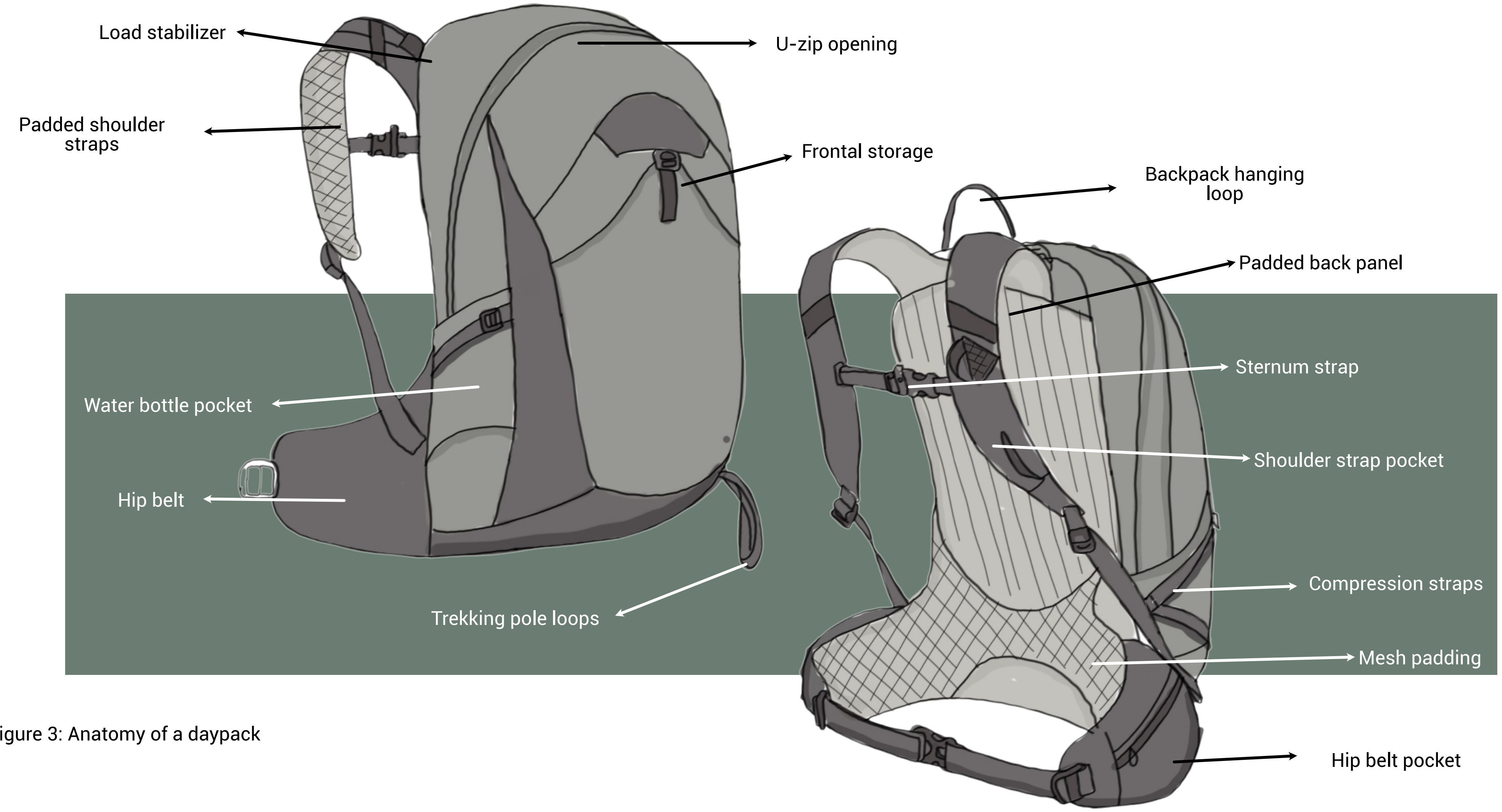


Figure 3: Anatomy of a daypack

BACKPACK ERGONOMICS

Research question - What are the important characteristics when designing a (fast-hiking) backpack?

Gathered from the user survey that can be found in appendix C, participants have expressed the importance of comfort in a backpack. The following section will address the impacts of backpacks regarding posture, perceived (dis)comfort, and safety precautions with heavy loads. The additional research help determine important aspects of a backpack that can increase the level of safety for women as expressed in research question "What are the important characteristics when designing a (fast-hiking) backpack?" This was done through desktop research and user survey.

POSTURE

It is recommended that load carriages should not exceed 10%-15% of the user's weight (Brackley et al., 2004) and can increase to 30% body mass under the right circumstances. Exceeding the recommended thresholds affect the trunk, neck, or spine which can lead to back pain and other musculoskeletal injuries (Kim et al., 2019). Figure 5 shows the effect on one's posture with the increase in backpack load.

With an increase of backpack weight, the center of gravity shifts backwards and causes extension of the back (Yusuf et al., 2008). To counterbalance the extension moment, abdominal muscles will contract and/or users will lean forward to balance the shifted center of gravity. From the same study, backward inclination of trunk posture is unchanged with different loads (10%, 15%, and 20%), approximately about -3° to -4° but prolonged carriage of this deflection leads to postural discomfort and muscular pain of the back, neck, and shoulders.

Figure 5: Normal (left) versus bad (middle & right) posture (Newitter, 2016)

TAKEAWAYS

It is necessary to support normal posture and spinal alignment of users while walking/running and minimize postural discomfort. Additional support can be implemented at the hips and compression straps which brings the backpack's load close to the midpoint of the spine.

PERCEIVED DISCOMFORT

Discomfort can be defined as a "mental or physical uneasiness: annoyance" according to the Merriam-Webster dictionary while comfort can be defined as the absence of discomfort. Comfort and discomfort do not have fixed definitions as it is reliant on the use context, people tend to assume that they are opposite sides of one scale. Feelings of comfort and discomfort are subjectively rated and are often affected by one's physical, psychological, physiological, and environment factors. Discomfort is commonly associated with physical connotations such as pain, soreness, numbness, or stiffness while comfort is associated with the feeling of relaxation and wellbeing (Looze et al., 2003). Therefore, it is beneficial to treat the entities independently due to the different underlying factors when assessing user's (dis)comfort (Zhang et al., 1996).

In the following survey (can be found in appendix D, the overall focus is around the perceived discomfort for participants in various areas at a specific time stamp. Quantification of discomfort levels are justified with a numerical scale from 1 (barely noticeable) – 5 (pain). It is important to note that pain can lead to discomfort however, there are non-pain related, physical and psychological factors that can lead to discomfort (Ashkenazy et al., 2019). Psychological factors include feelings of unpleasantness, embarrassment, uncertainty, fear, or stress.

BACKPACK SAFETY

General backpack load is recommended at 10% - 15% of one's body mass without causing long term injuries. Exceeding the limits can increase one's physical stress and cause discomfort and bone muscle pain. According to Simpson et al., 2010, pain experienced for majority of users are in the neck, shoulders, upper back, and hips. Lower body pain in legs, knees, and ankles can be found in heavy loaded backpacks that are waist supported and trekking through uneven terrains (Simpson et al., 2011).

Therefore, to ensure backpack comfort and posture, the following are important.

- Ensuring torso and waist belt fit for even distribution of load on shoulders (20% load) and hips (80% load)

- Maintaining backpack's center of mass closest midpoint of the spine therefore, heavy, bulky items are packed in the mid-section (closest to the back) while light items are packed on top and bottom

- Optimizing the usage of backpack features such as load shifters, compression straps, sternum clips, and hip belts for stability

TAKEAWAYS

Evaluation of backpack discomfort are highly subjective and vary based on user. Users who frequently hikes have established a greater duration of interaction with the backpack therefore, high levels of discomfort are unlikely to occur. The feeling of discomfort can be seen as high in the initial stages and becomes less noticeable after longer periods of time. User perception and expectations of product comfort can influence their overall assessment.

GENDER DIFFERENCES

Research question - Do gender differences affect user's ability and performance?

BODY COMPOSITION

It is known that men are inherently larger and taller compared to women. There are many aspects that contribute to the gender differences that plays a role on one's physical performance and safety such as body composition. Body composition differs between men and women in terms of bone structure and density, fat distribution, and muscle mass.

Bone Structure and Density

In males, due to an increase of testosterone levels which results in an increase of muscle mass, strength, and bone cross sectional area (Lang, 2011). When compared to their female counterparts, with an increase of estrogen, bone mass increases but overall cross-section area does not which gives women a slimmer, smaller stature than men. Other development experience for adolescent girls includes an increase in body mass, breast growth, and wider hips.

Fat and Muscle Distribution

As stated by Bredella, 2017, men have more lean mass while women have more body fat of the same body mass index (BMI). Men are more likely to accumulate the mass in the trunk and abdomen area whereas women accumulate them in the hips and thighs. Even though more fat content can be found in women, most of the fat is characterized as peripheral subcutaneous fat (fat that is stored between muscle and skin rather than around the organs) which is beneficial to women's metabolism and insulin sensitivity (Nuckols, 2020). Similarly with the muscle mass, women have greater proportion of Type 1 fibers which contribute to the ability to pump blood to the muscle to provide oxygen and metabolites which allow women to exert less and are more fatigue resistant than men.

Breast Development

Changes to the breast structure and function can be seen during puberty with the influence of hormonal levels for adolescent girls. Anatomically, the structure of men and women's breast consist of the same fibrous (connective) and adipose (fatty) tissue and sits in front of the pectoral muscle. However, women possess also possess glandular tissue that consists of lobes (that divides into lobules) and ducts that allows for the production and delivery of breast milk (Pandya et al., 2011).

Variation in breast size, shape, and density can be influenced by many factors such as genetics, age, weight, and exercise. According to Brown et al. (2012), body mass and BMI are positively correlated to breast mass (or chest circumference) as shown. As women's breasts mainly contain adipose fat tissue, it can be said fat mass attribute to a greater increase in both smaller and larger breasted women.

From Tairych et al. (1998), skin sensitivity around the breast decreases significantly when breast size and ptosis (breast sag) increase. Therefore, smaller breasted women size tends to experience chest sensitivity and discomfort earlier than others due to the lack of fatty tissue.

ANTHROPOMETRY

Anthropometry influences a wide range of industries, services, and products from occupational injury prevention, architectural design, health risk determination, and physical capabilities. In a sport context, anthropometric characteristics such as height, weight, or arm/leg length can put an athlete in an advantageous situation dependent on the sport (Thirumagal, 2013).

In the study by Carter-Thuillier et al., it explores the relationship of anthropometric variables to physical performance in females and males college athletes. In certain fitness tests such as vertical jump, men were at an advantage due to their height. However, in other fitness tests such as change in speed direction, women outperforms men due to their lower center of gravity which allow for quicker horizontal acceleration. In other aspects of the fitness tests, both gender performance were similar where in men, there was a strong correlation between height and agility (i.e., taller athlete were less agile) whereas in women, there was a strong correlation between body mass and agility (i.e., heavier athletes were less agile).

A relationship can be seen between anthropometry and physical performance but little is influenced based on the athlete's gender. However, the methods for conditioning or training might differ for women and men due to their body characteristics.

Figure 6 portrays the anthropometric differences of Dutch adults based on their 50th percentiles.

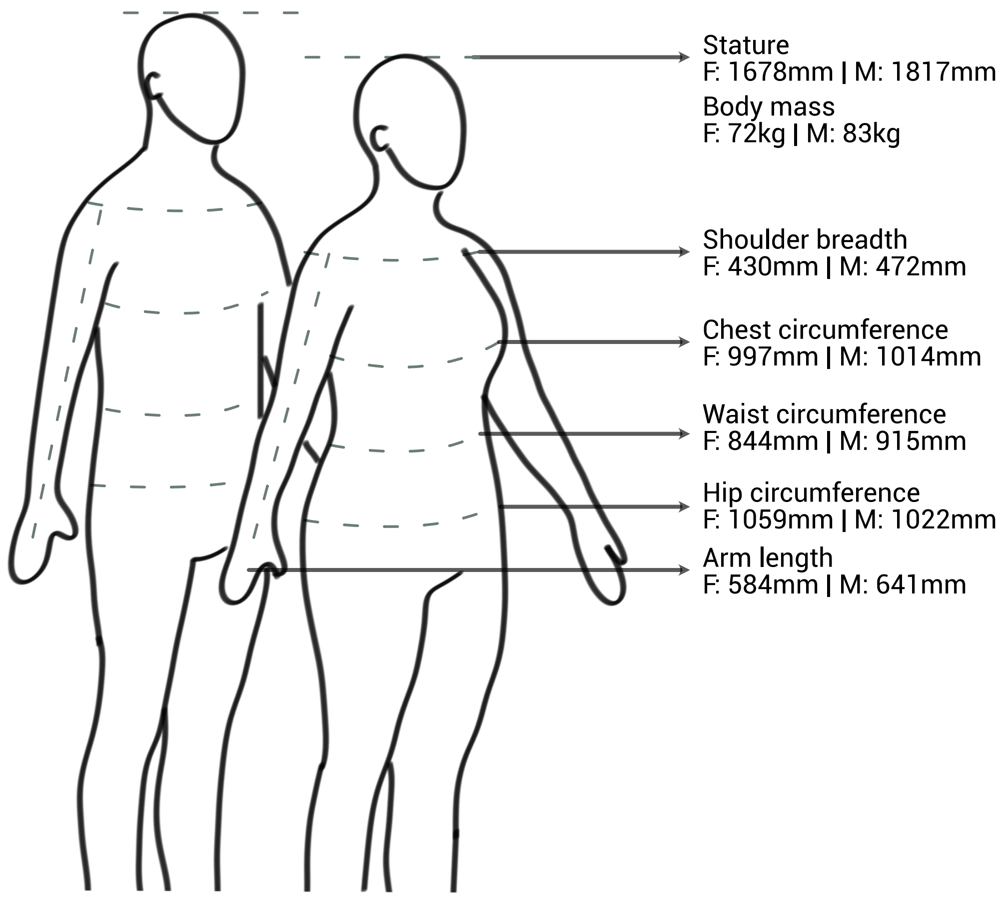


Figure 6: Anthropometric differences of the 50th percentile adult Dutch men and women

RISKS OF INJURIES

Any form of load carriage is identified as the primary musculoskeletal injury for both men and women, especially for long duration such as in the military or for hiking. Research have shown that women are more susceptible to load carriage injuries and it increases the risk of lower limb stress fracture, pelvis stress fracture, and injuries to the hip, knee, ankles, or back (Wendland et al., 2022; Krupenevich et al., 2015).

Likelihood of these injuries can be based on the structure of the pelvis as women have a wider pelvis, which results in a greater Q-angle and hip adduction. With a greater Q-angle and hip adduction, there is an increase of stress over the knee area which affects its health and functionality. A Q-angle is defined as the quadriceps angle that is form from the quadriceps muscles and the patella tendon (Khasawneh et al., 2019).

TAKEAWAYS

Due to variability in body composition of women and men, the design should accommodate the variance in body shape and sizes. Especially in torso shape, presence of breasts and its size/ shape, and hip width as they are the critical factors that can influence backpack design.

Table 1: Summary of gender differences

ASPECT	FEMALE	MALE
Hormonal levels	More estrogen than testosterone	More testosterone than estrogen
Growth spurt years	Two years growth spurt period (Barhum, 2022)	Two years before puberty and three years for growth spurt period (Barhum, 2022)
Physical differences	Generally shorter Breast development Curvier	Taller in stature and size Chest development Pronounced Adam's apples = larger voice box
Bone structure differences	Shorter bones Wider hips (larger Q-angle) and torso Center of gravity located in hip region Higher estrogen = reduces bone growth but regulates bone mineral	Longer bones (femur and tibia) Larger skulls Center of gravity located in the waist region Higher testosterone = improve bone size More bone development at muscle attachment sites
Bone density	Lower bone density Menopause accelerates rate of bone loss More prone to calcium deficiency	Higher bone density
Body fat %	~10% higher body fat than men (Karastergiou, 2012) Stores body far in hips and thigh areas More peripheral subcutaneous fat. Helps metabolism and insulin levels. (Nuckols, 2022)	Stores body fat in trunk and abdomen areas More visceral fat (Nuckols, 2022)
Body muscle %	30-35% muscle by weight More Type 1 fibers = tires slower Capable of switching between Type 1 & 2 fibers (Nuckols, 2022)	40-45% muscle by weight More Type 2 fibers = tires faster Uses Type 1 fibers first then shifts to Type 2 fibers (Nuckols, 2022)
Anthropometry	Ability is impacted by body mass (i.e., Heavier athletes means lower agility level) (Carter et al., 2019)	Ability is impacted by height (i.e., Taller athlete means lower agility level) (Carter et al., 2019)
Risk of injuries	Acute angles of thigh bones positioning = higher stress on knees and ankles Smaller ACL volume = prone to tear (Barnett, 2021)	Higher rate of hip and groin injuries

3.1 EVALUATING PRODUCTS ON MARKET

Research question - What are the challenges with current products on market?

Currently, there are many companies such as Osprey, Gregory, and REI who have developed women specific sizes and design. Modifications include smaller backpack sizing, contoured shoulder straps (J-curve vs S-curve as shown in figure 7), contoured hip belt shape, higher adjustability of sternum straps, and additional padding in the hip region.

Figure 7: S-curve (left) versus J-curve (right) shoulder straps Source: SectionHiker

Based on desktop and user research, user's purchasing behavior can be rated in the following categories: comfort (25%), versatility (25%), ease of use (25%), weight (15%), and durability (10%) where the percentages represent the weighing of each category. Users prioritize comfort and versatility for long duration hikes. As well as ease of use for quick access and storage of contents therefore, they are weighted higher than the backpack weight and durability.

Evaluation of fit can be divided into the comfort and ease of use category based on the design for adjustability which accommodates users of varying body types. Collection of input regarding fit is further elaborated in the following chapter.

Quantification of comfort and versatility are given in forms of tallies.

COMFORT

A tally is given for each of the suspension system that the backpack has such as formed back panel, user's back does not directly touch the back panel (high ventilation), padded hip belt, and padded shoulder straps.

VERSATILITY

A tally is given if backpack has compression straps, hip belt pockets, hydration bladder, water bottle pockets, rain cover, and external loops for attaching additional gear.

EASE OF USE

The backpack is rated based on if the torso sizes are adjustable or fixed, backpack openings, placement of storage pockets, and how "easy" the system can be adjusted while on the move.

DURABILITY

Durability is rated based on the materials used and its resistance to wear and tear. This was collected based on what the manufacturer states online.

WEIGHT

Weight is rated based on the raw backpack weight (without contents within) and how it compares to the others. This was collected based on what the manufacturer states online.

Results can be found in appendix B.

Figure 8: Recommended women's daypacks based on online blogs/forums on a comfort and versatility scale

For this section, the Osprey Tempest 20L and the Sea to Summit Ultra-Sil 20L day packs are analyzed (figure 9) as they represent two sides of the evaluation scale in each category. The goal of this comparison is to assess two products that are on opposite ends of the spectrum to help understand user's needs/wants/preferences. As well as, collecting inputs on the pros and cons of current products on market to aid the future design. Further assessment of current products on market can be found in appendix B.

Figure 9: Osprey Tempest (left) & Sea to Summit Ultra-Sil (right)

COMFORT

Immediate distinctions and expectations of comfort can be placed on the two daypacks. The Sea to Summit lack structure, padding, and support due to its design and prioritization of weight and compactness. On the contrary, the Osprey Tempest has features such as a hip belt, sternum strap, and compression straps to allow users to adjust their comfort during the journey. Osprey Tempest (4) to Sea to Summit (0)

VERSATILITY

Versatility is defined as how functional (or not) backpack features are for the user. The Osprey Tempest has many compartments and external features which allows the users to strap additional equipment without compromising functionality. While the Sea to Summit has one main compartment for storage, three loops at the bottom of bag for additional attachments and can be fully collapsed. Osprey Tempest (5) to Sea to Summit (1).

EASE OF USE

While on the move, it is necessary to be time efficient therefore, one must be able to easily locate items within the backpack. With multiple methods of backpack opening, the U-zip is the most popular because it allows packing customizability and accessibility.

Even though both backpack's opening is similar, Osprey has more than one main storage compartment for better organization and reach as well as, an external compartment for a hydration pouch. From an adjustability standpoint, Osprey contains more features capable of adjustment such as the hip belt, load shifters, and compression straps.

WEIGHT

Fast hikers are looking to move as swiftly and efficiently as possible on trails and to do so, every gram matters from necessary equipment to raw backpack weight. When prioritizing lightweight packs, comfort and durability are sacrificed. There is low presence of padding, frame rigidity, and durable materials used hence why the Sea to Summit Ultra-Sil bag is rated highly for weight but poorly for comfort. Osprey Tempest (879g) to Sea to Summit (85g)

DURABILITY

Nylon is the common material used for the backpacks as they present higher durability, water protection, and weight as compared with polyester bags. For both daypacks, Denier nylon is used throughout the bag and the durability level is based on how the fabric is weaved. Osprey Tempest uses a 420-Denier nylon and Sea to Summit uses a 30-Denier nylon so in time, it can be expected that the Sea to Summit backpack will tear earlier than the Osprey Tempest.

TAKEAWAYS

Women specific backpack design involves smaller backpack sizes, in terms of torso length and volume, and variance in shoulder strap and hip belt shape to better fit women's bodies. As well as increase in padding for the hip areas.

8 of the 11 researched backpacks do not come in multiple sizes and only three offer adjustable torso length. Multiple backpack sizes can contribute to better personalized fit for women of different body types.

3.2 USER PRODUCT INTERACTION

USER SURVEY

METHOD

A survey was organized to collect user data to formulate a persona that conveys the target group's needs, experiences, behaviors, and motivations. This was done online through Google Forms and posted on hiking blogs and forums. Following the method as outlined in the Delft Design Guide, this helps understand the interaction between the user and the product and pinpointing challenges they are facing (Van Boeijen et al., 2020).

The survey comprised of two themes: *1. What are user's motivation and experiences when it comes to (fast) hiking? 2. What is the interaction between the user and their backpacks? Do women prefer women specific backpacks?* Results can be found in appendix C.

RESULTS

Of the 47 participants, 44 (94%) identifies as a women, 2 (4%) identifies as non-binary, and 1 identifies as male. 40 (85%) of participants were from ages 18 - 45 and the remaining 7 (15%) were 45+. When asked for their ethnicity, 32 (68%) identifies as Caucasian, 8 (14%) as Chinese, 4 (7%) as Other, and 3 (6%) as Unknown.

From the 47 participants, all are frequent hikers (at least 2-3 times a month) where the average duration is approximately 3+ hours at a time. Where their pace falls between normal walking pace and fast walking. When asked about their backpacks, 26 participants stated they purchased a unisex backpack, whereas 14 participants chose a women specific backpack, and the remaining users are unsure.

In terms of level of comfortability, 25 rated their day packs 4 out of 5 for the high level of comfortability from the suspension system. Participants were asked to justify their answers and of the 25, all participants mentioned there could be areas of improvement. From the answers, participants have included feedback on aspects they are unsatisfied with which leads to bag discomfort. The feedback includes overall size of the backpack being too large for women, misplacement of hip belt straps causing chaffing and movement, misplacement of sternum straps, and width/length of shoulder straps.

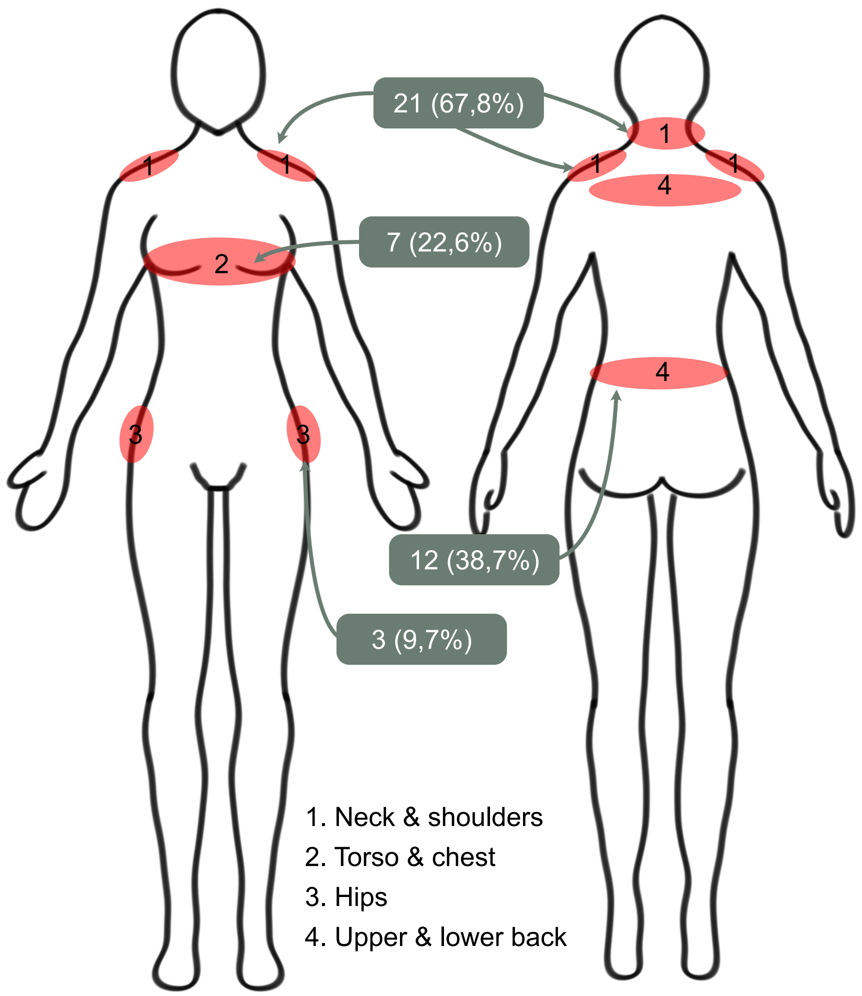


Figure 10: Pain areas based 31 of participant's responses

Discomfort is experienced in the following areas: neck and shoulders (64,5% of responses), upper or lower back (38,7%), torso and chest (19,4%), and hip (9,7%) as shown in figure 10. Reasonings being, ill-fitting of backpack due to torso length, shoulder strap and hip belt adjustability, shoulder and hip shape causses chafing, underpadding of shoulders and hip, and placement of sternum strap directly over chest.

DISCUSSION

It is important to note that results collected are from the standpoint of traditional hikers and not fast hikers. The differentiation can be determined based on the speed of the hiker, traditional hikers' pace is ~4kmh majority of the time while fast hikers will fast walk the flat trains and inclines, and jog on declines (~6,5-11kmh). The overall pace of participants is divided evenly between normal walking pace and fast walking. Although there are differences, similarities can be drawn from the needs of the participants that is applicable to fast hikers as well.

More than 50% of the participants opted for a unisex backpack for the following reasons: unavailability of women specific backpack, limitations of backpack capacity/volume, and felt that it fitted well in store therefore, it is "good enough".

It can be said that due to the selection of a unisex backpack as opposed to a women specific backpack, it led to misfit and overall discomfort of strap placement, shape, and adjustability. Of the participants who selected a women specific backpack, they are more content with the fit as it adequately padded and sized for their bodies. However, in some cases some participants were too tall or built for women's pack which led to shoulder strap and hip belt discomfort. Due to the misfit, it negatively impacts the load distribution which leads to greater pain in the neck/shoulder and lower back region. Because of hip belt slippage and limits of strap adjustability, majority of the load is endured by the shoulders which increases the pain in the neck and shoulder areas. As well as inadequate padding of the shoulder and hip straps for larger capacity backpacks.

CONCLUSION

The intent of the survey is to understand user's behaviors and motivations for (fast) hiking and personal experience with their backpacks. This study was able to identify two major areas of discomfort which are the neck/shoulder and upper/lower back. Reasons for discomfort is due to misfit and non-optimized shape of straps which leads to poor pack distribution or slippage. Those who opted for women backpacks experienced less discomfort due to the consideration of women specific features.

TAKEAWAYS

- 20% of the backpack's hip belt does not wrap around wider hips comfortably which causes slippage and poor load distribution
- Chest discomfort experienced are due to the placement of the sternum strap that is constricting for women of larger bust size
- 40% of the backpacks are "too large" for users which causes rubbing on the tailbone
- Women specific backpacks are limited in capacity and volume.

4 ANTHROPOMETRIC DATA

In this section, it explores two public datasets: DINED (Dutch) and ANSUR II (American) in order determine the critical body parameters that is relevant for the development of a women specific backpack.

4.1 DATABASE BACKGROUND

For this project, a user-centered design approach is adopted with consideration of user anthropometry aimed to minimize negative health consequences such as musculoskeletal injuries and pain (Dianat et al., 2018). Considering user anthropometry, it will assist in the decision making of adjustability, size, and shape of the design process to determine the optimal fit of a women's fast-hiking backpack (van Boeijin et al., 2020). This section explores the relevant anthropometric parameters, how they affect backpack sizing, and how the use of 1D/2D anthropometry can fill in the gaps.

TARGET GROUP

An overview of the target group can be found below,

- Adults (18-45)
- Women (identifies as female)
- General focus within Europe and USA
- Includes all body shape and physique (slim to curvy)
    - P5 – P95 of the proposed parameters

Due to some limitations of DINED software, raw data were exported to draw useful relationship such as torso length and waist circumference at the iliac crest to determine backpack sizing. The following design decisions are based on data collected from two databases: DINED (Dutch students, Female, 17-27) and ANSUR II (US Army Personnel, Female, 18-45). Other databases of DINED such as Dutch adults were not used due to missing parameters needed therefore, supplement of the US database was used to provide more user information.

DESCRIPTION OF DATABASES

DINED – a TU Delft tool that contains 1D, 2D, 3D anthropometric data of various populations to help designers create better products. The tool allows for exploration, comparison, and utilization of anthropometric data as described in Steenbekkers et al., 1998. Data of certain populations can be found on 4TU research data. Limitations include that within the data used, it represents Dutch students from the age of 17-27, but not a full representation of Dutch adults.

ANSUR II – an open-source database of US Army and Marine Corps anthropometric data of 95 standardized body measurements and 3D body scans (Gordon et al., 2014). Data were collected from over 6000 soldiers (4.082 males and 1.986 females). Limitations include that among the 6.000 datasets, it cannot be approximate for the US civilian populations. Relevant information can be drawn but to be aware that data might not accommodate most user population in intended manner.

.

4.2 BODY PARAMETERS

As explained in the discomfort section, users are prone to unwanted pressure and injuries from ill-fitting backpacks. Therefore, multiple body dimensions are taken in consideration to ensure optimal fit and comfort (figure 11 and table 2). Among those parameters, torso length and waist circumference are most useful when it comes to sizing of the backpack to prevent poor fit.

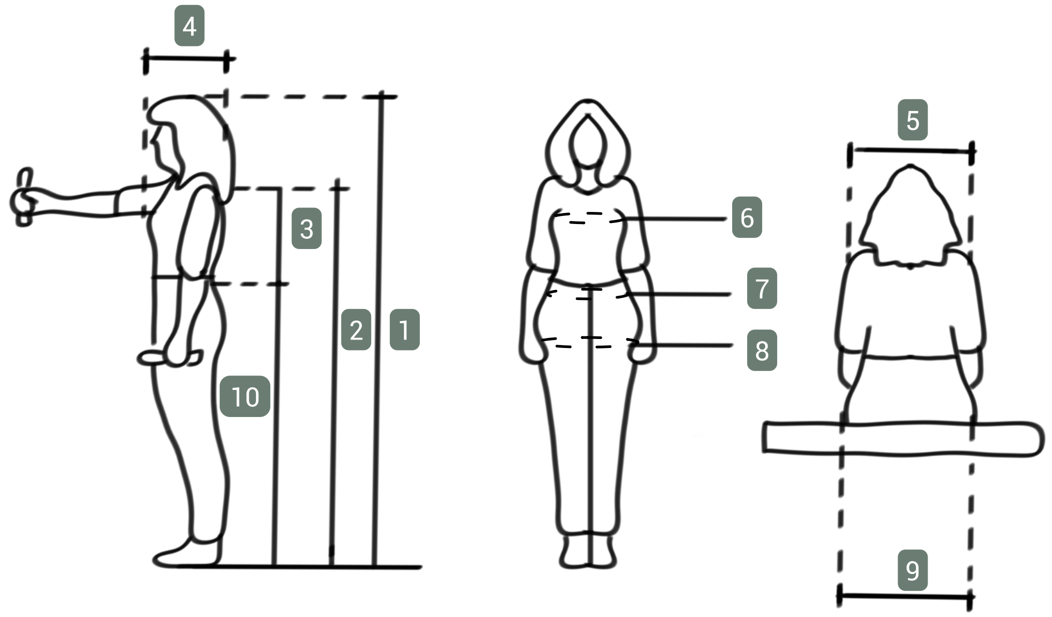


Figure 11: Anthropometric measurements

Table 2: Body measurements needed

	PARAMETER	SOURCE
1	Stature	DINED & ANSUR II
2	Shoulder height	DINED & ANSUR II
3	Torso length	ANSUR II
4	Chest depth	DINED & ANSUR II
5	Shoulder breadth	DINED & ANSUR II
6	Chest circumference	DINED & ANSUR II
7	Waist circumference (at iliac crest)	ANSUR II
8	Hip circumference	DINED & ANSUR II
9	Hip breadth (sitting)	DINED & ANSUR II
10	Iliac crest height	ANSUR II

TORSO LENGTH & WAIST CIRCUMFERENCE

Current daypacks are available in three options, one size with fixed back length, one size with adjustable back length, or multiple sizes with fixed back lengths. The selection of which backpacks is measured based on torso length which is the distance from the C7 vertebra to the iliac crest (figure 12). In some instances, a stature range is given but it is best to not select sizes based on height. Reasonings being there are many uncertainties with users such as those who are tall with short torsos and vice versa.

The second criteria for consideration aside from torso length is the adjustability range of the hip belt. Ensuring a tight fit of the hip belt can alleviate stress off the shoulders and distributed over a larger surface area. Waist circumference should be measured at the omphalion, or at the iliac crest to obtain an accurate value (figure 12). The hip belt is intended to wrap around the top of your pelvis tightly and should not slip during the journey.

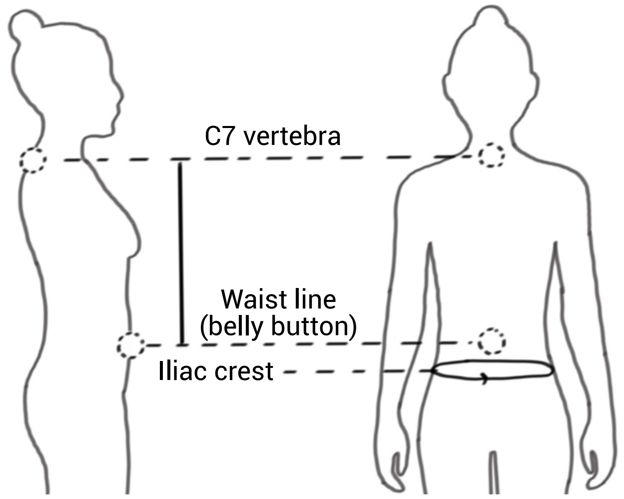


Figure 12: Measuring torso length and waist circumference

With the two parameters, a sizing chart can be created as shown in figure 13. The graph was generated off of samples of the DINED Delstu 2016 and ANSUR II databases. Although low correlation can be found between torso length and waist circumference, the chart provides useful information whether it is useful to have one or multiple backpack sizes to accommodate a wider range of women. Delstu (P5-P95) or the yellow rectangle of figure 13 represents the 5th and 95th percentile of female Dutch students for both torso lengths and waist circumference.

In this scenario, it is helpful to see how designing a backpack with only Dutch women anthropometrics in mind might affect the usability and fit for American women. Current backpacks on the market are designed with multiple populations in mind to ensure a wider range as shown in figure 14. The graph was generated off of samples of the DINED Delstu 2016 and ANSUR II databases. Women's XS/S and S/M are referenced off Osprey Tempest 20, Unisex S/M is referenced off Osprey Talon 22, and Women's One Size is referenced off Gregory Juno 24. Measurements were collected online from the corresponding manufacturer.

Table 3: Torso length data in mm

	P1	P50	P99
DINED Dutch Students 2016	359	468	597
ANSUR II	367	426	493

Table 4: Waist circumference data in mm

	P1	P50	P99
DINED Dutch Students 2016	688	765	936
ANSUR II	668	860	1113

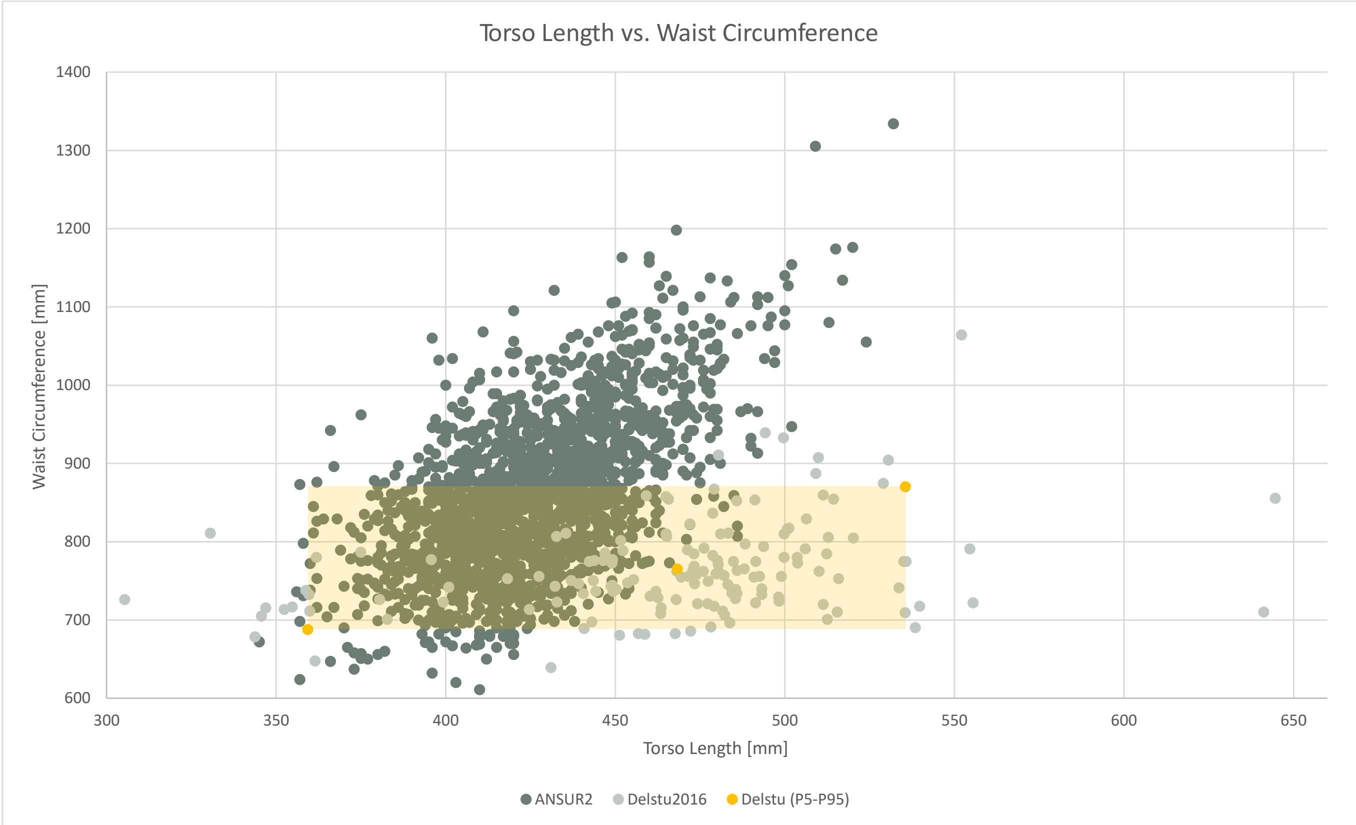


Figure 13: Torso length vs. waist circumference of DINED and ANSUR II

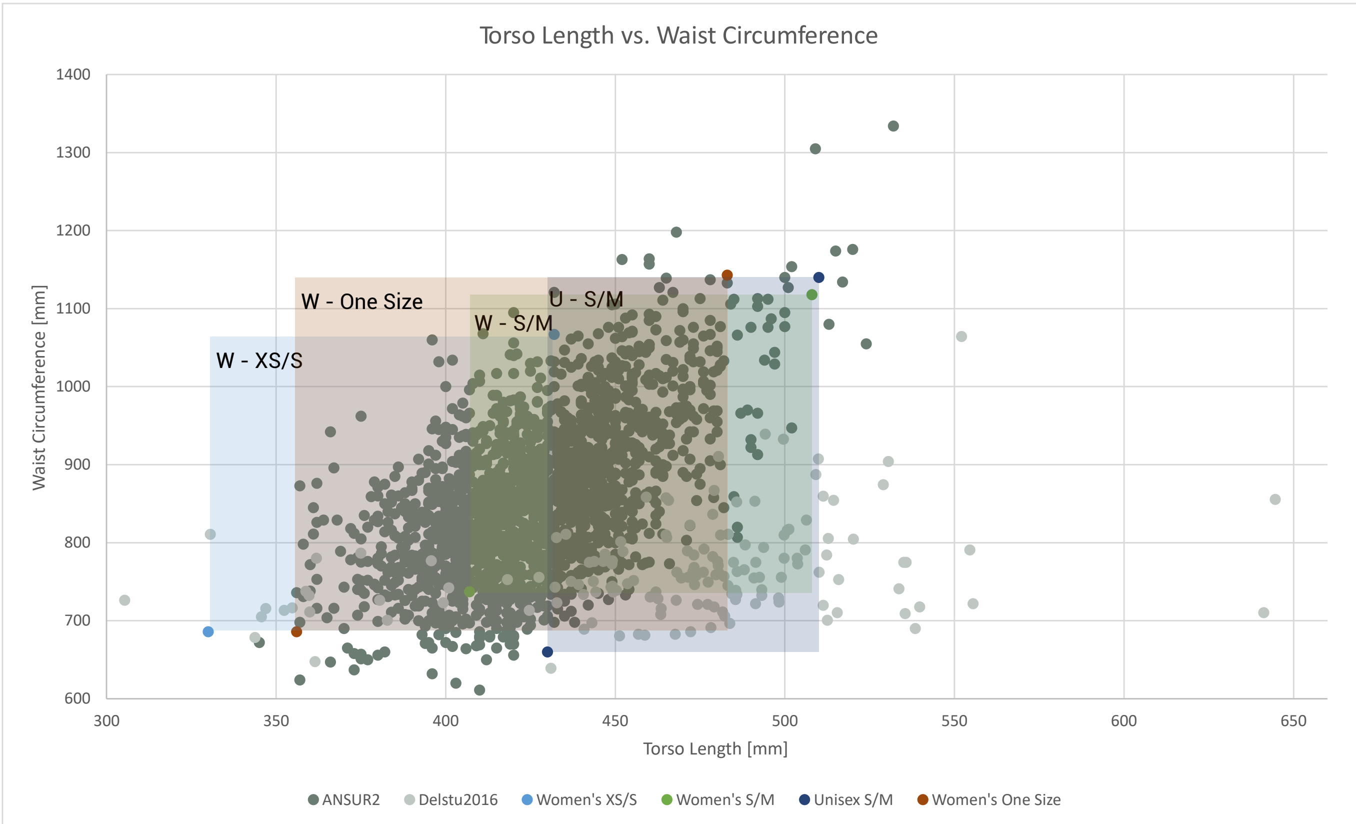


Figure 14: Torso length vs. waist circumference of DINED and ANSUR II

CHEST DEPTH & CIRCUMFERENCE

Similarly, to ensuring the fit of the backpack on the users, chest depth and circumference influence the perceived discomfort due to the presence of breasts for female hikers. As mentioned in the survey (appendix D), participants experience discomfort after long durations from the shoulder straps and placement of the sternum clip.

The discomfort could be the result of the specific shoulder strap as it is not as accommodating to women of larger bust while applying undesired pressure on the side of breast when tightened. The same can be said for the sternum strap as it lays in the middle of the chest rather on top or bottom.

Differences in chest circumference between the databases can be grouped into blouse sizes, from size 32 – 50, as shown in figure 15. From this, it can help pinpoint where the variability occurs and accounting for women of different population.

When comparing the two datasets, common sizes for Dutch and American women are sizes 36 – 42 and less variability in bust size can be seem in smaller blouse sizes as compared with larger blouse sizes.

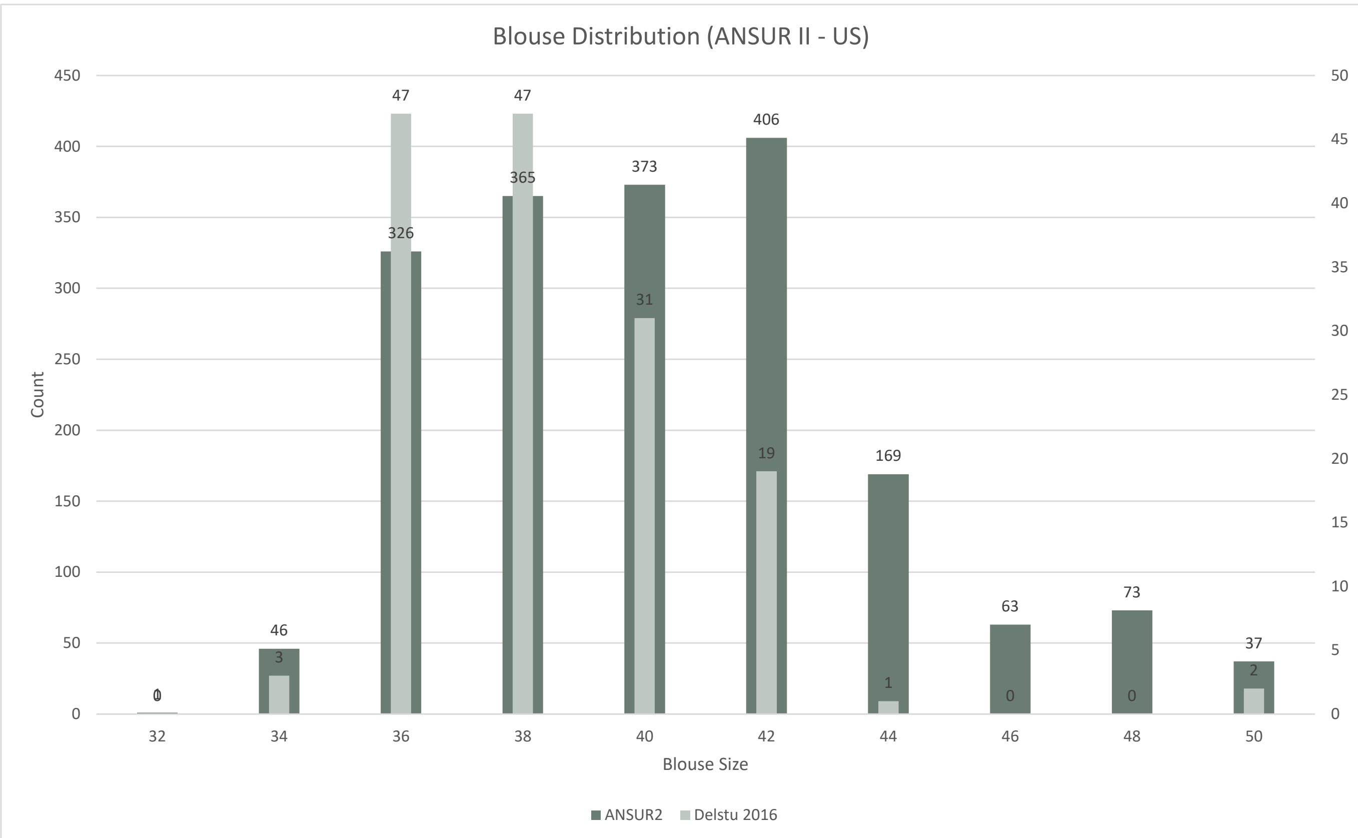


Figure 15: Comparison of dataset based on blouse size

Another relationThe changes in breast mass (or chest circumference) can be seen as directly proportional to one's body mass and BMI (Brown et al., 2012).

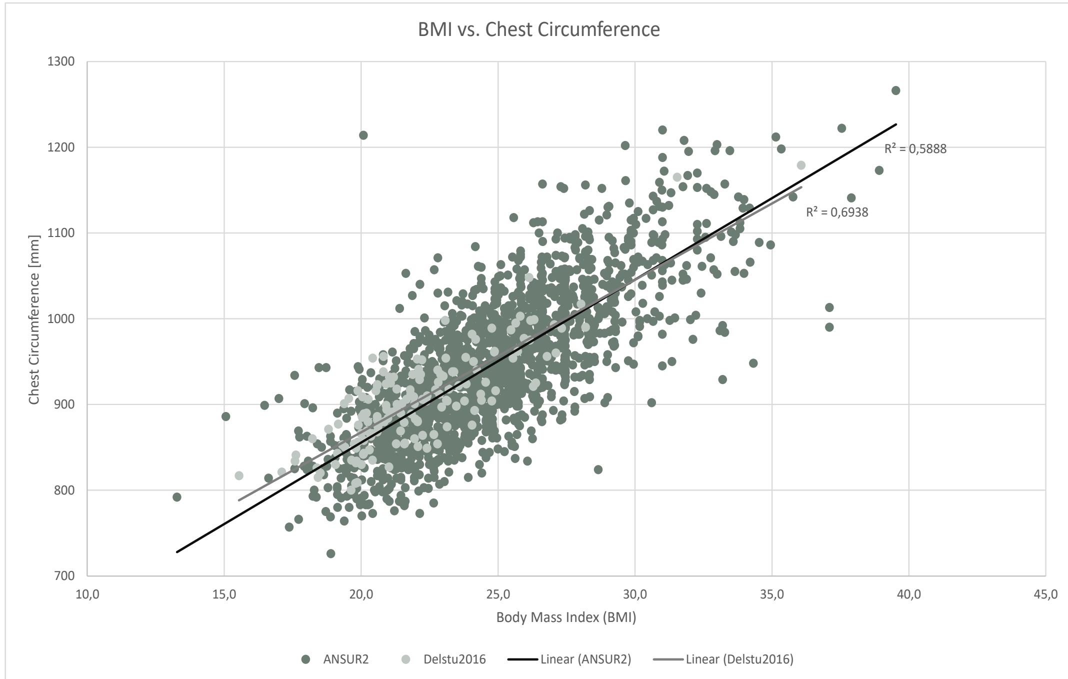


Figure 16: Correlation between body mass index and chest circumference

The aim of the exploration of shoulder strap shape and adjustability should reduce the overall chest pain experience from users. Table 5 and 6 portrays the P1, P50, and P99 of chest depth and chest circumference of Dutch and American women.

Table 5: Chest depth data in mm

	P1	P50	P99
DINED Dutch Students 2016	213	242	293
ANSUR II	190	247	319

Table 6: Chest circumference data in mm

	P1	P50	P99
DINED Dutch Students 2016	827	906	1104
ANSUR II	786	946	1158

SHOULDER & HIP BREADTH

Shoulder and hip breadth are taken into consideration to determine the shape patterns of a female's body. The female body silhouette is classified in four categories: oval (O) shape, triangle (A) bottom X spoon shape, hourglass (H), and inverted triangle (V) top X shapes (Varuskan et al., 2011).

From table 7 and 8, it can be said that shoulder and hip breadth measurements are merely secondary parameters that should be taken into consideration to define the overall shape of the backpack. Common backpack shapes on market for women can be seen in figure 17. Given that based on capacity and volume, shape might differ.

Table 7: Shoulder breadth data in mm

	P1	P50	P99
DINED Dutch Students 2016	388	418	473
ANSUR II	323	366	406

Table 8: Hip breadth data in mm

	P1	P50	P99
DINED Dutch Students 2016	343	382	454
ANSUR II	334	399	485

Figure 17: Gregory Jade - tapered where bottom is slightly wider (left) vs. Sea to Summit Ultra-Sil - narrow oval look (middle) vs. REI Co-Op Trail - square look (right)

A shoulder-hip ratio established which will define the design in terms of backpack shape. To move swiftly on the trails, backpacks should not be wider than the user's back to prevent a disturbance in range of motion of arms and legs.

5 RESEARCH OVERVIEW

As gathered from the research phase, insights and design requirements can be formulated. As well as overall dimensions of the backpack based on anthropometric data. This serves as a starting point for the ideation phase.

5.1 DISCUSSION & RESULTS

Useful insights and data were gathered from the literature and desktop research in combination with surveys to answer the questions below.

Main research question:

How can the design of (fast hiking) backpacks be better adapted for women?

Sub-research questions:

What are the important characteristics when designing a (fast-hiking) backpack?

Backpacks comes in numerous forms and their usage might differ based on the scenario such as educational purposes, recreational/ military use, and/or just for aesthetics. The design of each form is tailor to the application and in this context, it looks into a design of a fast-hiking backpack for women. Fast-hiking requires users to be in constant motion whether it is walking or running therefore, backpack ergonomics (enforcing good posture), (dis)comfort (alleviating pain points), safety (consideration of maximum load conditions and backpack features that helps load distribution) , and anthropometrics (creating better fit) are critical characteristics for the user.

Do gender differences affect user's ability and performance?

Gender differences plays a small role therefore, having a gender specific gear can benefit user's ability and performance. As well as, taking the correct safety precaution when it comes to high load carriages. Women, by nature are built physically and anatomically different than men which does not mean they are at a disadvantage, but their design needs differ. There is more focus on proper load distribution (more on hips than shoulders), improved fit (correct backpack length and width), and optimized strap shapes (contoured shoulder and hip straps) that accommodates the presence of breasts and varying hip widths for women's backpack.

What are the challenges with current products on market?

User research in forms of survey and questionnaires provided insights on user's needs, wishes, behaviors, and motivations. Doing so aided in pinpointing the issues and challenges with current backpacks on the market and how they can be improved. Additionally, it helps diminish any unconscious biases and assumptions based on the user group.

Of the participants from the survey, many owned unisex backpacks as opposed to women's backpack due to availability and sizing. Due to the fact unisex design favors men, participants experience poor fitting and discomfort especially around the chest area due to the shoulder strap shape and sternum strap placement. As well as the hip area due to the little accommodation to women's wider hips and contour. Hence, greater consideration of gender differences, externally and internally are be taken into consideration for future design.

CONCLUDING DIMENSIONS

From the anthropometric research, numerical values are determined based on two populations, Dutch and American therefore, design will aim to accommodate the smallest and largest sample of each parameter. This can be summarized in table 9 as they are based on the data from DINED Delstu 2016 and ANSUR II. The body measurements selected correspond to how it will affect the overall sizing or adjustability range of the backpack such as shoulder and hip strap ranges. Further information about the individual data of both populations can be found in appendix D.

The challenge is to accommodate the variation on body sizes and shape with one size fits all backpack and it is recommended that there be at least two backpack sizes to prevent misfit. It is also advised to diversify the sample by accounting for different population. To determine whether design for the 5th and 95th percentile of Dutch women will fit other population such as the 5th and 95th percentile of French women or Spanish women who are known to be smaller in size and stature. This can be further elaborated in the following section.

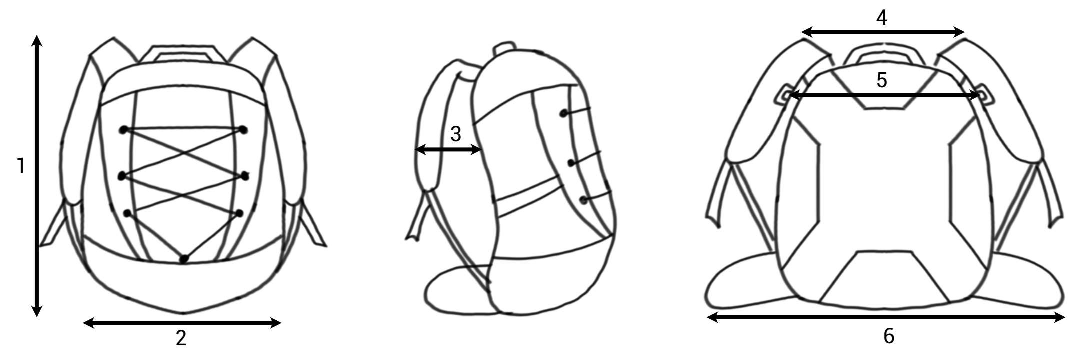


Table 9: Backpack dimensions based on average of DINED and ANSUR II data in mm

	0 - HEIGHT	1 - SHOULDER HIP LENGTH	2 - BACKPACK BOTTOM WIDTH	3 - SHOULDER STRAP LENGTH	4 - SHOULDER STRAP DISTANCE	5 - STERNUM STRAP LENGTH	6 - HIP BELT LENGTH
	Stature	*Torso length*	*Hip breadth*	*Chest depth*	*Shoulder breadth*	*Chest circumference*	*Waist circumference*
P5	1549	385	348	206	403	825	708
P50	1649	429	398	247	448	943	853
P95	1767	481	454	293	498	1090	1032
Range	218	96	106	87	95	265	325

ASSUMPTIONS MADE

It is important to note that measurements of torso length were calculated based on shoulder height minus iliac crest height. As DINED did not provide sufficient data regarding height at the iliac crest, an approximation ratio was applied based on the calculation of stature to iliac crest from ANSUR II data. The following was applied to DINED data,

- For stature below 1626mm, the iliac crest height is 62,9% of stature.
- For stature 1626– 1829mm, the iliac crest height is 58,5% of stature.
- For stature above 1829mm, the iliac crest height is 51,3% of stature.

Similarly for waist circumference (omphalion), a multiplier of 1,06 was applied on the waist circumference measurement at the midpoint. The factor was approximated based on the average values found at the midpoint versus the iliac crest from Lemoncito et al., 2010 study of the impact of waist circumference variation on metabolic syndrome.

CLOTHING ALLOWANCES

Clothing combinations are categorized in under, mid, and top layers. As recommended by REI, underlayers include nylon/polyester t-shirts plus undergarments (2mm thick ± 1mm), mid layers include fleece/insulating jackets (3-5mm thick ± 1mm), and lastly, top layers include a breathable rain jacket (1-2mm ± 1mm) (Bolitho, 2022). Dependent on the season, total layer thickness can range from 2mm (warmer climate) to 9mm (colder, wet climates). Design should account for the interaction of materials to ensure that there is minimal resistance during the journey as expressed by survey participants.

ACCOUNTING FOR POPULATION DIFFERENCES

It is important to note that anthropometric parameters are based on two populations: Dutch and Americans. The Dutch represents the upper percentile of Europeans in all aspects and a scaling factor can be applied to adjust the design ranges to be better fit for other populations. The usage of American data is based on company research as their main market encapsulates Europe and the US.

Figure 18 graphically illustrates the percent differences of the body parameters when compared to Dutch adults (DINED 2004, ages 20-40). The data samples of the varying populations were collected off of DINED and the parameters chosen are based on its relevance to backpack design such as stature, sitting height, hip circumference, chest depth, and etc. Positive values represent the percentage larger Dutch adults are compared to the respective population and vice versa. This provides an insight on how designers should adjust overall shape and sizes of backpacks for certain population of women. Or, determining the middle ground to accommodate more than one population.

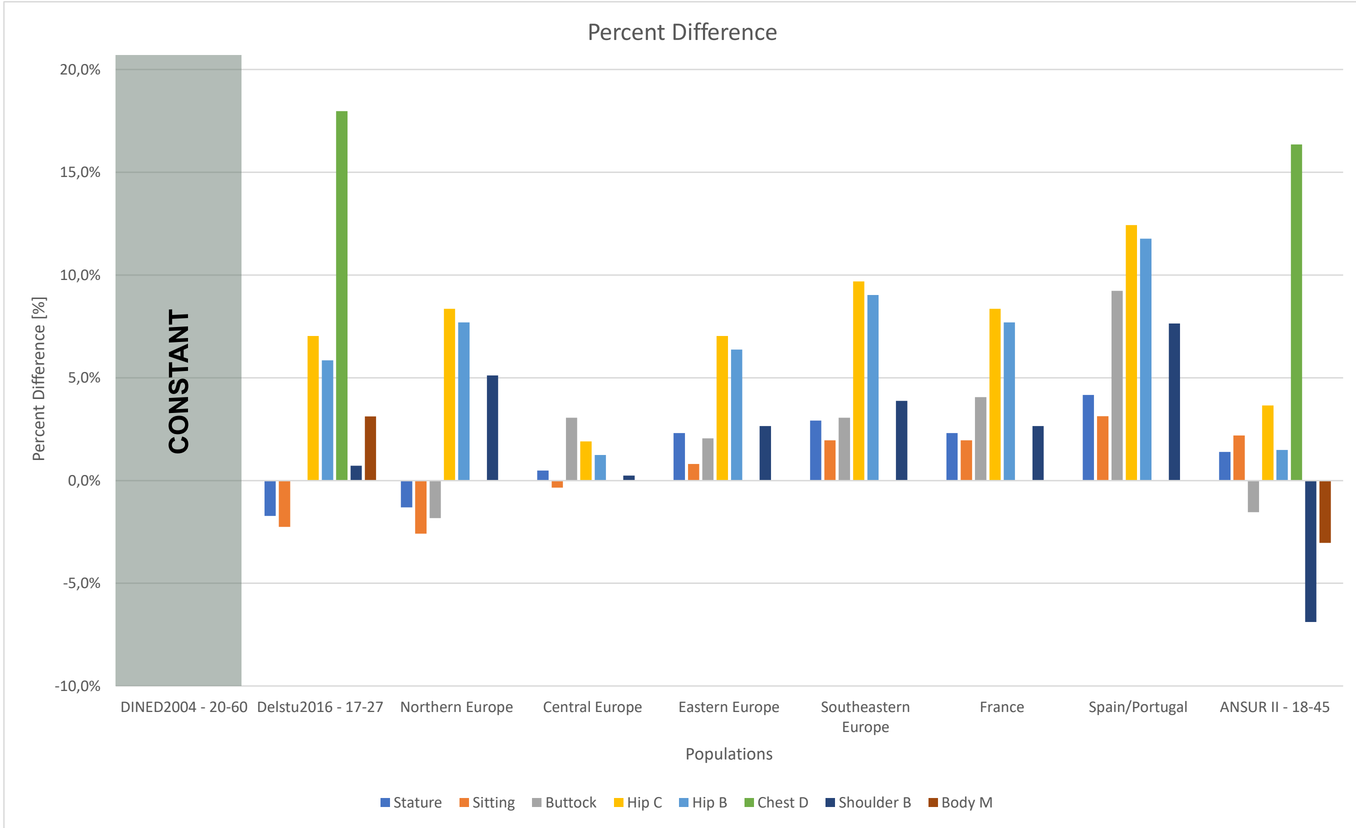


Figure 18: Graphical representation of the percent differences of populations

5.2 DESIGN REQUIREMENTS

To guide the design process, design requirements are set based on the research conducted in the preliminary phase.

The requirements are sorted into five categories: anthropometry, safety, comfort, performance, and ergonomics. Evaluations of concepts are crossed check with the table below to determine the one that fulfills the most criteria and be used as a basis for the final design. As well as to determine whether the final design satisfies the requirements and can be deemed as a success.

Table 10: List of reqruirements

CATEGORY	TAG	REQUIREMENT
Anthropometry	A1	Backpack's length is to fit women's torso between the range of 348mm – 481mm (1549mm – 1767mm based on stature)
	A2	Shoulder straps to be adjustable for torso (348mm – 481mm) and chest depth range (206mm – 293mm)
	A3	Hip belt to be adjustable between the range of 708mm-1032mm based on hip circumference
	A4	Design should fit women between the 5th-95th percentile for both torso length and waist circumference (OM)
	A5	Backpack's width should be smaller than user's back width
Safety	B1	Design should maximise load distribution in the hips instead of the shoulders (ideally: 80% - H, 20% - S)
	B2	Design should enable center of mass to be closest to the body as possible
	B3	Design should support normal standing posture (no kyphosis) and trunk angle while jogging (8-10 deg)
	B4	Straps and buckles should allow for users to quickly exit in case of emergencies
Comfort	C1	Design should reduce chafing of shoulder straps on shoulders and chest area
	C2	Design should reduce undesired pressures on side of chest and under armpits
	C3	Design should have adequate padding for users on the shoulders and hip areas
	C4	Design should prevent hip belt from sliding off
Performance	D1	Design should keep inside contents dry
	D2	Design should have the minimum suspension features (hip belt, sternum strap, compression straps)
	D3	Design should allow for back ventilation
	D4	Design should have a capacity of 25L or less
	D5	Design should be adapted for women's features
	D6	Design should have all common features of a hiking backpack
Ergonomics	E1	Design should allow for user's full range of motion when jogging/ running
	E2	Design should allow user to optimize usage of the backpack features
	E3	Design should have specific internal compartments to allow user to efficiently distribute load

6 DESIGN

In the design phase, it outlines the ideation process using mindmapping and the How-To method to generate ideas and solutions. Viable ideas were taken to conceptualization to further develop into three concept directions. Three concepts were evaluated to the design requirements and from that, concept 3 proved to have the most potential which kicked off the embodiment process.

6.1 IDEATION PROCESS

To kickstart the ideation process, a mind map was generated to better visualize the information collected from the research phase. With this process, it assisted in the structure of insights, pinpointing the challenges, finding inspiration, and produce new ideas/solutions. Backpack was determined to be the centralized theme and stakeholders, market, interaction, and anatomy being the four sub-themes. The mind map can be found in appendix F.

Following, the How-To method was carried out to assist in the idea generation according to the challenges found in research and the established design requirements. This brainstorming session was organized with two others. Both participants were brief on the problem statement and the intent of this session which was to invoke creative ideas/ solutions.

Participants were prompt with the following How-To questions,

- "How can we carry light/heavy items?"
- "How can we safely/tightly secure a pack to your body?"
- "How can we adapt a backpack to women of different heights or bust sizes?"
- "How can we increase (shoulder, hip, back) comfort?".

Participants were asked to write down their answers on paper as well as the freedom to verbally express potential solutions to the problem if it arises. As a result, this session helped generate new idea directions and revealed existing products that can be used as a form of inspiration for this project.

To narrow and further develop the lists of ideas, three criteria were selected from the list of design requirement that the idea must entail: minimize undesired discomfort on shoulders and chest, can be adapted to multiple body shapes/sizes, and hint of novelty. The selection for these requirements is a reflection based on the research conducted, mainly the challenges women face with products on the market that could be improved. While accounting for novelty, the idea directions selected to be further developed were the concept of a posture corrector straps, pull over vest straps, and baby wraps. Elaboration of the concept directions can be found in the following section. Details of the session can be found in appendix F.

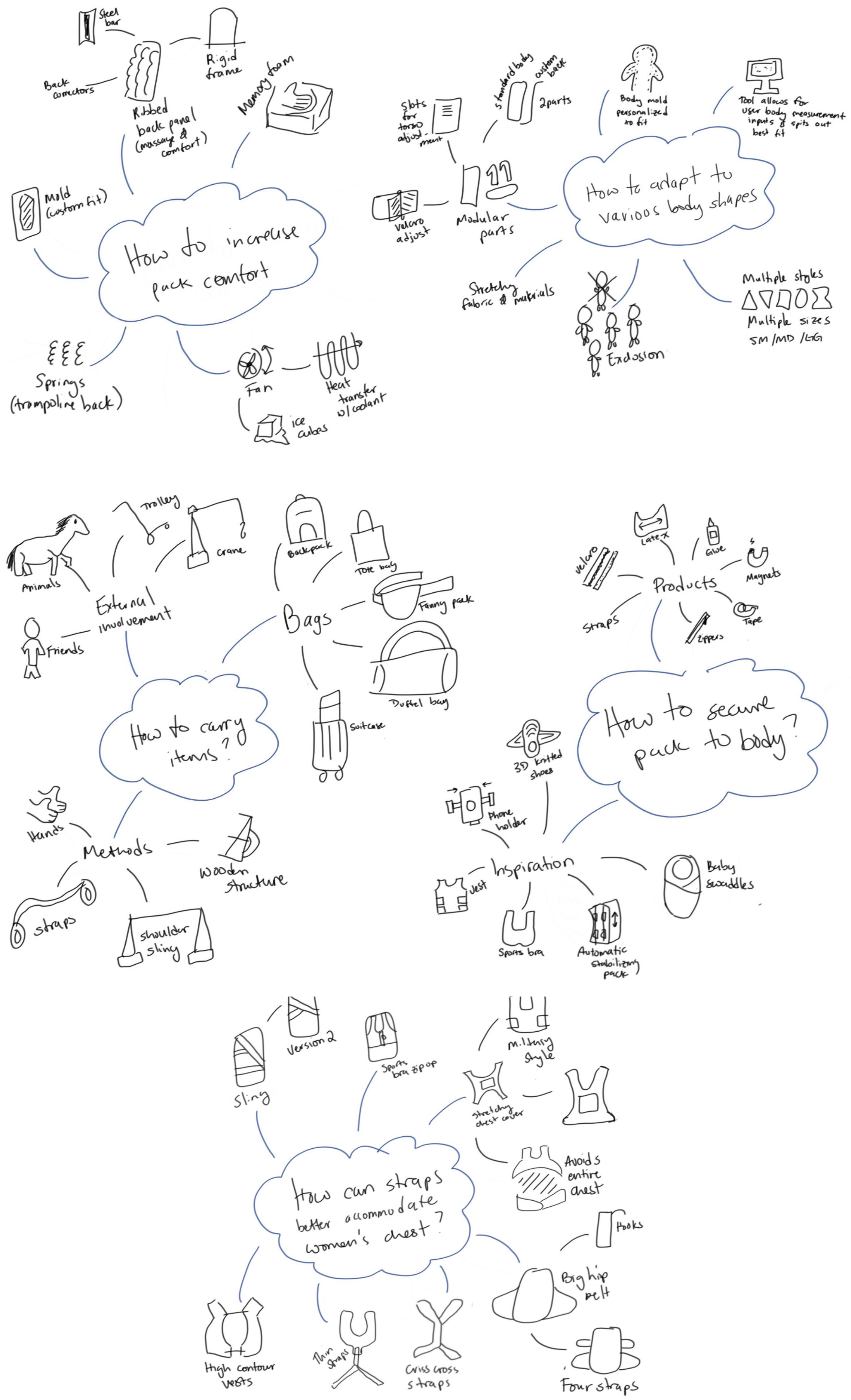


Figure 19: Results of the brainstorming session

6.2 CONCEPT DIRECTIONS

SEMI CONVENTIONAL

This concept embodies the look and features of a conventional daypack with a novel approach for shoulder straps inspired by medical braces and posture correctors. It is commonly seen that user's posture can be easily affected based on backpack load which leads to the risk of neck and shoulder pain. Therefore, with this approach, it enforces good posture and prevent slouching and increase in trunk angle when jogging or running. As opposed to the traditional s-curve shoulder straps, the x-shape straps eliminate the need for a sternum strap and meets in the middle of the torso.

With this method, it minimizes the contact of the straps with user's chest area as well as the chances of undesired chaffing and rubbing of the underarms. As for load distribution, there is more surface area in contact with the body and a hip belt to efficiently distribute the load and stabilize the backpack during motion.

Further development will be needed to evaluate whether the x-shape straps will induce better posture as well as provide more comfort to the user.

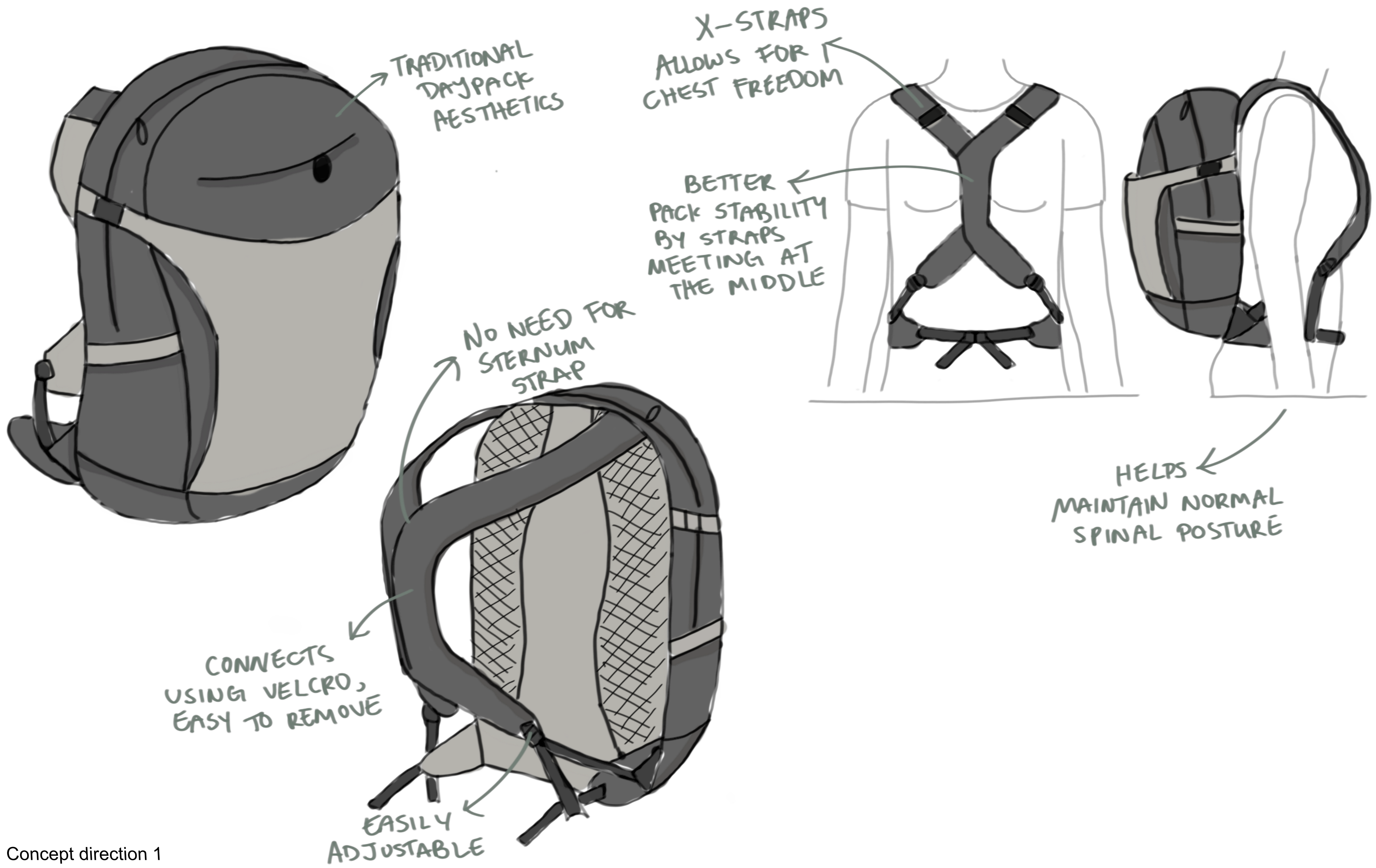


Figure 20: Concept direction 1

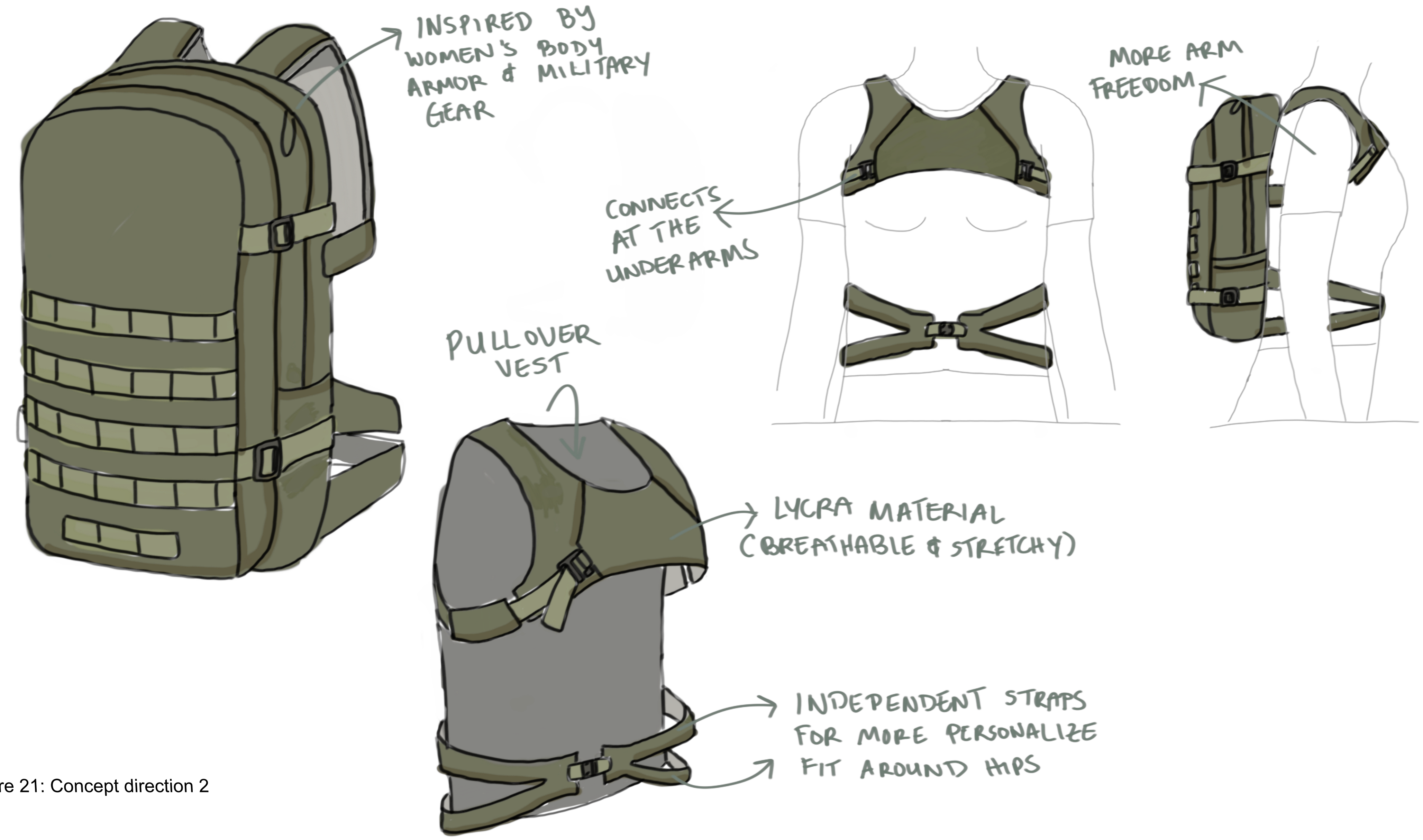


Figure 21: Concept direction 2

PULLOVER VEST

This concept presents an alternative way of carrying straps inspired by women body armor and military equipment. Instead of a vest that covers the entire torso, this approach utilizes fabrics like lycra to cover the sternum area that is breathable and easily can stretch. Adjustment of the straps can be done in the front, and it connects on the underside of the arms giving more freedom for the chest.

As for the hip belt, it differs from the conventional contoured hip strap as it splits into two straps that can be independently adjusted to fit around women's wider hips. Although this concept direction allows for better adjustability, it might compromise the ability of the hip belts to be load bearing which might increase the risk of injury.

Further development will need to be done to find the best strap thickness and orientation to be able to bear majority of the backpack load.

STRAPLESS

This third concept is the most extreme as it introduces the idea of a strapless backpack. This was inspired from an idea direction from the brainstorming session of how working mothers carry their babies in certain regions of the world. Babies are wrapped to the mother's back with a long cloth while leaving the mother's hands free to do their tasks. However, in a fast-hiking context, it does not provide enough pack stability while jogging or running therefore, shoulder hooks can be implemented as a point of attachment of the pack to the body that can allow users to move freely.

As opposed to the flexible shoulder straps, the shoulder hooks would be made of stiffer material such as hard plastic or metal, that sits on the shoulders and bears little to no load of the backpack. Load distribution would be fully on the oversized hip belt that wraps around the lower torso leaving full clearance of the chest area allowing for user's full range of motion.

Further development will be needed to validate the removal of shoulder straps and whether the oversized hip belt can safely bear the backpack load and provide stability without compromising comfort..

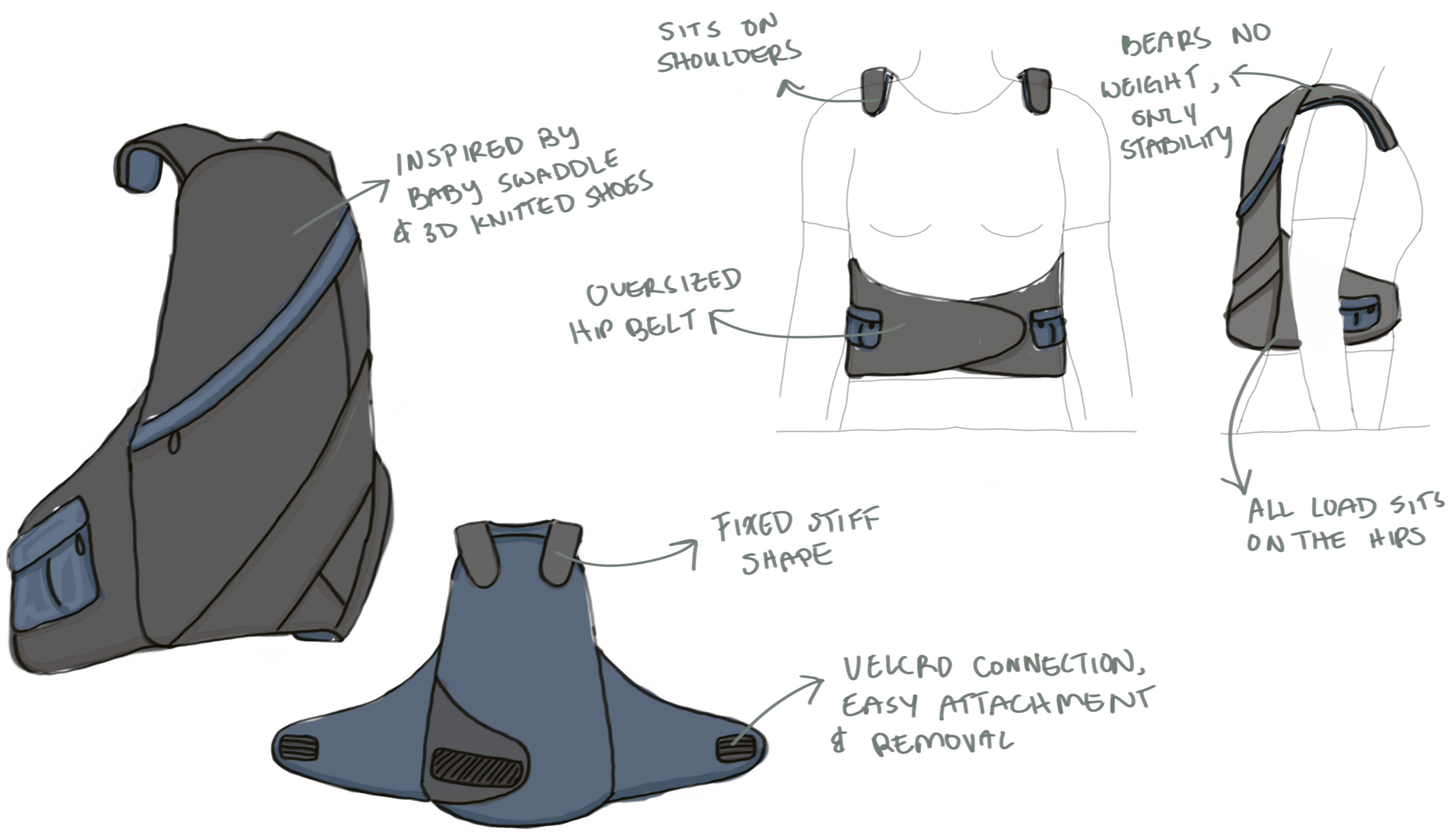


Figure 22: Concept direction 3

6.3 CONCEPT EVALUATION

The method, Weighted Objectives, was used as outlined in the Delft Design Guide to evaluate the proposed concept direction (Van Boeijen et al., 2020). This method was chosen not only for its dualism of assessing concepts systematically and analytically but stimulate discussions and allow for the combination of (current or new) ideas. From the established design requirements, six criteria were chosen to be fundamental for this project after weighing it based on importance as shown in table 11.

WEIGHTED CRITERIA

PRESSURE DISTRIBUTION 25

It is advisable for backpack loads to be distributed along the hips instead of shoulders due to a larger surface area that help minimize the risk of injuries for women. This is important because it affects user's performance, safety, and stability while on the trail.

COMFORT FIT 20

Due to the nature of fast hiking, it is important to prolong the absence of discomfort for the user to optimize their performance. Areas of discomfort can be seen on the neck, shoulders, back, and around the vicinity of the chest where chaffing and rubbing occurs due to the shoulder straps. This is assessed based on the intended materials used, placement of the strap, and its shape.

CHEST ACCOMODATION 25

Differences between men and women comes down to the chest area especially for women with larger busts. Users find that placement of the sternum strap is not ideal and shoulder strap oftentimes chaffs and interferes with their hiking journey. Therefore, the design should efficiently place stability straps without interfering with the chest area.

SIZE & EASE OF ADJUSTABILITY 15

This is an important criterion because the backpack's sizing system must be able to fit a percentile of women. Adjustability is a must to accommodate various body shape and sizes of women without compromising fit or functionality.

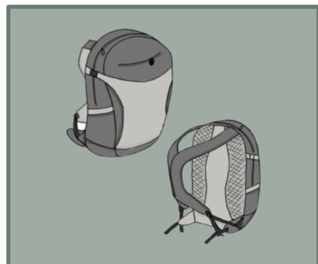
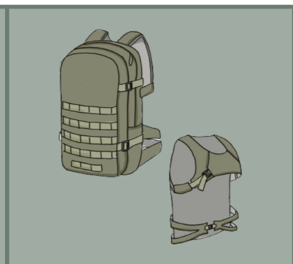
PACK STABILITY 10

Fast hiking is a relatively fast-paced activity where users are jogging or running on uneven terrains. The constant movements can cause backpack swaying where if not centralized, it can affect the user's posture, control, and negative impact on body joints. The backpack should have the ability of be compressed and adjusted to fit the body as well as possible.

NOVELTY 5

Based on the client's feedback, to enter a competitive market where women specific backpack already exists, the design must be innovative and can be of inspiration for new technologies to emerge. Such as using stiff materials or eliminating the idea of shoulder straps altogether can bring a new and unique perspective into the industry.

Table 11: List of requirements

							
		SEMI-CONVENTIONAL		PULL OVER VEST		STAPLESS	
	Weight	Score	Total	Score	Total	Score	Total
Pressure distribution	25	3	75	3	75	4	100
Comfort fit	20	3	60	4	80	3	60
Chest accomodation	25	2	50	3	75	4	100
Size & adjustability	15	4	60	3	45	2	30
Pack stability	10	5	50	3	30	2	20
Novelty	5	3	15	4	20	5	25
TOTAL	100	310		325		335	

CONCLUSION

As a result of the weighted objectives, the third concept direction had a higher overall scored compared to the others. When compared to a potential maximum score of 500, all three concepts score very similarly. Semi-conventional at 62%, pullover vest at 65%, and strapless at 67%.

The strapless concept scored well in the load distribution, comfort fit, and accommodation for women's chest due to its novelty of replacing shoulder straps of flexible materials with shoulder stabilizers made of stiffer materials and an oversize hip belt. However due to this, the third concept scored poorly in the size and ease of adjustability and backpack stability. With that in mind and based on the inputs, it was decided to further develop the strapless concept direction as it shows potential in alleviating the issues with current backpacks with added novelty.

6.4 DESIGN OVERVIEW

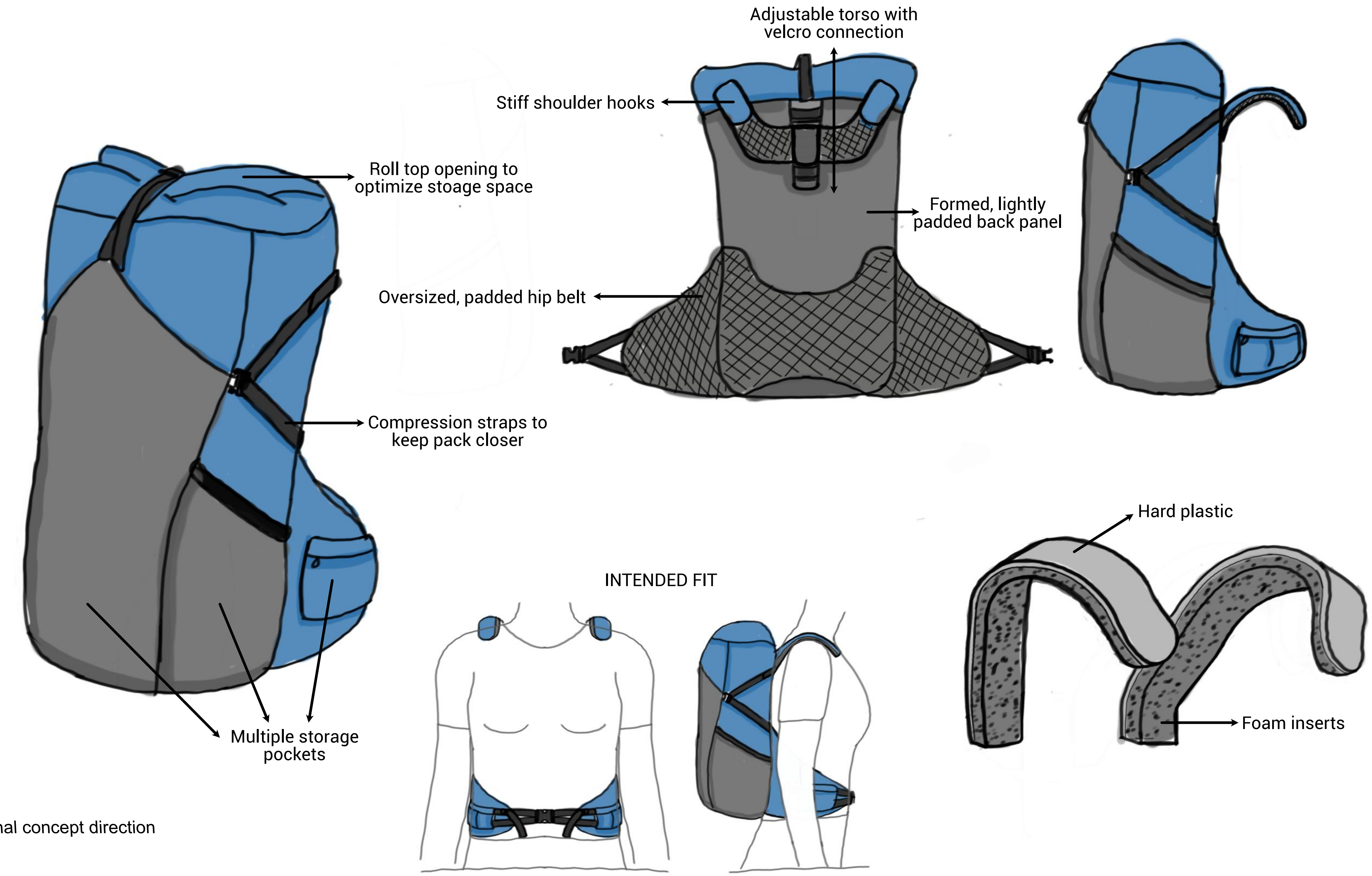


Figure 23: Final concept direction

Figure 23 illustrates the design overview of the strapless concept direction. The concept embodies the ultralight fastpacking perspective of minimalistic features to reduce overall weight of materials with a unique perspective by eliminating the usage of shoulder and sternum straps. Replacing them with adjustable shoulder hooks to fit women of various torso lengths and an oversized hip belt that will carry majority of the backpack load. The shape of the shoulder hooks and contoured hip belt are modelled after DINED 3D mannequins to ensure fit of selected percentile of women.

This concept minimizes user and strap interaction as it is responsible for discomfort experienced in the neck, shoulders, and chest area due to unwanted rubbing of the underarms and chest areas. This concept allows for more range of motion of the upper torso for users without compromising pack stability.

From an aesthetic perspective, this concept still adopts traditional fastpacking features and functionality such as optimizing storage space with a roll top opening and large storage pockets for easy access to equipment and personal belongings while in motion. Unlike most ultralight packs, this concept intents to having a padded internal frame to provide structure, ventilation, and load distribution of the contents in the backpack.

6.5 EMBODIMENT

PROTOTYPE 1

The main goal of the prototype one is to validate the carrying system and to prove whether implementing shoulder hooks can replace conventional shoulder straps without compromising usability and functionality. As well as assessing how the shape and construction of the straps would interact with one's body and how the user might perceive the prototype when in use.

Prototype one is made up of four parts: the main body, 3D printed shoulder hooks, cardboard back panel, and an oversized hip belt. All parts were removeable from the main body to determine the most optimize shape for the shoulder hooks and hip belt. As this is a proof of concept, the main body was constructed half the size of the intended volume (~11L) with nylon fabric. General dimensions of prototype one can be found in figure 24.

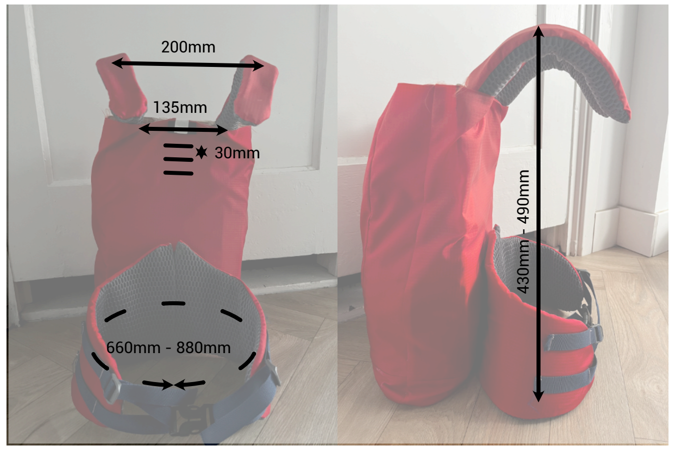


Figure 24: General dimensions of prototype one

The shoulder hooks were modelled using SolidWorks with the assistance of 3D mannequins from DINED of target group to ensure fit of the shoulder profile then 3D printed using PLA. A small layer (~2cm) of open-celled foam was used as padding and finally, enclosed in the nylon-spacer mesh fabric (figure 25).

Initially, the shoulder hooks were made to be fixed to the back panel but that restricted adjustability. Therefore, slots were made into the cardboard back panel to allow for adjustability based on user's torso length between 430mm – 500mm.

Figure 25: Shoulder hooks

The intent of the hip belt is to be constructed larger than the common hip belt where it has more area contact with the user's abdomen area to secure and carry the weight of the pack. The hip belt was made as two separate parts that was secured onto the main body using Velcro (figure 26).

The hip belt has a small layer of open-cell foam acting as padding enclosed in the nylon-spacer mesh fabric and nylon webbing straps that is adjustable between 680mm – 880mm hip circumference. The shape of the hip belt has slightly contoured ends to wrap around women's hips better than straight shape hip belts that is better fitted for men as shown in figure 26.

Figure 26: Oversized hip belt

The fit can be shown on the mannequin in figure 27.

Figure 27: Prototype on mannequin

COMFORT & MOBILITY TESTING

As fast-hiking is an on the move sport, there are certain requirements for the range of motion and movements that the backpack must fulfill without restricting the users. The comfort and mobility test asks participants to assume various postures and movements that fast hikers will experience during their journey such as, bending over, jogging, and crouching. The selected posture and movements selected for testing of this prototype can be found in figure 28.

Method

The testing conducted was based on observations and an unstructured interview regarding the fit and comfort of the prototype therefore, no quantitative data was collected. The data and insights were collected from two female participants, ages 25-27 who fit within the target group.

Procedure

First off, participant's body measurements (height, torso length, and waist circumference) were also taken to provide more information on how the prototype fit onto users with varying body dimensions. Then, participants were asked to try on the prototype which has been loaded to ~2kg of items and to give first impression of its fit and comfort and revealing any pain points that might stood out.

Lastly, participants were asked to execute the poses and movements in figure 28 and were asked to provide feedback when assuming the positions. Additionally, participants were asked to walk some distance to prolong the interaction with the pack and any discomfort would develop due to the motions.

Results

Regarding the carrying system, both participants expressed that freedom of movement for the arm and shoulder compared to the conventional shoulder straps. As well as the weight can be felt more on the hips rather at the shoulders and the hooks were mainly used as supports. However, the unfinished pack was only loaded with 2kg worth of items and with increasing weight, there will be a noticeably difference on the interaction of the hooks to the user's shoulder.

Due to the current build, the pack is quite small therefore, range of motion and movements such as fast-walking feels very secured and stable. However, when it comes to the extreme movements such as running and jumping, the pack sways and the shoulder hooks tend to fall off the shoulders. Participants stated that the shape of the hooks and hip belt can be better optimized for the next iteration and be fixed on the main body.

TAKEAWAYS

Carrying system
- Prototype does not reflect intended capacity which makes it difficult to fully assess

Shoulder hooks
- Change to fabric that has more grip
- Length should be increased to wrap over collarbone
- PLA is flimsy, should be printed thicker
- Softer padding is preferred

Hip belt
- Change to fabric that has more grip
- Shape is not ideal and does not wrap around the body as well
- Increase padding thickness

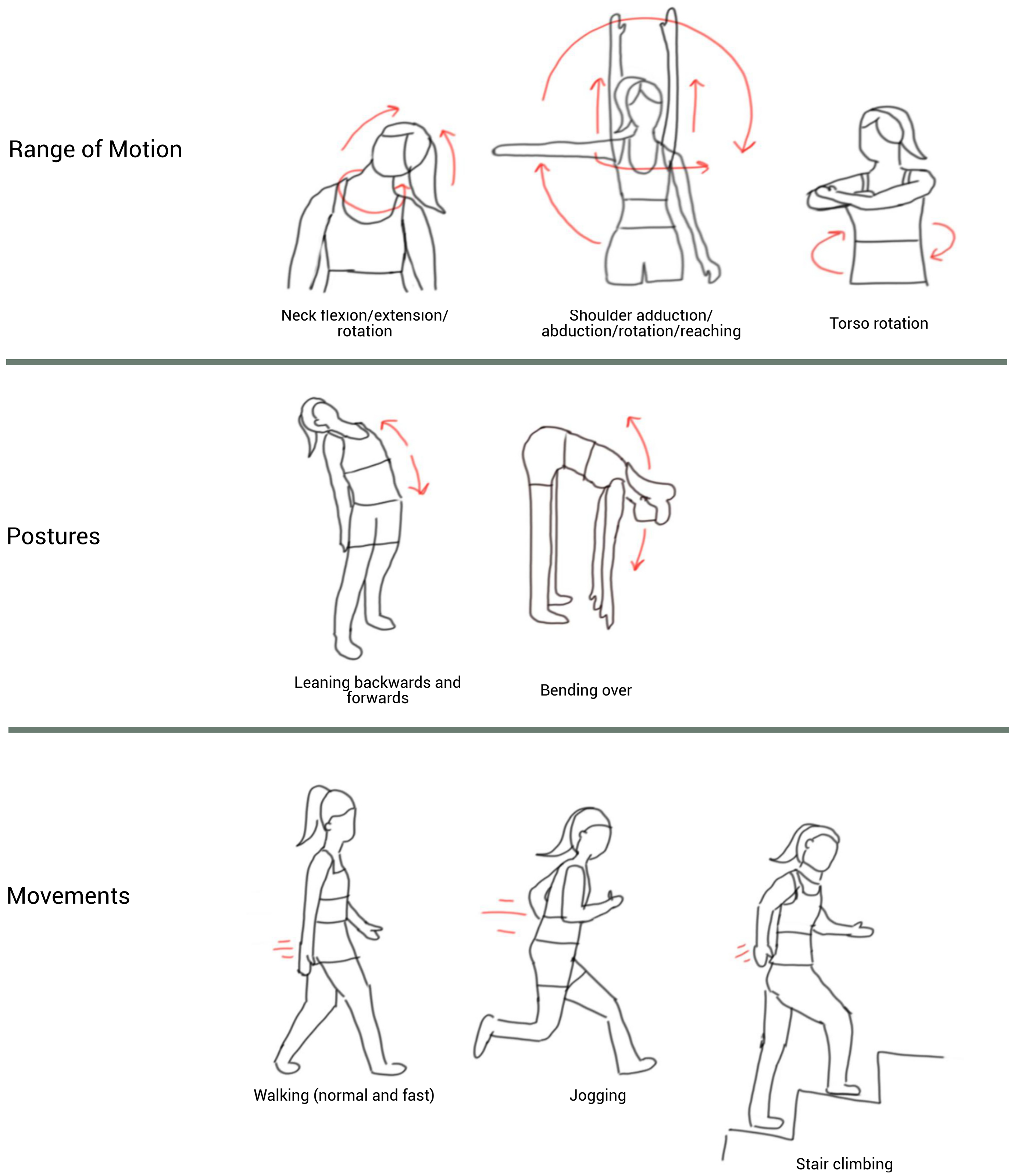


Figure 28: Mobility assessment

Figure 29: General dimensions of prototype two

PROTOTYPE 2

Based on the insights gathered from prototype one, a second iteration was made with modifications to the shoulder hook and hip belt shape. As well as the main body to reflect the intended capacity and seeks to test the system's functionality.

As opposed to the previous prototype, prototype two is a complete backpack with intended components and features such as fixed hip belt, internal frame, water bottle pockets, a roll top opening, and a capacity of ~25L (weight ~350g). General dimensions can be found in figure 29.

Modifications of the shoulder hook shape can be shown in figure 30. Padding of the open cell foam has been increased to ~3cm and a layer of rubber is sewn on top of the nylon-spacer mesh fabric to prevent the slipping that occurred during prototype one's testing.

Figure 30: Changes in shoulder profile. Prototype one: yellow. Prototype two: grey

Adjustability of the shoulder hooks for users of varying torso are as shown in figure 31 utilizing slots placed at ~3cm apart and Velcro. The adjustability ranges between 400mm - 510mm.

Figure 31: Adjustability system of shoulder hooks

Modifications to the hip belt shape can be shown in figure 32. Similarly, the padding of the open cell foam of the hip belt has been increased to ~4cm and hip belt is fixed to the main body to act as a better weight distribution along the hips.

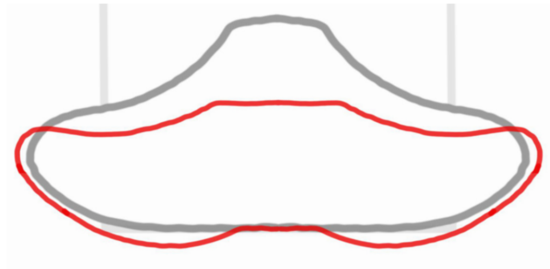


Figure 32: Changes in hip belt profile. Prototope one: grey. Prototype two: red

Webbing straps are made longer to allow for a greater adjustability range. The adjustability ranges between 540mm - 900mm.

Figure 33: Hip belt fixed to main body

Figure 34: Prototype on user

FIT, COMFORT, & MOBILITY TESTING

Method

The testing conducted was based on observations and a structured interview regarding the fit and comfort of the prototype. The data and insights were collected from four female participants, ages 24-30 who fit within the target group.

Procedure

The testing procedure of prototype two is like prototype one that asks for participant's body measurements and assume certain poses and motion. Detailed outline of the testing procedure can be found in appendix G which includes the questions asked. Participants will go through the procedure with the backpack is loaded ~4,5kg of items which reflects the lighter side of fast hiking.

Results

All participants were of relative height with varying body shape and can be summarized in table 12. Participant's clothing was taken into consideration to determine whether thickness of clothing can alleviate discomfort short term.

Table 12: Mean and standard deviation of body dimensions

	Mean ± SD
Height [mm]	1,597.5 ± 40,85
Torso Length [mm]	435 ± 33,17
Chest Circumference [mm]	888 ± 83,18
Hip Circumference[mm]	845 ± 89,16

Initial impression of the prototype both included curiosity and doubt of the strapless carrying system. Doubt revolved around the stiff shoulder straps as it might not be as comfortable. All four participants were content with the overall aesthetics, padding of the hip belt and shoulder hooks but not with the lack of padding on the back panel.

After trying on the prototype, all participants expressed some discomfort on the shoulders due the strap's placement on the collarbones due to its current profile. However, all were content with the weight distribution of the system on the hip belt and how it wraps around their bodies. When executing the mobility portion of the testing, all participants were able to assume all range of motions, postures, and movements with ease, however, have convey the discomfort of the shoulder straps. Especially when asked to jump, leap, and jog with the pack, the top half of the pack felt unstable and slips due to the shoulder strap but the bottom of half of the pack remained stable and secured.

Indicated level of discomfort can be summarized in figure 35. As all participants experience discomfort differently, it is difficult to draw conclusions based on the four participants. However, it can be concluded that the initial discomfort felt on the collarbones existed throughout the duration of testing and it could have overshadowed discomfort felt in other areas.

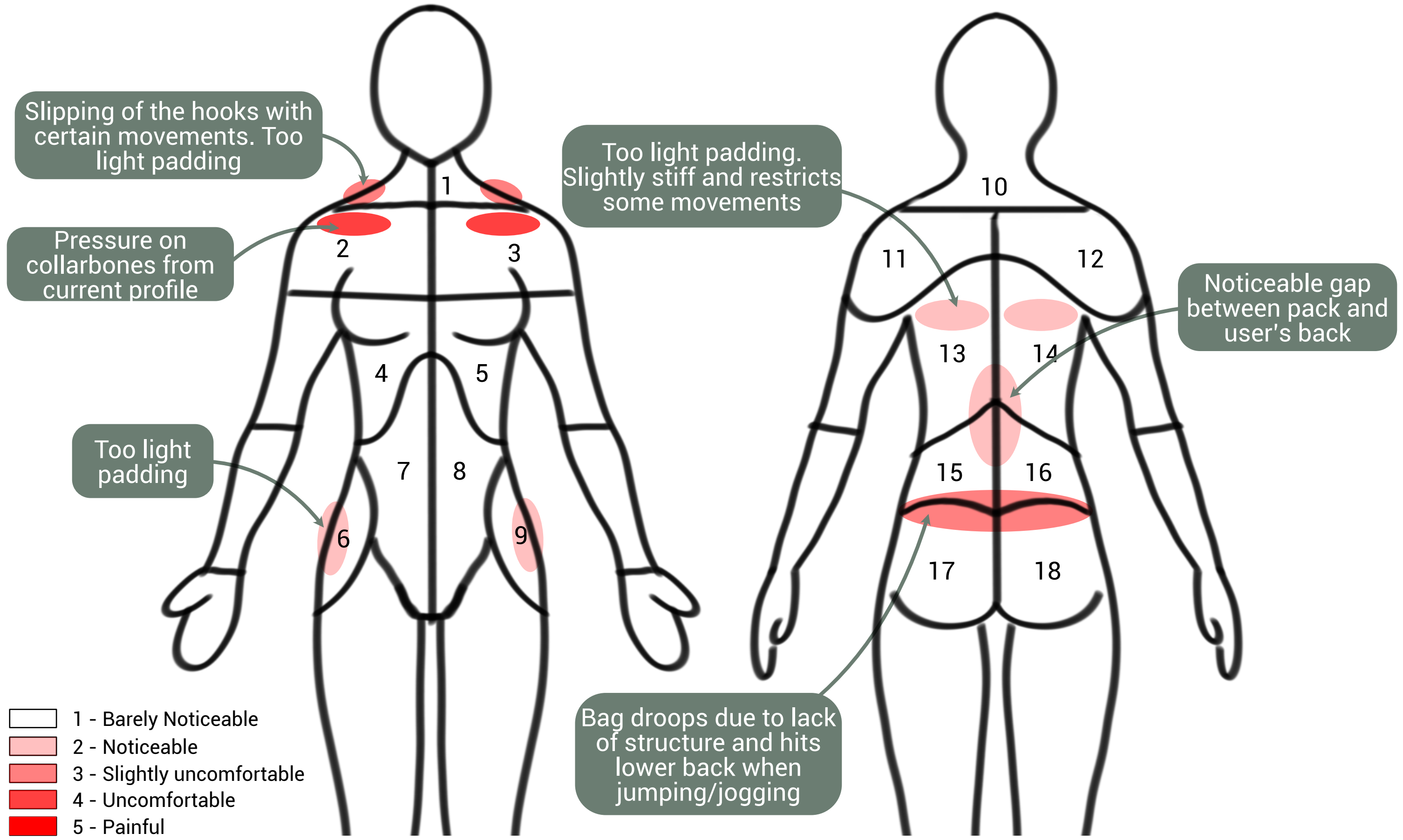


Figure 35: Discomfort areas from testing

TAKEAWAYS

Overall

- Prototyping errors could have affected the perceived discomfort of users
- Pack should have some internal structure as it is currently not fitting to user's back
- Pack should have some rigidity, so it does not sway and droop at the bottom
- More stability at the bottom half of the pack than the top

Shoulder hooks

- Less shoulder/collarbone discomfort is experienced with users of slimmer build
- Added rubber fabric help reduce slipping but can be better for more dynamic movements
- Wrapping of shoulder hooks should be to user's preference. Current profile does not allow for adjustments.
- More slots for adjustability for users who are smaller

Hip belt

- Little to no issues with tested users. It is securing pack to body well with minimal slipping
- Padding could be more uniform and thicker
- Straps needs to be longer

7 FINAL DESIGN

In this section, the final design is introducted that outlines the intended aspects and features which was tested and validated through a fit, comfort, and mobility assessment.

7.1 DESIGN EXPLANATION

Figure 36: Final prototype (~25L)

KEY FEATURES

The final design can be seen in figure 36 as it depicts the intended aspects and features. As the sport prioritizes weight, the final design has minimalistic features fast hikers need while on the trail such as elastic side pockets for water bottles or trekking poles, side compression straps to keep the pack closer to the body, formed internal frame, an elastic frontal pocket for quick access to snacks or personal items, and lastly, a roll top opening to optimize storage for multi-day trips.

Figure 37: Some of mentioned features

While one of the main features for improve fit and comfort for women of the final design is the hip belt. Can be seen as slightly larger than conventional hip belt with a two-point webbing strap system that is easier to tighten and loosen as needed. The hip belt has a thin layer of foam padding (~3cm) for ultimate comfort for long duration journeys and the straps can be adjustable for users of the lower and higher percentile, from a waist circumference of 688mm – 1035mm.

Figure 38: Hip belt shape

The other main feature of improve fit and comfort for women are the padded stiff and bendable shoulder hooks. Constructed out of hard plastic as the main structure connected with aluminum wire to allow for flexibility and lastly, a layer of foam padding as cushion on the shoulders.

Figure 39: Bendable shoulder hooks

It is expressed from user research that many female hikers experience discomfort in the chest and shoulder area due to the shoulder straps and sternum strap. With this design, it distributes majority of the backpack's load onto the hips therefore, the stiff shoulder hooks act as a stabilizer. This gives freedom to the upper torso, especially the chest area while still providing pack stability. Additionally, the torso is adjustable for users with torso sizes from 360mm – 540mm.

Figure 40: Adjustable torso

Further elaboration can be found in the following section.

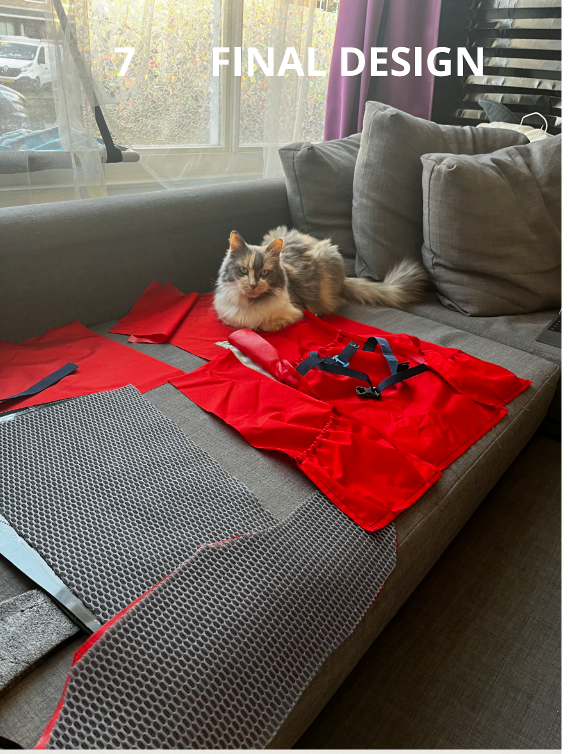


Figure 41: Overview of final prototype (~25L)

7.2 FINAL PROTOTYPE

MATERIALS

The final prototype is comprised of three main parts, the main body, hip belt, and shoulder hooks using similar materials (figure 41). The fabric that is used for the external parts of the prototype is ripstop nylon (red) which is a reinforced nylon that is more resistant to tearing and is lightweight which makes it an advantageous material for a backpack. In combination with a 3D spacer mesh (dark grey) which is a 3D knitted fabric that can offers a balance of comfort and ventilation. The 3D spacer mesh can be commonly used for the back sided of the backpack that will provide some cushion and air ventilation to the user's back and/or hips. All were sewn together using nylon thread.

Connecting parts of the backpack uses nylon webbing straps in combination with various plastic hardware such as ladder locks, quick release buckles (hip belt), or g-hooks (compression straps) as shown in figure 42. As for padding, open cell foam is used rather than closed cell foam because it is softer and beneficial for ventilation therefore, it is used for shoulder hook and hip belt padding.

Figure 42: Backpack hardware - quick release buckle (left), ladder lock (middle), g-hook (right)

To give the backpack structure, an internal frame is made from a sheet of thin plastic and 4mm craft aluminum wires to distribute pack loads evenly onto the hips. This is the same aluminum wire used in the bendable hooks.The rigid material used for the shoulder hooks is polylactic acid, also known as PLA.

PRODUCT USE

Prior to putting on the backpack, it is advisable to have the shoulder hooks in the correct torso slots. The shoulder hooks are an independent system that is not fixed to the main body therefore, it is easier to adjust. The system utilizes webbing slots and a Velcro connection to fix them to the back panel as shown in figure 43. With the six slots, users with torso sizes from 410mm - 500mm can comfortably fit. For this prototype, additional straps were added to the system to reduce backpack sway by adding more connection points as shown in figure 44. This is only a temporary fix for the final prototype, but the envisioned design will utilize an alternative method and larger range of torso adjustability.

Figure 43: Final prototype adjustable torso system

Figure 44: Additional straps added to adjustable torso system to reduce sway

As shown in figure 45, the shoulder hooks have bendable ends which allow users to alter to their liking. As collected from previous testing, a fixed profile might be a good fit for a small percentage of the target group but not the majority therefore, introducing flexible parts will allow for greater accommodation of various body shape and sizes. The system has three points that can be bent and are located at the ends because from prior testing, it is advisable to avoid applying pressure on the collarbones which leads to high discomfort. Hence, the shoulder hooks are much longer compared to the profile in prototype 2.

Figure 45: Bendable ends of the shoulder hooks

Figure 46: Prototype on user (me)

7.3 FINAL PROTOTYPE TESTING

FIT, COMFORT, & MOBILITY TESTING

METHOD

The testing conducted was based on observations and a structured interview regarding the fit and (dis)comfort of the prototype. The data and insights were collected from five female participants, ages 23-30 who fit within the target group.

PROCEDURE

The final prototype testing is similar to prototype two that asks for participant's body measurements and assume certain range of motion, poses, and motion. Detailed outline of the testing procedure can be found in appendix I which includes the questions asked. Participants will go through the procedure with the backpack is loaded ~4,5kg of items which reflects the lighter side of fast hiking.

PARTICIPANTS

All participants were of varying height and body shape. Figure 47 shows the body measurements of the participants compared to the combined dataset as summarized in table 13 (DINED & ANSUR II - women, ages 18 - 45), in percentiles. This helps visualize the spread of the measured group to validate the fit of the prototype and its current dimensions.

Table 13: Mean and standard deviation of body dimensions based on combined data

	Mean ± SD
Height [mm]	1649 ± 68,71
Torso Length [mm]	429 ± 30,87
Chest Circumference [mm]	943 ± 80,44
Hip Circumference [mm]	853 ± 99,46

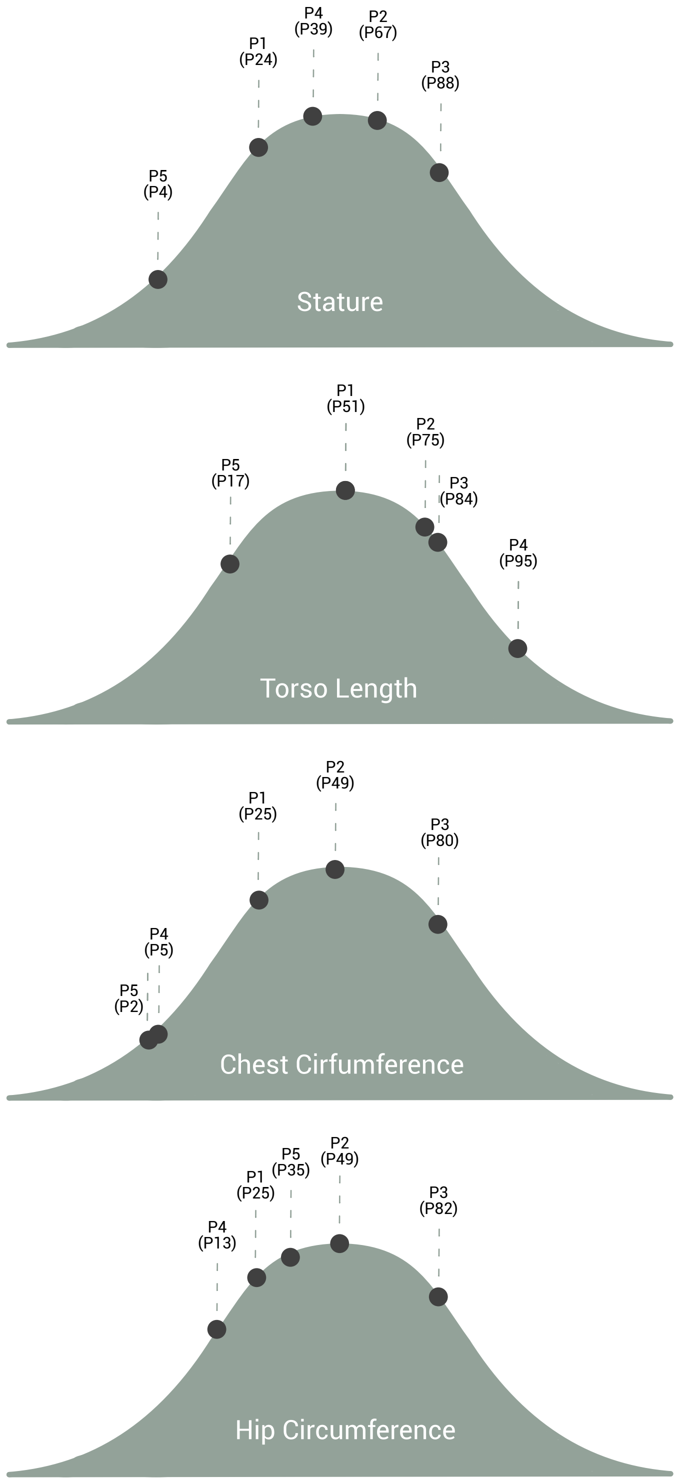


Figure 47: Spread of participants measurements: torso length, chest and hip circumference. Bell curves generated based on DINED & ANSURR II data.

RESULTS

Of the five participants, three participated in the previous testing of prototype two while two were newer to the study. First impressions of the final prototype were positive. Previous participants were able to see the prototype progression and newer participants expressed interest and curiosity in the unique straps.

After trying on the prototype, the things that jumped out are the unformed back panel (-), adjustments of shoulder hooks (+/-), and pack weight felt on the hips rather than the shoulders (+). The 4mm craft aluminum embedded into the back panel is too pliable and with no rigidity which causes pack to lose its shape. Due to the unformed back panel, there was a gap between the participant's back and the backpack which created an "off feeling" for some (figure 48).

Figure 48: Gap between user's back and prototype

Two participants mentioned that it is nice to be able to adjust to their preference of the shoulder hooks, but it is difficult to adjust when the backpack is on. All participants were pleased with the little weight they felt on their shoulders as all 4,5kg were loaded on their hips. Lastly, participants were asked to rate the stability and fit of the backpack and the results average 3,4 (stability) and 3,9 (fit) out of 5.

For the mobility section, initial levels of discomfort were rated to compare to later levels of discomfort. Based on participant's feedback and observations, all aspects of the mobility section were able to be performed with slight ease. However, there were difficulties in the higher dynamic movements such as jumping, leaping, and running as the backpack bounces more than preferred and the bother of having to bend the shoulder hooks back to desired shape. Motions such as walking, light jog, and stair climbing were satisfactory by all participants.

The indicated levels of discomfort can be summarized in figure 49. It can be stated that the shoulder hooks displayed more of a mental discomfort rather than physical due to the annoyance of having to readjust compared to prototype two.

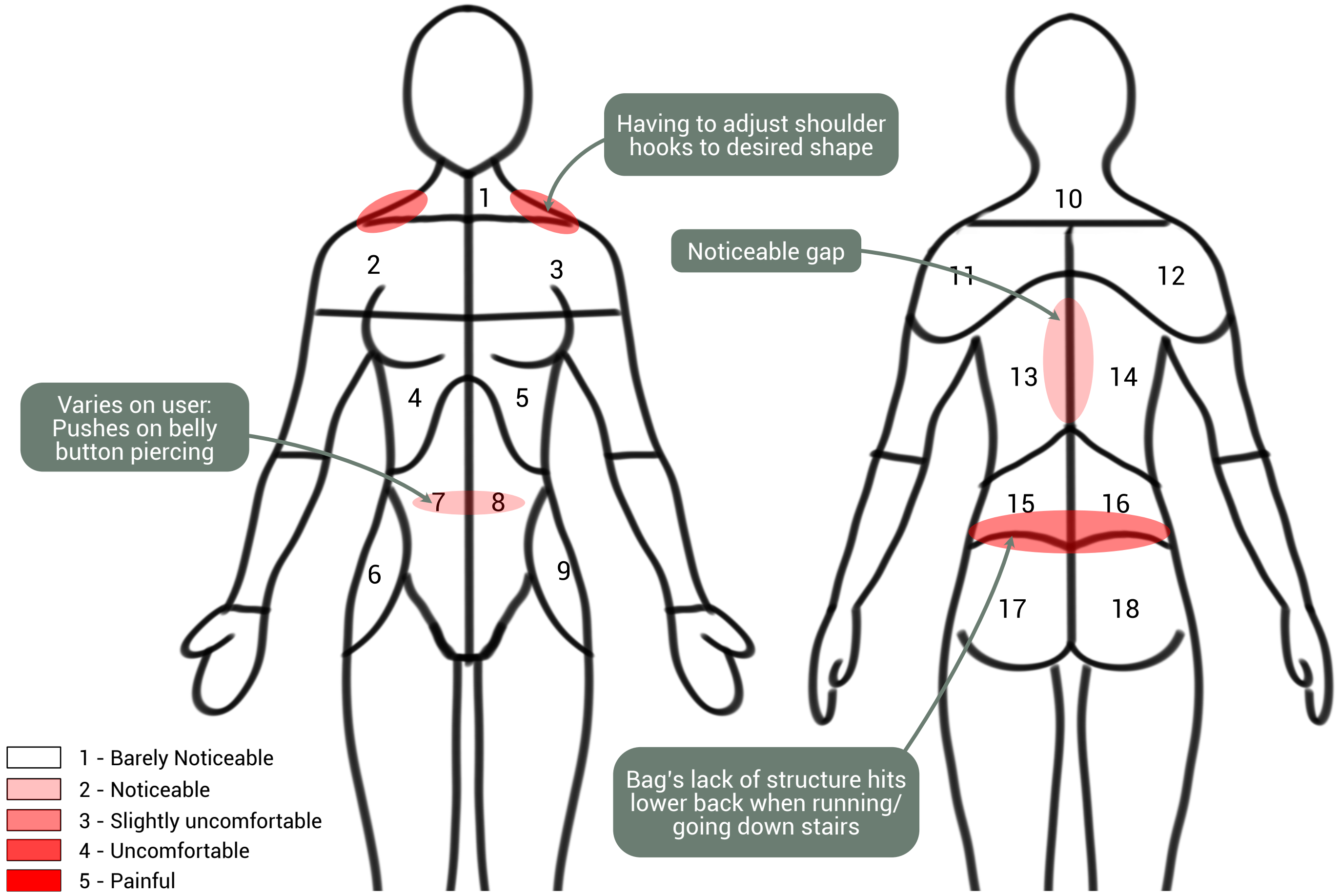


Figure 49: Discomfort areas from testing

CONCLUSION

When compared to the previous prototype, the final prototype displays improvements based on the feedback of the test users. The slimmer, tapered shape and built of the main body were an improvement for the fit but lack of structure bring about discomfort. Stability is still an issue for the final prototype, potentially caused by not having a fixed system for the shoulder hooks to the main body and how the hip belt is sewn in the middle of the back panel as opposed to the sides. Similarly, to prototype two, prototyping errors could have affected the perceived discomfort of user for this iteration.

In regard to fit, the study aimed to have a diverse group of participants to validate the concluding dimensions of the backpack as proposed in "Research Overview". It can be concluded that the current dimensions of the final prototype can accommodate users within the 5th and 95th percentile in terms of stature and torso length. Limitation in adjustability for hip circumference is due to length of webbing straps which can be determined to be a prototyping error. It is recommended that additional testing to be done to further evaluate the fit of users.

TAKEAWAYS

Overall

- Additional strap to be added to improve stability of the backpack or fix the shoulder hook system to the back panel
- Current method of putting on the backpack is inefficient and difficult especially if pack weight increases
- Final prototype does not fully match fast-hiking contexts. Further improvements needed to accommodate running.

Back panel

- Little adjustments made to torso size therefore, a fixed back length can be explored in next iteration
- Pack should have a formed internal structure for fit, comfort, and load distribution to the hips. Can improve the stability of the backpack as well.

Shoulder hooks

- Current wires are too pliable, needs something that can be bent and holds its shape
- Have the entire length of the shoulder hook to be bendable instead of just three points near the ends

Hip belt

- Little to no issues with tested users
- Preference of softer, thicker padding and longer straps

8 DISCUSSION AND CONCLUSION

In this section, evaluation of the project as a whole is discussed in relation to the initial project assignment as well as, tips and tops of the final prototype. Limitations of the projects are formulated as general recommendation for the next iteration. Lastly, assessment of the product's feasibility, desireability, and viability is addressed.

8.1 DISCUSSION

The objective of this project was to, “design a backpack suitable for fast-hiking with women optimized sizes, features, and accessories.” The design process began with trying to understand what the challenges were, why this was needed, and how current products on the market are designed. To improve the fitting of backpacks for women hikers, it was examined how the role of gender affected user’s ability and performance. As well as, how considering anthropometry can provide useful insights on the sizing of backpacks specifically for women.

It was revealed from user research that women hikers faced high levels of discomfort on their neck/shoulders, chest area, and lower back due to the misfit of backpack size and unoptimized placement and shape of the shoulder/sternum/hip straps. With these identified issues, this was prioritized during the ideation and concept generation to explore solutions that reduced shoulder and chest discomfort while improve overall fit. This introduces the final design of a strapless carrying system that replaces conventional shoulder straps with stiff, bendable shoulder hooks allowing for freedom of the shoulders, chest, and arms with pack load will be fully distributed onto the hips.

The prototype and testing phase of this project has proven, to an extent, the feasibility of stiff, bendable shoulder hooks as opposed to conventional shoulder straps. However, further development is needed to better validate the carrying system to fit it within the fast-hiking context. In other words, the prototype functions well in the context of slow-paced of hiking but faces some difficulties when extreme movements are taken such as running downhill. This is further elaborated in the following section, General Recommendations.

GENERAL RECOMMENDATIONS

ANTHROPOMETRY

It is advised to diversify the dataset to include multiple populations to provide insights on the differences in upper body anthropometry. For this project, as there is supple data for American women, it can be used as a control and dimensions can be adjusted based on the intended market. Additionally, as oppose of determining sizing based on user’s stature, it is more insightful to collect information based on torso length to ensure better fit of the backpack.

OVERALL BACKPACK

Based off the collected user testing, interviews, and learnings, general embodiment recommendations are compiled below that should be taken into account in the next iteration to increase the feasibility and viability of the design.

Shape and size

Current shape, size, and dimensions of the backpack is satisfactory based on testing results. Fit and comfort is satisfactory but can be improved. It is recommended that further testing needs to be conducted with intended materials such as tent, sleeping bags, food, etc. to check overall sizing and capacity of the backpack.

Shoulder hooks

Another iteration is needed to dial in the shape of the bendable shoulder hooks. Currently, the final prototype shoulder hooks are made of PLA and 4mm craft aluminum wires which are too pliable/malleable and has no strength to hold its shape during fast movements. Additionally, constant bending of aluminum wires causes stress points in the metal which can increase material failure.

It is recommended to transition away from aluminum wires to stainless steel coils, commonly seen in gooseneck tubing (figure 50). Doing so, it introduces a material of higher strength and stiffness to withstand the constant bending while holding its bent shape. Stress points and cracks can be eliminated in coils and the combination of a softer outer wire can reinforce the shoulder hooks.

Figure 50: Example of product that uses gooseneck tubing (right) and how its made (left)

It is recommended to offer an adjustable torso system as that will allow for greater fit and accommodation of women of various body shape and sizes. However, the overall system can be changed where the shoulder hooks clicks and locks to the main body with keyhole slots rather than Velcro/straps. Figure 51 visualizes this idea but does not reflect envisioned method.

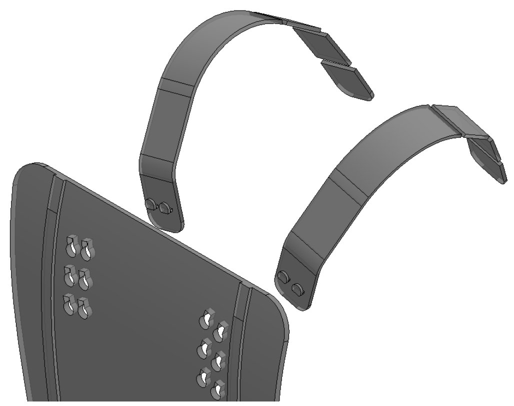


Figure 51: Proposed method of utilizing keyholes for attachment of shoulder hooks to back panel

Internal frame

From the user testing, perceived discomfort was found from the lack of structure and rigidity of the internal frame. It is recommended in the next iteration to contain pre-bent aluminum rods (6061-T6 aluminum alloy is commonly used) in combination with a foam HDPE (high-density polyethylene) plastic sheet as lumbar support. Implementation of stronger rods can help load distribution and increase the capacity/volume of the backpack.

As opposed to a straight plastic sheet, it is advised to have it slightly concave to the one’s back for improved fit and reduces the gap found between the user’s back and the backpack. This can be visualized in figure 52.

Figure 52: Proposed internal frame for next iteration

Stability

It is recommended to add another connection point on the backpack to reduce the side to side sway experience during motion. Additionally this can bring and keep the pack closer to the body which can reduce the risk of injuries from a bouncy pack. However, it introduces more straps to the system that will have to connect with the user’s body. This can be visualized in figure 53.

8.2 CONCLUSION

For the introduction of a strapless backpack for women, various factors are to be taken into account to develop a functional product. This includes further development as outlined in General Recommendations. Even so, the final design embodies the potential of being a women specific design for fast-hiking backpacks.

FEASIBILITY

As previously mentioned, the final design shows potential to become a functional product however, exploration of materials and attachment are to be explored. Specifically for the internal frame and bendable shoulder hooks as they are the current obstacles of prototype 3. Other aspects of the backpack such as size/shape of the backpack, hip belt, and other features are satisfactory according to user testing.

The envisioned product will be constructed of similar materials used for the final prototype (ripstop nylon, 3D spacer mesh, backpack hardware, etc.). Additional manufacturing methods can be envisioned for the development of the formed HDPE internal frame with the keyhole system compared to traditional methods. It is possible to have an adjustable or fixed system however it is suggested to adopt the adjustable system as it allows for flexibility and a one size fits all backpack.

It can be said that the results from the final prototype were very positive with limitations of the shoulder hooks being too pliable. Although, once materials and overall assembly changes, the design can be envisioned as a functional prototype after supplemental testing.

DESIRABILITY

For women, the final design proposes a fit that is tailored for the female body with optimized shapes and features. Based on initial user research, many users express the discomfort of shoulder and sternum straps and larger sizing of current products on market. The final design accounts for women's upper anthropometry to define backpack dimensions and ranges of adjustability that will fit the 5^{th} and 95^{th} percentile of women. The strapless system allows the load of the backpack to be distributed onto the hips where the shoulder hooks act as stabilizers and allows for freedom of the upper body specifically the chest regions. Additionally, the hip belt is contoured at the ends that hugs women's hips and prevent slippage during movement. With this system, user's mobility is improved, and discomfort can be prolonged.

VIABILITY

As mentioned in the General Recommendations, the final design requires additional development and testing in order to validate the bendable shoulder hooks. However, based on the evaluation of the final prototype, it offers the possibility of a strapless backpack that is adapted for female fast hikers. This concept introduces something unique into the market that sparks interest and curiosity of users as shown from the final prototype testing. This can be concluded as a positive remark for the future of this strapless design with further development.

8.3 REFLECTION

Before the start of this graduation thesis, I was struggling to find a topic that catered to my needs and interest. There were many skills I wanted to develop and improve, and industry areas I wanted to explore. Coming across this topic to design a physical product for a minority group happened to check off all the requirements I wanted in a graduation thesis. One can say it was too coincidental!

Initially, I struggled in getting adjusted to the pace and taking on the leading role for this graduation project. Luckily, I was able to step into the role confidently with the motivation and encouragement of my supervisors and the client during the meetings. Also, I feared that communications would be difficult trying to coordinate everyone's schedule as the client resides outside of the Netherlands. Surprisingly, we did not face these troubles and was able to meet in an efficient manner which did not affect the project's progress.

I enjoyed the split in this project as the first stage focused on user's needs/wants/ challenges and anthropometric research which then was able to be implemented in the later stages of ideation and embodiment. I found the ideation/conceptual stage to be the toughest because coming from a mechanical engineering background, my focus was on, "would this really work?" which subconsciously eliminated potential ideas and solutions and limited the creative process. As I was able to take a step back and with the help the supervisory team and some creative facilitation books, I was able to restart the process and wind up with a unique design that reflected the research conducted.

I am very pleased with the embodiment stage with the prototypes made and user testing. This increased my knowledge in conducting ergonomic studies regarding user's comfort and discomfort which presented useful insights to the development of the fast-hiking backpack. As well as incorporating anthropometry into the designing a product that is more personalize for women.

In the end, I am proud of the project outcomes as I was able to deliver anthropometric research regarding designing backpacks for women, a functional prototype, and an ergonomic evaluation. Additionally, I have acquired new skills, refined current ones, and ready for the next steps in my design journey.

Figure 54: Onwards!

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