ADAPTIVE CLOTHING DESIGN: FROM FOCUS GROUP EVALUATION TO FUNCTIONAL PROTOTYPES

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ABSTRACT

The importance of adaptive clothing has grown considerably in response to the needs of individuals with physical disabilities, whether congenital or acquired. This study explores the principles of user-centred design in developing adaptive clothing, using a framework informed by focus group discussions. The aim was to gather detailed insights to guide the design process, ensuring that users' needs and preferences are effectively addressed. To achieve this, three separate focus groups were created, comprising 7 medical staff, 5 patients from the surgical department, and 12 patients undergoing rehabilitation. This diverse representation sought to address the different needs associated with varying mobility levels, treatment durations, and care requirements. The approach aims to understand the experiences and needs of adaptive clothing users thoroughly. As a result, an effective adaptive design was developed, focusing on clothing that is not only functional and visually appealing but also genuinely meets the users' needs.

KEYWORDS

Adaptive Clothing Design; Digital Fashion; Human Factors; Human-Centred Design; Disability; Focus Group.

INTRODUCTION

Recently, the adaptive clothing market experienced substantial growth, focusing on inclusive design for apparel and footwear tailored to individuals with various congenital or acquired functional impairments, whether resulting from injuries or chronic diseases [1]. At the same time, scientific interest in developing such clothing has also increased [2-3].

The variability in terminology has continued to be a challenge within the field. There are several possible terms to describe this type of apparel. While "functional" and "inclusive" clothing are commonly used [4], the term "adaptive clothing" more accurately defines garments that are designed to be both practical and visually appealing, as well as ergonomic, to meet an individual's specific needs [3, 4]. For this reason, we employ the term "adaptive" in our recent research.

Research on adaptive clothing and design is diverse and interdisciplinary. Therefore, researchers often focus on specific clothing types [5, 6], disabilities [3, 7-11], regions [3, 12], age groups [13-15], and other factors such as purpose - for example, hospital patients undergoing treatment [10, 16-17], etc.

Effective adaptive clothing design requires an interdisciplinary approach that integrates psychology, physiotherapy, design, and engineering. This combination aims to create attire that is comfortable, functional, and fashionable. The literature review revealed that adaptive clothing design is centered on meeting the needs of individuals with disabilities, specifically ensuring their physiological and psychological comfort when wearing clothing [2, 3]. This encompasses several aspects, including:

- the use of innovative technologies [2, 3, 18-19],
- biomechanical and functional principles for ensuring the comfort of apparel [11, 12, 17, 20],
- socio-cultural and psychological aspects [3, 8, 12, 21],
- aesthetic and emotional reactions [3, 15, 16]
- barriers or the impact of adaptive clothing on the quality of life of individuals with functional impairments [3, 7, 12, 22].

Innovations in adaptive clothing aim to design garments made from materials that are easy to put on and take off. For instance, magnetic zippers are being

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used to simplify the dressing process [2, 3]. These advancements also involve creating fabrics with specific features, such as antibacterial and hypoallergenic properties [3]. Additionally, there are materials designed to heat immobile body parts of individuals with disabilities, utilising electrically conductive threads [18]. Moreover, shape-memory fabrics are being developed to adjust to the unique needs of each user [19].

Advances in computer technology enable us to evaluate the areas of greatest stress and pressure on the body during the design phase of adaptive clothing, allowing informed decisions to be made and assessed through 3D visualisation and to leverage digital tools for inclusive design [11, 20].

Several studies in the field of adaptive clothing focus on biomechanics and ergonomics aimed at achieving comfort for individuals lying down [10], those in wheelchairs [9, 16], clothing usability during movement [17], and ease of putting on and taking off garments [13, 14]. They also explore how materials can provide comfort and support, considering physiological limitations [3, 17]. In the study [17], this aspect included characteristics of hospital patients' motor regimes, such as general, ward, semi-bed, bed, and strict bed, alongside the topography of medical procedures and regions affected by physical, psychophysical, chemical, and biological factors on clothing. Based on this, recommendations were made for designing adaptive clothing tailored to different patients depending on their motor regime [17]. The ergonomic design for adaptive clothing focused on how the shape and structure of garments can maintain physical comfort [11], reduce joint and muscle load, and how appropriately chosen materials can facilitate movement and lessen discomfort during wear [8].

Except for the studies aimed at enhancing physical comfort in the development of adaptive clothing, several referenced studies [2, 3, 7-9, 15] also examine the psychological and socio-cultural aspects of clothing design for individuals with functional impairments. The key points of the research were how adaptive clothing helps individuals with disabilities maintain their independence, boost their self-esteem, and how it influences social integration and reduces social barriers.

Challenges related to clothing can significantly hinder individuals with disabilities and their families from fully participating in society [21]. The lack of suitable clothing creates barriers related to functional, sociopsychological, cultural, sensory sensitivity, and fashion consumption issues, which affect their ability to engage in social activities, maintain relationships, work, and participate in daily events. These combined barriers highlight the importance of sociopsychological factors in shaping experiences associated with adaptive clothing consumption [3, 5, 12, 22].

The social inclusion of individuals with disabilities is a crucial issue. Experts from various fields, including clothing design [9], are working to develop products that address their specific needs. In response to this challenge, researchers have proposed innovative and technological solutions for adaptive clothing. These solutions focus on personalisation and adaptation to new lifestyles, promoting social inclusion and integration, especially for individuals with multiple sclerosis. Another study [19] examines the impact of ergonomic design on adaptive clothing, highlighting its role in boosting a person's self-confidence and ability to dress independently, ultimately improving their quality of life. This research also stresses the importance of the aesthetic appeal of adaptive clothing in maintaining social standing and contributing to an individual's overall well-being.

One way to improve the social inclusion of people with disabilities is to involve them at each stage of the clothing development process, thereby building trust and collaboration with them. This approach will help create comfortable, stylish, and fashionable adaptive clothing that meets their needs [14].

Integrating digital tools and innovations into the design process can support aesthetic requirements. CLO 3D digital modelling to create ergonomic designs and assess the psychophysiological effects of colour allows for the optimisation of colour combinations for individuals with limb injuries and the generation of design sketches in a sport-casual style aimed at daily use, comfort, and social settings inclusion [23].

In [16], interviews were conducted to explore patients' emotional reactions to adaptive clothing in university hospitals. The findings revealed that patterns and motifs designed with healing proportional ratios can positively influence a patient's condition, effectively creating clothing intended for healing. Patients reported that specific clothing designs provided them with a sense of trust, stability, and comfort. Additionally, the design of apparel for patients not only shapes the brand image of medical institutions but also enhances the quality of medical care by focusing on patient recovery.

A survey [2] found that clothing has a significant impact on mobility, self-care, and various personal factors. Approximately 49% of individuals with functional impairments identified essential clothing design features that should be considered [2]. Additionally, research on the online consumption of adaptive clothing has identified that functionality is the primary requirement for consumers, whether shopping in-store or online [1].

To address inclusion challenges, it is crucial to promote disability-inclusive fashion by adopting advanced mass customisation technologies. These studies [12, 23] proposed strategies for developing inclusive fashion products that enhance the well-being of individuals with disabilities. As a result, there

is a pressing need for a universal fashion market that caters to both disabled and non-disabled consumers, regardless of their physical differences [12, 24].

To gain a thorough and contextual understanding of the purpose of adaptive clothing and the adaptive design process, as well as to promote innovations in this field, a user-centred design (UCD) approach is employed [3, 12, 14]. UCD is a design method that prioritises the user throughout the design process [3]. It focuses on understanding the user's needs and limitations to guide design choices. A key aspect of this methodology is iterative prototyping, which enables users to interact with physical products in real-world conditions. This process allows designers to refine garments based on direct user feedback and experience. Emphasising user experiences and processes is essential for creating products that not only function effectively but also meet users' aesthetic preferences [3].

In [12], using UCD established the fundamental requirements for designing adaptive outerwear, which, through parametric digital modelling, allows customised options based on different sizes and physical conditions, blending both functionality and aesthetics. Similarly, other research has demonstrated that adaptive clothing design should go beyond utility to incorporate sensory, cultural, and aesthetic aspects, ensuring comprehensive inclusion of people with disabilities [6]. Building on this, a wide range of clothing-related barriers, from mechanical and ergonomic issues to sensory discomfort and social stigma, were identified. Overcoming these barriers requires continuous communication with consumers throughout the entire design process. This type of collaboration not only enhances garment quality, functionality, and inclusiveness but also promotes social integration, contributing to users' physiological and psychological comfort through fashionable, accessible design.

Despite a growing interest in adaptive fashion, there remains a significant gap in studies focusing on clothing design for individuals with limb injuries, amputations, or partial loss of limb function. This group comprises stroke survivors and individuals affected by illness or trauma. In Ukraine, the ongoing military conflict has intensified this need by increasing the number of traumatic injuries caused by mines and explosives. Developing adaptive clothing for these individuals is both urgent and socially vital.

A review of current literature highlights several key requirements for high-quality adaptive clothing for individuals with limb injuries. Firstly, the adaptive design must overcome functional barriers [3, 7, 12]. Garments should be customized to suit specific physical conditions, especially limb amputation, asymmetry, or support devices such as prostheses or other aids. Functional comfort must be considered for the physiological and physical attributes of consumers with disabilities [12]. For physiological comfort and hygiene, materials should be soft, breathable, and skin-friendly, meeting high ergonomic and hygienic standards [2, 3]. Adaptive clothing must possess suitable aesthetic qualities [3, 7, 12, 23] that match current fashion trends, allowing individuals to showcase their style while ensuring practicality and dignity. The design of adaptive clothing should aim to enhance the wearer's psychological comfort [3, 7]. These requirements will be aimed at creating adaptive clothing that not only fulfils practical needs but also supports the dignity and personal expression of individuals with limb injuries.

To validate this suggestion, three categories were outlined [25]:

- Functional Comfort: This includes the ease of adapting to different activities, quick access to fasteners, and the simplicity of putting on and taking off items.
- Physiological Comfort: This encompasses sensory comfort, thermal regulation, fit, and the weight of the fabric.
- Psychological Comfort: This refers to aesthetic and expressive satisfaction, the appropriateness of items for daily life in a hospital setting, as well as considerations of privacy and dignity.

To avoid limiting the depth of user input and to reduce opportunities for a more thorough exploration of user challenges. Therefore, it is advisable to organize structured, face-to-face focus groups involving not only individuals with limb injuries but also specialists such as designers, doctors, psychologists, and sewing professionals [3, 25]. This will enable a more holistic and expert-driven discussion, providing comprehensive insights into user needs and enhancing the adaptive design process. Importantly, user engagement should be integrated at every stage of the design—from preliminary research and conceptual sketching to the expert evaluation of prototypes.

EXPERIMENTS

Materials

The research aimed to explore users' needs and evaluations of experimental adaptive clothing. To gather insights, the study was conducted with a diverse group of participants, including medical specialists (such as surgeons and rehabilitation experts with experience in treating injuries), patients with various injuries and functional movement limitations, and professionals specializing in sewing, product design, and technology. This composition was selected to provide comprehensive insights into the requirements and challenges faced by users of current adaptive clothing.

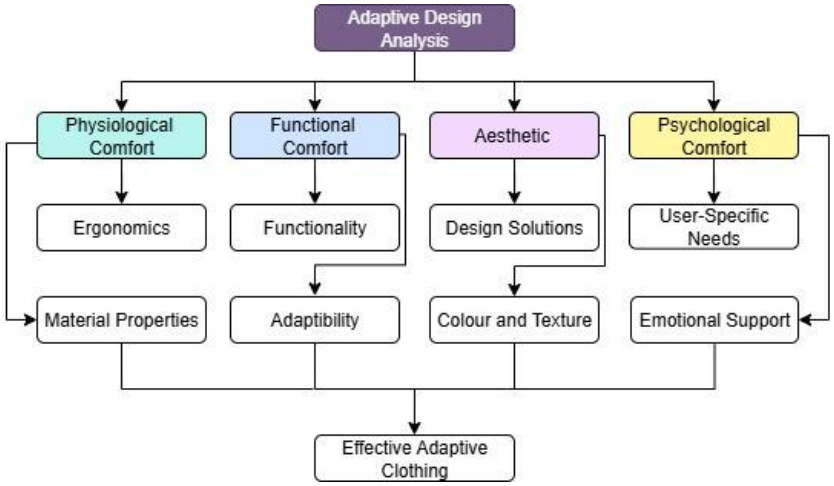

Figure 1. Comfort categories for effective adaptive clothing.

The structure for analysing user needs for adequate adaptive design is illustrated in Figure 1. This model identifies four core domains of comfort: physiological, functional, aesthetic, and psychological. To consider aesthetics, we established it as a distinct comfort category. Each domain includes subcategories derived from resource analysis.

Experimental Design

To establish these requirements (Fig. 1), specific restrictions were introduced. This was necessary because many aspects of the requirements could hinder conducting high-quality personal interviews with respondents because of the lengthy survey process. This is particularly important for patients in the surgical department, who are essential for meeting the survey's time constraints. As a result, the scheme outlined identifies four key groups of requirements for adaptive clothing.

Physiological comfort addresses ergonomics and the properties of materials. Functional comfort focuses on the necessary functions of garments and their adaptability. Aesthetic aspects cover user-friendly design solutions and psychosocial considerations in colour selection for apparel. The psychological comfort involves factors related to dignity, emotional well-being, and societal inclusion.

The research was conducted in two stages. The first stage involved a questionnaire survey, as described in the previous article [26], along with the development of prototypes – Experimental Adaptive Clothing. After the production of this clothing, samples were included in a focus group survey conducted during the second stage.

To build trust and gather honest responses from focus group participants, a team of four experts visited the hospital's surgical department and rehabilitation centre from March 9 to May 25, 2024. The four conducted focus group discussions using the questions listed in Table 1, with one person responsible for audio recording and another for photos and videos.

Two to three meetings were held with each focus group to build an emotional connection. The respondents were positive about the survey and became increasingly open, especially during the second and third meetings. Respondents openly discussed personal experiences. Some points of these discussions involved sensitive topics and the barriers they encountered in their clothing-related lives. They shared thoughts about current barriers and offered suggestions for potential adaptive design solutions.

A detailed methodology for conducting focus group surveys in hospital settings, surgical departments, and rehabilitation centres has been developed to address the requirements for adaptive clothing effectively. This methodology highlights principles of inclusivity, user experience, an interdisciplinary approach, and the integration of digital technologies for data collection and analysis.

During the preparatory phase, three distinct Focus Groups were created based on the objectives of the study: 1) medical staff, 2) patients from the surgical department, and 3) patients from rehabilitation centres. The number of groups reflects the varying needs associated with different mobility levels, treatment durations, and care specifics for individuals with injuries. Participant selection was based on established guidelines [12] that considered factors such as gender, age, and functional disabilities.

The development of the focus group scenario involved creating a survey through semi-structured interviews conducted across three Focus Groups. This process followed a pre-prepared set of key questions based on a UCD approach (Fig. 1), emphasising the active involvement of users in the adaptive apparel design process (Table 1). The questions were divided into five sections. The first

Table 1. Sample interview questions.

Section	Requirements	Key Question Number (KQ)	Sample Questions
1 Main information	General	KQ1	What is your injury?
		KQ2	What clothing did you wear during treatment?
		KQ3	Have you previously used adaptive clothing? If so, which one?
		KQ4	What difficulties do you encounter when putting on or removing clothing?
2/ 3/ 4/ 5 Prototype Assessment of the ES/EP/ET/ESh	Physiological Comfort	KQ5	What should the quality of textile materials be for adaptive clothing, such as that used in ES/EP/ET/ESh?
		KQ6	How do you assess the comfort and practicality of the neckline in the ES/ET?
		KQ7	How do you evaluate the sleeve width and length of the ES/ET for comfort?
		KQ8	What are your thoughts on the convenience of the leg width in the EP/ESh?
		KQ9	How would you evaluate the convenience of short length?
	Functional comfort	KQ10	How easy is it to put on and take off the proposed ES/EP/ET/ESh?
		KQ11	How easily can you access medical procedures or use medical devices while wearing ES/EP/ET/ESh?
		KQ12	What specific requirements or preferences do you have regarding the functionality of ES/EP/ET/ESh, such as ease of application, types of fasteners, fabric choices, and any special features?
		KQ13	How would you evaluate the convenience of the fasteners in the ES/EP/ET/ESh?
		KQ14	What are your thoughts on the convenience of the pockets in the ES/ET?
		KQ15	What is your opinion on the convenience of the hood in the ES?
		KQ16	What is your opinion on the convenience of the waistbands in the EP/ESh?
	Aesthetic	KQ17	Does this clothing look like everyday regular wear to you, or does it seem like a specialised medical product?
		KQ18	How suitable is the colour scheme of the ES/EP/ET/ESh?
		KQ19	What colours make you feel confident, calm, energised, etc.?
		KQ20	What emotional reactions are caused by the appearance of ES/EP/ET/ESh?
		KQ21	What fashion elements would you like to see in adaptive clothing? For example, asymmetrical designs, textured materials, contrasting inserts, logos, etc.
	Psychological comfort	KQ22	Does this clothing help you maintain your sense of self-worth during treatment or rehabilitation?
		KQ23	Does this clothing help you feel more independent?
		KQ24	Is it vital for you to be able to dress/undress yourself without help?
		KQ25	What emotional reactions are caused by the comfort of ES/EP/ET/ESh?
		KQ26	Does this clothing suit your style and age?

section was the same for all respondents, while sections two to five were customised based on the type of injury and the patients' needs for adaptive clothing (a sweatshirt, pants, a T-shirt, or shorts).

The described approach aims to gather data on users' experiences and preferences regarding adaptive clothing and evaluate the experimental adaptive items.

Focus Group meetings were held in hospitals and rehabilitation centres, using online digital platforms to understand specific needs and garment design elements better. The Focus Group interviews were conducted by a moderator experienced in working with individuals with disabilities or patients, along with a specialist knowledgeable in design thinking methods. Both experts also possessed knowledge in garment design and technology.

Data collection methods include free audio and video recordings of discussions, along with materials used to stimulate conversation, such as photos, 3D models, and clothing samples.A digital survey platform featuring an active QR code enabled participants to comment on and evaluate the experimental design solutions. This corresponds with the ideas of user involvement in the creation and development of adaptive clothing, as outlined in the research.

RESULTS AND DISCUSSION

The Survey of Focus Groups: Demonstration/Testing of Prototypes and Data Collection

(a) (b) (c)

Figure 2..The initial design solutions for the Experimental Sweatshirt (ES) and Pants (EP) (a), the Experimental T-Shirt (ET) (b) and the Experimental Shorts (ESh) (c).

In the survey conducted, three Focus Groups were allowed to evaluate the experimental adaptive clothing (prototypes), which included a sweatshirt (ES), pants (EP), a T-shirt (ET) and shorts (ESh) (Fig. 2).

Staff and patients had the opportunity to familiarise themselves in detail, examine and wear the experimental adaptive clothing.

The ES and EP are designed for everyday wear during the transitional season and are aimed at younger and middle-aged individuals. They feature a straight silhouette. The sweatshirt has a hip-length cut with long, sewn-in sleeves and a hood. Its design includes adjustable textile fasteners along the side sections of the front and back, as well as the lower parts of the sleeves. These fasteners allow for customisation in fit, connecting the front and back, as well as the sleeve sections.

The pants are long and feature strips along the side seams, fitted with textile fasteners that secure the front and back sections together. Additionally, they have side pockets integrated into the seams. The waistband includes an elastic ribbon with adjustable laces. These laces allow for a customised fit on both the left and right sides of the pants and act as join points on the waist when the pants are separated into front and back sections.

The ET and ESh were designed for everyday summer wear aimed at younger and middle-aged users. These items feature a straight silhouette. The T-shirt extends to the hips, with a round neckline and short, sewn-in sleeves. Its front and back necklines are adorned with bias tape. The side seams of both the front and back, as well as the lower sleeve allowances, are equipped with textile fasteners, Velcro. These fasteners secure both the front and back sections of the T-shirt, as well as the sleeves.

The shorts have a straight silhouette and sit above the knee. They are made of separate front and back sections, which also include textile fasteners, such as Velcro, to join both parts. Side pockets are conveniently built into the seams of the shorts' front section. The waistband features a wide elastic band and decorative laces that can be tied on either side to provide an adjustable fit, serving the same function as the pants.

During the survey, interviewers asked key questions and recorded the emotional responses of both patients and doctors to the Experimental Adaptive Clothing samples. The main aim was to ensure that the garments not only offered convenience and comfort during treatment but also encouraged positive emotions in patients through their high-quality design.

In Focus Group 1, which included six specialists in physical and rehabilitation medicine, participants evaluated experimental samples of adaptive clothing and expressed approval of their relevance and usefulness. They provided positive feedback on the design solutions, particularly noting the textile fasteners that allow for easy separation of the clothing into sections. This specific property allows easier access to the torso and limbs for medical procedures without requiring complete undressing. It also simplifies the process of putting on and taking off clothing for users with functional disabilities, enhancing their comfort during rehabilitation.

However, the experts provided some valuable feedback. They suggested enhancements to the hood's design and recommended increasing the colour options for the adaptive garments.

During the interview, one doctor demonstrated the practicality of a sweatshirt by mimicking the limited function of his right hand. He found the product helpful but recommended adding loops or grips to make it easier to handle.

Focus Group 2 consisted of five patients from the hospital's surgical department, all of whom had sustained severe injuries from bullet and shrapnel wounds. Table 2 presents the specific locations of their injuries. This information highlights the various challenges these people face daily and emphasises

Table 2. Injuries and physical activity restrictions among patients in Focus Group 2.

Patient number	Location of injury	Availability of medical devices, prostheses, bandages, etc	Nature of the limitation of physical activity
Patient 2A (Fig. 3a)	Left hand	Apparatus for external fixation on the shoulder, forearm and hand of the left hand	The hand is fixed, and the movement of the hand is limited. It is difficult to dress oneself, bend down, and lie down to sleep, making it uncomfortable.
Patient 2B	Torso from the left side	Plaster bandages	Restriction of movements of the trunk and left arm.
Patient 2C (Fig. 3b)	Right buttock, right leg	Bandages	Unstable walking, unable to bend the leg at the knee, challenging to bend over, and difficult to dress oneself.
Patient 2D (Fig. 4a)	Left hand	Apparatus for external fixation on the shoulder, forearm and hand of the left hand	The hand is fixed, limiting the movement, making it challenging to dress oneself, bend over, and sleep comfortably.
Patient 2E (Fig. 4e)	Right leg	External fixation device on the thigh and lower leg of the right leg	The leg is fixed, the movement of the leg is limited, it is difficult to dress yourself, it is uncomfortable to sit, lie down, or sleep

how such traumatic injuries affect their overall well-being and recovery.

Patient 2A, aged 35-40 years, was seen wearing a red knitted sweatshirt with a Velcro fastener along the left shoulder and sleeve seams, a gift from a hospital roommate, Patient 2B. Volunteers adapted this sweatshirt into clothing suitable for his needs. The garment features a deep armhole measuring between 23 and 25 cm and has wide sleeves throughout, which Patient 2A finds comfortable and convenient.

"Adaptive clothing should be tailored for individual injuries and needs, ensuring it does not cause allergies or sores. It is essential to use natural materials, and ready-made items can be modified as needed. Additionally, clothes choice may vary depending on the weather season."

Patient 2A provided feedback on the ES he trialled. While he liked the design, he noted that the sleeves were too narrow to fit his Illizarov apparatus, and the opening was smaller than he required. He suggested that a hood was unnecessary, as he predominantly remains in a supine position, and it could cause discomfort.

Patient 2B, aged between 30 and 35 years, sustained shrapnel wounds to the torso. During the assessment, three plaster bandages were applied to the torso wounds: two on the back, one on the left side near the shoulder blade and armpit, and another on the front of the left chest area. After the injury, Patient 2B was admitted to the hospital, where he was offered the choice of suitable adaptive clothing tailored to his needs. He selected a jersey sweatshirt with Velcro closures on the shoulder, at the top of the sleeve, and underneath the sleeve, with the closures positioned on the left side due to his injury.

"I used the sweatshirt for some time, and it was convenient. The choice of clothing largely depends on the nature of the injury. For most situations, oversized T-shirts and hoodies, preferably in size XL, are suitable for nearly everyone. If the individual requires larger sizes, custom-made clothing may be necessary. Using Velcro for fastening can be a beneficial option, although it may lose effectiveness after each wash. Zippers can also be advantageous as they allow for expansion in the width of the clothing. These solutions are similar for shoulders, sides and sleeves. Additionally, for individuals who have specific areas of the body exposed due to the Illizarov apparatus, separate capes can be provided for the arms and legs. These capes must have fasteners and are designed to shield healing areas from external elements while offering the necessary support during the recovery process."

At the time of the interview, Patient 2B did not require adaptive clothing. He had a positive impression of the adaptive clothing (ES and ET), specifically the black colour, which he felt suited him well. He was open to alternative colours, including dark grey and blue, and also mentioned that a green option would be acceptable, as it did not tire him. He emphasised that dark colours are preferable due to the potential for blood seepage from his wounds, which could stain lighter fabrics and make them difficult to clean.

Regarding fasteners, he found the Velcro strap easy to use and preferred it over zippers, buttons, or magnets, as these alternatives could cause discomfort and pressure on the soft tissues when lying down.

Patient 2C, aged 40-45 years, sustained injuries to his right buttock and right leg, resulting in limited knee mobility. During the interview, he was wearing regular knitted sweatpants and mentioned having difficulty putting them on and taking them off. He responded

(a) (b)

Figure 3. Patient 2A (a) and Patient 2C (b).

(a) (b)

Figure 4. Patient 2D (a) and Patient 2E (b).

positively to an experimental pair of pants, although he found it challenging to bend down and fasten the lower Velcro fasteners when they were fully unfastened. Additionally, Patient 2C appreciated the ESh, noting its comfort and the necessity of such clothing during the warm summer months.

Patient 2D, aged between 30 and 35, has sustained an injury to his left arm, requiring the use of an external fixation device. He wears a grey knitted sweatshirt with a left-side fastener accompanied by ties along the upper and lower sleeve seams, which merge into the side seam. At his request, his mother modified the sweatshirt by resewing the shoulder seam to make it easier to wear. Patient 2D finds it convenient to pull the sweatshirt over his head. However, he needs help to tie the fastener because the ties are too short for him to do so comfortably, especially considering the bulkiness of the fixation device on his arm. Having worn the external fixation device for a month, Patient 2D reports it causes significant discomfort, particularly during sleep. Its weight forces him to support it with a neckband, which leads to pain in his cervical spine. So, he has expressed a positive perception of alternative fasteners in ES, specifically praising the convenience of "Velcro". He also provided favourable feedback regarding the ET design, indicating a preference for it over non-adaptive clothing.

Patient 2E, aged 45-50 years, sustained a wound to the right leg, requiring the use of an external fixation device that extended from the thigh to the shin. At the time of the interview, Patient 2E was dressed in sweatpants made from a knitted fleece fabric, featuring through-fasteners along the side seams secured with Velcro tape, located on both legs. These pants, which he received from volunteers at a hospital, are quite roomy, with a leg width of 25 cm at the bottom. The right pant leg was unbuttoned to accommodate the fixation device. Patient 2E consistently wore these pants at all times, both during the day and at night while sleeping.

Having worn the external fixation device for a month, Patient 2E faces the prospect of an additional surgery due to improper bone growth, necessitating continued use of the apparatus for an extended period. In terms of undergarments, he wore adaptive briefs that also feature Velcro fasteners on both sides.

“When using an external Illizarov fixation device, it is advisable to choose pants with adjustable legs with fasteners or Velcro. In most cases, the legs should be flared or styled like harem pants. Additionally, the waistband should feature an elastic band and the laces for the waist adjuster, for a better fit and comfort.”

During the interview, Patient 2E responded positively to the adaptive clothing options available (EP and ESh), especially valuing the convenience of the Velcro fasteners. When asked about his adaptive clothing needs, he mentioned that he would require three items: two pairs of pants (one insulated, one lightweight), and a pair of shorts.

Generally, all the recommendations from Focus Group 2 for enhancing adaptive products are summarised as follows:

- Create alternative sweatshirts without hoods, which may be more comfortable for patients who spend time lying down.
- For hooded sweatshirts, lower the front of the hood to improve comfort and usability.
- Widen the sleeves of the sweatshirt and the pant legs to provide a better fit for patients who wear medical devices.
- Incorporate adjustable waistbands in pants and shorts for a personalised fit.
- Add custom elongated loops for easier gripping and fastening clothing.
- Broaden the Velcro strips and use rounded edges to increase comfort.
- Avoid added thickness in adaptive clothing to prevent discomfort in the areas of injury.
- Use dark colours, such as black, blue, dark grey, and green.

Focus Group 3 consisted of twelve patients and two staff from the hospital's rehabilitation department (Fig. 5). This department specialises in treating patients with diseases and injuries related to the musculoskeletal system. The group was engaged in discussion, demonstrations and evaluations of experimental adaptive clothing sets. During the experiment, the following data were collected and analysed. The responses of the most engaged participants are detailed below.

Patient 3A, aged 45 to 50, has lower limb injuries and uses two crutches for mobility. When asked about the requirements for adaptive clothing, he expressed specific demands for the textile fasteners:

"The Velcro must be of superior quality; otherwise, after approximately ten uses, it will no longer remain secure properly."

Patient 3B, a man aged around 40 to 45 years who has undergone an above-the-knee amputation of his left leg, currently relies on crutches for mobility and is awaiting prosthetic fitting. He has shared valuable insights about clothing adaptations that can improve comfort and practicality for people with amputations:

"For those who have no legs, it is necessary to make a pants leg up to the knee."

This change would make using the bathroom easier, as he noted that excess fabric often drags on the floor. Additionally, he emphasised the importance of having a kangaroo pocket on sweatshirts for various personal devices. Patient 3B also mentioned the inconvenience of fastening adaptive products with ties; he also discussed the usefulness of hooks as fasteners on pants:

"For fasteners, it is better to use Velcro, because the ties can come loose. I used underpants with ties, but they loosen during sleep, and you wake up without them. When the Velcro on the pants at the waist stopped being fastened, my wife sewed hooks on the waist for fastening, making it more convenient. The hooks are imperceptible in the product, and they nicely fix the pants on the waist."

Overall, his suggestions demonstrate a clear understanding of the challenges faced by amputees and the practical solutions that can improve their daily lives.

Figure 5. The Focus Group 3.

Patient 3C, a man aged between 50 and 55, has a left leg amputated below the knee and relies on two crutches for mobility. He emphasised the importance of adapting clothing for individuals with lower limb amputations. Additionally, he noted the impracticality of using zippers in adaptive clothing:

"To make it comfortable, the leg of the pants below the leg amputation should be cut off. Zippers are inconvenient during the rehabilitation stage; they get in the way. In cases where prosthetic legs will be used, standard sports pants can be worn, designed to allow for leg length adjustments with fasteners or Velcro. However, the pants should roll up normally to the knee; this applies to those who have lost a limb below the knee. It is also possible that the pant leg comprises parts that can be connected with zippers, but most men tend to forget where they have placed each part."

Patient 3D, a man aged between 30 and 35, expressed appreciation for the design and recommended spreading the colours for adaptive clothing.

"The hood is needed, it's also good that the sweatshirt is fully unzipped on both sides and split into front and back. Prints can appear on adaptive clothing just like they do on everyday wear, but with a motivational subtext. The colour scheme can be varied yet subtle, featuring shades such as khaki, grey, black, and dark blue, which are versatile and suitable anywhere."

Patient 3E is a 25- to 30-year-old man who uses two crutches due to an orthosis on his right leg and a bandage on his left wrist. He voiced concerns about his mobility, mentioning that the orthosis often slides on the floor.

"The orthosis slips too much on the floor, and I would like to wear breathable socks over it to increase comfort."

The other respondents offered similar comments and answered the key questions in a comparable way. During a discussion, other members of Focus Group 3 shared their ideas for improving adaptive clothing. They proposed adding a kangaroo pocket to a sweatshirt and developing innovative disposable adaptive garments for the operative and postoperative periods. The attending staff provided further design suggestions to enhance clothing comfort and functionality. Key proposals included moving the product's hanger to the outside of the back, removing the hood to prevent discomfort while sleeping, adding pockets for phones and other devices, and designing a grommet in the middle seam of pants and shorts for catheter insertion. Additionally, suggestions were made to include internal fasteners for urine and catheter containers, as well as to enable adjustable widths in pants and sleeves to suit individual patient needs.

Data Analysis and Discussion

Seventeen patients from Focus Groups 2 and 3 sustained various injuries, including hands (17.6%), torso (5.9%), buttocks (5.9%), and legs (70.6%), with leg amputations accounting for 29.4% and musculoskeletal damage - 5.9% (KQ1).

During the treatment, participants wore one or two types of adaptive clothing items (KQ2). These included knitted sweatshirts and hoodies (17.6%), T-shirts (11.8%), and pants or shorts, depending on the season (64.7%). Some individuals used adaptive clothing with fasteners such as Velcro (74.6%), ties (5.9%), or hooks (5.9%). Others opted for standard clothing, which proved to be difficult to wear (11.8%).

In Focus Groups 2 and 3, 88.2% of respondents had previously used adaptive clothing (KQ3). They appreciated features that made dressing and medical procedures easier, although 41.2% highlighted limitations with specific fasteners or designs.

The challenges reported (KQ4) include narrow sleeves that do not fit over external fixation devices (17.6%), small openings that limit access (47.1%), excessive fabric that drags on the floor for amputees (23.5%), and difficulties in fastening regular clothing with ties (41.2%) or zippers (58.8%). Additionally, a significant majority of respondents (94.1%) found that complete undressing during rehabilitation is problematic.

In general, eight medical staff members and five patients with hand and torso injuries evaluated the experimental adaptive clothing, focusing on the ES and ET. The same staff and twelve patients with leg injuries assessed the EP and ESh.

The physiological comfort of adaptive clothing was evaluated by twenty-five participants from three Focus Groups (KQ5-KQ9).

Participants indicated that the textile materials should be soft (80%), breathable (88%), hypoallergenic (64%), and gentle on the skin to prevent sores or allergies (16%). They also emphasised the importance of high-quality, durable textile fasteners, such as Velcro (76%), that can withstand repeated washings.

Eighty per cent of respondents indicated that lower or split neckline design solutions (hood, neckband, etc.) are more comfortable and accessible, especially for patients who need to lie down, emphasising the importance of comfort and practicality in neckline choices.

The sleeve width and length must be sufficient to accommodate medical devices and external fixators

(32%), to ensure ease of movement and accessibility (36%).

The respondents noted that the leg width in pants was adequate as long as it could fit external fixation devices and facilitated movement (52%). Shorts were commonly preferred for spring, summer, and autumn, especially when they provided comfort, effortless dressing, and accessibility to medical sites or devices (100%).

The significance of functional comfort in adaptive clothing (KQ10-KQ17) is determined by how easily garments can be worn and removed, and how the garment elements relate to their functional purpose. This was recognised as the top priority during the treatment phase (100%). Participants from all Focus Groups expressed a preference for loose-fitting clothing equipped with high-quality Velcro fasteners and designs that are specifically tailored to assist individuals with limited mobility. They preferred customisable options that cater to individual injury details, including features such as openings, pockets, and adjustable fastener positions.

Clothing that facilitated access to medical procedures and devices was highly valued, with 100% of participants supporting garments with side fasteners and 44% favouring removable sections, which minimise the need for complete undressing.

Velcro fasteners were preferred for their ease of use, quick fastening, and adjustability (96%). Participants also valued rounded edges and wider strips, which improved comfort (60%).

Pockets were regarded as practical and helpful in carrying essentials such as phones or other medical and non-medical devices, with 92% of respondents highlighting their significance.

The inclusion of a hood was seen as optional. Some participants (36%) found it unnecessary or potentially uncomfortable for lying patients, while others (20%) appreciated it for warmth or style.

The waistbands in both the EP and ESh were adjustable, elastic, and had laces for a personalised fit, receiving positive feedback from 64% of respondents. This design ensures both comfort and practicality.

In terms of aesthetics (KQ18–KQ22), a majority of respondents (78%) found adaptive clothing to be similar to everyday clothing. The colour scheme received positive feedback, particularly for darker tones; black received 100% approval, dark blue 60%, dark grey 92%, khaki 100%, and dark green 52%. These darker colours are effective at concealing dirt and evoke positive emotions, fostering a sense of calm and confidence. Focus group participants indicated that they found certain fashionable elements desirable, including inserts (48%), textured materials (28%), and prints with motivational inscriptions (88%).

Psychological comfort was evaluated through KQ23–KQ27. All patients agreed that clothing should uphold dignity, encourage independence, and minimise the need for external assistance. For many, the ability to dress and undress independently was crucial (62%). Respondents reported that adaptive clothing significantly reduces anxiety by making dressing and undressing easier (64%), facilitating medical procedures (82%), and enhancing self-esteem (72%).

By mapping user responses (KQ1-KQ26) to requirements shown in Fig. 1, a correspondence graph of human-centred adaptive clothing solutions was developed (Figure 6). It summarises users' expressed needs alongside the relevant adaptive design solutions identified during the focus group survey analysis. This highlights the importance of physiological, functional, aesthetic, and psychological comfort as viewed through specific, actionable design elements. The latter aim to address the challenges faced by people with limited mobility, injuries, those using medical devices during treatment or rehabilitation, or individuals with limb amputations.

Based on this analysis, design improvement suggestions for the adaptive clothing prototypes were developed (Figure 7). These suggestions were recommended for four adaptive products.

The design solutions developed through this user-driven process have been turned into refined product prototypes, as shown in Figure 8. A private company manufactured these prototypes under grant agreement No. 44033-CBB-CCI, which was funded by the Goethe-Institut, the German cultural center at the Embassy of the Federal Republic of Germany in Ukraine. The improved versions of the sweatshirt, T-shirt, pants, and shorts incorporate collective feedback from all three focus groups. Both patients and medical professionals contributed significantly to the final design modifications of the garments, clearly expressing their preferences for specific construction and styling techniques.

These garments not only demonstrate enhanced technical functionality but also embody a UCD philosophy that promotes dignity, independence, and emotional resilience during treatment and rehabilitation. This approach helps reduce barriers related to clothing challenges.

The survey conducted with three focus groups revealed significant potential for improving adaptive clothing used in the rehabilitation of patients with injured or amputated limbs. Improvements to these garments should prioritise greater aesthetic, physiological, functional, and psychological comfort, as well as adaptability to meet the needs of injured individuals. Therefore, this study confirms that the design of adaptive clothing, from Focus Group evaluation to creating functional prototypes based on testing experimental products, will greatly enhance quality of life and user satisfaction.

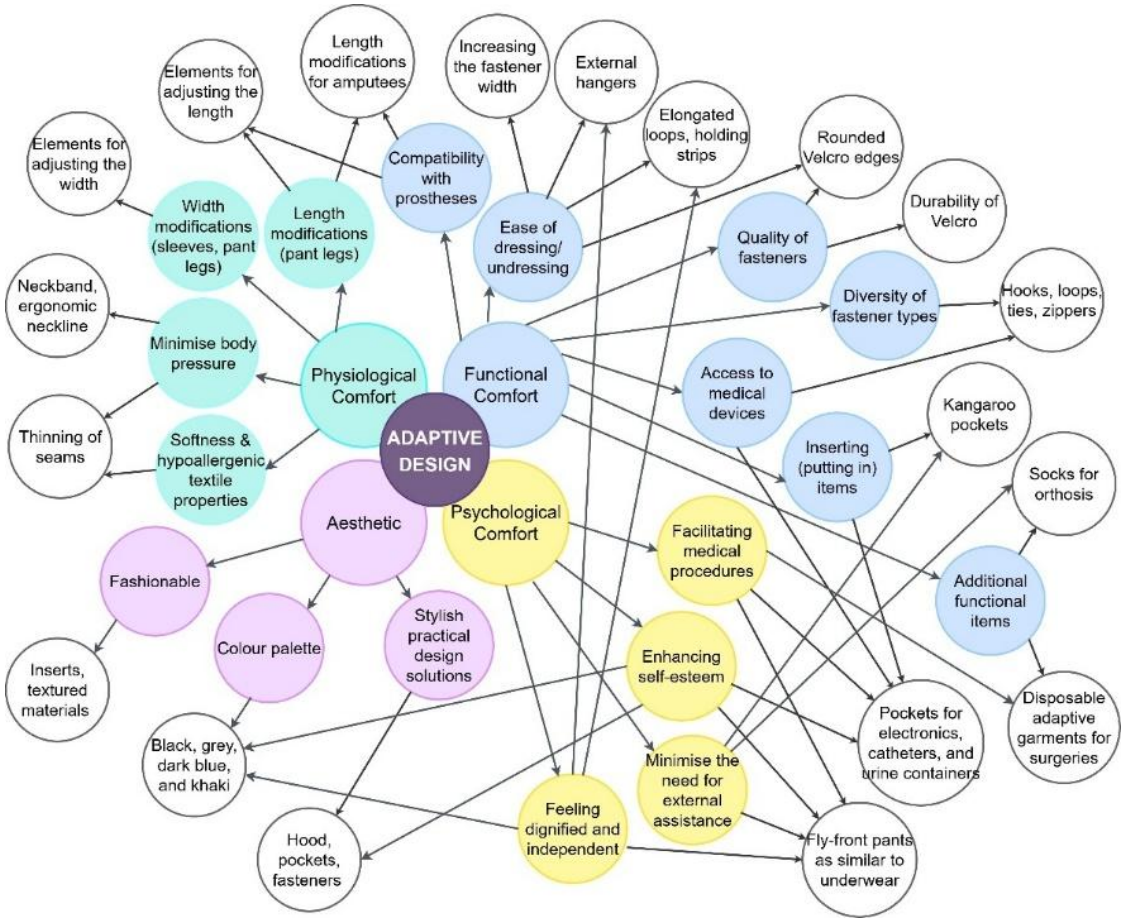

Figure 6. Correspondence graph of users' needs and adaptive design solutions.

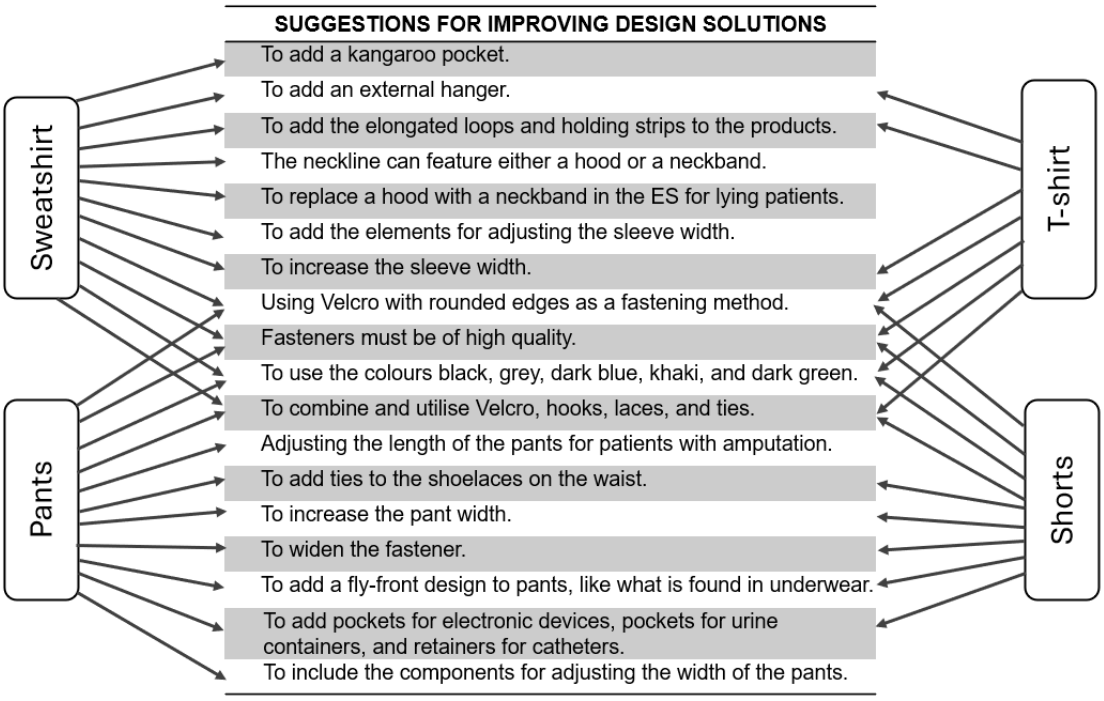

Figure 7. Enhancing the design solutions of the Experimental Adaptive Clothing.

(a) (b) (c)

Figure 8. The improved design solutions for the sweatshirt with hood and pants (a), the T-Shirt and shorts (b), and the sweatshirt without hood and shorts (c).

CONCLUSIONS

This study adopts a user-centred approach to designing and evaluating adaptive clothing for people with injuries or mobility challenges. By collecting feedback from medical professionals, surgical patients, and rehabilitation centre participants, the research identifies four key domains of comfort—physiological, functional, aesthetic, and psychological—that are essential for effective adaptive clothing design. The research assesses prototypes, including sweatshirts, pants, T-shirts, and shorts, using co-design methods. Insights from focus groups indicate that participants highly value comfort, accessibility, adaptability, and psychosocial factors such as dignity, independence, and style relevance. Adaptive design elements like adjustable Velcro fastenings, wider sleeves and pant legs, modular options, and colour choices are directly connected to user-reported challenges and needs. The obtained results contribute to both the theoretical and practical foundations of adaptive design and emphasise the importance of involving users throughout the product development process. This research combines interdisciplinary knowledge at the intersection of clothing design, rehabilitation medicine, and human-centred innovation. The study promotes inclusivity by highlighting the needs of individuals with temporary or permanent injuries, thereby improving their autonomy, emotional well-being, and participation in daily activities through adaptive clothing that supports recovery and social integration. Furthermore, the results provide insight for garment manufacturers to explore a growing niche market segment focused on adaptive clothing. Further research should focus on validating this methodology across diverse clinical populations and geographic regions to ensure its broader applicability.

In the future, there should be a greater focus on integrating digital technologies such as 3D body scanning and CLO 3D [9, 11]. These technologies offer promising opportunities for creating more efficient and personalised designs in adaptive clothing.

Additionally, future research could investigate the potential of innovative materials, including smart textiles [27, 28] and antibacterial fabrics [3, 29-31], as well as elements that provide therapeutic health benefits [32, 33]. These advancements could enhance both physiological comfort and the durability of products. Long-term studies are also recommended to evaluate the ongoing psychological and functional benefits of adaptive clothing in terms of users' recovery, independence, and overall quality of life.

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