E-textiles Assisting Healthcare, Rehabilitation, and Well-being — To whom, for What, and How?

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***Abstract*— The use of e-textiles in healthcare, rehabilitation, and well-being (referred here as assistive e-textiles) is spreading for its obvious benefits, such as monitoring of physiological signals and vital signs. Although there are versatile studies on individual applications of assistive e-textiles, there are not many that include in the design process a wide variety of stakeholders who have roles in development or use of assistive technology. To provide stakeholder-oriented design knowledge regarding the development of assistive e-textiles, we organized five multidisciplinary ideation workshops for 50 participants with different backgrounds and roles. Many distinct ideas were created that targets a diverse set of users from different age groups, ability levels and even for non-human actors. Participants came up with ideas related to work environment, rehabilitation, healthcare, and daily life. This article presents those findings and discusses how those can help designers and researchers in the field.**

Keywords*— *Fashion/Clothing, Health – Wellbeing, Individuals with Disabilities & Assistive technologies

I. INTRODUCTION

Wearable applications in healthcare, rehabilitation, and well-being have had an ample amount of interest in the recent years. Particularly, with the growing number of people needing healthcare and rehabilitation and the limited resources in these fields, wearables, such as garments, rings, and patches, which can monitor physiological signals and vital signs, such as heart rate, respiration rate, blood pressure, pulse rate, blood oxygen saturation, glucose levels, body temperature and skin perspiration [1]-[5] have become valuable resources for those fields.

E-textiles are an especially interesting part of wearables and relevant to healthcare and rehabilitation fields, as clothing is already part of our daily living, and those fields require wearing and deploying many different types of clothing for different occasions (in this study, the concept of the e-textiles refers to all pieces of clothing with smart technology, such as garments, gloves, and shoes).

There is a growing interest to the utilization of e-textiles for a variety of applications in the healthcare and rehabilitation, as well as in the broad field of well-being (referred in this study as assistive e-textiles). For example, monitoring cardiac health [6]-[8] and depression [9] by e-textiles have been studied a lot lately, as well as the possibilities that e-textiles have diagnosing, preventing, and managing various health-related problems [2][9].

Involving stakeholders in the design process from the beginning is critical and, especially in fields where the stakeholders have experiences that are hard to relate to, such as healthcare and rehabilitation, involvement of stakeholders from the beginning has been found critical by previous studies [10][11]. For example, occupational therapists (OT) have been successfully involved in co-design creation of 3D printed 'do-it-yourself assistive technology' (DIY AT) [12], 3D-printed assistive technology [13] and DIY toolkit for smart soft objects [14], which has shown that OTs, as experts, can create tools that will help their clients, and it was beneficial to include them in the making process. As the interest in co-design of assistive technology has been rising lately, it would be important to also research the viewpoints of multidisciplinary experts on assistive e-textiles. Therefore, there is a need and a motivation for studies creating stakeholder-oriented design knowledge that can help designers and researchers who work on assistive e-textiles to benefit from.

To fill this gap, we organized five multidisciplinary ideation workshops for 50 participants with different backgrounds and roles in development or use of assistive technology in healthcare, rehabilitation, and well-being, and subsequently thematically organized and analyzed the ideas obtained via the workshops. In the workshops, we aimed at gathering concrete needs based on clinical expertise or the newest higher education teaching. In this article, we present our findings, and discuss how those can help designers and researchers in the field by giving practical directions. We expect the results of this research to be beneficial for researchers and companies developing e-textiles, for whom the results can work as support for the design process, as well as for experts from the fields of healthcare, rehabilitation, and well-being, for them to understand the future potential of e-textiles and start asking for specific technology solutions.

The work has been funded by the Academy of Finland (decisions 332168, 337861 and 337653).

978-1-6654-8439-8/22/$31.00 ©2022 IEEE

II. BACKGROUND

In healthcare, a dominant subject for research on assistive e-textiles and other wearables has been cardiac health and cardiac monitoring [6]-[8]. In addition, studies have, e.g., examined monitoring depression [9], breathing in sleep apnea patients [15], and movement of bedridden patients [16]. Through monitoring of physiological signals and vital signs, wearable solutions can also help to diagnose, prevent and manage several health-related problems (e.g., epilepsy, diabetes, cardiovascular illness, Parkinson's disease) [2] [9]. Further, e-textiles and other wearables can help in rehabilitation in versatile ways [2][17] —for example, by measuring the patient's movement and eliciting muscle contraction during function [17], by monitoring body postures in movement or in a static state [18] or by providing stimulus (e.g., haptic, change of temperature) to the user [2][19]. Furthermore, assistive e-textiles can be used to develop individually targeted training programs and to prevent injuries [2]. As a final example, research around smart gloves, as alternative and augmentative communication (AAC) to either support or replace verbal expressions has been active [20][21]

As described, the utilization of e-textiles and other wearables in healthcare and rehabilitation is getting more widespread each day. Although e-textile research has shown advances in materials and manufacturing methods, true industry-scale commercialization is still uncertain [22]. Other wearable technologies, such as smartwatches and rings, have gained a larger market share than e-textiles [23][24]. Also, it has been hard with the e-textiles to achieve the same demands as ordinary textiles: for example, flexibility, stretch, wash durability, and wear comfort [23][25]. According to [26], users of e-textiles need them to be affordable, fashionable, and enjoyable. Further, consumers' versatile body sizes and shapes need to be considered [23]. Unfortunately, many times the development of e-textile-based products begins as technology-driven, and the real users of the developed new products are taken into the development process at its end, when the product is almost ready, whereas they should be considered early at the design stage [10][11][27]. Although there have been studies on many individual applications in the fields of healthcare and rehabilitation, there is a lack of studies that explore the broader design space for assistive e-textiles. In this study, we aim to address this problem with a stakeholder-oriented approach in the process of ideation for assistive e-textiles in healthcare and rehabilitation.

III. IDEATION WORKSHOPS AND DATA ANALYSIS

This study investigated who the people are who could benefit from assistive e-textiles, what assistive e-textiles could be used for in healthcare and rehabilitation, and how assistive e-textiles could be used in this context. Answers to these questions were attained via five ideation workshops that were held in spring 2020. The ideas obtained via the five workshops were organized and analyzed thematically.

A. Participants

The workshops were organized in four different organizations for a total of 50 people. The education or profession of the participants is presented in Table 1. The aim of the workshops was to bring together a wide range of experts and experts to come in the fields of education, social and health care, and health technology in order to gain the widest possible and most multidisciplinary view of smart clothing applications. The participants were selected through purposeful sampling, which is a technique widely used for identifying and selecting individuals or groups of individuals, who are especially knowledgeable about or experienced with phenomena of interest [28], which in this study were healthcare and rehabilitation contexts. The profession of six participants is not published, because a person may be identifiable due to their professional title.

TABLE I. WORKSHOP PARTICIPANTS' EDUCATION OR PFORESSION

Participants' education / profession	N
Teaching staff (occupational therapy, logopedics, psychology, physiotherapy, technology)	10
Physiotherapists	3
Engineer	2
Speech therapist	2
Occupational therapy student	27
Not published[1]	6

[1]Information is not published, because person may be identifiable due to professional title.

B. Workshops

As a research methodology, the workshop´s purpose is to gather data for the topic discussed [29]. The Zoom video meeting service was used as a platform for the workshops. The workshops were recorded. There were 5–15 participants in a single workshop, and each workshop lasted 2–3 hours. Each participant attended only one workshop. Every workshop was held by 5–6 researchers. Three of the researchers focused on practical implementation, such as giving instructions, screen controlling, and scheduling. The rest of the researchers sustained the conversation and asked questions to help refine the ideas collected from the participants. The main phases of the workshops are presented in Fig. 1. In ideation, the participants were wanted to focus on quantity rather than quality, since, as [30] points out, remarkable ideas are usually the result of the combination of many distinct ideas created by the group of people. The idea behind having many ideas without focusing on their quality is that they prompt discussion and, as a result, the combination of several different ideas usually leads to more useful results [31][32].

C. Data Analysis

The ideas were examined by thematic analysis, by categorizing the ideas in an inductive way [see, e.g., [33]]. Firstly, the researchers familiarized themselves with the data (by watching the recorded videos) and then all the ideas written by the participants from the ideation slides were moved to one text file. In case the written idea remained unclear, the discussion about it was reviewed in the video recording. If the transcriptions of the recorded workshop videos held any new ideas that weren't in the ideation slides, they were also added to the text file.

Next, the ideas were grouped into three separate files according to the three research questions. The ideas were more closely examined and initially categorized by six

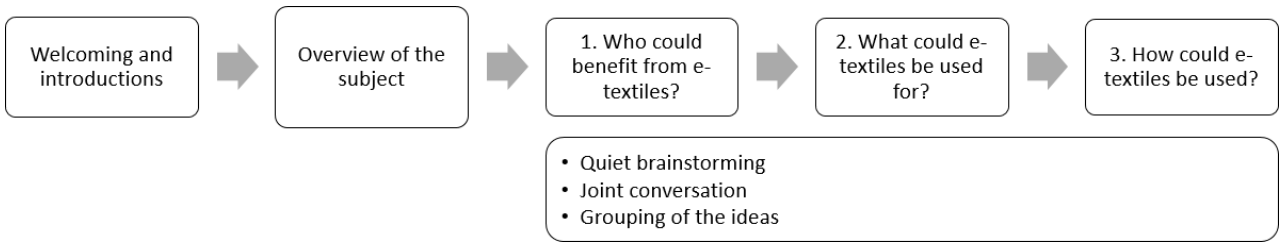

Fig. 1. Main phases of the workshops.

researchers. After the first categorization round, the categories were discussed and reviewed. If necessary, categories that overlapped were grouped together. Next, the subcategories for each of the research question were formed by three researchers [see e.g., [34]]. The categories were then reviewed again by four researchers, who were not included in the original subcategorization. This phase took place to make sure that multiple perspectives were considered [34]. The titles of the categories were polished, and some examples of the ideas were noted down (see Tables 3, 4 and 5). While polishing the categories, two researchers also counted how many ideas were included in each category. The number of ideas occurring in the workshops were discussed to elaborate the overall understanding of the ideas presented and to support the descriptive documentation of the results. Finally, the occurrences of each category were compared among the five workshops.

IV. Results

About 500 ideas related to the research questions were created in the workshops. The discussion was very lively, and the ideas developed and were seen from new viewpoints during the workshops.

A. Who could benefit from assistive e-textiles?

As seen in Table 2, the participants' ideas in answer to the first research question were divided into three main categories: people whose ability to function is typical, people whose ability to function is limited, and animals. The first two categories were mentioned in all workshops, but the last one, animals, was mentioned in only one workshop (Table 2). Also, the total number of produced ideas was tremendously higher in the first two main categories (total of 124 ideas) compared to the third main category of animals (total of 3 ideas).

In all of the workshops participants found that people of all ages could benefit from assistive e-textiles. There were ideas ranging from unborn babies to elderly people, covering about all areas of our lives—for example, work, studying, leisure, sports and surveillance.

As we move on to more specific ideas, different levels of ability to function (typical and limited) was a topic that was much discussed and to which many ideas related. Therefore, people whose ability to function is typical and people whose ability to function is limited, forms the first two main categories in Table 2. People with physical limitations or communication difficulties were seen as potential assistive e-textile users in all five workshops (Table 2). E-textiles were, for example, seen as user-friendly interfaces for smartphones, tablets and computers, and thus tools to expand the limitations caused by a physical or communication disability. As an example of this, one participant said: "It [assistive e-textile] allows different users who may not be able, who do not have cognitive abilities to use complex devices, such as telephones or something else, so they are able to participate with these [e-textiles]". In a few (two and three) workshops, participants mentioned that people with autism spectrum disorder or with attention issues, respectively, could benefit from e-textiles. A participant suggested, for example, that the e-textile could give feedback to the user—for example, children with ADHD (attention-deficit/hyperactivity disorder) or difficulties concentrating—that now is the time to go calm down outside the classroom.

TABLE 2. THE CATEGORIES AND SUB-CATEGORIES OF WHO COULD BENEFIT FROM ASSISTIVE E-TEXTILES. THE CROSSES MARK IN WHICH WORKSHOPS EACH CATEGORY WAS MENTIONED.

Category	WS1	WS2	WS3	WS4	WS5
People whose ability to function is typical (total 11 ideas)	x	x	x	x	x
People whose ability to function is limited (total 97 ideas)	x	x	x	x	x
People with memory disorders	x	x		x	x
Physically disabled people/people with motoric challenges	x	x	x	x	x
People with autism spectrum disorder			x	x	
People with communication difficulties	x	x	x	x	x
People with sensory impairments	x	x	x		x
People with attention issues		x		x	x
Animals (total 3 ideas)			x		

The smallest main category, animals, is also worth highlighting. The workshop ideas related to animals were about, for example, monitoring animals (vital signs, pain) and helping the animal owner take care of the animals in depending on the feedback given by e-textiles. The need for such assistive e-textiles is supported by the reported substantial increase in veterinary care spending [35]. Research also shows that quality of life and pain management are particularly important to pet owners [36], not to forget farmed animals and expensive racehorses. Even though in this study it arose in only one workshop, animals could be a valuable e-textile user group, also considering the interaction with pets in the context of healthcare (e.g., emotional support animals).

B. What could assistive e-textiles be used for?

Participants came up with total amount of 241 ideas about what assistive e-textiles could be used for (Table 3). Ideas were categorized based on the environment or situation in which the idea is used. Four main categories were found: work environment, rehabilitation, healthcare, and daily life.

Apart from healthcare, the other three main categories were further divided into subcategories. Examples of ideas related to different subcategories are presented in Table 3.

Ideas for work environment and daily life were created in all workshops, whereas ideas related to healthcare and rehabilitation were produced in three and four workshops, respectively (Table 4). Mof the ideas produced in workshops were related to daily life, which is an interesting result.

Most of the ideas in the category of work environments were related to safety and ergonomics. These ideas concerned people in different fields, for example, radiation workers in healthcare as well as nuclear power stations. Several ideas also pointed out that e-textiles could help identifying and monitoring things related to well-being at work and workload. It has been studied that individual exposed to the same stressors at work will respond and cope with those stressors in diverse ways [e.g., [37]]. As one participant said: "The same work task is not as stressful to others so then there could be the individual work arrangements" [based on the information received from the assistive e-textile solution]. Also, school environments (from the perspective of work environments, e.g., teachers, school helpers) were actively discussed. It was brought up that in a classroom, one or two adults are generally responsible for 25+ students. By following the emotions of the students, it would be, for example, possible to have a break when a certain percentage of the students start to become restless.

In the category of rehabilitation, ideas were created related to neurological, mental health, speech and language, and bodily (e.g., physiotherapy, occupational therapy) rehabilitation. E-textiles were envisioned to be used especially for assessment, follow-up, and feedback. For example, one participant noted that occupational therapists have different therapy methods concerning self-regulation and emotional regulation and thought that assistive e-textiles could be used as a new type of aid in rehabilitation and therapy. Several participants ideated that with the help of e-textile, children could tell or show how they feel and in which body part the feeling is felt. This could help them in expressing their emotions and communicating about them. It was also brought up that assistive e-textiles could benefit everyone involved in the rehabilitation process: it could benefit the customer and close ones as well as the therapist. As one participant stated: "With ADHD children there is a lot of practice around relaxing, staying still, and monitoring one's own body, alertness, that's where it is going. It would be interesting to see how the child can calm down on his own and how much there is going on". One example mentioned regarding to calming down was that the e-textile could play music if the child moves just a little and if they start to fuss around the music stops. Another participant explained that the idea is not that the child should be completely still, but to learn how to regulate their own movement. One very timely topic was the potential use of assistive e-textiles for e-rehabilitation, which has been especially on the table due to the COVID-19 pandemic but also has been an active research area during the last few years [e.g., [38][39]].

The third category, healthcare, included ideas related to both patients/customers and workers in healthcare and social service. Participants discussed that e-textiles could be used to measure things, for example, sweat or heart rate, in hospitals or at patients' homes, and the results could be transferred directly to a doctor´s phone or computer. They thought that both the patient and the doctor would then benefit from the assistive e-textiles, and patients' follow-up could be more efficient and constant. Such e-health, like e-rehabilitation, has been actively studied and developed recently [40][41], for example, to respond to the growing number of patients, improve patient safety, and provide efficiency and cost savings. It was said multiple times that e-textiles could also be helpful in preventing pressure ulcers. One participant said: "If you think, like in healthcare, turning the patients or changing their positions [is] done at certain intervals, but it is possible that someone would need it more often than others". There were also multiple ideas related to different patient groups, such as people with epilepsy or narcolepsy. Many participants brought up how useful it would be if the e-textile could warn about a coming epileptic fit. This could possibly increase the patient`s safety as the epileptic fit starts.

Considering the category of daily life, the ideas were versatile, for example, the possibilities of e-textiles being used to control surroundings and to support executive functions or communication were discussed in all workshops (Table 4). As one participant ideated, assistive e-textiles could be a user interface through which the lights dim, or the TV channels change, or a way to remotely connect with somebody. This would suit both people with limited ability to function (for example, to support independent living) and people with typical abilities to function (just to make life easier). Emotions, expressing and recognizing emotions, as well as emotion regulation were brought up in three different workshops. One participant said that both children and adults can have challenges in recognizing their emotions in daily life, and e-textile garments could provide guidance for taking control of the emotion or even warnings, for example, in the case of anger. In people with Asperger syndrome or high-functioning autism, difficulties with emotional expression and mood regulation are widely discussed in the literature [e.g., [42]]. Finally, ideas for hobbies and free time (e.g., riding, jogging) and sports (e.g., monitoring and setting a pace) were brought up in three workshops. It especially seems that e-textile-based body monitoring technology could benefit healthcare, rehabilitation, as well as work and daily life.

TABLE 3. WHAT COULD ASSISTIVE E-TEXTILES BE USED FOR? EXAMPLES OF THE IDEAS PRODUCED IN THE WORKSHOPS.

WORK ENVIRONMENT
in different fields e.g., industry, office, social services and health care ▪ **Safety and ergonomics:** one's own security and ergonomics e.g., work clothes and protective equipment in different conditions/circumstances, dirt, radiation, communication with device ▪ **Research:** e.g., measurements, observation, and documentation in human sciences ▪ **School:** e.g., group management (e.g., when it's time for a break), to help concentration in lessons
REHABILITATION
e.g., assessment, follow-up, feedback, practice, maintaining functioning/functional ability, desensitization ("hypersensitive people"), activation, motivation, remote therapy, encouraging participation, practicing self-regulation, for everyone involved in the rehabilitation process, reducing/inhibiting perseveration ▪ **Neurological:** e.g., neglect ▪ **Mental health:** e.g., circadian rhythm, optimization of medication time and effect of medication on sleep, relaxation exercises ▪ **Speech and language:** e.g., speech and language therapy: articulation, pragmatic skills, narrative, interaction, word finding, vocabulary, linguistic concepts ▪ **Bodily:** e.g., physiotherapy, occupational therapy, remote therapy, practicing sequences and control of movements, learning posture, ergonomics, recognizing body movements

and tension, recognizing posture, to support movement, touch desensitization, feedback, muscle activation, perception of surroundings
HEALTHCARE e.g., measurement (sweating, blood sugar, fetus) and follow-up (breathing, COVID, heart rate, blood pressure, sleep), different patient groups (e.g., sleep apnea, diabetes, epilepsy, narcolepsy, cerebral vascular accident /stroke, muscle diseases), home care, hospital care, pain relief, pressure ulcers
DAILY LIFE e.g., intelligent/smart driving, measurement (steps, UV radiation, body, movement, eating/drinking, alertness, sleep), focusing of the look, distances and location, to remind/wake up/raise the alarm ▪ **Safety:** e.g., calling for help, user warning; anticipation of a seizure, fall, etc.; supervision; to attract attention ▪ **Control of the surroundings:** e.g., use of devices, functions of the home environment (opening of doors, regulation of lights and voices) ▪ **Executive functions:** e.g., dressing, supporting the living at home, independent action/operation ▪ **Communication:** e.g., in noisy environments, sign interpretation ▪ **Emotions:** e.g., expressing and recognizing emotions, emotion regulation ▪ **Hobbies and free time:** e.g., orienteering, riding, jogging ▪ **Sports:** e.g., monitoring and setting a pace for the performance, eSports, coaching

TABLE 4. THE CATEGORIES AND SUB-CATEGORIES OF WHAT ASSISTIVE E-TEXTILES COULD BE USED FOR. THE CROSSES MARK IN WHICH WORKSHOPS EACH CATEGORY WAS MENTIONED.

Category	WS1	WS2	WS3	WS4	WS5
Work environments (total 30 ideas)	x	x	x	x	x
Safety and ergonomics	x	x	x		
Research			x	x	
School		x	x	x	x
Rehabilitation (total 77 ideas)	x	x	x	x	
Neurological		x	x		
Mental health			x		
Speech and language	x	x	x	x	
Bodily	x	x	x	x	
Healthcare (total 34 ideas)	x		x		x
Daily life (total 100 ideas)	x	x	x	x	x
Safety	x	x	x		x
Control of the surroundings	x	x	x	x	x
Executive functions	x	x	x	x	x
Communication	x	x	x	x	x
Emotions	x	x		x	
Hobbies and free time		x	x		x
Sports	x	x	x		

C. *How could assistive e-textiles be used?*

In the case of research question "How could e-textiles be used?", the ideas produced in workshops were categorized into four main categories: user interface (how would the e-textile work, i.e., input and output), features (what features are needed in e-textiles), textile (what kind of e-textiles are needed, for example, garments, shoes, sheets, pillows), and flow of information (to/from the user, real-time/delayed), as shown in Table 5.

TABLE 5. HOW COULD ASSISTIVE E-TEXTILES BE USED? EXAMPLES OF THE IDEAS PRODUCED IN THE WORKSHOPS.

USER INTERFACE ▪ **Input** ▫ Touch: e.g., wrinkling, squeezing, rubbing, brushing, stroking, wipe, claps, touch series, intensity of touch, slap, accurate vs. coarse, body to body – multiple people, single – own body, body to object, class/degree of urgency with different touch ▫ Buttons: e.g., button location, intensity of pressing ▫ Writing and drawing ▫ Gestures and movements: e.g., turning/transforming gestures into speech ▫ Voice, speech, airflow, eye control ▪ **Output** ▫ Haptic, light, color, voice
FEATURES ▪ **Automaticity:** activates when wearing, unnoticeable, automatic feedback, alarm, no deployment ▪ **Customizability:** e.g., favorite cloth, accuracy adjustment, individual placement, and programming, tightening and temperature changes, adjustment of size ▪ **Other features:** e.g., cloth/garment learns, identifies movements and pressure, charges from the movement
TEXTILE ▪ **Clothing items:** e.g., glove, band, insole, shoe, cap, sock, collar, sequin garment, bodysuit/overalls, pressure garment ▪ **Other textiles:** e.g., bedclothes, mattresses, seat cushion cover, soft toys, pillows
FLOW OF INFORMATION ▪ **To the user/from the user:** e.g., information to the wearer, professionals, or close relative; to receive information from other with the help of the piece of smart clothing, communication with other people ▪ **Real-time/delayed:** collecting real-time information/data for later processing; to transfer data to another form or another device

In the category of user interface, participants in all workshops ideated that assistive e-textiles could be controlled by different forms of touch. This was also seen as way to overcome physical limitations; as an example, one participant said about communicating through gestures: "Those users may not always be able to learn such required gestures but it [the e-textile] should be able to define that when you do this it means that...". Thus, touch-based inputs were seen as an adaptable and user-friendly way to control e-textiles. Especially interesting was that in all workshops, the participants ideated e-textile inputs that were not connected to the textile itself, such as using voice, speech and eye control as inputs to the e-textile. Also, airflow was brought up as an input, as one participant created an idea that the e-textile inputs could be navigated by blowing (airflow) the textile. Further, participants suggested several types of output (e.g., haptic, light, color, voice), which shows that different kinds of stimuli are needed for people with various needs and preferences.

Individual needs surfaced also in the category of features, as customizability was one of the most-discussed topics. Many participants thought that the e-textile should be comfortable and in a suitable place and size for the individual, not to forget that it should look good. For example, the challenges in current smart watches were discussed. One participant said it is challenging, as "the watch must touch my skin to monitor my heartrate, which makes it challenging to see the watch". It was further discussed whether smart watches could be replaced with elastic reflector bands, for example, to also avoid skin irritation. According to the participant comments, it should also be possible to adjust the

e-textile and its features and user interface. One participant particularly said that users may not always be able to learn the required inputs and the e-textile should be adjusted to the needs of the individual. In addition to customizability, automaticity was also considered an important feature, because it was thought that some of the users might have difficulties starting the e-textile device and it would also make the use of the e-textile more unnoticeable. As has also been previously studied, in an ideal situation, the technology becomes a part of its user's life instead of a distraction from it [43].

In the category of assistive textiles, a surprisingly wide range of other textiles (besides clothing items) were brought up—for example, bedclothes, mattresses, and pillows (Table 6). Versatile pieces of clothing were mentioned, starting from shoes and gloves to overalls (Table 6). Specific clothing items were mentioned in three workshops, whereas other textiles were specified in two workshops. Based on these viewpoints, future intelligence could be integrated into any textiles around us. For example, one participant said: "When monitoring patients in a hospital, it could be either a shirt or a mattress as long as there would be something [an assistive e-textile] available that registers the movements of the patient".

Although there were only eight ideas in the category of flow of information, this topic came up in all five workshops. It seems that it would be important that the information passing through the e-textile could pass from the user to another person and vice versa in real time. Information could be shared to outside experts, such as nurses or doctors, but also to close contacts, for example, for monitoring a relative from a distance. However, as some participants pointed out, it is also important for the user to be able to stop the flow of information when desired. Further, not all types of data need to be shared to other people. As brought up by a participant, there are cases when it is only necessary to save data for possible later processing (either by the user or by an outside expert).

TABLE 6. THE CATEGORIES AND SUB-CATEGORIES OF HOW ASSISTIVE E-TEXTILES COULD BE USED. THE CROSSES MARK IN WHICH WORKSHOPS EACH CATEGORY WAS MENTIONED.

Category	WS 1	WS 2	WS 3	WS 4	WS 5
Functioning (total 60 ideas)	x	x	x	x	x
Stimulus quality (input)	x	x	x	x	x
Touch	x	x	x	x	x
Buttons	x		x	x	
Writing and drawing				x	x
Gestures and movement		x	x	x	x
Voice, speech, airflow, eye control	x	x	x	x	x
Stimulus quality (output)	x	x	x	x	x
Haptic, light, color, voice	x	x	x	x	x
Features (total 31 ideas)	x	x	x	x	x
Automaticity	x	x	x		
Customizability	x		x	x	x
Other features	x	x	x	x	x
Textile (total 24 ideas)			x	x	x
Clothing items			x	x	x
Other textiles			x	x	
Flow of information (total 8 ideas)	x	x	x	x	x
To the user/from the user	x	x	x	x	x
Real-time/delayed	x	x	x	x	x

V. DISCUSSION

When we consider who could benefit from assistive e-textiles, i.e., e-textiles with applications in the fields of healthcare, rehabilitation and well-being, the participants in all workshops found that people of all ages could use them, and there were ideas ranging from unborn babies to elderly people. Ideas were created for people with different levels of ability to function (typical and limited in different ways), and when considering what e-textiles could be used for, the created ideas for daily life (for example functions of the home environment, such as opening of doors, regulation of lights, communication in noisy environments, hobbies, such as orienteering, riding, jogging and eSports) seem to be beneficial to different types of people, also for people without any special needs. Interestingly, these ideas for daily life were created in all workshops, whereas ideas related to healthcare and rehabilitation were produced in three and four workshops, respectively. Thus, although the participants of the workshops were from the fields of healthcare and rehabilitation, they especially found assistive e-textiles to benefit our well-being in our everyday lives in versatile ways. These results are in line with recent research, such as hats used to listen to music or answer phone calls and socks to measure foot pressure and walking distance [3]. It is also worth highlighting that despite the focus was only on human users, the participants created ideas also for animal e-textiles. Even though in this study it arose in only one workshop, animals could be a valuable new e-textile user group, for example by taking advantage of assistive e-textiles monitoring animals (vital signs, pain).

When further considering what e-textiles could be used for, the created ideas in the category of healthcare, where measurements (e.g., sweating, blood sugar, fetus) and follow-up (e.g., breathing, COVID-19, heart rate, blood pressure, sleep), as well as specific patient groups that could benefit from such technology (e.g., diabetes, epilepsy, narcolepsy, cardiovascular illness, muscle diseases), were brough up, are in line with the earlier studies [1]-[5][9]. Further, according to the created ideas, e-textiles could benefit different forms of rehabilitation (neurological, mental health, speech and language, and bodily) in versatile ways (e.g., assessment, follow-up, feedback, activation, motivation, remote therapy). While the other forms of rehabilitation are supported also by recent technical research [e.g., [2][17]-[19]], according to our literature check, the use of e-textiles for speech and language therapy seems to be very unstudied field. Thus, that is seen as a topic where multidisciplinary collaboration (engineers, designers, and speech and language therapists) is needed. It is likely that the participants (being professionals from fields and healthcare and rehabilitation) have been familiar with assistive e-textile applications in their fields at least in some level. Another major category in what e-textiles could be used

for, according to the participants' opinions, are different work environments, which were mentioned in all workshops. This category has been actively studied from the viewpoints of safety, where e-textiles can, for example, detect critical heat levels for firefighters or give an alarm if a fisherman falls into the water [5]. However, schools as work environments, which were actively discussed in four workshops, seem to be a less studied category, which indicates that another interesting multidisciplinary collaboration is that between engineers, designers, and teachers.

When considering how assistive e-textiles could be used, although the focus of the workshops was originally on wearable e-textiles, a surprisingly wide range of other textiles were brought up by the participants—for example, bedclothes, mattresses, and pillows. Such e-textiles have recently been studied [e.g., [10]], and they could further widen the possibilities of assistive e-textiles. For example, e-textiles in forms of soft toys were discussed in one workshop. Soft toy-integrated electronics are especially interesting options for children with special needs. They could also provide the desired customizability; each child could get the needed assistance from the favorite toy. In an earlier study, where occupational therapists were asked to use a DIY-toolkit to turn everyday soft objects into smart devices, it was noted that these smart devices, such as soft toys and pillows, could be used to, for example, fine motor exercises or balance and coordination exercises [14]. When considering the features of e-textiles, customizability and automaticity were much brought up, as the use of such technology solutions should be easy. Similarly, earlier research outcomes have indicated that sustainable design interventions in healthcare need to come with clear information and personal guidance [10].

It was a bit surprising that sustainability was not a topic brought up in the workshops. The integration of electronics into textiles raises new challenges to garment sustainability, for example, by making recycling the pieces of clothing very hard [44]. The United Nation's Sustainable Development Goals [45] should also be applied to assistive e-textiles. When e-textiles are developed for mass production and for extensive use in our daily lives, the sustainability issues must be considered from the beginning of the product development process. Many times, the electronics in e-textiles utilize environmentally harmful or scarce materials, or even toxic chemicals, which increase the environmental risks of both the e-textile industry and the actual e-textile garments [44]. However, it has been stated that even though e-textiles have sustainability risks, they can be more sustainable than normal clothes, but the e-textiles need to offer better user value, longevity, and user attachment [46].

As mentioned, industry-scale commercialization of e-textiles is still uncertain [22]. Ref. [47] recently discussed challenges and important issues in the development of e-textiles, including ethics, operating features, reliability-related issues, legislation and regulation, design process, comfort and design, cost and commercial potential, and health issues. Even though the participants in these workshops were instructed to create ideas freely and without thinking of the technical implementation, it is worth taking a short look at the feasibility of some potential technical solutions behind the created ideas. The electrical circuit in e-textiles is often done from conductive yarn or conductive textiles [20] or conductive inks and conductive polymers [3], which can be seamlessly integrated into textiles and already provide suitable electrical properties. A variety of sensors are used in e-textiles today, for example, moisture measurements using resistive [48] or capacitive [49] sensors. Further, fully functional products have been created, which answer the needs brought up in the workshops. For example, an electrocardiography shirt has been reported [50], which feels like a normal compression cloth. However, even though the sensors in that shirt are comfortable, they need proper compression to function reliably, which may be uncomfortable to many users. Hence, the sensor development is an essential part of a truly comfortable and reliable e-textile, and there is a lot of research work to be done in that area. Furthermore, many of the developed measurement solutions need a battery, usually a lithium polymer (LiPo) battery [3], but there are not many battery technologies that would be comfortable, indistinguishable, and endure washing in a washing machine. Some e-textile sensors use energy harvesting [51] or wireless power transfer [52], but even in these cases, usually some kind of an energy storage is needed. Promising studies using supercapacitors as energy storage have been done, and the supercapacitors can be manufactured for e-textiles with processes that are widely used in the textile industry, such as screen printing and spray coating [51]. The use of supercapacitors enables battery-free e-textiles [52] but a small, indistinguishable, washing machine-durable energy storage solution is one thing to be further studied and developed before e-textiles can be truly adapted to our daily lives.

VI. Conclusions

Although there have been versatile studies on e-textile applications in the fields of healthcare, rehabilitation, and well-being, there has been a lack of studies that involve in the design process a wide variety of expert stakeholders who can benefit from assistive e-textiles, i.e., e-textiles with applications in the fields of healthcare, rehabilitation, and well-being, and transfer their expectations and thoughts. This study is responding to the lack of wide-perspective studies on who the people are that could benefit from assistive e-textiles, what assistive e-textiles could be used for, and how assistive e-textiles could be used. The answers to these questions— opinions of experts from healthcare and rehabilitation—were gathered in five multidisciplinary workshops.

The workshops resulted in ideas for people of all ages from newborns to elderly, as well for people from a typical ability to function to versatile people whose ability to function is limited. Further, some ideas for animal e-textiles were presented. Participants came up with a total of 241 ideas about what assistive e-textiles could be used for. Four main categories were found: work environment, rehabilitation, healthcare, and daily life. The main categories of how assistive e-textiles could be used (a total of 60 ideas) were user interface (how would the e-textile work, i.e., input and output), features (what features are needed in e-textiles), textile (what kind of e-textiles are needed, for example, garments shoes, sheets, pillows), and flow of information (to/from the user, real-time/delayed).

Acknowledgments

We thank all participants in the workshops.

References

[1] L. Castano and A. Flatau, "Smart fabric sensors and e-textile technologies: a review," Smart Materials and Structures, vol. 23(5), pp. 1-27, April 2014.

[2] T. Fernández-Caramés and P. Fraga-Lamas, "Towards The Internet-of-Smart-Clothing: A Review on IoT Wearables and Garments for Creating Intelligent Connected E-Textiles," Electronics (Basel), vol. 7(12), p. 405, December 2018.

[3] C. Gonçalves, A. Ferreira da Silva, J. Gomes and R. Simoes, "Wearable E-Textile Technologies: A Review on Sensors, Actuators and Control Elements," Inventions (Basel), vol. 3(1), p. 14, March 2018.

[4] J. Lee, D. Kim, H. Ryoo and B. Shin, "Sustainable Wearables: Wearable Technology for Enhancing the Quality of Human Life," Sustainability (Basel, Switzerland), vol. 8(5), p. 466, May 2016.

[5] S. Seneviratne, et al., “A Survey of Wearable Devices and Challenges,” Proc. IEEE Communications Surveys and Tutorials, vol. 19(4), pp. 2573–2620, July 2017.

[6] Y. Bazi, et al., “Real-Time Mobile-Based Electrocardiogram System for Remote Monitoring of Patients with Cardiac Arrhythmias,” International Journal of Pattern Recognition and Artificial Intelligence, vol. 34(10), p. 2058013, September 2020.

[7] J. Pevnick, K. Birkeland, R. Zimmer, Y. Elad and I. Kedan, “Wearable technology for cardiology: An update and framework for the future,” Trends in Cardiovascular Medicine, vol. 28(2), pp. 144-150, February 2018.

[8] M. Teferra, et al., “Electronic textile-based electrocardiogram monitoring in cardiac patients: a scoping review,” JBI Database of Systematic Reviews and Implementation Reports, vol. 17(10), pp. 1958-1998, October 2019.

[9] L. Sequeira, et al., “Mobile and wearable technology for monitoring depressive symptoms in children and adolescents: A scoping review,” Journal of Affective Disorders, vol. 265, pp. 314-324, March 2020.

[10] M. Houben, R. Brankaert and E. Wouters, “Stakeholder Perspectives on Design Interventions in Dementia Care,” Proc. Designing Interactive Systems Conference 2020 (DIS '20), Eindhoven, Netherlands, Association for Computing Machinery, New York, USA, pp. 43-47, July 2020.

[11] C. Stary, et al., “Towards stakeholder-centered design of open systems- Learning from organizational learning,” Proc. European Conference on Cognitive Ergonomics 2015 (ECCE '15), Warsaw, Poland, Association for Computing Machinery, New York, USA, Article 26, pp. 1-8, July 2015.

[12] K. Slegers, K. Kouwenberg, T. Loučova and R. Daniels, “Makers in Healthcare: The Role of Occupational Therapists in the Design of DIY Assistive Technology,” Proc. 2020 CHI Conference on Human Factors in Computing Systems, pp. 1–11, April 2020.

[13] M. Hofmann, et al., “Occupational Therapy is Making”: Clinical Rapid Prototyping and Digital Fabrication,” Proc. 2019 CHI Conf on Human Factors in Computing Systems, pp. 1–13, May 2019.

[14] A. Moraiti, V. Vanden Abeele, E. Vanroye and L. Geurts, “Empowering occupational therapists with a DIY-toolkit for smart softobjects,” Proc. 9th International Conference on Tangible, Embedded, and Embodied Interaction, pp. 387–394, January 2015.

[15] W. Mongan, et al., “Real-time detection of apnea via signal processing of time-series properties of RFID-based smart garments,” Proc. IEEE Signal Processing in Medicine and Biology Symposium (SPMB 2016), Philadelphia, USA, IEEE Signal Processing in Medicine and Biology Symposium, 1–6, December 2016.

[16] R. Angelova and D. Sofronova, “E-textile for non-invasive control of the body movement of bedridden patients,” IOP Conference Series, Materials Science and Engineering, Bristol, United Kingdom, vol. 1031(1), p. 12029, 2021.

[17] R. McLaren, F. Joseph, C. Baguley and D. Taylor, “A review of e-textiles in neurological rehabilitation: How close are we?,” Journal of Neuroengineering and Rehabilitation, vol. 13(1), Article 59, June 2016.

[18] Z. Abro, Y. Zhang, C. Hong, R. Lakho and N. Chen, “Development of a smart garment for monitoring body postures based on FBG and flex sensing technologies,” Sensors and Actuators A: Physical, vol. 272, pp. 153-160, April 2018.

[19] A. Ometov, et at., “A Survey on Wearable Technology: History, State-of-the-Art and Current Challenges,” Computer Networks, vol. 193, April 2021

[20] A. Mehmood, et al., ”Development, Fabrication and Evaluation of Passive Interface Gloves,” Textile Research Journal, vol 91(23-24), pp. 3023-3032, December 2021.

[21] M. Ahmed, B. Zaidan, A. Zaidan, M. Salih and M. Lakulu, “A review on systems-based sensory gloves for sign language recognition state of the art between 2007 and 2017,” Sensors (Basel, Switzerland), vol. 18(7), p. 2208, July 2018.

[22] A. Komolafe, et al., “E-Textile Technology Review-From Materials to Application,” IEEE Access, vol. 9, pp. 97152–97179, 2021.

[23] D. Tyler, et al., “Wearable electronic textiles,” Textile Progress, vol. 51(4), pp. 299-384, October 2019.

[24] B. Ariyatum, R. Holland, D. Harrison and T. Kazi, “The future design direction of Smart Clothing development,” The Journal of The Textile Institute, vol. 96(4), pp. 199-210, August 2005.

[25] M. Chen, et al., “Smart Clothing: Connecting Human with Clouds and Big Data for Sustainable Health Monitoring,” Mobile Networks and Applications, vol. 21(5), pp. 825-845, July 2016.

[26] A. Perry, L. Malinin, E. Sanders, Y. Li and K. Leigh, “Explore consumer needs and design purposes of smart clothing from designers’ perspectives,” International Journal of Fashion Design, Technology and Education, vol. 10(3), pp. 372-380, September 2017.

[27] R. Cooper and M. Evans, “Breaking from tradition: Market research, consumer needs, and design futures,” Design Management Review, vol. 17(1), 68-74, January 2006.

[28] J. Creswell and V. Plano Clark, Designing and conducting mixed method research, 3rd. ed., SAGE Publications Inc. Thousand Oaks, United States, 2018.

[29] R. Ørngreen and K. Levinsen, “Workshops as a research methodology,” Electronic Journal of e-Learning, vol. 15(1), pp. 70-81, April 2017.

[30] P. Hamilton, The Workshop Book, 1st. ed., Pearson Education, United Kingdom, 2016.

[31] D. Gray, S. Brown and J. Macanufo, Gamestorming: a playbook for innovators, rulebreakers, and changemakers, 1st. ed., O’Reilly Media, Inc. Sebastopol, USA, 2010.

[32] J. Schell, The art of game design: a book of lenses, 3rd. ed., CRC Press, Boca Raton, USA, 2020.

[33] D. Thomas, “A General Inductive Approach for Analyzing Qualitative Evaluation Data,” The American Journal of Evaluation, vol. 27(2), pp. 237-246, June 2006.

[34] G. Guest, K. MacQueen and E. Namey, Applied thematic analysis, SAGE Publications, Inc. Thousand Oaks, California, 2012.

[35] L. Kogan, R. Schoenfeld and S. Santi, “Medical updates and appointment confirmations: Pet owners’ perceptions of current practices and preferences,” Frontiers in Veterinary Science, vol. 6, Article 80, March 2019.

[36] R. Heuberger, M. Petty and J. Huntingford, “Companion Animal Owner Perceptions, Knowledge, and Beliefs Regarding Pain Management in End-of-Life Care,” Topics in Companion Animal Medicine, vol. 31(4), pp. 152-159, December 2016.

[37] J. Barling, K. Kelloway and M. Frone, Handbook of work stress, SAGE Publications, Inc. Thousand Oaks, California, 2005.

[38] A. Peretti, F. Amenta, S. Tayebati, G. Nittari and S. Mahdi, “Telerehabilitation: Review of the State-of-the-Art and Areas of Application,” JMIR Rehabilitation and Assistive Technologies, vol. 4(2), p. e7, July 2017.

[39] J. Prvu Bettger and L. Resnik, “Telerehabilitation in the Age of COVID-19: An Opportunity for Learning Health System Research,” Physical Therapy, vol. 100(11), pp. 1913-1916, November 2020.

[40] M. Fisk, A. Livingstone and S. Pit, “Telehealth in the context of COVID-19: Changing perspectives in Australia, the United Kingdom, and the United States,” Journal of Medical Internet Research, vol. 22(6), pp. e.19264-e19264, June 2020.

[41] S. Gajarawala and J. Pelkowski, “Telehealth Benefits and Barriers,” Journal for Nurse Practitioners, vol. 17(2), pp. 218-221, February 2021.

[42] A. Klin and F. Volkmar, ”Asperger Syndrome: Diagnosis and external validity,” Child and Adolescent Psychiatric Clinics of North America, vol. 12(1), pp. 1–13, January 2003.

[43] A. Case. 2016, Calm Technology: principles and patterns for non-intrusive design, 1st. ed., O’Reilly Media, Inc. Beijing, China, 2016.

[44] G. Goncu-Berk, “Smart Textiles and Clothing: An Opportunity or a Threat for Sustainability?,” Proc. Textile Intersections, Loughborough, UK, September 2019.

[45] United Nations, “The 17 Goals,” Retrieved September 3, 2021 from https://sdgs.un.org/goals

[46] S. Ossevoort, “Improving the sustainability of smart textiles,” Multidisciplinary know-how for smart- textiles developers, Woodhead Publishing, pp. 399–419, 2013.

[47] E. Sipilä, et al., “Technology-related Challenges in Smart Clothing – Viewpoints from Ideation Workshops,” Proc. of the 9th IEEE International Conference on Serious Games and Applications for Health (SeGAH ´21), August 4-6, 2021, Dubai.

[48] M. Frydrysiak, “Comparison of Textile Resistive Humidity Sensors Made by Sputtering, Printing and Embroidery Techniques.” Fibres and Textiles in Eastern Europe, vol 28(5), pp. 91-96, 2020.

[49] M. Martinez-Estrada, B. Moradi, R. Fernández-Garcia and I. Gil, “Impact of Manufacturing Variability and Washing on Embroidery Textile Sensors,” Sensors, vol 18(11), p. 3824, November 2018.

[50] L. Lopez Ruiz, et al., “Self-Powered Cardiac Monitoring: Maintaining Vigilance with Multi-Modal Harvesting and E-Textiles,” IEEE Sensors Journal, vol. 21(2), pp. 2263-2276, January 2021.

[51] S. Yong, J. Shi and S. Beeby, “Wearable Textile Power Module Based on Flexible Ferroelectret and Supercapacitor,” Energy Technology (Weinheim, Germany), vol. 7(5), p. 1800938, May 2019.

[52] M. Wagih, N. Hillier, S. Yong, A. Weddell and S. Beeby, “RF-Powered Wearable Energy Harvesting and Storage Module Based on E-Textile Coplanar Waveguide Rectenna and Supercapacitor,” IEEE Open Journal of Antennas and Propagation, vol. 2, pp. 302–314, February 2021.