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Towards E-textiles in augmentative and alternative communication – user scenarios developed by speech and language therapists

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ABSTRACT
Purpose: E-textiles have been the focus of interest in health technology, but little research has been done so far on how they could support persons with complex communication needs. A global estimate is that 97 million people may benefit from Augmentative and Alternative Communication (AAC). Unfortunately, despite the growing body of research, many persons with complex communication needs are left without functional means to communicate. This study aimed to address the lack of research in textile-based AAC and to build a picture of the issues that affect novel textile-based technology development.
Materials and methods: We arranged a focus group study for altogether 12 speech and language therapists to elicit user scenarios to understand needs, activities, and contexts when implementing a novel, textile-based technology in a user-centred approach.
Results and conclusion: As a result, we present six user scenarios that were created for children to enhance their social interaction in everyday life when using textile-based technology that recognizes touch or detects motion. The persistent availability and the individual design to meet a person's capability along with ease of use and personalization were perceived important requirements. Through these scenarios, we identified technological constraints regarding the development of e-textile technology and its use in the AAC field, such as issues regarding sensors and providing power supply. Resolving the design constraints will lead to a feasible and portable e-textile AAC system.

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KEYWORDS
E-textiles; complex communication needs; augmentative and alternative communication (AAC); focus group; user scenarios; user-centred design

➤ IMPLICATIONS FOR REHABILITATION

- E-textiles are a novel approach to Augmentative and Alternative Communication (AAC) for children with motor dysfunctions and intellectual disabilities.
- -A portable AAC system implementing e-textiles for children with complex communication needs will enable several activities in daily-life situations. Therefore, further research is needed to resolve the design constraints to reduce the bulkiness of technology embedded in textiles, e.g., looking into the possibilities of passive and battery-free solutions.
- The developed user scenarios offer a starting point for developing initial prototypes for touch-based and motion-detection systems to enhance social interaction and motivation for persons with complex communication needs.

Introduction

E-textiles have been the focus of interest in health technology, but little research has been done so far on how they could support persons with complex communication needs. It has been estimated that globally, 97 million persons with complex communication needs may benefit from using alternative and augmentative communication (AAC) [1] to enhance their communication and participation opportunities. The term "complex communication needs" refers to diverse communication deficits in which natural communication methods, such as speech, writing, and gestures, are insufficient to fulfil the person's functional communication needs. These communication deficits can result from developmental or acquired disabilities spanning all ages; these deficits can be permanent or temporary [2], including persons with cerebral palsy, Down syndrome, and intellectual disability. However, the need for support depends on one's functional and individual characteristics, not on one's diagnosis.

AAC is a term that describes a variety of methods, devices, and strategies to support persons with complex communication needs – from unaided to aided methods [1]. Unaided methods, which do not require external tools, include facial expressions, signs, and gestures. Aided methods refer to the need for external supports, including dedicated speech-generating devices and different speech-output-technologies used *via* a computer or mobile device. These technologies require an access method in which the standard means is to operate the device directly by pointing or touching [1]. An example of a speech-generating device is a

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hand-held electronic device that plays pre-recorded words when a designated button is pressed by a finger. AAC's positive effects on social-communication outcomes are demonstrated in research [3,4]. Researchers have been actively creating new high-technology devices, mainly new mobile applications, for this diverse group [4,5].

Unfortunately, despite the growing body of different options for AAC and their acknowledged benefits, the evidence suggests that a vast number of persons with complex communication needs are still left without the means to communicate [6–8], indicating an overall low usage of communication aids [8]. Stancliffe et al. [6] report that only 3.4% of nonspeaking adults out of 13,000 users of intellectual and developmental services in the United States used aided AAC, leaving the remainder relying mainly on only gestures or body language. Iacono et al. [7] report that many students lack access to functional forms of AAC. Significant challenges remain regarding the hardware and software needed and the individual characteristics to reach a genuinely functional AAC system to meet the users' real-life needs.

Previous studies have identified several barriers affecting the use of high-technology AAC devices that vary across individuals, AAC modalities, services, and environments, including the device's user-friendliness and users' cognition and motor abilities. Technical problems related to the devices are commonly identified barriers [8–11]. Technical issues, such as limited battery life [10] and unreliability [9], may lead to frustration [8]. Many systems are complex, hard to use, and a lot of time is required to generate a message [8–11]. Moreover, some devices, such as eye gaze and head-pointing systems, and touch-enabled systems are expensive, slow to use, and their portability poses problems [11]. The limited portability leads to them being unavailable within and across different environments [10,11]. Furthermore, some systems such as eye gaze technologies [11] require specific circumstances, including lighting requirements and assistance with using the technology. All these factors limit AAC devices' usage in everyday life [11] and therefore are prone to be rejected or abandoned [12].

A person's characteristics also impact how AAC devices are utilized, such as their cognition abilities, movement abilities, and attitudes [8,10,13]. Lack of motivation to engage in AAC [10,12] reduces initiating interaction and spontaneous communication [10] and may lead to discarding the device. A common challenge is physically operating the device, resulting in slow and inefficient communication and frustration [8]. Many cannot perform pointing or swiping currently needed to access different technologies, such as AAC technology, the internet, or social media [14]. Therefore, the necessity to create new technologies that will consider the lessons learned from previous research is urgent, especially for those with severe motor impairments [14–16] and those with significant language and cognitive limitations, such as intellectual disability [14,17,18].

Looking into different technological advances may improve AAC solutions and resolve some of the existing challenges. Textiles have the benefits of being pervasive, durable, and comfortable, thus offering a promising approach to deploying them in the AAC field. The critical need to integrate the enabling technologies into textiles is acknowledged by Marculescu et al. [19] who state that integrating electronic components into textiles enables access to technology anytime, anywhere, and by anyone because everyone wears clothing; furthermore, e-textiles can be individualized to meet anyone's preferences.

E-textiles, also known as smart or intelligent textiles, are a fast-growing industry in health technology [20,21]. They can be described as made of conductive and comfortable-to-wear materials or as ordinary clothing items with conventional sensing, actuating, and data transmission modules [21]. Table 1 presents a few examples of e-textiles manufactured by Less EMF Inc.

Dunn et al.'s review [20] describes the many applications of e-Textiles to specific areas of health, such as neurology, movement disorders, sleep, and mental health. Some examples of recent advances are controlling the body movement of bedridden patients [22], and diagnosing, preventing, and even rehabilitating some health-related problems [23,24]. Despite the growing body of research and a range of applications created to implement e-textiles for different fields, there is a lack of insight into how they could support persons with complex communication needs.

Elo et al. [25] recently organized five multidisciplinary ideation workshops for 50 participants with different backgrounds, such as teaching staff and therapists, including speech and language therapists (SLTs), to explore the possibilities of wireless e-textiles. Their findings suggest that wireless e-textiles could be beneficial in, e.g.,, speech and language rehabilitation and in supporting daily-life communication, safety issues and controlling surroundings, therefore underlining textiles' possibilities in enabling

Table 1. Examples of e-textiles.

E-textile (Commercial name)	Image	Material	Surface resistivity
Pure Copper Polyester Taffeta Fabric		Copper 35%, polyester	0.05 Ohm/sq
Stretch Conductive Fabric		Silver coated, knitted, 76% nylon and 24% elastane,	$<$ 1 Ohm/sq (unstretched)
Shieldit Super Fabric		Nickel/copper plated, polyester	$<$ 0.07 Ohm/sq

Table 2. User scenarios for textile-based AAC.

SCENARIO	1 - "Dinner time discussion"	2 - "Mom, come here"	3 - "Rock'n'roll lover"	4 - "Freezing outside"	5 - "I want cheese"	6 - "Ironman on a swing"
For whom was the scenario created?	A pre-school-aged, non-speaking child with cerebral palsy who uses a wheelchair.	A 5-year-old child with cerebral palsy who uses a wheelchair and has decreased voluntary movement.	A nonspeaking schoolboy who loves rock'n'roll and finds a mobile device very difficult to use due to motor challenges.	Pre-school aged child with an intellectual disability (mild or moderate) who is active and mobile.	A nonverbal 5 – 6 -year-old child with Down syndrome, who is learning signs.	An energetic 4-year-old boy with a severe speaking disability and finger anomalies who uses approximate signs.
What is the context of use?	The child is at home having dinner.	He is at home watching a show. He wants to talk to his mother, who is in a different room.	He is playing an air guitar for fun.	The child is outside feeling cold.	The child is at home having dinner and wants cheese but accidently signs "bread".	He is outside and wants to get on a swing, but someone is already using it.
What is the present barrier?	The child's motor abilities prevent him/her from using existing technology.	His motor abilities prevent them from using existing technology.	His motivation for using existing AAC technology is low.	The current AAC system is unavailable, far away or not with them.	The current AAC methods are hard to use.	The current AAC system is unavailable, far away or not with him.
What kind of e-textile technology would be used?	The technology is embedded in four textile patches on the wheelchair table tray.	The child has removable e-textile patches attached to clothing or a chair with Velcro.	A wide textile belt is divided into two parts: each hand has an instrument.	The technology is embedded in an illuminating vest.	The child and his/her parents are wearing e-gloves. The child also has an e-sleeve.	He is wearing e-gloves and a vest with an "Ironman" speaker in it.
Why is the technology used?	The child answers their mothers' questions by saying "yes", "no", "more," or "help".	The child wants to alert mother to come.	The child plays the air guitar. The skill can later be used to motivate him to initiate communication.	To ask for help and tell others that he/she is cold.	The child learns to use the correct signs to get what he/she wants.	He tells his friend "It's my turn" to get on the swing.
How is the technology used?	The child flails or slaps the textiles, activating the output from a smartphone.	The child touches the patches, and the mother gets the message of "mom, come here!" from a speaker embedded in a wristband or an earring.	He scratches, touches, and moves the hand on the belt by imitating the movements made when playing an air guitar through the belt chords.	The child presses the vest. The speech could come directly from a speaker. Alternatively, the message could be directed to a supervisor outside.	The technology detects the finger squeezing and the stroking and direction of the sign, creating a hologram of the sign.	He signs "my turn," the system recognises approximate signs and activates the pre-programmed utterance spoken through the speakers.
What happens?	A typical conversation commences during dinnertime.	Mother hears the message through the speaker and comes.	Entertainment for the boy and independent access to the fun.	The child gets help.	Parents help the child to sign correctly. The motor execution of the sign is learned.	His friend, who does not understand signs, understands the message.

technologies. However, the research in e-textiles in the AAC field is limited.

The primary interest in utilizing textiles in the AAC field has been developing gloves to facilitate an interpretation system for those using sign language [26]. Ahmed et al. [26] reviewed vision- and glove-based methods, as well as a hybrid method combining the two, for detecting motion to create an interpretation system for sign language. They conclude that many difficult problems must be solved, such as cost, portability, bulkiness, and challenges regarding the different technologies, before these gloves become a reality in improving communication. Theil et al. [27] created clothing for persons with deafblindness. Messages to someone with deafblindness are translated *via* a specific board into vibro-tactile signs displayed to them using a haptic wearable. Fleury et al. [28] developed portable, fabric-based switches used as a speech-generating device (SGD) worn on the wrist. The prototype was made from conductive fabrics and allowed four messages to be recorded and played out. The paediatric user in their case study preferred the fabric-based solution to the alternative one, and more frequent communication was demonstrated in natural environments. The researchers suggest further research on fabric-based SGDs for nonverbal children.

The described textile-based AAC systems still have limitations from the usability and feasibility standpoints. For example, they carry rigid electronics that can pose barriers to daily use, such as issues related to bulkiness, the need for maintenance and, their high cost, which have been acknowledged as barriers to using AAC. Therefore, they would likely score low on wearability according to a ranking system developed by Pantelopoulos & Bourbakis [29]. Reducing such limitations would improve their usability and feasibility, and a few promising prototypes have been created to this end. Mehmood et al. [30] created a prototype that detects simple gestures using passive radio frequency identification (RFID). The researchers predict this passive and cost-effective sensor could be a way to monitor human gestures. Vihriälä et al. [31] introduced wireless textile patches for persons with severe motor disabilities. The RFID components were placed inside four textile patches on a wheelchair table tray and touched to activate the preprogrammed spoken word from a mobile application.

Including persons with complex communication needs in a user-centred approach poses specific challenges in the design process of novel AAC technology in which the intended person is not yet identified. Nevertheless, developing novel technologies in the AAC field must involve identifying the intended users, their capabilities, needs, and expectations that then leads to prototype creation and iterative user testing resulting in the final product [32] in real-life contexts [33]. Therefore, beyond the critical role a person with complex communication needs plays, other stakeholders may act as proxies to them.

Other key stakeholders typically include caregivers and professionals from various disciplines, such as educators and therapists [1]. SLTs have a primary role in assessing, selecting, and implementing AAC strategies, methods, and devices [34] and work to prevent, assess, diagnose, and treat speech, language, social communication and cognitive-communication disorders in children and adults. Thus, SLTs can be seen as proxies for persons with complex communication needs. Due to their specific experience in implementing AAC with their clients, it is reasonable to assume that they would provide valuable information in considering the end users' needs and skills early in the process. This study is part of a research project that aims to explore novel textile-based technology in the AAC field [35].

It is now well established from a variety of studies that many persons with complex communication needs are unable to utilize existing AAC systems, so the need to create novel technology is crucial [14–18]. Some research has been carried out on creating textile-based prototypes in the AAC field, although there is a lack of insight into how they could support persons with complex communication needs in their everyday lives. To include SLTs in creating concept-stage user scenarios in which the textile-based AAC is used we arranged focus group discussions to generate ideas and understand requirements and to identify design constraints. We defined e-textiles in this context as wireless technology embedded in textiles. We will publish in this paper the six concrete user scenarios the participants created in which textile-based AAC is implemented in daily-life situations.

Materials and methods

We chose the qualitative, exploratory focus group methodology described by Guest & Namey [36] because it is appropriate for generating new ideas within a social context [37] and has previously been used in studies to gather the key stakeholders' views in AAC design [38,39]. We adopted the workshop approach [40] to create user scenarios during the focus group discussions. User scenarios are concrete stories about understanding people's needs and envisioning new activities and technologies [41] that are used in a user-centred design approach to generate ideas and understand requirements [42,43]. Designing interactive systems includes considering a range of perspectives that take people, activities, contexts, and technologies (PACT) into account [42,43].

Participants

We selected the participants through purposeful sampling – common in exploratory study designs [36] and widely used specifically to reach knowledgeable or experienced participants interested in the subject [44]. The participants had to have (1) at least three years of experience working as an SLT and (2) to have implemented AAC methods at least once a week during the previous year to be included in the study. Recruitment was carried out *via* an e-mail distribution list for 1338 members of the Finnish Association of Speech and Language Therapists and *via* posting on two social media groups for SLTs. In-person recruitment also provided more availability for participation. Thus, two focus groups were organized for 12 consenting SLTs whose experience ranged from 6 to 36 years (mean 20,4 years) to create user scenarios. Participants reported using AAC regularly, ranging from 1 to 5 days a week (mean 3.67 days). The discussions were arranged using Zoom due to the Covid-19 pandemic. A pilot study was conducted before the focus group discussions.

The participants completed an online survey (Microsoft Forms) for demographics and to consider the problem we wanted to find solutions for before the actual discussions were held. They were asked to focus on their personal experience [40] and list facilitators for and barriers to current AAC methods, which were collated for the focus group discussions. Having done some thinking in advance saves time [40]. They reported their experience in AAC with the following client groups: persons with intellectual disability (10), developmental language disorder (10), autism spectrum disorder (8), Cerebral Palsy (2), hearing loss (2), progressive neurodegenerative diseases ($n = 1$), and brain injury/tumor ($n = 2$). No participant was experienced using AAC with persons with acquired communication disorders. All participants were familiar with using gestures and signs. Most reported using aided AAC, such as pictures and high technology supports, such as robust mobile technology-based and computer-based solutions. Some reported using simple SGDs with a limited number of switches, and a few were experienced in eye gaze technologies. Most participants ($n = 8$) worked with paediatrics, two of whom also worked with adults ($n = 2$). One participant worked with adults and three did not reveal this information.

User scenario development in focus group discussions

The user scenarios were developed in focus groups according to the workshop methodology [40], which suggests that the content of idea development should contain three sections: (1) Create, (2) Evaluate and (3) Develop. The length of each group was about two hours. The discussions were recorded and transcribed verbatim. A focus group topic guide was used to ensure that all participants had the same basic information regarding the discussions' content and flow.

The "Create" section's goal was to create many options, possibilities, and directions. The participants shared and discussed user stories during this process of their real or imagined experiences of persons with complex communication needs, which is a first step in user-centred, user scenario development [42]. This first section was approximately 60% of the discussion, as suggested by Hamilton [40]. Firstly, the participants discussed the pre-assignments with the moderator – an experienced speech therapist and doctoral student researching new AAC technologies. Participants could add to the moderator's lists of facilitators and barriers. Secondly, participants were offered a description of the potential e-textile solution, including that it is wireless, washable and looks and feels like normal textiles. They were also informed about how the technology could be accessed – by touching it, writing or drawing on it – and the textile's ability to detect movement. Lastly, the participants discussed and created several ideas regarding the technology's possible purposes. The participants were reminded that they could ideate freely without considering the technology's actual development or potential restrictions.

The "Evaluate" section's goal was to identify the key barriers that e-textiles could solve, which was 10% of the discussion. The participants looked at the list of barriers they had identified with the currently available AAC systems when evaluating this section's ideas, then they used stamps in Zoom's annotating tool to vote on the two they felt could be overcome with e-textiles. A few participants could not use the tool, so they were permitted to vocalise their opinion and one researcher added their votes manually. Three of the most-voted-for barriers in each focus group were selected for further exploration.

The "Develop" section's goal was to fully expand some of the ideas and generate user scenarios. This section was the remaining 30% of the discussion. Participants were split into three pairs in both groups for further ideation. Each pair was assigned one barrier to work with in separate Zoom breakout rooms. They were advised to use any previously discussed idea or situation or continue freely creating new concepts. The questions guiding the participants to develop user scenarios were 1. Who would use the textile? 2. How old are they? 3. Why can they not use natural speech? 4. What is the situation? 5. What would they want to say/do? 6. To whom would they communicate? 7. Where is the e-textile-based AAC? 8. How would it be used? 9. What would happen? These questions were developed to elicit scenarios according to the PACT framework [43]. After completing the assignment, the pairs presented their user scenario to the whole group and discussed each other's scenarios. One researcher typed the answers to each question on a whiteboard seen by everyone during each presentation. This elicited feedback from the participants and offered an opportunity to clarify anything unclear and therefore improved validity [36]. The whiteboards were saved as screenshots and later checked for accuracy from the transcripts by the first author. The first author also added necessary but missing information to the initial scenario descriptions. The finalized scenarios were further reviewed and discussed with the research team to ensure that they include all necessary details. Finally, the first author translated the scenarios from Finnish to English.

This study complied with good scientific practice and ethical guidelines. Ethical approval was not required for this study based on a set of guidelines drawn up by the Finnish National Board on Research Integrity. Information sheets and a privacy notice were provided, and consent was collected online (Microsoft Forms). Withdrawal of consent to participate at any point was explained. The purpose of this study and ethical considerations were again explained in person at the beginning of the focus group.

Results

We now present the six finalized user scenarios, created by the SLTs, for implementing e-textiles in the AAC field that were the result of the iterative process of generating ideas: 1. "Dinner time discussion", 2. "Mom, come here", 3. "Rock'n'roll lover", 4. "Freezing outside", 5. "I want cheese", and 6. "Ironman on a swing". We present these scenarios in Table 2. They include a description of the person with complex communication needs, the context in which the e-textile technology could be used and why it would be used, and the barrier the participants kept in mind when creating the scenario. Furthermore, the scenarios demonstrate details about the e-textile technology and what would happen if such technology were used.

All six scenarios in this study were created for children, one of whom was school-aged; the rest were preschool aged. These children had varying disabilities, e.g., motor and intellectual disabilities, resulting in complex communication needs. The participants provided additional details about the functional ability and the factors affecting it even though the specific condition was frequently mentioned when describing the person for whom the scenario was created. For example, in "dinner time discussion" the child was described as nonverbal, except for occasional vocalizations due to severe dysarthria and low cognitive abilities. The child's interaction skills, such as joint attention, were good. Furthermore, the child, who could not understand pictures or symbolism, could not use eye gaze technologies. "Ironman on a swing" was further described by stating that speech development was not expected for years. He enjoyed communicating through signs and could combine a few of them to make a short sentence, although signing was hard.

The proposed textiles in which the technology was embedded included articles of clothing, such as a sleeve, a belt, a vest, and textile patches close to the user. The methods of activating the technology were described as touching and detecting movement. The textile patches, belt, and vest were all used by touching (e.g., flailing, slapping, pressing, scratching) the designated areas on the textile in four scenarios (see scenario descriptions 1–4 in Table 2.). Scenario illustrations that implemented touching to activate the technology are presented in Figure 1.

The technology was activated by movement in two scenarios. Gloves and sleeve were used to interpret signs by recognizing the signs attempted, the direction of the movement, and the squeezing of the fingers (see scenario descriptions 5–6 in Table 2). Scenario illustrations that implement motion detection are presented in Figure 2.

The participants also described the personal preferences, aesthetics, and functional features of the proposed device in some scenarios. The speaker in "Ironman on a swing" should be blue and cool – just like the one Ironman has. The textile patches in "Mom, come here" were described as having figures or colours for differentiation. The patches in "Dinner time discussion" needed to feel different from each other; the areas on the patches should be large and clearly distinguished. Furthermore, the boy's preferred music genre was utilized in "Rock'n'roll lover" to create a motivating device for him.

Each scenario described a scene from the children's daily lives, such as having dinner with their families, playing outside or by themselves, and watching a show at home. Five of the scenarios were communication-oriented, meaning they enhanced social interaction by using the e-textile as an interface for speech output *via* a smartphone or direct speaker in a vest. The children could request their turn in play, have discussions with their families, and ask for help. Furthermore, the e-textile could help initiate interaction, as in "Mom, come here" in which the message would be delivered *via* an earring or a wristband worn by the mother. One scenario was quite different: the purpose for using the e-textile in "Rock'n'roll lover" was more motivational and oriented towards creating the motivation to initiate communication by focusing on entertainment first.

Discussion

This study's participants created six user scenarios in which textile-based AAC is implemented in daily-life situations. The scenarios describe the reasons why the AAC is used, the person's functional abilities and the way the technology could be used, all of which are important in identifying the users, their capabilities, needs and expectations, and are crucial in developing novel AAC methods [32]. The created user scenarios included descriptions according to the PACT framework [43] and highlighted the textile-

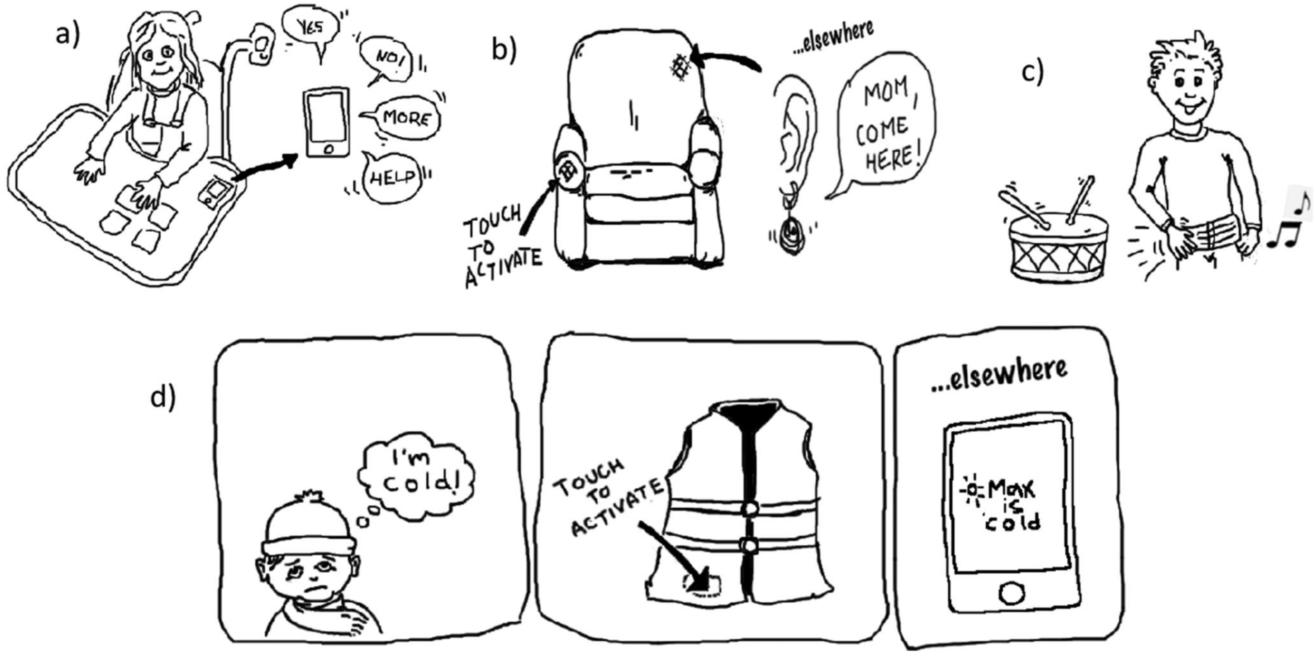

Figure 1. Scenarios where touch was used to activate the technology a) "dinner time discussion" b) "mom, come here" c) "rock'n'roll lover" d) "freezing outside".

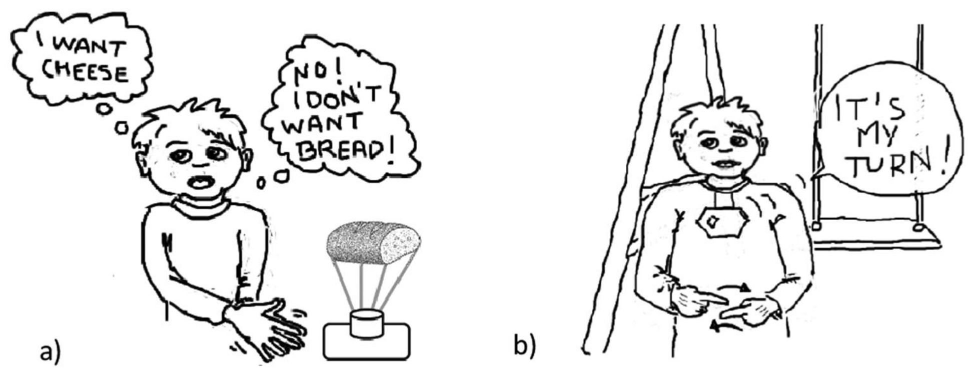

Figure 2. Scenarios where movement was used to activate the technology a) "I want cheese b) "ironman on a swing".

based AAC technology requirements, such as being persistently available, easy to use, and accessible for persons with significant motor disabilities.

In this section, by focusing on the methods of activating the technology, we discuss how e-textiles can enhance social interaction for persons with motor and intellectual disabilities. Furthermore, we pinpoint the importance of music and offer a discussion on how to enable creating entertainment with e-textiles. We then discuss the technological considerations to accomplish e-textiles in the AAC field. We conclude by discussing the limitations and future research.

Enhancing social interaction and promoting motivation through e-textiles

According to the participants, textile-based technologies can enhance children's social interaction and increase motivation in everyday life, such as at home and outside on the playground. The ability to make requests, share information, and initiate interaction are crucial for everyone and included in the list of the purposes that communicative interactions generally fulfil [1].

Textile-based AAC for persons with motor or intellectual disabilities

Participants created scenarios for children with motor and intellectual disabilities who urgently need new solutions [15–18]. AAC is sometimes quite complex and hard to use independently, especially for persons with intellectual disabilities, and those in the beginning stages of learning to communicate [1], suggesting that an easier solution with lower requirements for learning would be a viable option, such as in the "I want cheese" scenario.

One core challenge for persons with motor difficulties is finding an AAC solution that can be used with their functional ability to support their communication and participation. The advantage of using the textile-based AAC is that the technology is designed to meet the person's capability; the fine motor skills needed for most existing devices are not required. Thus, the technology should allow imprecise movement and be designed for an individual's functional capabilities [35]. For example, the person can use flailing, slapping, scratching, or approximate signs to reach the desired purpose. Another advantage is that a textile-based solution is persistently available, increasing the individual's opportunity to communicate frequently during the day. Interestingly, however, the technology was envisioned to be integrated into removable items or accessories, such as gloves, a belt, or a vest. An easy and fast attachment to clothing or other everyday items, e.g., with Velcro would enable removability, and therefore increase both the functionality and transformability of the proposed device. Conversely, removability may reduce communication opportunities as the need for assistance increases.

Three user scenarios in this study used touching to activate the e-textile technology and were created to meet the individual's capabilities. The scenarios resemble some of the simple, existing SGDs, such as the single message or static multi-message devices [8] in which recording one or multiple messages is possible. A similar concept was used in a fabric-based SGD created by Fleury et al. [28] that was operated by touching a designated spot on a wristband, allowing four pre-recorded messages to be stored and replayed. However, the existing SGDs and this prototype have electronics that increase the size of the device and have a limited power supply.

The method of operating the technology was *via* motion detection in two scenarios. Interpreting gestures or signs is essential because gestures or signs are only helpful in the environments in which they are understood, limiting communication opportunities [1]. Furthermore, sometimes the attempt to produce a gestural movement can be very approximate, making them hard to understand, even in their immediate environments. Persons with intellectual disabilities could be one of the largest beneficiaries of textile-based technology because most nonspeaking adults with intellectual disabilities rely only on gestures or body language [6]. Using signs is also very common with children with various disabilities [1].

Several available technologies can recognize touch and detect motion, such as different kinds of sensors, skin electronics, and interactive textiles [32,45–48]. One example of interactive textiles is the Project Jaquard [47], in which touch-sensitive textiles are made from highly conductive yarn. Everyday objects made from these textiles can be digitally interactive and operated by touch. However, the drawback of this innovation for a person with complex communication needs is that not all items of clothing can be fabricated and deployed so they can be used as AAC. These technologies require quite complex electronics and/or power sources, limiting their practical use and decreasing their value in the AAC field.

Providing output

While the textile should be wireless and battery-free, external technology must be included to provide the power source and desired output, e.g., connected to a smartphone or external mobile reader. Using and owning smartphones and tablets is common among persons with disabilities [49], implying that connecting the textile with, e.g., a smartphone, is a valid solution. For example, designing the textile as an interface for other technology – existing or developed solely for this purpose – will allow access to the desired output, such as speech, sounds, or pictures, and enable compatibility with mainstream applications, such as the Internet and social media, for seeking information, entertainment, education, and online services [50].

In a few scenarios, the speaker was integrated into a vest or belt enabling its usage without a smartphone while reducing the textiles characteristics of being washable and maintenance-free. In "I want cheese", the output was in the form of a hologram, which would provide excellent feedback for users and create a learning platform. However, the technology that could provide holograms is very bulky; thus, this characteristic leads to limited portability and, therefore, to limited opportunities for communication and participation.

The importance of music and applications for textile-based solution

"Rock'n'roll lover" describes a situation in which the person uses the e-textile to create music and, consequently, is motivated to use a touch-based AAC-system. Music increases creative development, academic achievement, and motivation [51]. Alluri et al. [52] have studied brain responses, revealing that listening to music activates the brain's emotional, motor, and creative areas. Music therapy interventions have benefitted many persons with disabilities [53]. Music seems to be a powerful tool to enhance communication and other skills for everyone. However, persons with severe motor impairments sometimes lack the ability or opportunity to play musical instruments [54].

Interesting applications exist in which people can use their own movements to play or influence the music played. *Music maker* is one example of a camera-based tool that converts a person's hand or foot movements into musical and visual feedback [55]. *Drumpants* is a wearable devices that can be attached to pants or anywhere to create drum sounds [56]. All applications could allow a person with disabilities to be engaged in musical tasks. However, while these devices are intriguing and useful, they require bulky electronics, batteries, maintenance, and assistance for set up. We envision these applications could be helpful in specific circumstances, e.g., for therapy or during music lessons in which assistance and maintenance are available. Shaikh et al. [57] recently created passive RFID-based music player textile prototypes. This type of battery-free solution could be further developed into a personal assistive wearable that could fulfil the needs of the person described in "Rock'n'roll lover", enabling entertainment, e.g., during their free time.

Technological considerations

These user scenarios highlight that specific attention should be placed on creating technology that is always available/easily portable, battery-free, personalized, easy to use, and designed individually to meet the communicative needs and functional abilities of a person with complex communication needs. Wearing the technology would solve a part of the problem. Marculescu et al. [19] point out that this enables access to the technology anytime, anywhere, and by anyone using the textile. However, the issues regarding design constraints, such as on-body hardware, sensors, and batteries must be resolved before the benefits of these scenarios can be realized. Sipilä [58] recently discussed challenges in developing e-textiles, including operating features, reliability-related issues, comfort and design.

The electrical circuit in e-textiles is often made from conductive yarn or conductive textiles [30] or conductive inks and conductive polymers [59], which can be seamlessly integrated into textiles and already provide suitable electrical properties. Various sensors are used in e-textiles, e.g., moisture measurements using resistive [60] or capacitive [61] sensors. Thus, many of the needed technologies already exist.

Most measurement solutions need a battery, usually a lithium polymer (LiPo) battery [59]. However, few battery technologies would be comfortable, indistinguishable, and endure washing in a washing machine. Some e-textile sensors use energy harvesting [62] or wireless power transfer [63,64], but even in these cases, some kind of energy storage is usually needed. Promising studies using supercapacitors as energy storage have been done [62] that would enable battery-free e-textiles [64]. However, a small, indistinguishable, and washing machine-durable energy storage solution is something to be further studied and developed before e-textiles can truly be adapted to our daily lives.

One solution is to look at the possibilities that passive RFID technology may provide. This traditional identification and sensing technology, particularly in the ultra-high frequency (UHF) range, may offer a viable option to serve persons with complex communication needs. The passive RFID technology is maintenance-free, battery-free, and cost-effective, giving it significant advantages over many other solutions [65,66]; thus, it may resolve some of the design constraints previously discussed.

In the AAC field, some researchers have focused on matching the location of the person and automatically presenting context-specific vocabulary *via* the RFID-tag [67]. Wang et al. [68] used commercial RFID-devices to create a breath-activated system to spell words or sentences. Furthermore, RFID-technology has been utilized in a touch-based AAC system for persons with motor impairments [31]. Such an application would deploy a person's ability to use touching as human-technology inputs, making technology usage simpler and more individualized.

Limitations

The limitations are related to the number of participants and thus the number of focus groups. In this study, 12 SLTs discussed their ideas and perspectives resulting in six user scenarios that provide a design base for prototyping. We used SLTs as proxies for persons with complex communication needs because of their specific experiences with communication disabilities and the AAC field, and because we didn't know who the intended users were. All SLTs meeting the inclusion criteria after using multiple channels to reach eligible participants were included in the study. As a result, two focus groups were formulated. Recommendation of four groups to reach data saturation for the purposes of qualitative studies was not accomplished [69]. Therefore, the results should be interpreted with caution and cannot be generalized to include all ideas for all persons with complex communication needs created by SLTs. That said, the first group generates 60% of new ideas and the percentage declines rapidly after that [69]. Thus, we obtained applicable ideas to develop prototypes.

Furthermore, all persons with disabilities differ, requiring individualized solutions. Among the limitations is the lack of scenarios developed for adults. Moving forward, applications directed toward adults must be considered. We acknowledge the importance of other proxies, such as family members, educators, and other therapists.

Future work

These user scenarios provide several recommendations to enhance social interaction and motivation through e-textiles and to improve technologies' feasibility in the AAC field. Resolving the design constraints will lead to useful, concrete scenarios for prototyping [32,41–43]. Therefore, we will next investigate how the design constraints could be solved and then progress to creating prototypes and fine-tuning them with other stakeholders, such as other therapists and family members. After prototyping, the technologies must be tested for their feasibility and performance in real-life situations.

Including persons with complex communication needs in the iterative user testing can be difficult, as discussed in the introduction. The problem is twofold. First, due to their complex communication needs, they cannot use speech or writing effectively to participate in the study. Second, designing novel technologies for those who cannot use existing technologies means that they have no alternative or augmentative method for communicating, i.e., they cannot use AAC. Therefore, using proxies and observation is justified to include them to the process as much as possible. However, if AAC is being used to some extent, Beneteau [70] has provided a framework for how to use qualitative methods with persons using AAC. The review did not include papers focusing on co-designing AAC with users, but it brings important insights that must be carefully considered when including them as primary participants. Another direction of future work includes developing applications for rehabilitation and motivation.

Furthermore, the lessons learned from these scenarios, such as focusing on capability, personalization, resolving power supply issues, and ensuring the devices' availability, will guide other researchers to design and develop novel AAC solutions with or without textiles.

Technology has a major role to play in creating better AAC solutions, but it cannot solve every problem. For example, more attention needs to be placed on the environmental factors that reportedly affect AAC's implementation [9,10,12].

Conclusions

Focus group discussions were arranged for SLTs to create user scenarios for a novel high-technology solution using textiles as an AAC method. E-textiles were perceived as a viable possibility for children with complex communication needs, especially for those with motor and intellectual disabilities. The six scenarios created offer an excellent starting point for developing initial prototypes for touch-based and motion-detection systems. Furthermore, a scenario for creating entertainment was brought up. Developing user scenarios further and prototyping them to create initial solutions are vital in making a case to continue expanding the possibilities of employing e-textiles in AAC.

These results, along with other research in e-textiles, will guide us and other researchers to develop feasible textile-based AAC solutions and applications for rehabilitation and motivation. The suitability of any AAC solution must always be considered case by case. Future research and development of AAC solutions should focus on how to make devices portable, and easy to use and on how to personalize devices based on users' individual abilities and preferences, while not forgetting the environments where people live. Understanding the whole picture will lead to better products and better outcomes.

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