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Multidisciplinary development of Smart Jacket for elder care

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Abstract

Limitations in physical and cognitive functioning are common among elderly people. Due to these limitations, activities of daily living, such as dressing, can be difficult, even with the help of another person. The limitations may also challenge using the assistive tools meant to support the independent living of elderly people. One significant assistive tool is a nurse call -button whose aim is to support the elder's independent living and ensure the assistance of others when needed. In severe cases, using of such assistive tools is entirely prevented because of the user's limited abilities.

The purpose of this study was to create a solution for the above-mentioned challenges with smart clothing. The objectives of this study were to design a Smart Jacket that 1) is easy to put on and 2) includes an easy-to-use nurse call button. The product development utilized design thinking through four different Smart Jacket versions, three of which were evaluated in multidisciplinary design workshops. The newly designed and created upper-body garment with assistive zippers in the sleeves can be put on when assistance is available without any movement of the user's upper limbs.

Further, the developed passive RFID (radiofrequency identification)-based jacket with integrated nurse call -button is functional without an on-jacket energy -source and is thus maintenance free. The nurse call -button is functional more than four meters from an RFID reader antenna. Based on the initial expert evaluations, the developed Smart Jacket could operate as part of a bigger safety system, for example in an elderly care unit or domestic care, bringing a needed new alternative as merged nurse call -button and assistive cloth.

Keywords: RFID, workshops, garments, older people, participatory design

Introduction

Activities of daily living (ADL) is an assessment scale to measure functional ability and independence [1]. It describes valuable and meaningful activity, such as bathing, dressing, toileting, and transferring [1–4]. Aging itself reduces ADL, which is highly related to various aging-associated diseases and marks of lowered functioning [5], whereas abilities to act are related to increased health, well-being, and quality of life [6–9]. Functional abilities vary individually, making the elderly a heterogenous group [10]. Often age-associated conditions have an influence on mobility, resulting in weakened physical functioning [11,12] and pain, which are common among the elderly, may affect behavior and might show as resistance to care or withdrawal [13].

The overall ability to function is compose of functional, mental and cognitional abilities. Often morbidities of the elderly cause limitations in more than one area [14,15]. For example, physical functioning is a combination of muscle performance, endurance, mobility and flexibility, neuromuscular control, stability, and postural equilibrium [16]. Mental and cognitional abilities, such as absorbing, processing and benefiting from information, are needed in activities of daily living. However, the cognitive abilities weaken during aging [17,18]. For instance, dementia syndrome is a persistent and progressive decline of cognitive abilities [19], known from its traits such as memory loss, communication and language impairments, and challenges in executive functioning interfering with daily living [20]. Cognitive challenges may have an influence on how a person is able to perform daily activities such as self-dressing [21].

To give a brief review of the commonality of the phenomena of challenges in daily activities: musculoskeletal conditions affect 1.71 billion people worldwide, and they cause pain; limitations in mobility and dexterity, shown as infections in joints; and changes in bone structure and muscles [5,22]. Additionally, neurogenerative disease affects approximately 8 million people globally, comprehending Parkinson's disease [23], multiple sclerosis [24], and amyotrophic lateral sclerosis [25], which all come with rigidity. In addition, frailty syndrome's prevalence is causal with high age [26]. Last but not least, adding to these phenomena, 55 million people with dementia symptoms worldwide [27] are more likely to have challenges in activities of daily living [28].

The nurse call system is a personal emergency system. Its aim is to increase security [29] and, through it, add to the activity and independence of the user [30–32] A basic nurse call system has a call button that activates the call from the user to personnel to summon help when needed [29]. Nurse call systems available on the market are, for example, bracelets, wristbands, and necklaces that collect data from users [33]. These solutions are widely used in care units (hospitals, wards, nursing homes, rehabilitation units, and assisted living), but in recent years they have been implemented in home environments too. Certain elderly people's limited functioning may not only make dressing difficult, but also cause challenges using assistive technology – for instance, nurse call. An acknowledged datum is that aging itself weakens fine motor skills and muscle strength in upper extremities [12,34].

Thus, the upper-body garments and nurse call systems currently on market do not meet the needs of elderly, creating an urgent need for products that are designed emphasizing the user and their abilities. In light of this, the study's aims were set: to design an upper garment that 1) is easy to put on and 2) includes an easy-to-use nurse call button.

Material and methods

The design process utilized design thinking [35–38]. The base of design thinking relies in the 1950's when Robert H. McKim introduced a design theory based in human needs; in other words, the theory states that design's ultimate purpose is to increase the well-being of users by satisfying their basic needs [39,40]. The main stages of design thinking are to 1) empathizing 2) defining 3) ideating 4) prototyping and 5) testing [38,41].

The majority of design thinking processes start with empathizing and in this stage often information of phenomena under the scope is searched, and emotional-physical understanding of the user is gathered. After the first stage, defining and ideating follow, and the basic plan of the design is sketched [42,43]. The third stage is creating a prototype. Prototyping provides the physical means for iteration and inspecting the early failures [42]. Testing enables the iteration, and it provide a gestalt view of the problem context [42]. The design process should always involve the designers and users, or at least the persons nearby the user surface if the actual end users are not available [44].

This development process started by empathizing with the user, and both dressing situations were observed: independent and assisted dressing. When empathizing with the dressing efforts, the researchers noted that pressing a nurse call button and dressing in upper-body garments may be difficult for similar reasons: challenges in motor skills and reduced upper limb movements. The second stage was to define the mentioned study questions, and after that, the ideation researcher did began inspecting clothes and designs in order to ideate the possible outcomes. The fourth stage (prototyping) yielded the first prototype (Table 1), and after this the design thinking stages alternated between stages of prototyping and testing (in workshops).

Prototyping and testing in workshops

The design workshops in this study were arranged in one senior care facility aiming to select the participants nearby the user surface. All the voluntary participants had 2–15 years' working experience in senior care at the time workshops were arranged. Four design workshops were held, and altogether 9 professionals (3 practical nurses, 2 registered nurses, 2 physiotherapists and 2 assistive workers) were included in them. In each workshop there were four to five participants. The workshops were kept short and lasted a maximum of one hour per workshop. The strict restrictions in senior care units during COVID-19 limited the number of available participants, and the number of participants remained relatively small.

Insights were gathered by taking notes and all the workshops followed the same structure: after welcoming the participants, the prototype under evaluation was presented and tested. The testing contained two different situations: 1) person sitting in chair and 2) person lying in bed. Both situations were simulated by participants to get more authentic information on how the prototype would work in practical use. The participants were encouraged to discuss the prototype's benefits and pitfalls; moreover, the researcher asked questions that arose during the test situation. At this early stage of research, the prototypes were only dressed on the expert participants.

Easy-to-dress jacket development

To begin the development process, the originally designed upper garment was purchased, and closer inspection showed that when dressing elders, both the elder and the assistant had major difficulties getting the garment on without the use of force.

The first prototype (Table 1) was presented in workshop 1, which had five participants. To the first prototype, the researcher imped two zippers into an widely available pullover, aiming to reduce the need for significant upper limb movements and forcing. The researcher took notes on how to improve the prototype, and considerations taken into account were the following: The long zippers were perceived to be easy to use, although the starting point of zippering was distinctly challenging, due to the choice of zipper model. Prototype 1 had a separating zipper instead of a closed bottom. On the other hand, the assistive zippers did allow the design to be fitted, and testing revealed it to be beneficial. While the participants dressed the person in the wheelchair and in bed, it was noticed that prototype 1 was easy to put on in different positions. Interestingly, the participants discovered that zippers needed to be relocated to a more accessible area because of the possibility of “tight arm,” referring to abducted arm.

Forthwith, the alterations were made to create prototype 2 (Table 1). Contrarily to prototype 1, prototype 2 had the assistive zippers in a more accessible area, and the zipper type selected was now closed-bottom. Prototype 2 left the cuffs closed to ease the sleeve dressing. In addition, the zipper tooth size was increased, with the intention to make zipper closing smoother. Differing from prototype 1, prototype 2 was made in the form of a jacket. In other words, prototype 2 had three zippers: one on each sleeve and one in front.

The second workshop included four participants. Each one of the participants noted that bigger teeth on the zippers and having three zippers altogether enhanced the design in prototype 2. There were some suggestions to color code the assistive zippers to set them apart from the front middle zipper and ease the start of dressing. Some felt that prototype 1 operated more fluently, and cloth was perceived as more adaptive to elders’ needs with open cuffs and open-bottom zippers, rather than prototype 2’s closed cuffs and closed-bottom zippers.

To continue the developing process, prototype 3 (Table 1) was created, with adjustments based on workshop 2. Prototype 3 had separating zippers in an accessible area and had color coding in assistive zippers; in other words, the color of zippers on the sleeves differed from the front zipper so they would be easier to open and close without hesitating. The third workshop consisted of four participants that concluded the prototype 3’s assistive zippers and space in sleeves were perceived to be positive features. No major ideas for improvement were raised.

The upcoming implementation of an easy-to-use nurse -call -button required deliberation of the optimum location. One of the participants noted that it could be placed on the sleeve near the bicep, but another participant noticed that if it was located on either sleeve, users with limited movement on that side could not use it. The participants acknowledged the best outcome was to attach it near the middle line where a hand or palm could reach it and access would not depend on which arm was be functional. According to the participants, the button should be larger than normally used in wristbands. The nurse call -button was added to prototype 3, and thus the fourth protype was complied.

Jacket-integrated nurse call -button development

Technology imped to prototype 3 was passive RFID, which has shown its potential in health care applications [45,46]. Passive RFID technology is battery-free and thus a fully maintenance-free technology for identifying RFID-tagged objects or people. The cost of RFID microchips and conductive e-textiles (used as the antenna) is only cents. The use of propagating electromagnetic waves in the UHF (ultra-high frequency) frequency range enables the data to be read from the distance of several meters (the distance between the RFID reader antenna, which provides the needed power for the RFID tag, and the clothing-integrated RFID tag), even near the lossy human body [47,48]. Thus, it is an optimal technology for clothing-integrated technology solutions, such as a jacket-integrated nurse call.

The electro-textile tag antenna (design presented in Fig. 1, previously used in [49]) was fabricated from non-stretchable nickel-plated Less EMF Shieldit Super fabric that has a thickness of 0.17 mm and a sheet resistance of 0.07 ohm/square. The electro-textile has hot-melt glue on the back side and was ironed to the shirt. The IC (NXP UCODE G2iL RFID IC) has wake-up power of −18 dBm (15.8 µW). It has conductive copper pads for simple attachment and was attached to the electro-textile antenna with conductive silver epoxy (Circuit Works CW2400), as presented in Figure 1.

The tag is initially readable to an external RFID reader and can be "switched off" by covering it with the hand, which blocks the tag from the RFID reader. This on/off change can then be used as a digital input to any connected device, as described in detail in [49]. The setup includes a ThingMagic Mercury M6 RFID reader, which operates at the European standard frequency range (865.6–867.6 MHz) and a circularly polarized RFID reader antenna connected to the M6 reader through a connecting cable. The reader system is connected to a computer through Wi-Fi. When the RFID tag antenna is covered for three seconds, the alarm is switched on in the connected computer.

Table 1. Developing process of the Smart Jacket, assistive zippers marked with green color.

Prototype under evaluation	Notes taken	Changes to next prototype
	***Workshop 1*: five participants**	
	One long zipper per side is handy	
	Zipper closed near hem; if left open, more space is available	*X*
	Need to pay attention how to zip it at the beginning, (finding the parts)	*X*
	Nice to dress when user is sitting and easy to dress when user is lying in bed	
	Fitted design +, usually "tighter the arm, looser the shirt"	*X*
Prototype 1	Closing zipper under armpit is still challenging if "tight arm"	*X*
	If the cuff were closed, the beginning would be easier to find	*X*
	Nice that the zippers are kind of hidden, looks like original garment	
	Zippers should be handled carefully because increased skin trauma risk	*X*

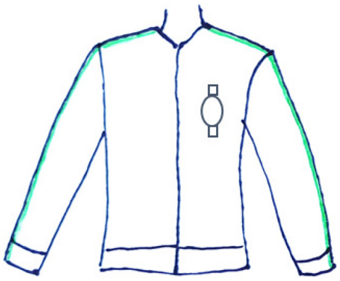
 **Prototype 2**	***Workshop 2*: four participants**	
	Bigger zipper teething is better	*X*
	Zippers located in more visible area, is ok (i.e., blood pressure is easier to take)	
	Must pay attention to what zippers are closed and opened	*X*
	Cuffs closed does not work fluently, works better with open cuffs	*X*
	Easy to dress user on bedrest	
	Three zippers are better than one, the front middle is nice too	*X*
	Color coding in zippers is one way to make jacket easier to put on	*X*
 **Prototype 3**	***Workshop 3*: four participants**	
	Blood pressure and blood sample could be taken easily	
	Central venous catheter is used more easily	
	Easy to dress	
	I like the design, it does not look like hospital clothes	
	Nurse call -button could be assembled on bicep Is it removable? (do not serve user with plegia) If near middle line, does not matter which arm uses	*X*
	Big zippers are a good thing	
	Sleeves are spacious, good	
 **Prototype 4**	**End of the product development process**	

Figure 1. Dressing in the Smart Jacket. The first sleeve is slied into in the usual way (a) and the second sleeve is brought to the other side from back to front. The assistive zipper is opened, and the front is brought underneath the arm (b), arm stays still, cloth adapts. Finally, the assistive zipper and front zipper are closed (c). The nurse call button is activated with covering the tag's circle area (d).

Results and discussion

Evaluation of the ready-made Smart Jacket

Prototype 4 is the jacket with easy- to- dress design and RFID technology imped: the Smart Jacket. The Smart Jacket is put on in a different manner than the originally designed upper-body garments, as shown in Figure 1. The assistive zippers allow dressing without moving one's arms, and the cloth adapts to the user's limb limitations, if dressed with an assistant.

The laboratory measurement setup includes a ThingMagic Mercury M6 RFID reader (865.6–867.6 MHz) and a circularly polarized RFID reader antenna connected to the M6 reader through a connecting cable. The operating power used for the M6 reader in this study is 28 dBm. The functional distance from the RFID reader antenna (as presented in Figure 2) was measured to be around 4.2 meters. Thus, the nurse call –button is operative. The alarm is activated when a hand is covering the tag's circle area for three seconds (as shown in Figure 1).

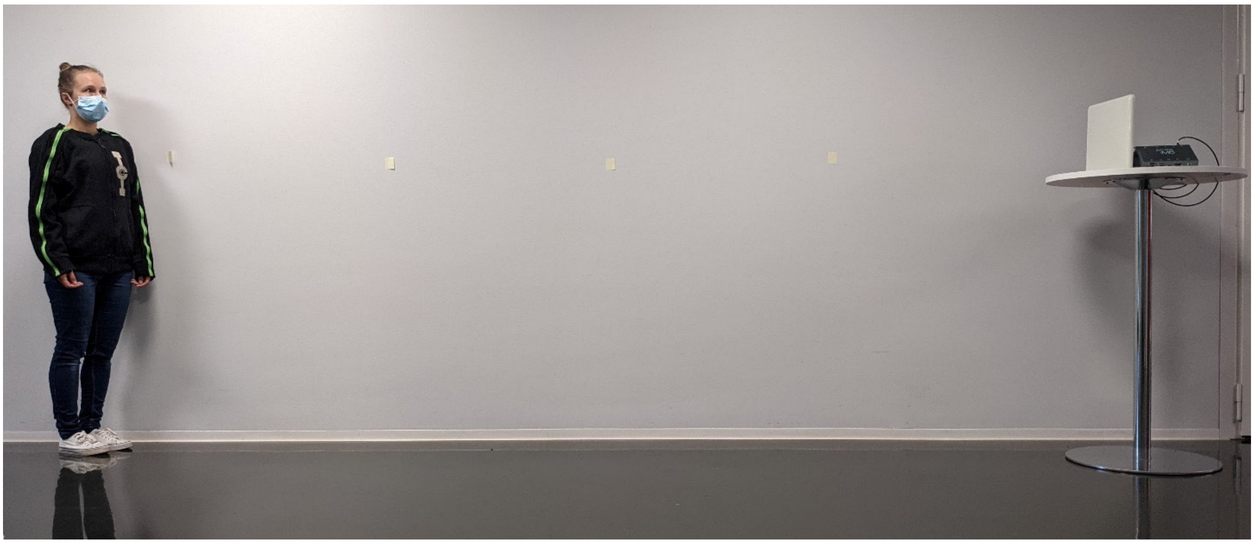


Figure 2. Figure 2. Measurement setup in a laboratory: The read range (i.e. functional distance from the RFID reader) of the nurse call -button is 4.2 meters.

Discussion

Unlike average upper-body garments, this prototype adapts to the body's limitations and can be put on without any arm movements with the assistance of another. The second major finding is to utilize RFID technology as a nurse call -button. As the conventional nurse calls are accessorized [31], this product development aimed to use the garment as a platform. This study thus offers a decent example of an age-friendly garment that has technology imped.

Rarely, if ever, are fashion designs generated from a limited-ability point of view. This design process aimed to avoid movements that would be adverse to elders, respecting their frail and restricted bodies. Thus, although all the sicknesses mentioned are age-related, the younger population has a variety of limitations as well, and Smart Jacket could also serve younger users with special needs. In this study the end users' comfort was the central focus, although, somewhat surprisingly, the assistants found their task (to dress the elder) more fluent and pleasant with Smart Jacket as well. The process also offered views on how to improve the design for hospital usage (Table 1, workshop 3). This might suggest that the assistive design would have advantages in a wider user group too.

As introduced previously, the ability to act in daily living is related to well-being and quality of life [6–9]; on the other hand, perceived safety [30–32] often becomes an issue when assessing whether an elder is capable to live at home or should move into a care unit. Even when one is living in a care facility and assistance is available, the challenges in ADL in different forms exists and might difficult the mentioned dressing and usage of the nurse call. A variety of sicknesses [2,5,11–15,17–25] limit elders' abilities. Some affect cognitive abilities; other limit the movements of upper limbs, causing multiple barriers to use a nurse call or difficulty dressing.

The ongoing trend to merge technology with garments and multidisciplinary dialog is an efficient way to advantageous outcomes. For this reason, this study was conducted with design thinking, a method that could gain more value when developing user-centered products [35–42].

The passive UHF RFID in Smart Jacket played the role of nurse call, but alternatively it could be used in different applications to help people: instead of making a notification, the "button" could turn the lights on or assist in speech. In addition, multiple buttons could be integrated in the same garment and either they would serve the same joined purpose, or they could be programmed separately offering a variety of needed outcomes: one could play the role of nurse call, another could dim the lights and the third could say "help!" out loud or send (for example, through the connected computer or mobile phone) the desired message. The major advantage of this kind of technology is that it can be integrated into cloth quite freely, and most importantly, the user's individual abilities define the location of the button.

As described earlier, RFID technology has been utilized in health care applications [45,46] and also commercialized solutions already exist, especially in fields on identification and localization. To integrate the created Smart Jacket with existing nurse call –systems, the task isn't impossible, but demands careful system integration to redeem its place as an alternative nurse call -button. When thinking further, to wider system integration, it might be beneficial to create a linkage between the Smart Jacket and for instance digital Patient Health Record (PHR). This could be done through, e.g., Wireless Local Area Network (WLAN). If the Smart Jacket would be working in sync with PRH, it would be interesting to add sensors to track bodily functions, such as temperature, blood pressure and heartbeat, i.e., information that is regularly updated to PRH. When using passive RFID technology, securing the data and keeping it private is a challenge that developers have already started to tackle with encryption and with block algorithms that avert the interrogator from accessing the data [50]. However, using passive RFID technology demands a remarkable data base, which has found to be a barrier of implementation [51].

At this early stage of research, washability of the jacket was not evaluated. Machine washing of electro-textile RFID tags has been studied [52], and it is likely that a thin protective coating will be needed to protect the antenna and the IC from water and mechanical stresses [53]. However, there are several possible coating materials available that have a minimal effect on the performance or appearance of the RFID tag [54].

Altogether, the present study lays the groundwork for future research to exploit passive RFID applications in garments. Even so, considerably more work will need to be done to determine how to integrate the Smart Jacket into a bigger safety ecosystem in indoor usage and what the needed parameters are to include a wearable device that supports the elder's daily activities.

Limitations of the study

The study was limited in several ways. The prototype was only tested with the participants of workshops, and none of the participants had authentic limitation of functional or cognitive abilities. Further, measurements were only taken in one location, from the chest, and the study did not examine the measurements for example, from the back or sleeves. No measurements under the fabric were included in this study. Notwithstanding these limitations, the study offers valuable insights on the design process of age-friendly upper-body garments.

Conflict of interest

None declared.

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