

Technology acceptance and perceptions of robotic assistive devices by older adults – Implications for exoskeleton design

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Word count: 6635

ABSTRACT

This study explored and interpreted insights expressed by a cohort of older adults related to their life experience, their experiences using or assisting someone with assistive devices, and their perceptions of robots and robotic assistive devices, including lower limb exoskeletons. A grounded theory study was undertaken with 24 older adult participants over the duration of five months. Each participant participated in a structured interview regarding their experiences with technologies, and perceptions of assistive technologies. Themes from the interviews were coded using Nvivo software. Five main themes emerged from this study – 1) Aging & life stage experiences, 2) Quality of Life, 3) Assistive Technologies, 4) Health Conditions & Care, 5) Products & Service Systems, which have influenced new constructs for a hybrid design tool that incorporates stages of Usability and TAMs (Technology Acceptance Models) to gauge a) Perception, b) Experience and c) Perceived Impact by older adults of lower limb exoskeletons. Emerging technologies such as robotic assistive devices require specific enquiry to understand how best to optimize acceptance by older adults and avoid feelings by them of frustration, embarrassment and ultimately abandonment of these devices.

Keywords: Older Adults, Technology Acceptance; Exoskeletons; User Centered Design; Grounded Theory,

1 Introduction

People of all ages are benefitting from the intervention and assistance provided by robots and exoskeletons in clinical and home settings [1-3]. Physical assistant robots and exoskeletons could improve Quality of Life [4, 5] and it is stated that there is a need to focus on technologies that can maintain health and prevent decline [6]. However, older adults can experience the ‘digital divide’ [7] whereby the pace of emerging technologies does not always match ability to use these technologies. This can impact on day to day task management and experiences when interacting and using devices such as computers, phones or coffee makers [8]. In turn, this can become a source of frustration or reluctance to use these devices. The ongoing process of change that is experienced from conception to death [9] and a ‘lifespan approach’ to design can expedite acceptance by implanting adaptability and flexibility features that facilitate older adult use. The perspectives and role of users in design and evaluation has been highlighted as a challenge regarding technology acceptance of assistive technologies [10]. It has also been stated that family members may influence older adults acceptance of technology [11]. In addition, Graafmans et. al, [12] express the need for further development and understanding that outlines peoples acceptance and use of technology that is beyond chronological age. User centered design determines a requirement to involve, identify and define user needs in the process of research and design [13-18]. Other disciplines discuss ‘client-centered’ approaches and how clients must be part of decision making and tailoring of therapy and support programmes [19, 20].

Exoskeletons are expected to become a common assistive technology within the years to come [21], and potential for wheelchair users to adopt exoskeletons as mainstream mobility devices [22]. A lower limb exoskeleton, as is the focus with this research, is defined as a “*multi joint orthosis that uses an external power source to move at least two joints on each leg, which is portable and can be used independent of a treadmill or body-weight support*” [23]. These emerging robotic assistive devices are further developing to include soft robotic features that will enhance wear ability and acceptance. XoSoft [24] is one such soft robotic lower limb exoskeleton under which the current research was motivated and funded. Older adults have been identified as one of the user groups that can benefit from intervention and assistance wearing soft lower limb exoskeletons such as XoSoft, to assist mobility and ambulation.

A review of the literature about Technology Acceptance Models (TAMs) [25-29] and robotic assistive devices identified gaps perceived that would be critical to underpinning and optimising acceptance of lower limb exoskeletons by older adult users [29]. In addition it was noted that despite there being numerous future focussed technology studies [30], there are generally few studies relating to perceptions and acceptance of robotic assistive devices by older adults [31], with many related studies limited to internet use and access [32]. A number of limitations of TAMs have been documented such as a dependence on user self-reporting and short exposure to such technologies. However, it is also acknowledged that TAMs have influenced design and design terms such as ‘user-acceptance’, ‘diffusion’, and ‘adoption’ [33]. Our review of the literature [29] did not identify any specific TAMs relating to acceptance of exoskeletons by older adults, however an example of a TAM that measured older adults’ acceptance of social robots was deemed helpful to this research [28].

Our previous review [29] identified a knowledge gap and a justification for a qualitative study of and with older adults. The challenge was to capture and analyze factors related to experience and acceptance of assistive technologies and perceptions of soft lower limb exoskeletons by older adults. This approach has been recognized as helpful to understanding and defining knowledge that is helpful to assistive technology device development and service delivery challenges [10].

2 Methods

The purpose of the study was to extract and interpret insights expressed by older adults related to their life experience, their experiences using or assisting someone with assistive devices, and their perceptions of robots and robotic assistive devices, including lower limb exoskeletons. This research was conducted ‘in the wild’ [34] using grounded theory [35, 36] with a philosophy based on a ‘constructivist’ approach, whereby data and analysis were generated from the interactions and experiences with participants, and other sources of data [37]. There is a difference between the gathering, and rigor of quantitative & qualitative studies [38]. Constructing grounded theory [37], requires crucial elements as a means to display rigor to the research and its outcomes, they include the following:

Memo-writing, research question(s), recruitment and sampling of participants, data collection, initial coding, focussed coding and categorisation. Constant comparison is ongoing and continues throughout the data collection to the build of theory [37]. There are a number of Computer Assisted Qualitative Data Analysis (CAQDAS) software packages available to assist the steps and stages of qualitative data gathering and analysis [39]. In the present study Nvivo [40] was used in conjunction with traditional qualitative gathering and analysis methods to analyze and interpret data.

2.1 Participants & sampling method

A purposive sampling method [41, 42] was used to recruit 24 older adults. Participants were sourced through local community groups in Ireland. The local community groups were specifically approached based on members profiles (typically older adults) or health groups related to another of the Primary User (PU) types identified from the XoSoft project (e.g. Stroke support groups). In addition, snowball sampling [43] was initiated as a means for engaged participants to inform appropriate individuals they knew about the study and invite those individuals to contact the researcher if they wished to participate. Publicly available contact details were used by the lead researcher (LS) to make contact with local community group organizers, who were requested by the researcher to:

- Notify their members of the opportunity to participate in the study,

or offer that:

- The researcher would attend a group meeting to provide a brief introduction to the XoSoft project, inviting members to participate or to decline participation in the study.

For the purpose of this study, older adult candidates were identified as, 60+ years, living independently within the community, and with no cognitive impairment.

The study was approved by the University of Limerick Research Ethics Committee (ref: 2017_05_04_S&E).

2.2 Data collection

Prior to the beginning of each session, the participant was issued with an information and informed consent form, and were invited to complete a Mini-Cog assessment [44]. This was administered to determine the presence or absence of cognitive impairment. It was understood that, should there be a negative response to the Mini-Cog assessment, this would exclude the participant, and they would be thanked for their time and advised that on this occasion it would not be possible to continue with the session. All 24 participants passed the Mini-Cog assessment, and the sessions proceeded in each case.

Each session was recorded using audio and image capture, as advised on the information sheet, and consented to by the participants. All participants were anonymised, and a code was applied as a reference to each, e.g. XOKKQOF14.

Intensive interviews [37] were held with participants in their own home, or a place of their choosing. There were nineteen sessions in total conducted between May and October 2017. The sessions involved 24 participants (see table 1) with a mixture of one to one or conjoint interviews.

Table 1 Overview of participant and session types

Session participants	Number of participants	Number of sessions
Male	4	4
Female	10	10
Male & Male	2	1
Male & Female	8 (4M + 4F)	4
Total	24	19

Each session was opened informally by the researcher engaging with conversations about the journey, or weather, or other aspects deemed comfortable to develop rapport. A template was used for memo-writing. It included six open-ended questions. These questions were developed as per title of research and to advance emerging ideas [37], and were led by the participants expression and insights:

- (1) What are your experiences using or helping someone to use assistive devices and/or technologies such as 1) glasses or hearing aids, 2) computers or smart phones, 3) rollator or wheelchairs?
- (2) Describe any difficulties or barriers to using a technology device?
- (3) If you are/were to experience reduced mobility, how does it/would it affect your quality of life?
- (4) When I mention robotic assistive devices, describe what that means to you?
- (5) What is your opinion of older adults being supported by robots to do tasks and activities?
- (6) How do clothing and dressing options change as we age?

Rich in-depth understanding was gained of older adult experience and perceptions towards technologies, emerging technologies, aging and life-stage changes. Each interview was recorded on a digital file (for transcribing verbatim). In addition, the template was used by the researcher during each interview to memo and document the progress of each session. Memo-writing according to Charmaz [37] “*affords an interactive space and place for exploration and discovery*”. This memo-writing assisted with transfer of thought to action and new topics to introduce during the following interview sessions with new participants.

Memo-writing in the context of this research and as per a grounded theory approach was captured through interview notes, reflective journaling and visualisation or mapping by hand to drawing sheets and digital info-graphics.

The audio files from each session were uploaded to Nvivo. In addition, image and video files were coded, anonymised and stored securely on the University server.

Nvivo was used to build a database of material and data gathered. In addition, a more standard action was used to develop theory e.g. post-it notes, affinity diagramming and further memos supported the interpretation of the data.

2.3 Data Analysis

Line by line examination of the data are required for a grounded theory approach [39]. Coding is considered the first step of data analysis, [36]. Saillard [39] discusses how the interactive activity of going through categories from codes to build theory

is an analytic process and traditionally the researcher will identify words from the interview transcripts that have relevance or meaning. Nvivo is a software programme typically used by researchers interpreting grounded theory or mixed methods data [39, 40]. It was used to assist with developing the codes into categories and themes, in conjunction with traditional manual methods of memo-writing, mapping and affinity diagramming. This activity ensured rigor and applied constant comparison as categories developed. Each of the transcribed interviews were uploaded to Nvivo. Each interview was then coded on a line by line basis, identifying each code by a relevance to a comparative category that developed alongside the other interviews as they were transcribed.

3 Results

This study was conducted with independent living older adults in a number of locations in Ireland. Over 976 minutes of conversations were recorded and transcribed verbatim. The transcribed interviews were uploaded to Nvivo for line by line coding. In total 1391 codes were generated from over 8000 lines of text. This activity induced review and reflection time to pursue thought and interpretations of data. It required action to visualise the codes out of the digital space and use additional methods on wall space (post-it notes, affinity diagramming, mapping) to develop these interpretations.

This activity assisted understanding and thinking through the emerged codes and interrelations that would develop interpretations of data. An example of this code to theme development is displayed on Table 2.

Table 2 Example of analysis as it developed from lines of transcript, through to codes, category and theme

Excerpts from interview sessions	Code (Examples)	Category	Theme
M01: But as things change, the system will change, and the nurse will be, told. Oh, the blood pressures high or whatever it could be.	Robotic Trousers– ‘ Monitoring ’	Robotic Trousers Description: Lower limb exoskeleton was a term not used during conversations settling more for robotic trousers based on literature reviewing and initial questionnaire discussions with older adult groups. Perceived usefulness and stigma were discussed, as well as perceptions and enhancement/quality of life.	Assistive Technologies Description: Existing assistive devices such as wheelchairs, hearing aids are captured here as well as perceptions to the emerging technologies and robotic devices that could be part of the assistive technology assistance in the future.
F28: I suppose if I take my aunt again it's her legs are weak so if there was a robotic type thing that would hold her up and give her the strength and maybe it would be connected to her legs that would support her and then she'd actually be able to move with the support of it.	Robotic Trousers – ‘ Perceptions ’		
M03: I'd love to go that way, you know, rather than a wheelchair, I could walk around my own house, it gives me more opportunity to stay in my own house, if I want to make my own tea. Because it gives you back your lot of independence, you know what I mean? (if you had robotic trousers)	Robotic Trousers – ‘ Perceived Usefulness ’		
F23: And then you could control him (robotic trousers) rather than if you were employing someone to do your home, it's not quite the same is it! So that they would obviously be, it would be important, that they fit you very well.	Robotic Trousers – ‘ User Expectations ’		
Summary of workflow from Codes to Categories to Themes:			
The complete study referenced over 8000 lines, defining 1391 codes.	The 1391 codes developed 85 different categories	The Category ‘ <i>Robotic Trousers</i> ’ contained 18 codes (four example codes in second column) relating to understanding and perceptions of these emerging technologies.	The theme ‘ <i>Assistive Technologies</i> ’, had two main core categories within the theme, namely: ‘ <i>Assistive Devices</i> ’, and ‘ <i>Robots & RADs</i> ’ – <i>robotic trousers was within this category.</i>

Five main themes emerged from the data, which are detailed in Table 3 along with descriptions. The five themes are presented, including a selection of highlighted categories or codes considered relevant to understanding how older adults engage in day to day activities, and how they would see a world with reduced mobility or robotic assistance.

Table 3 Five main themes emerged relating to the purpose of enquiry

Theme	Description
Aging & life stage experiences.	How the aging experience is shared by day to day interactions with others, ability and self-awareness.
Quality of Life (QoL)	How Quality of Life is impacted as a result of day to day activities or experiences, as per ADLs (Activities of Daily Living [45]) and interactions. Aging impacts e.g. physical decline on our ability to enjoy or have a QoL.
Assistive Technologies	Existing assistive devices such as wheelchairs, hearing aids were discussed with views to self-use and assisting others use these devices. Perceptions to the emerging technologies and robotic devices that could be part of the assistive technology assistance in the future were expressed with views to their benefits and likewise concerns.
Health Conditions & Care	Many topics (own health conditions, family members e.g. dementia) were discussed and how these health conditions are experienced throughout life. In addition, the management and monitoring of these conditions, as well as interactions and relationships with family, health professionals and appointments.
Products & Service Systems	Various product and service system topics discussed and the benefits but likewise challenges of using such as mobile phones, plugs and technology.

3.1 Theme 1: Aging and life stage experiences

Participants discussed their aging experience, sharing how they go about day to day tasks. ‘Accessibility’ described how it can challenge or empower older adults. Getting into and out of buildings, cars or accessing public transport, computers, and packaging were frequently commented on. Difficulties accessing doors, baths, public spaces were often related to as mobility challenges. In turn, an awareness of ‘slowing down’ was documented –

F26: “I’ve slowed down so much as regards walking it’s driving me mad”.

M19: “I’d be too tired to do anything the next day you know.” (session note - effects of post-stroke when doing day to day tasks).

Mobility was noted as critical to maintaining day to day tasks and interactions with others. Having the ability to go for walks, or to drive a car distinguished a sense of autonomy and independence. ‘A fear of...’ was consistently discussed of developing Dementia – Alzheimer’s. Stories were shared of siblings or other family members that had Alzheimer’s and how it had affected the individual as well as the worry and concern the family felt supporting and caring for their loved one.

Aging was sometimes commented as a pleasurable stage of life. Expression was shared about freedom, and not feeling bothered or upset by events that perhaps would have been worrisome at a younger stage of life. There was evidence of enjoying the value of time and social outings. Relationships with friends, neighbours and family members were discussed as well as the joys and lows of family interactions, e.g. not wanting to become a burden to children; being helped with technology such as computers and internet apps – banking, flights.

Self-Identity, with awareness to aging, e.g. participants would discuss the ‘granny’ look or how others were ‘old’ (despite referred persons being of a similar age)

F23: *I wear jeans, all of the normal stuff. I don't believe in that 'granny thing'.* In addition, image was expressed particularly in relation to the way the body changes. Female participants discussed items such as under-garments – foundationwear (roll-on/corset) that were viewed as enhancing body image when they were younger.

The risk of falls was another concern about aging, and one that sometimes was not accepted or perhaps recognised -

F17: *“no, I don't fall over”,* (session note - participant has had at least two falls in five years and uses a walker/stick to assist mobility).

The results of this theme suggest how the experience of aging can be a pleasurable one, but also one that has concern to health, relationships and self-awareness. By offering supports and enhancements, where required and mindful to ensuring self-efficacy for the older adult, products and service systems can be supportive to the aging experience.

3.2 Theme 2: Quality of Life

Quality of Life was determined by the participants as an ability to choose and do things as they wished, having choice in their lives. Gardening offered pleasures of work satisfaction with resulting growth, smells and sounds of bees and birds. Gardens were often noted as places that had been adapted or were being planned to, with solutions such as raised beds to facilitate ease of movement. In addition, perceived risk of falls within the home, particularly bathrooms was noted with many participants opting to adapt or plan trips to the bathroom;

M14: *“and if (wife) is away, I would put the phone on the floor of the bathroom”* (session note- fear of falling and not being able to call for help). Or removing their bath and choosing to install a shower.

Pleasures of life were documented in almost a reflective satisfied perspective:

M15: *“So that is a lot to do with, once you get, say you get to a certain age, I mean, your mortgage is paid off, your kids are gone, they're married, all mine are married, and gone, and um, so there's only my wife and myself, and eh, we're managing quite well.”*

However, some participants had concerns about money which appeared to limit choice of preferences to do things, with some participants experiencing anxiety regarding moneys and money management.

Identity and stigma of labelling self, or others was also captured and evidenced in this theme:

F16: *“he’s more, a manual worker;”* (session note - wife explaining how husband has less interest in technology). It also appeared that using an assistive device such as a wheelchair can affect self-identity and perceived acceptance (or not) to be social. Participants had witnessed or experienced reluctance to use assistive devices such as wheelchairs; often because of a sense that it identified you as needing help and unable to operate independently.

A further aspect of self-perception was image and opinion to clothing that is worn as we age, topics such as style, colour, comfort and safety were discussed;

M15: *“Velcro straps are fine, I don’t mind; they’re actually... laces are a damn nuisance because they tend to eh, unravel, and you could step on the damn things”* (shoelaces, and tripping over).

Colour was discussed with impressions that colour can reflect how the wearer is feeling, e.g. having a mood, or being depressed (wearing black). Other participants noticed the colours they preferred now, but not when younger. Example of ‘comfort’ was shared; wearing fine clothes when out socially but enjoying more comfortable styles once at home.

Technology was a source of satisfaction to in-home activities such as browsing on computers, listening to music or connecting with loved ones not living close-by,

M16: *“during the winter months now, I’d probably stay on that, (iPad) I’d probably spend from 6 o’clock in the evening, till about half ten, (on iPad in Winter months) then I’d watch a bit of television”.*

Computer use was often accessed independently, but on occasion; assistance and trust were transferred to seeking help from family members to book flights or banking. Some participants had inherited smart phones from family members, or family members purchased computer tablets for participants as a means to improve inter-family connectivity and technology use.

The above comments express the importance of Quality of Life as shared by the participants. Tasks, activities and technology play important roles in how Quality of Life is experienced and enjoyed, or not.

3.3 Theme 3: Assistive Technologies

This theme relied on discussions around existing assistive devices (e.g. wheelchairs, hearing aids, glasses) to explore future and emerging devices that involve robotic assistance. The most common conversations regarded glasses and hearing aids, followed by wheelchair use and experience. With regards to everyday use of such devices, there was an appreciation of the assistance they offer; however, some challenges were noted also:

Glasses: experiences wearing glasses with hearing aids was often a cause of discomfort. Options of varifocals, Bi-focals and contact lenses at times presented challenge to usability, and disorientation of vision while adjusting to wearing and use. There were negative and positive comments regarding image and how glasses can enhance or influence someone’s ‘look’.

Hearing aids: Discussion about these assistive devices included commentary about cost, service system, and purchase options. A number of participants had purchased them and abandoned them, leaving the hearing aids in the packaging or drawers. Problematic factors were documented: wearing hearing aids with glasses are a challenge for some who indicated that they sometimes cause discomfort and contribute to sweating. In addition, the main difficulty and reason hearing aids

were abandoned was a sense that they did not accommodate layers of conversation, where more than one person spoke in a group. This experience led to frustration for participants. It was often noticed by people close to them that they were not wearing the hearing aid, due to the fact the person with hearing loss would sometimes interrupt or miss the topic of conversation. At times these devices had been an expensive investment with a participant sharing they had cost her €4,500. Other participants mentioned a grant they could avail of from the state to assist with this cost.

Wheelchair: Participants discussed wheelchairs, and their use more from the perspective of having helped others or witnessed family members in wheelchairs. Comments frequently were about the changes and adaptations (e.g. cars, home) that are necessary if mobility is reduced. Two participants shared experiences of using wheelchairs temporarily, mainly when on outings, or travelling abroad. The participants were married and had other conditions (male; heart attacks, diabetes, female; stroke x2). The option to use wheelchairs was dependent on either family members or airport staff etc. being arranged to assist the couple. Generally, on a day to day basis they would use an adapted car and walking sticks to assist mobility. In their home they also had a stair-lift installed which opened up full access to their home again.

Conversations about robots and robotic assistive devices were varied. At times, participants appeared challenged mainly because robotic assistive devices are not yet as familiar as established assistive devices e.g. hearing aids or wheelchairs. Some considered them 'hard to imagine' because they had never seen them. Others believed them to be a prosthetic of sorts that replaced a limb or a joint. During sessions where participants were unsure and perceptions of robotic assistive devices were asked, items such as stair lifts, mobility scooters, and kitchen devices (electronic can openers) were identified by participants as likely to have robotic features and capacity. This appeared to connect the perceived usefulness robots and robotic assistive devices could have. There was an assumption that robotic assistive devices would be expensive, with a view by some that they could not afford it. Participants were asked about what life might be like with assistive robots and would they be accepting of these in an older adult's world. Generally, there was a positive view of their potential and how they could support day to day activities such as toileting, gardening and cooking. Robots potentially were seen as companions, or a 'butler' (worker) type; which at times challenged the 'trust' to immerse and avail of the ability and service the robot could provide. In relation to robotic trousers, participants appeared happy with the concept of a pair of trousers that could offer mobility assistance. Some indicated they would like them worn under existing clothing, citing reasons such as:

Not wanting to be noticed as wearing or appearing to wear the same clothes all the time.

Maintaining a choice to select outer layers was preferred.

To be autonomous and selecting a fashion or style preferred by the individual, and not dictated by the robotic trousers.

Participants indicated that they had a preference for robotic trousers to be tailored. This expression appears to be linked with optimising trust in the device. Other reasons cited included - aging and body change, and new or existing health conditions that cause change or require adjustment and tailoring specific to the individual.

3.4 Theme 4: Health conditions and care

Each participant discussed openly the various aspects of their health, and experiences in hospitals or clinics as well as relationships with health professionals, doctors etc. In addition, the organizing and taking of medication for some was a regular response, with tablet splitters, 30-day organizer containers and pharmacist support noted.

As we age falls can become a risk factor in clinical and home settings [46]. Some participants had experienced falls (n=6), and at times blamed themselves e.g. over burdening themselves with items that blocked their view and disoriented their footing (carrying bedding and a bed-sheet straggling on the floor). Participants sometimes commented as having ‘wobbly feet’, blaming this for falls or near falls. Others commented that getting up too quickly after sitting or lying down could lead to a wobble or a fall.

A story was shared about the impact of wearing or not personal alarm pendants in relation to falling;

F14: *“Yes, ‘um that came about because we had at least three people in our group who were saved because of it, and we had one lady who didn’t ever wear it but she had it on the table beside her bed and she fell out of the bed on top of it, and um it went off, but she didn’t (trigger it) and she rolled in underneath the bed (session note - participant is involved in one of the social groups visited. After this episode was shared with the group, she noticed change in behavior with an increase in people wearing personal alarms.) “her daughter came as a result of the call and when she arrived to her house they couldn’t find her, they knew she had pressed it (personal alarm) and only for that, it would have been, maybe the been the next day before somebody would have been in the house. You know that was a really big lesson”.*

The above narrative is an example of the influence incidents can have on wear and use behavior and how this experience influenced a social group to begin wearing personal alarms. At times these alarms are devices that some people are reluctant to adopt or accept for fear of triggering them unnecessarily and troubling the support network/provider. Others view of personal alarms is as a badge that highlights a persons’ vulnerability. It would appear that items such as personal alarms need to display real benefits, that exceed the reluctance for them to be adopted and used as assistive devices.

A number of the participants discussed experiences of hospital or medical appointments. In relation to staying in a hospital due to illness or surgery, there appeared to be an effort by participants not to be a burden, or to be a “good patient” and not bother the staff. One episode shared by a male participant was of having a fall while in the shower during a hospital stay, commenting,

M17: *“There was, but I didn’t use it.” (an alarm in the shower area of hospital) “I fell over in the shower. I was just finishing, believe it or not I finished showering, I finished shaving, I put paper towels on my head, I put my pajamas back on and I walked back to the ward. I had (got) 7 staples in my head” (as a result of the fall). This was one interview with a married couple, and both of them interviewed on separate days. A few days later on return to meet the gentleman’s wife, she brought up the same incident, and almost with disbelief and empathy at how he had managed the episode. She reflected -*

F27: *“But why didn’t he go to her (nurse)?” (session note - participant confused why husband fell in hospital and didn’t*

immediately ring alarm or go to nurse for assistance). Other experiences that were documented, were feelings that sometimes the nurse knew more about the participant and could suggest more relevant devices based on ‘knowing the patient’. This appeared to enhance the trust between the nurse and participant. Other episodes of the community nurse paying visits to assist with caring for loved ones at homes, helping management of ‘PEG’ - feeding, (feeding by tube and bypassing the mouth) or managing infection etc.

3.5 Theme 5: Products & Service systems

Various products and service systems were discussed during each of the sessions, alternating from current experiences with cars, electric plugs, telephones, mobile phones, computers, computer tablets and apps. When it comes to future design and thinking about robots, perceptions and comments varied from “*amazing*” to “*frightening*”. Regarding computers and computer use, commentary appeared at times to be self-critical and judgmental of the participants capacity to learn, stating a sense of being “*too old to learn*”. Learning to use a computer sometimes presented a fear that the participant might break it if they pressed the wrong button. In addition, a number of participants stated a preference now to use computer tablets, due to flexibility of use and being less cumbersome than a PC or laptop.

Other reasons a computer tablet was preferred at times to a phone for internet or browsing and viewing use, related to usability – ease of use, comfort with screen size and vision, as well as more space to place fingers for browsing, typing etc. Typing and texting on phones presented a challenge to vision and dexterity. Texting was not used by a number of participants, with a preference to talk on the phone, especially at night or in poor light –

M19: “*At night-time now I’d have to get my glasses, I wouldn’t be able to read a text now*” (on mobile phone). Not using the texting option on phones was viewed by many as a challenge because they did not do it frequently enough, therefore forgetting how. In addition, there was a fear that despite delivery confirmation, perhaps a text could be sent to the wrong person. Voicemail, and accessing messages left by callers, presented difficulty to some participants stating they felt embarrassed to admit that they did not know how to access their voicemail.

Comments were made in some of the locations visited about internet availability. This related to service, or options such as satellite, dongle or general broadband service. Most participants had good internet connection quality. One participant that was living in a rural location felt somewhat frustrated that the service was not strong or reliable enough for streaming or more complex options (he operated a business). Participants also discussed owning and using landline phones and mobile phones. The usability of landline handsets was sometimes preferred to mobile phones with perceptions about them being easier and offering further features; e.g. speed dial and convenience to browse phone contacts. A number of participants no longer had a landline handset in their homes, or broadband. These participants tended to prefer a mobile phone. This preference on occasion was associated with cost, and the convenience to operate just one phone that enabled flexible and mobile use.

Going out and about when not choosing to walk often involved conversations relating to using a car. Getting in and out of vehicles presented challenges particularly to participants with foot problems, e.g. plantar fasciitis. In addition, a comment was noted by one participant that he recalled collecting his elderly mother in his jeep. His mother had mobility limitations but found to his surprise that she experienced ease getting in and out of a higher type vehicle than a standard car.

4 Discussion

The aim of this study was to explore and interpret insights expressed by a cohort of older adults related to their life experience, their experiences using or assisting someone with assistive devices, and their perceptions of robots and robotic assistive devices, including lower limb exoskeletons. This approach is encouraged in order to situate and emphasize ‘people’ within assistive technology systems [47]. The themes revealed how aging can be challenged or enhanced by accessibility and mobility. When this challenge impedes on Quality of life it can be a cause of limitation for the older adult. Technologies and assistive devices are intended to be supports that enhance life and the lived experience. TAMs have had numerous models developed as a means to optimize adoption of technology. We know that there are few TAMs that measure this adoption by older adults, and none have been revealed to consider emerging robotic assistive devices e.g. lower limb exoskeletons. When reviewing literature, it became apparent that traditionally TAMs had been applied in work settings to gauge acceptance of technology applications by users. They have in recent times become tools to measure technology acceptance by people in home or social settings. The aging population will continue to increase in the coming years [48] and technologies will continue to be developed and emerge to market [49]. Acceptance of these technologies will be critical to them fulfilling design intent; that is, to assist and enhance the lived experience of people. There are currently some models that are specific to older adults and acceptance of technologies [28].

Tools of acceptance and guidance are available for health care professionals when assessing suitability of existing assistive devices (e.g. wheelchairs) by users, e.g. HAAT [50], MPT [51]. Robotic assistive devices such as lower limb exoskeletons are emerging and innovative. They are not currently mainstream. Typical usability tests are limited to exploring instances of experience with no perceptive or reflective stages recorded. There is guidance to safety requirements for the design of exoskeletons [4] but not specific user centered design guidance. User involvement and consideration to design requires an awareness to current situations or practices as well as contemplating future situations and applications [52]. The design teams of complex wearable lower limb exoskeletons need to understand and learn from what the user is experiencing and recording this experience formally as a means to efficiently conceptualize and develop the device further.

We introduce a new Iterative Design Assessment model and tool that supports interactions between design teams and test users/participants that measure perception, experience and perceived impact of exoskeleton prototypes [53].

This research has identified how older adults perceived emerging and robotic assistive technologies. It was clear and evidenced that participants felt challenged or unsure when asked about what a robot or robotic assistive device was. The five themes that emerged from analysing and interpreting the fieldwork, provided broad understanding of expression by older adults about the acceptance of lower limb exoskeletons. The themes holistically generated knowledge that was the basis for 3 new constructs as part of the development of our new model [53]. These new constructs are: 1) Experiential Perception (EP), 2) Self-Liberty (SL), and 3) Quality of Life Enhancement (QOLE).

4.1 Construct One: Experiential Perception

Experiential perception is defined as ‘the perception the older adult has of the interaction with the lower limb exoskeleton when using and wearing it’. It requires the older adult to express a view of what it might be like to try the lower limb exoskeleton, prior to the usability testing of it. It is anticipated that expressed opinions will assist with reducing fear or anxiety, or gauge excitement and curiosity about the lower limb exoskeleton (as discussed in Theme 3, 4 & 5).

4.2 Construct two: Self-Liberty

The research also revealed insights of older adult’s experience and understanding that influence by others using devices or being trusted to assist with using technology can enhance adoption and use. In addition, a desire to be independent and not a burden was commonly expressed. The new construct identified called ‘self-liberty’ applies items in it that enquire after the usability testing the older adult’s intention to consider or desire to have a lower limb exoskeleton assist with day to day tasks and activities. It is defined as ‘autonomous perceptions of control by the older adult when using or wearing the lower limb exoskeleton’. Specifically, it asks the older adult to express their belief whether they can independently manage the service system and operation of a lower limb exoskeleton (as discussed in Theme 1, 2 & 3).

4.3 Construct three: Quality of Life Enhancement

A further new construct was identified following the numerous expressions of ability and choice about daily interactions and life. The construct ‘Quality of Life Enhancement’ specifically enquires to what value wearing and using a lower limb exoskeleton would bring to life and daily experience. Could a lower limb exoskeleton potentially enhance Quality of Life for the older adult? It is defined as ‘relating the use of the lower limb exoskeleton to activities and instrumental activities of daily living’ (ADI, IADL[45, 54]) (as discussed in Theme 2, 3 & 5).

In addition to these new constructs, it is envisaged a number of familiar constructs used in existing TAMs will support the creation of this new model, that is intended for use by design teams when developing lower limb exoskeletons with older adult users. It is believed that further development of this tool will support adaptation to measure acceptance of other emerging technologies with different user groups.

Currently, Health Care Professionals rely on assessment tools to assess suitability of traditional assistive technologies such as MPT [55]. Emerging technologies may need to be learned by trial and error [49, 56], however older adults are also conscious of maintaining competencies as a means to not feel alienated or redundant from society [57] therefore, these technologies need to be easy and comfortable to use [49]. The involvement of people in the process of design is seen as critical for acceptance of lower limb exoskeletons [58].

5 Conclusion

It is clear that in the coming years emerging technologies such as lower limb exoskeletons will become a part of everyday lives for people to assist with maintaining health and lifestyle. Soft robotics will broaden the abilities of these devices to become wearable garments. In addition, the technology required to manage these garments, such as robotic trousers need to be accessible; and not so complex to leave user groups such as older adults feeling excluded, and unable to engage and use these technologies. Technology Acceptance Models have traditionally been tools that predict acceptance of technology by user groups. This grounded theory study emerged a number of themes that led to the development of three new constructs. These constructs are a critical feature of our new Technology Acceptance Model for exoskeletons. Robotic assistive devices have the potential to inspire and encourage a Quality of Life without barriers or stigma experienced. In addition, adaptability of robotic assistive devices is required, regarding a person's changing health or life condition which, in turn ensures maintaining good experience to enhance living and day to day activities. The service system for the robotic trousers would need to manage and notify people regarding problems or issues. Cost is critical to accessing and availability to purchase or use for all not just those that are financially able – this could limit the marketability of robotic trousers. However, if design teams do not identify the unmet needs older adults have to accepting and using/wearing these devices, then there is also the potential for frustration, embarrassment and ultimately abandonment of these devices.

Acknowledgements

This research was completed as part of the XoSoft project, which has received funding from the European Union's Horizon 2020 framework programme for research and innovation under grant agreement number 688175. This publication also emanated from research supported in part by [REDACTED]

The funding agencies played no role in the writing of the manuscript.

Conflict of Interest: The authors declare that they have no conflict of interest.

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