Exoscore – A design tool to evaluate factors associated with technology acceptance of soft lower limb exosuits by older adults.

Linda Shore*, Valerie Power*, Bernard Hartigan*, Samuel Schülein**, Eveline Graf***, Adam de Eyto*, Leonard O'Sullivan*.

**Design Factors Research Group, School of Design and Health Research Institute, University of Limerick, Limerick, Ireland*

*** Geriatrics Centre Erlangen, Malteser Waldkrankenhaus St. Marien, Erlangen, Germany*

**** Institute of Physiotherapy, School of Health Professions, Zurich University of Applied Sciences, Winterthur, Switzerland*

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Abstract

Objective This pilot study proposed and performs initial testing with Exoscore, a design evaluation tool to assess factors related to acceptance of exoskeleton by older adults, during the technology development and testing phases.

Background As longevity increases and our ageing population continues to grow, assistive technologies such as exosuits and exoskeletons can provide enhanced quality of life and independence. Exoscore is a design and prototype stage evaluation method to assess factors related to perceptions of the technology, the aim being to optimise technology acceptance.

Method In this pilot study, we applied the three-phase Exoscore tool during testing with 11 older adults. The aims were to explore the feasibility and face validity of applying the design evaluation tool during user testing of a prototype soft lower limb exoskeleton.

Results The Exoscore method is presented as part of an iterative design evaluation process. The method was applied during an exoskeleton design R&D project. The data revealed the aspects of the concept design which rated favourably with the users, and the aspect of the design which required more attention to improve their potential acceptance when deployed as finished products.

Conclusions Exoscore was effective to apply in three phases of evaluation during a testing session of the soft exoskeleton. Future exoskeleton development can benefit from the application of this design evaluation tool.

Application This study reveals how the introduction of Exoscore to exoskeleton development will be advantageous when assessing technology acceptance of exoskeletons by older adults.

Precis

Exoskeleton and exosuit development can benefit from user-centred approaches that document participants' experiential insights throughout the design process. This paper introduces the Exoscore evaluation tool and results from a pilot study in the application of the method with users as performed during the design of a soft lower limb exoskeleton.

1. Introduction

Exoskeletons and exosuits have the potential to improve mobility and augment human performance in a meaningful way (Bhatnagar *et al.*, 2017; Borisoff *et al.*, 2017; Fosch-Villaronga & Özcan, 2019; Huysamen *et al*., 2018; Robinson, MacDonald & Broadbent, 2014; Yandell *et al.*, 2017) . There is increased focus on exoskeletons as mobility aids for specific cohorts, such as older adults (O'Sullivan *et al.*, 2015; Shore *et al*., 2018a; XoSoft, 2016). Reduced ability is a major factor that can impact on independence and autonomy to conduct daily activities (Bedaf *et al.*, 2017; Mitzner, Sanford & Rogers, 2018). Longevity is increasing (WHO, 2018) and despite challenges to mobility, there is still opportunity to enjoy a good quality of life as we age (Rowe & Kahn, 2015; Stones & Gullifer, 2016). People who experience physical limitation due to injury or disability can be supported by exoskeleton interventions to engage in rehabilitative exercises and activities (Huysamen *et al*., 2018).

The acceptance of emerging technology by older adults may be affected by a number of factors (Heerink *et al*., 2010), such as perceived usefulness (Czaja *et al.*, 2019) and trust of the technology (Sanders *et al.*, 2019). Older adults often require a perception of need (Hanson, Takahashi & Pecina, 2013) before adoption of a technology.

Recent developments of Technology Acceptance Models (TAM) consider specific users, such as older adults and technologies like social robots, computer tablets and mobile phones, often in home or social environments (Chen & Chan, 2014; Chen *et al.*, 2017; Czaja *et al.*, 2019; Heerink *et al.*, 2010; Luijkx *et al*., 2015) whereas TAMs were traditionally developed to gauge and assess acceptance by users, often in work environments (Davis, 1985; Venkatesh & Davis, 2000; Venkatesh *et al*., 2003).

Literature review of TAMs have detailed constructs to explain how older adults adopt gerontechnology in home and social settings (Chen & Chan, 2014; Heerink *et al.,* 2010). The following constructs have been proposed to explain acceptance of exoskeletons by older adults: Perceived Usefulness (PU) (Davis, 1985; Venkatesh *et al*., 2003), Effort Expectancy (EE) (Venkatesh *et al.*, 2003), Anxiety (ANX) (Chen & Chan, 2014; Heerink *et al.*, 2010; Venkatesh *et al*., 2003), Gerontechnology Self-Efficacy (SE) (Chen & Chan, 2014), Attitude Towards Technology/Attitude Towards using the Technology (ATT, ATUT) (Heerink *et al.*, 2010; Venkatesh *et al*., 2003), Behavioural Intention (BI) (Venkatesh *et al.*, 2003), Perceived Adaptiveness (PAD) (Heerink *et al*., 2010), Social Influence (SI) (Venkatesh et al., 2003) and Trust (TRUST) (Chen & Chan, 2014; Davis, 1985; Davis, 1989; Heerink *et al.,* 2010; Venkatesh & Davis, 2000). Trialability (Rogers, 2003) is also highlighted as a relevant feature, particularly associated with a User Centered Design approach to developing complex wearable technologies such as exosuits and exoskeletons.

Understanding and involving users in design is crucial to identifying and defining user needs and gaps in meeting their requirements (Czaja *et al.,* 2019; Dreyfuss, 1955; Fosch-Villaronga & Özcan, 2019; Norman, 2002; Väänänen-Vainio-Mattila, Väätäjä, & Vainio, 2009). The authors here previously performed a qualitative study using a grounded theory approach, to understand ageing, technology acceptance and perceptions of exoskeletons and robotic assistive devices (Shore *et al*., 2018b; Shore *et al*., 2019). That fieldwork revealed three new constructs that we believe are relevant to the perception of a soft lower limb exoskeleton by older adults, namely: 1) Experiential Perception [EP], 2) Self-Liberty [SL] and 3) Quality of Life Enhancement [QoLE] that have not previously appeared in Technology Acceptance Models.

Usability is a critical factor of concept development and understanding the needs, requirements and experience within a context of use by a person (ISO, 2018). Usability testing is iterative and evolves as design teams learn about the user interactions and experiences of products or service systems, including applications with various user groups, such as older adults (Jordan *et al*., 1996; Krug, 2006; Nielsen, 1993; Pullin, 2009; Shore *et al.*, 2015; Wickens *et al*., 2003).

Based on these findings and previous relevant studies by the authors (Schülein *et al.*, 2019; Shore, 2015; Shore *et al*., 2018b; Shore *et al*., 2018c; Shore *et al*., 2018a), a new design model was developed to apply during development of exoskeletons with older adult participants. Figure 1 details this Iterative Design Assessment Model (IDAM, Shore *et al.,* 2019), which incorporates methods of usability and TAMs as a combined hybrid design approach. The process of creativity and design is captured within the double diamond (Design Council, 2014), furthermore, this iterative innovation building activity is expressed and encouraged in other theories and methods (Rogers, 2003; Wickens *et al*., 2003).

The Iterative Design Assessment Model is a design approach that captures reflective practice, interactions and engagement between designers and participants throughout each evaluation phase. As part of this development, we introduce here a new evaluation tool, Exoscore, based on our previous research (Shore *et al.,* 2019; Shore *et al.*, 2018a).

In this study, we present the Exoscore evaluation tool and results from a pilot study in the application of the method with users as performed during the design of a soft lower limb exoskeleton.

2. Method

2.1 Exoscore exoskeleton evaluation tool

Exoscore gauges older adults' perceptions and perceived impact of exoskeletons as assistance options for enhanced/increased mobility. Figure 2 displays how Exoscore fits within the Iterative Design Assessment Model. It is a three-phase tool: 1) Perception, 2) Experience and

3) Perceived Impact. All three phases include an introduction and communication to participants about the tasks at hand (completion of questionnaires, tasks, etc.). Three questionnaires were detailed/selected, one for each phase. Some of the items within the constructs of the questionnaires (e.g. Perception – ANX) were negatively worded; in such instances, a reverse scoring system was used. Reverse items are often used in questionnaires (Xijuan, Ramsha & Victoria, 2016). Refining the Exoscore tool will include reviewing all items to present results, easily scored and interpreted by design teams. The Experience phase for the purpose of this study relied on an existing usability tool, the System Usability Scale (SUS) (Brooke, 1996).

The final version of Exoscore is intended to have criteria to facilitate interpretation of scores, such as in the SUS. Future work is necessary to apply the method and collect further data with a large sample of end users to validate any such criterion.

[Insert Figure 1.]

Figure 1. *Work phases of Iterative Design Assessment Model (IDAM) (Shore et al., 2019). The three phases of Exoscore are included here: 1. Perception, 2. Experience, 3. Perceived Impact.*

[Insert Figure 2.]

Figure 2. *Placement of IDAM within the Double Diamond (Design Council 2014) process.*

The phases for each session are as follows:

- Perception Evaluation Phase – This phase is undertaken prior to experience and use of the exoskeleton by the participant. The participant is either shown the actual exoskeleton prototype/design or images and video of it while at concept development stage. They complete the review questionnaire based on the information provided.

- Experience Evaluation Phase – The participant performs usability testing with the exoskeleton concept and then completes the review questionnaire.
- Perceived Impact Evaluation Phase – After the usability testing, the participant completes this review questionnaire to ascertain the perceived impact that the concept could have on them.

2.1.1 Perception Evaluation Instrument:

The perception questionnaire is divided into five constructs, as detailed in Table 1, along with their sources and descriptions. Four of these constructs were previously detailed in other TAMs (Chen & Chan, 2014; Davis, 1985; Heerink *et al*., 2010; Venkatesh *et al.*, 2003). Each construct had items amended to include the term exoskeleton, in place of previous terms of TAMs mentioned, such as system, robots and technology.

Experiential Perception (EP) was included as a new construct to consider how the participant might anticipate using and wearing the exoskeleton. During fieldwork (Shore *et al.*, 2019), older adults expressed opinions relating to factors such as noise of an exoskeleton, weight of an exoskeleton, and self-image associated with wearing an exoskeleton. These factors were not specifically addressed as measurable in the existing TAM constructs and were deemed necessary to include as a means to optimize user acceptance. Table 2 details the Perception Evaluation questionnaire.

Table 1. *Perception Evaluation, constructs, descriptions, sources and adapted items.*

Construct	Description	Items
Perceived Usefulness | PU	The degree to which an individual believes that using a system would enhance his/her job performance (Davis, 1985; Venkatesh *et al.*, 2003).	1. Wearing the exoskeleton would assist with my mobility. 2. Wearing the exoskeleton would increase my mobility. 3. Wearing the exoskeleton would enhance my life.
Effort Expectancy | EE	The degree of ease associated with the use of the system (Venkatesh *et al.*, 2003).	1. Learning to use the exoskeleton would be easy for me. 2. The exoskeleton would be easy to use and wear. 3. I would be afraid to make mistakes using the exoskeleton.
Gerontechnology Self-Efficacy | SE	Gerontechnology self-efficacy involves a sense of being able to use the technology successfully (Chen & Chan, 2014).	1. I would need help from someone to use or wear the exoskeleton. 2. I could call on someone if I needed help using the exoskeleton. 3. I would like a help-manual for the exoskeleton.
Anxiety | ANX	Evoking anxious or emotional reactions when it comes to using the system (Chen & Chan, 2014; Heerink *et al*., 2010; Venkatesh *et al*., 2003).	1. I feel scared to wear the exoskeleton. 2. I would worry about the mistakes I could make wearing the exoskeleton. 3. I would look silly wearing the exoskeleton.
Experiential Perception | EP	The perception of the interaction by the person with the system (Shore *et al.*, 2019).	1. It is important the exoskeleton operates quietly when I wear it. 2. I would feel embarrassed wearing the exoskeleton. 3. The exoskeleton would be too heavy for me to use. 4. The exoskeleton looks exciting to wear and use.

Table 2. *Questionnaire issued to participants for completion in the Perception Evaluation Phase.*

PERCEPTION | Completed <u>before</u> testing with the exoskeleton

Items	Strongly Disagree				Strongly Agree
	1	2	3	4	5
Wearing the exoskeleton would assist with my mobility					
Wearing the exoskeleton would increase my mobility					
Wearing the exoskeleton would enhance my life					
Learning to use the exoskeleton would be easy for me					
The exoskeleton would be easy to use and wear					
*I would be afraid to make mistakes using the exoskeleton					
I would need help from someone to use or wear the exoskeleton					
I could call on someone if I needed help using the exoskeleton					
I would like a help manual for the exoskeleton					
*I feel scared to wear the exoskeleton					
*I would worry about the mistakes I could make wearing the exoskeleton					
*I would look silly wearing the exoskeleton					
It is important the exoskeleton operates quietly when I wear it					
*I would feel embarrassed wearing the exoskeleton					
*The exoskeleton would be too heavy for me to use					
The exoskeleton looks exciting to wear and use					

*Items require score to be reversed (e.g. 1 = 5, 2 = 4, 3 = 3, 4 = 5, 5 = 1)

2.1.2 Experience Evaluation Instrument:

Experience Evaluation in Exoscore is based verbatim on the SUS (Brooke, 1996). The SUS was used for the Experience phase as it had been used during previous testing of exoskeletons (Huysamen *et al.*, 2018; Huysamen *et al.*, 2018), and also during the XoSoft project. It is one of a range of testing tools that has been applied to test user interaction as development of the XoSoft concept. The SUS was developed for use with computer systems, and usually is completed by participants after they have interacted or used the prototype (Jordan, 1998). It comprises ten statements that participants indicate preferences (or not) from 1 (strongly disagree) to 5 strongly agree (see Table 3).

In this pilot study, SUS scores are calculated by totaling the score (0-4) for each item and multiplying the sum of the scores by 2.5. This output provides the overall SUS score. A score of 70 is considered acceptable, while a score of below 70 indicates concerns about the usability of a system that require addressing (Bangor, Kortum & Miller, 2009). The SUS method, as used in the Exoscore Experience evaluation instrument, is detailed in Table 3.

Table 3. *Exoscore Experience Evaluation Phase using the System Usability Scale items (Brooke, 1996).*

Items	Strongly Disagree				Strongly Agree
	1	2	3	4	5
I think that I would like to use this system frequently					
I found the system unnecessarily complex					
I thought the system was easy to use					
I think that I would need the support of another person to be able to use this system					
I found the various functions in this system were well integrated					
I thought there was too much inconsistency in this system					
I would imagine that most people would learn this system very quickly					
I found this system very cumbersome to use					
I felt very confident using the system					
I need to learn a lot of things before I can get going with this system					

2.1.3 Perceived Impact Evaluation Instrument:

As a type of reflective practice to assess how participants envision an exoskeleton in their lives, the participants completed the 'Perceived Impact' questionnaire. This evaluates the following constructs: ATUT (Venkatesh *et al*., 2003), ANX (Chen & Chan, 2014; Heerink *et al.*, 2010; Venkatesh *et al*., 2003), SE (Chen & Chan, 2014), BI (Venkatesh *et al.*, 2003), PAD (Heerink *et al*., 2010), SI (Heerink *et al.*, 2010; Venkatesh *et al*., 2003), SL (Shore *et al.,* 2019), QoLE (Shore *et al*., 2019), TRUST (Heerink *et al.*, 2010), (Table 4). Items were adapted to include the term exoskeleton as appropriate.

Two new constructs are introduced based on the fieldwork research by the current authors – Self-Liberty (SL) and Quality of Life Enhancement (QoLE) (Shore *et al*., 2019).

SL is described as the perceptions of control the user has to be autonomous and selective regarding how they use or experience the system. It differs from the existing construct Gerontechnology Self-Efficacy (SE) (Chen & Chan, 2014) by extending beyond using the technology successfully. SL is intended to measure the participant's self-intent and self-perceived capacity to manage the exoskeleton, as well as the service system.

QoLE measures how the older adult believes the exoskeleton can be a supportive and enhancing device when conducting everyday tasks and activities, both inside the home or out socially. The Perceived Impact Evaluation Instrument is detailed in Table 5.

Table 4. *Perceived Impact Evaluation constructs, descriptions, sources and adapted items.*

Construct	Description	Items
Attitude Towards Using the Technology | ATUT	Individuals overall affective reaction to using the system (Venkatesh *et al.*, 2003).	1. Wearing an exoskeleton is a good idea. 2. Exoskeletons are a bad idea as an aid to mobility. 3. I would wear an exoskeleton to help me with tasks.
Anxiety | ANX	Evoking anxious or emotional reactions when it comes to using the system (Chen & Chan, 2014; Heerink *et al.*, 2010; Venkatesh *et al.,* 2003).	1. I look silly wearing an exoskeleton. 2. Exoskeletons scare me. 3. I would make mistakes wearing an exoskeleton.
Gerontechnology Self-Efficacy | SE	Gerontechnology self-efficacy involves a sense of being able to use the technology successfully (Chen & Chan, 2014).	1. I could use an exoskeleton without another person's help. 2. I would need help when I am wearing an exoskeleton. 3. I would need an aid such as a walking stick when I am using an exoskeleton.
Behavioural Intention | BI	Behavioural Intention will have a significant positive influence on technology usage (Venkatesh *et al*., 2003).	1. If I needed an aid to help with my mobility, I would choose an exoskeleton. 2. I could imagine people with limited walking ability using an exoskeleton in 6 months' time. 3. I could imagine people with limited walking ability using an exoskeleton in 24 months' time.
Perceived Adaptiveness | PAD	Perceived ability of the system to adapt to the needs of the user (Heerink *et al.*, 2010).	1. An exoskeleton can be adapted if my condition changes. 2. I can use the exoskeleton to assist my mobility, where necessary.
Social Influence | SI	The impact of social influence on behavioural intention will be moderated by gender, age, voluntariness and experience (Heerink *et al.*, 2010; Venkatesh *et al.*, 2003).	1. Family and carers would like me to use an exoskeleton. 2. People who are like me should use an exoskeleton.
Self-Liberty | SL	Autonomous perceptions of control by the person (Shore *et al.,* 2019).	1. I am curious about using an exoskeleton. 2. I could use an app on my smart phone/tablet to monitor how the exoskeleton helps me. 3. I could manage the basic upkeep (e.g. washing, changing battery) of the exoskeleton, independent of my family/carers.
Quality of Life Enhancement | QoLE	Relating gerontechnology usefulness to IADL (Lawton & Brody, 1970) & ADLs (Katz *et al.,* 1963) (Shore *et al.*, 2019)	1. An exoskeleton would assist my ability to do tasks in the home. 2. An exoskeleton would assist my ability to do tasks outside the home. 3. I feel confident that I would not get harmed wearing the exoskeleton to perform day to day tasks. 4. I could attend more social events if I am wearing an exoskeleton.
Trust | TRUST	The belief that the system performs with personal integrity and reliability (Heerink *et al.,* 2010).	1. I would trust my mobility when wearing an exoskeleton. 2. I would trust the information/advice the exoskeleton system would give me.

Table 5. *Questionnaire as issued to and completed by participants during the Perceived Impact phase.*

PERCEIVED IMPACT | Completed after testing with the exoskeleton					
Items	Strongly Disagree				Strongly Agree
	1	2	3	4	5
Wearing an exoskeleton is a good idea					
*Exoskeletons are a bad idea as an aid to mobility					
I would wear an exoskeleton to help me with tasks					
*I look silly wearing an exoskeleton					
*Exoskeletons scare me					
*I would make mistakes wearing an exoskeleton					
I could use an exoskeleton without another person's help					
*I would need help when I am using an exoskeleton					
*I would need an aid such as a walking stick when I am using an exoskeleton					
If I needed an aid to help with mobility, I would choose an exoskeleton					
I could imagine people with limited walking mobility using the exoskeleton in 6 months' time					
I could imagine people with limited walking mobility using the exoskeleton in 24 months' time					
An exoskeleton can be adapted if my condition changes					
I can use an exoskeleton to assist my mobility, where necessary					
Family and carers would like me to use an exoskeleton					
People who are like me should use an exoskeleton					
I am curious about using an exoskeleton					
I could use an app on my smart phone/tablet to monitor how the exoskeleton helps me					
I could manage the basic upkeep (e.g. washing, changing battery) of the exoskeleton independently of my family/carers					
An exoskeleton would assist my ability to do tasks in the home					
An exoskeleton would assist my ability to do tasks outside the home					
I feel confident that I would not get harmed when wearing the exoskeleton to perform day-to-day tasks					
I could attend more social events if wearing an exoskeleton					
I would trust my mobility when wearing an exoskeleton					
I would trust the information/advice the exoskeleton system would give me					

*Items require score to be reversed (e.g. 1 = 5, 2 = 4, 3 = 3, 4 = 5, 5 = 1)

2.2 Pilot study of Exoscore

The purpose of this study was to pilot test the initial version of the Exoscore tool. This was performed by applying the three elements of Exoscore during design concept testing of a soft lower limb exoskeleton for older adults as part of the EU project XoSoft (XoSoft, 2016). Figure 3 is an example of participation during testing of the soft exoskeleton in a gait lab.

[Insert Figure 3.]

Figure 3. *Participant and Administrator during Pilot Study of Exoscore and Testing of XoSoft.*

Approval for the study was obtained from the relevant local research ethics authorities, as part of the approval for the wider XoSoft testing protocol: Clinical Ethics Committee of the Faculty of Medicine, Friedrich-Alexander University Erlangen-Nürnberg, Germany (No.72_18B), and Kantonale Ethikkommission des Kantons Zürich (Study-ID: BASEC-Nr. 2016-01406). Informed consent was obtained from each participant to participate in this research, and for this research to be submitted for publication. Participants were recruited during laboratory and clinical testing of the XoSoft prototype in Switzerland (Zürcher Hochschule für Angewandte Wissenschaften) and Germany (Malteser Waldkrankenhaus St. Marien), respectively.

2.3 Participants

Participants were eligible for inclusion if they presented clinically with mild-to-moderate mobility impairment. Participants were excluded if they presented with other conditions that would preclude them from safely completing the testing protocol (e.g. severe visual or cognitive impairment), were unable to walk under supervision for 10m, or had an acute illness that precluded safe participation.

Consideration was given to the size of sample as a means to investigate the feasibility (Johanson & Brooks, 2010) of Exoscore, with a sample size of 10-15 being deemed as a sufficient size (Hertzog, 2008). Eleven participants (six females, five males) took part in the study. Participants' characteristics are displayed in Table 6. Participants' primary diagnoses varied, as did the precise nature of their mobility impairments, however, all participants had Functional Ambulation Category (FAC) scores of five, indicating that they could walk independently on any surface (Holden *et al.,* 1986).

Table 6. *Summary of participants' characteristics.*

Participant	1	2	3	4	5	6	7	8	9	10	11
Gender	M	M	M	F	M	F	F	F	F	F	M
Age	69	79	72	52	58	48	85	68	82	54	76
Diagnosis	Stroke	Hereditary spastic spinal paresis	Incomplete spinal cord injury	Incomplete spinal cord injury	Stroke	Incomplete spinal cord injury	Gait impairment, falls	Post-polio syndrome	Spinal stenosis	Myasthenia gravis	Spinal stenosis
FAC	4	4	4	4	4	4	5	5	5	5	5

3. Results

3.1 Study Approach

The XoSoft soft lower limb exoskeleton concept was ~~shown and~~ introduced ~~explained~~ to the participants, after which they completed the Perception phase evaluation questionnaire. The Usability/Experience phase consisted of testing the feasibility of the XoSoft prototype by comparing the participants locomotion pattern prior to and during wearing and testing of the XoSoft prototype. The participants then engaged in locomotion tasks while wearing the Xososft prototype that related to daily life, but in a lab setting (e.g. donning, doffing, walking). The testing/wearing elements of the test session lasted approximately 20-30 minutes with the prototype and 40-50 minutes without, between each task a break of two minutes was also allowed. Following the tasks, the participants completed the Experience phase/SUS questionnaire. After testing, following some time to reflect on the concept and their experience, they completed the Perceived Impact Evaluation questionnaire. Testing sessions overall typically lasted up to 2.5 hours in total.

The data were reported as simple descriptive statistics and scores. It is suggested that pilot studies should rely on descriptive statistics, since the small sample size may preclude the valid use of other statistical methods (Lee *et al.,* 2014).

3.2 Perception Phase Evaluation

The descriptive statistics and scores from the Perception Phase Evaluation are detailed in Table 7. All 11 participants completed the questionnaire independently.

Perceived Usefulness score (70) would indicate a positive perception to using and experiencing XoSoft.

Effort Expectancy scores indicate small challenges when wearing and using the exoskeleton (65), but an expectation that learnability (84) and errors (84) would not detract from this.

Gerontechnology Self-Efficacy scores indicate a belief that some supports (persons, manual) will be required in order to adopt and use the exoskeleton (e.g. on average the sample had a low subscore (64) when it came to belief in their ability to operate the exoskeleton).

Anxiety scores would indicate some concerns felt by the participants regarding the operation of the exoskeleton, however, the aesthetics of wearing an exoskeleton were of a lesser concern (53).

Experiential Perception subscore of 67 indicates a perception of the experience of an exoskeleton. Factors such as noise (85), weight (67) and self or social perception while wearing the exoskeleton (69) indicate priorities and preferences to optimize experience. A score of note was the aesthetics of the exoskeleton, on this the score of 45 would indicate a need to review the visual appeal of wearing and using the exoskeleton.

Table 7. *Descriptive statistical results from the Perception Phase Evaluation of Exoscore.*

Construct	Item		Mean	Standard Deviation	Score
PU	Wearing the exoskeleton would assist with my mobility		3.55	1.13	71
	Wearing the exoskeleton would increase my mobility		3.45	1.13	69
	Wearing the exoskeleton would enhance my life		3.54	1.21	71
PU Subscore mean			3.55	1.13	70
EE	Learning to use the exoskeleton would be easy for me		4.18	1.25	84
	The exoskeleton would be easy to use and wear		3.27	1.42	65
	I would be afraid to make mistakes using the exoskeleton	RQ Adjusted	3.19		84
		Raw	1.81	1.25	
EE Subscore mean		RQ Adjusted	3.54		78
		Raw	3.08	.92	
SE	I would need help from someone to use or wear the exoskeleton		2.64	1.36	53
	I could call on someone if I needed help using the exoskeleton		3.45	1.44	69
	I would like a help-manual for the exoskeleton		3.45	1.75	69
SE Subscore mean			3.18	1.12	64
ANX	I feel scared to wear the exoskeleton	RQ Adjusted	3.73		95
		Raw	1.27	.65	
	I would worry about the mistakes I could make wearing the exoskeleton	RQ Adjusted	3.09		82
		Raw	1.91	1.30	
	I would look silly wearing the exoskeleton	RQ Adjusted	2.64		53
		Raw	2.36	1.57	
ANX Subscore mean		RQ Adjusted	3.15		76
		Raw	2.69	.79	
EP	It is important the exoskeleton operates quietly when I wear it		4.27	1.27	85
	I would feel embarrassed wearing the exoskeleton	RQ Adjusted	2.45		69
		Raw	2.55	1.44	
	The exoskeleton would be too heavy for me to use	RQ Adjusted	3.36		67
		Raw	1.64	1.43	
	The exoskeleton looks exciting to wear and use		2.27	1.49	45
EP Subscore mean		RQ Adjusted	3.08		67
		Raw	2.68	.78	

Valid N = 11 (listwise)

3.3 Experience Phase Evaluation

The experience phase results are detailed in Table 8. The results are the total score values for each participant, individual item scores are not meaningful on their own (Jordan et al., 1996). Results greater than 70 (Bangor, Kortum & Miller, 2008) indicate good usability of a system.

Table 8. *Results for Experience phase as per SUS scoring.*

	Experience (SUS)
1	95
2	55
3	17.5
4	60
5	42.5
6	82.5
7	80
8	47.5
9	7.5
10	95
11	40

3.4 Perceived Impact Phase Evaluation

The Perceived Impact Phase results, including sub scores for each construct, are displayed in Table 9. Adjusted scores are also displayed regarding items that were negatively worded and reverse scored according to assist interpretation. The subscores presented again are indicators of reflection and experience of the exoskeleton during the pilot study and by a small sample of participants. However, there was a good indication of a positive attitude towards the exoskeleton, ANX score reduces after the experience of the exoskeleton, (Perception = 76

Perceived Impact = 70). An important consideration about constructs such as ANX would be the scoring application that a high score of ANX should alert the design teams that there is a matter to address with the exoskeleton design. This could be interpreted as a valid construct to apply pre and post Experience phase. TRUST with a score of 75 is regarded a positive result whereby the participants after the experience of the exoskeleton felt it was a device that they would rely on for mobility and information support. PAD was very positive scoring 84, the participants perceived it to be adaptable and a feature of support to health condition changes. The construct SL presented the top result (88) indicating a sense of autonomy by the older adult to manage and operate the exoskeleton and system independently.

The lowest result was SI with average or below average scoring and a subscore of 57 which could indicate a reluctance to be perceived as dependent on or influenced by family/carers to wearing the exoskeleton. Overall this group had a sense that the intervention of an exoskeleton to support mobility could enhance quality of life (QoLE = 77). Again, these results cannot be relied upon as ‘proof of concept’ given the nature of sample size, testing environment and newness of the technology.

Table 9. *Descriptive statistical results for the Perceived Impact Phase Evaluation of Exoscore.*

Construct	Item		Mean	Standard Deviation	Score
ATUT	Wearing an exoskeleton is a good idea		3.82	1.40	76
	Exoskeletons are a bad idea to mobility	RQ Adjusted	2.73		75
		Raw	2.27	1.10	
	I would wear an exoskeleton to help me with tasks		4.18	.87	84
ATUT Subscore mean		RQ Adjusted	3.57		78
		Raw	3.42	.52	
ANX	I look silly wearing an exoskeleton	RQ Adjusted	2.45		49
		Raw	2.55	1.57	
	Exoskeletons scare me	RQ Adjusted	2.82		76
		Raw	2.18	1.25	
	I would make mistakes wearing an exoskeleton	RQ Adjusted	3.27		85
		Raw	1.73	1.10	
ANX Subscore mean		RQ Adjusted	2.84		70
		Raw	2.15	.90	
SE	I could use an exoskeleton without another person's help		3.73	1.27	75
	I would need help when I am using an exoskeleton	RQ Adjusted	2.45		69
		Raw	2.55	1.44	
	I would need an aid such as a walking stick when I am using an exoskeleton	RQ Adjusted	2.27		65
		Raw	2.73	1.62	54
SE Subscore mean		RQ Adjusted	2.81		70
		Raw	3.00	.71	60
BI	If I needed an aid to help with mobility, I would choose an exoskeleton		3.36	1.36	67
	I could imagine people with limited walking mobility using the exoskeleton in 6 months' time		3.54	1.44	71
	I could imagine people with limited walking mobility using the exoskeleton in 24 months' time		4.27	1.01	85
BI Subscore mean			3.73	.81	74
PAD	An exoskeleton can be adapted if my condition changes		4.18	.87	84
	I can use an exoskeleton to assist my mobility, where necessary		4.00	1.09	80
PAD Subscore mean			4.09	.77	82
SI	Family and carers would like me to use an exoskeleton		2.64	1.50	53
	People who are like me should use an exoskeleton		3.10	1.14	62
SI Subscore mean			2.86	.84	57
	I am curious about using an exoskeleton		4.27	1.19	85

SL	I could use an app on my smart phone/tablet to monitor how the exoskeleton helps me	4.27	1.27	85
	I could manage the basic upkeep (e.g. washing, changing battery) of the exoskeleton independent of my family/carers	4.72	.65	94
SL Subscore mean		4.42	.75	88
QoLE	An exoskeleton would assist my ability to do tasks in the home	3.82	1.60	76
	An exoskeleton would assist my ability to do tasks outside the home	3.64	1.63	73
	I feel confident that I would not get harmed when wearing the exoskeleton to perform day-to-day tasks	4.82	.40	96
	I could attend more social events if wearing an exoskeleton	3.09	1.76	62
QoLE Subscore mean		3.84	1.16	77
TRUST	I would trust my mobility when wearing an exoskeleton	3.73	1.62	75
	I would trust the information/advice the exoskeleton system would give me	3.73	1.55	75
TRUST Subscore mean		3.73	1.44	75
Valid N = 11 (listwise)				

Table 10 displays each of the participants' scores for each of the phases. The results of this pilot study display a number of variances that require further testing to understand and refine Exoscore. The scores presented in the Experience phase would indicate a positive usability experience for four of the participants (1,6,7,10) (above 70). However, there are inconsistencies between each of the phases (e.g. participant 8). Reasons such as personal ability, user expectations being met/unmet, or other personal factors not yet defined may explain these results. Further refinement of Exoscore may help with determining consistencies that are considered more reliable.

Table 10. *Score results for each phase of Exoscore and for each participant.*

Participant	Perception	Experience (SUS)	Perceived Impact
1	84	95	74
2	55	55	52
3	55	17.5	53
4	62	60	70
5	57	42.5	84
6	56	82.5	68
7	52	80	79
8	77	47.5	68
9	66	7.5	66
10	56	95	78
11	65	40	78

4. Discussion

As a pilot study, and the first occasion to put into practice the Exoscore tool, the focus of this study was learning (Lee *et al.*, 2014) about what was experienced and expressed by administrators and participants to the Exoscore phases and application. In accordance with the ethics application, the participants involved in this pilot study were:

- Reasonably healthy (no recent stroke, incomplete spinal cord injury episode).
- Walking without physical assistance from another person (walking aids were allowed).
- Able to read and understand the questionnaires and execute commands re tasks.
- Able and willing to participate in the study (signed consent form, etc).

To our knowledge, this is the first phased design evaluation tool that measures acceptance of emerging technologies such as lower limb exoskeletons. Furthermore, it is specifically designed to gauge and assess exoskeleton acceptance by older adults (Shore *et al.*, 2018a).

Exoskeletons are predicted to become a common assistive technology within the medium term (Young & Ferris, 2017). Usability tests (Brooke, 1996; Krug, 2006; Reiss, 2012) and TAMs (Chen & Chan, 2014; Davis, 1985; Heerink *et al.*, 2010; Venkatesh *et al*., 2003) offer reliable insights and assessments of user interactions with technologies in a number of contexts. Healthcare professionals currently avail of assessment tools (Cook, 2015; Scherer & Craddock, 2002) when assessing suitability of assistive technologies for people.

We identified a lack of evaluation tools specifically used to measure attitude and perception of lower limb exoskeletons and exosuits by older adults and used by design teams. We developed three new constructs, previously not used in TAMs (Shore *et al*., 2019) and introduced them as part of Exoscore. This new design evaluation tool is embedded within an IDAM (Shore *et al*., 2019) which encourages iterative and involved design phases between design teams and participants. This design paradigm sits within an established and proven design process (Design Council, 2014).

The exoskeleton as a wearable device will to some degree become an embodied appendage at times; design teams require understanding of that experience for the person who wears and uses the device. As discussed earlier and based on findings from our fieldwork (Shore *et al*., 2019), the wearability experience and factors such as noise of the exoskeleton operating can now be a measurable attitude (EP, Perception Phase).

Lower limb exoskeletons typically will be used by people who require assistance with mobility. Such users may have other health or lifestyle conditions that need to be considered. The construct PAD (Table 8, Perceived Impact) documents this requirement to adapt exoskeletons if there are changes to the older adult's condition or mobility.

Pilot Study Feedback:

Upon completion of the Exoscore pilot study, the administrators shared their experience applying Exoscore and some observations from the participants:

- It was described as 'easy to use'.
- It could be improved by revising some of the terminology and improving the introduction phase to enhance understanding of exoskeletons by the participants.
- The Perceived Impact Phase questionnaire made more sense to the participants, following the experience of the exoskeleton.
- In order to relate real-world experience and use of an exoskeleton in the home or social settings, it is suggested that a tool to test home use is developed.
- As a testing session with participants can take up to 2.5 hours, an awareness of this timeframe is needed and the possibility that the participant may experience fatigue or hurriedness when completing some of the questionnaires e.g. Perceived Impact.

Scoring

Because a pilot study is more about understanding and implementing the tool, it was interesting to note the results presented. The participants could perceive the exoskeleton to be useful. The score for ANX could indicate a perception of a sense of anxiety to individual use of the exoskeleton. As we age, anxieties may become more alarming or concerning than to our younger selves (Ostir & Goodwin, 2006; Wuthrich, Johnco & Wetherell, 2015). This construct results both during Perception and Perceived Impact Phases, which would indicate it as an important one to capture a sense of confidence or not by an older adult while being assisted by the exoskeleton. At initial viewing and prior to experience, EP construct (Perception Phase) the item concerning the look of the exoskeleton appears to have a lower result and could be down to the aesthetics of the exoskeleton, or other factors not yet defined. The 'look' of the exoskeleton may be a critical measure to evaluate acceptance or not of the exoskeleton.

Future opportunities

The iteration and development of Exoscore will include a specific introduction/module to the concept of exoskeletons and exosuits in general, and how they can assist people. Opportunities to facilitate interactions between participants and designers as exoskeletons is to be encouraged. Further testing with a larger sample size is required across several exoskeleton projects as a means to validate the approach. In addition, as testing of exoskeleton concepts are undertaken in lab settings, and similar to technology and TAMs (Venkatesh *et al*., 2003), an addendum will be developed for applying Exoscore to testing that is conducted in home or social settings (Heerink *et al.*, 2010).

However, lower limb exoskeletons will be controlled in multiple ways:

- The hardware required to interact with and manage the system (i.e. mobile phone, tablet, PC).
- The software, how will the system be viewed and used to manage frequently, particularly if changes or updates are required to the exoskeleton?

A specific design tool offering phased insights to understanding and iterating to user needs can efficiently adapt and apply changes to exoskeleton concept iteration. Exoscore was developed as a result of fieldwork analysis and results are based on older adult perceptions. However, there is an opportunity to generalize and open this tool as a mainstream tool for all user groups participating in testing and development of exosuits.

We believe a hybrid model that incorporates stages of usability testing, as well as self-reporting TAM phases, provides richer and efficient feedback at concept and iterative stages of design. Once the results are satisfactory, Exoscore affords the opportunity to proceed with developing a lower limb exoskeleton that ultimately has involved both users and design teams in a very user-centric way.

Exoscore goes beyond a typical usability test or technology acceptance assessment by encouraging participants to be expressive about exoskeleton assistance for their mobility requirements. As part of a User Centered Design process, it is an iterative model that facilitates discovery and definition of needs requirements to development of concept, optimizing the exoskeleton for delivery to market.

Limitations

Our small sample size limited concise results regarding reliability and validity of Exoscore. In order to validate Exoscore, it is critical that further studies have larger sample sizes and perhaps more than one exoskeleton project. Terminology of some of the items, particularly at Introduction and Perception Phase was confusing to some of the participants. These areas require revision to ensure improved experience and clarity of answers by participants.

3. Conclusions

Exoskeletons and exosuits will become a familiar technology in our day-to-day settings within the medium term. We introduced version 1 of Exoscore, a specific design evaluation tool that can assess acceptance of lower limb exoskeletons by older adults. Future day-to-day situations we experience as we age can be enhanced by lower limb exoskeleton interventions. Our fieldwork and literature review revealed gaps in current TAM's. This provided an opportunity to review the design process and how it can offer guidance to exoskeleton and exosuit development as a means to optimize older adult use, acceptance and experience of these robotic assistive technologies. We have introduced three new constructs to apply as part of a new design evaluation tool to measure attitudes of acceptance by older adults of exoskeletons.

Exoskeletons and exosuits that are trusted, useful and enriching to assisting with day-to-day tasks offer optimal value and quality of life experience for users of these emerging technologies.

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Key Points

- There is a requirement to understand and apply user insight and knowledge to exoskeleton design, specifically with older adult users.
- Older adults who experience reduced mobility, also experience a reduction in independence and autonomy to conduct daily activities, in turn affecting their quality of life.
- Current knowledge of technology acceptance indicates a requirement to introduce phases of evaluation and assessment of perceptions to lower limb exoskeletons by older adults.
- The complexity of exoskeletons and their acceptance in day-to-day living situations requires an iterative assessment and opportunity to analyse a concept during development, highlighting specific areas to address challenges or opportunities presented.

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Linda Shore is an Industrial Design Ph.D. candidate in the School of Design, University of Limerick, Ireland. Her research interests include older adults and technology acceptance, robotic assistive devices and the ageing experience.

Valerie Power is a post-doctoral researcher at the School of Design, University of Limerick and a Chartered Physiotherapist. Her research interests are in human factors in the design of assistive devices, rehabilitation technologies, and fall prevention in older adults.

Bernard Hartigan is a full-time lecturer on the BSc. Product Design and Technology course at the University of Limerick. Previously worked for 15 years as a senior industrial designer specializing in soft goods. His research focus is targets the design and manufacturing of performance wearable equipment for sport, rehabilitation and dance.

Samuel Schülein is Head of Movement laboratory of the Geriatrics Centre Erlangen, Germany. His research interests are in the area of mobility, gait analysis and fall prevention in older adults, wearable (soft robotics) technologies in clinical and homecare environments.

Eveline Graf is a post-doctoral research associate at the School of Health Professions. Her research interest includes movement and biomechanical analyses and the development, implementation and evaluation of new technologies in physical therapy.

Adam de Eyto is Head of the School of Design and an Industrial Designer. His research interests are in the areas of User Centered Design in soft robotics, design for sustainability, transdisciplinary education, humanising medical devices, behavioural change and soft product design.

Leonard O'Sullivan is an Associate Professor in the School of Design. His research interests are in human factors of human robot interaction to include exoskeleton interaction (hard and soft) and technology adoption aspects affecting users experience of robotics.