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## End user needs elicitation for a full-body exoskeleton to assist the elderly

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### Abstract

For ageing individuals, declining physical functional capacity can lead to loss of independence, decreased engagement in the community and reductions in quality of life. As such, solutions that can effectively and affordably supplement older adults' diminishing functional capacity, and thus facilitate maintained independence and social participation over time are urgently required. The AXO-SUIT project – funded by the European Commission under the Ambient Assisted Living Joint Programme – is developing assistive exoskeleton devices for older adults with impaired mobility and/or difficulties in performing activities of daily living. This paper will report on-going research which aims to identify end user needs, and thus provide inputs to specify the design requirements of the AXO-SUIT exoskeletons. The objectives of this initial questionnaire study are to identify the functional assistance requirements of potential end users of the AXO-SUIT in terms of mobility, reaching and handling, and full-body support for performing activities of daily living at home and in the wider community. The end user requirements identified will be used to formulate functional specifications for the AXO-SUIT lower-body and upper-body sub-systems, which will ensure that the AXO-SUIT prototypes will provide for the specific mobility, reaching and handling needs of end users, and also to provide useful insights into the perspectives and needs of end users in relation to assistive exoskeletons in general.

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## 1. Introduction

Ageing affects both individuals and society as a whole, and age-related issues are becoming increasingly more pertinent as global population ageing predictions become reality. According to the World Health Organization, the proportion of the world's population aged 65 years and over will double between 2010 and 2016, from approximately 8% to 16% [1]. At an individual level, degradation in personal mobility and handling capabilities due to ageing leads to loss of independence and a need to rely on others for a modest quality of life. Research shows that personal functional ability of older adults is essential to the maintenance of quality of life [2]. Solutions able to effectively and affordably supplement elderly people's diminishing functional capacity as they age are urgently required. In addition, many older adults are organised in senior clubs or care centres, where volunteers (many of whom are seniors themselves) help other elderly persons in their daily activities. Engagement in voluntary work has many potential benefits [3], and can be of great societal value in light of current ageing trends. However, some elderly volunteers may need physical assistance themselves to support their activities. Exoskeletons offer potential solutions to these requirements for physical assistance, both in aiding rehabilitation to improve physical function [4,5] and as assistive devices in their own right [6].

### 1.1. AXO-SUIT project overview

The AXO-SUIT project – funded by the European Commission under the Ambient Assisted Living (AAL) Joint Programme Initiative Call 6 – focuses on supporting voluntary work and daily activities of elderly persons by developing assistive devices designed to comfortably fit the human body (upper- and lower-body and the hands) and actively help the wearer. The project builds on a previous AAL Call 4 project EXO-LEGS aimed at enhancing the basic mobility capabilities of the elderly so that the lower-body assistive exoskeleton solutions can be extended to provide full-body support. The AXO-SUIT project brings together three universities and five companies active and experienced in research and development of assistive devices and aims to focus on new application scenarios. The target group for AXO-SUIT is healthy elderly persons who need to supplement their natural capacities for parts of the day to allow them to continue being active, independent, and engaging in voluntary work to help other less able peers. By wearing the AXO-SUIT, elderly persons will be able to move around more easily, reach for objects, and manipulate them to perform various chores around the home and garden such as shopping, cleaning, cooking and gardening. Physical assistant exoskeletons are covered in the new EN ISO 13482 [7]; as this ISO harmonized safety standard in personal care robots has been published and as the market develops, assistive exoskeletons are likely to be widely adopted to face the ageing societal problems in helping elderly persons stay active in their daily living tasks; hence the AXO-SUIT project is timed to develop the core technologies and prototype products for these new and emerging markets.

### 1.2. Identifying end user needs

The ability of AXO-SUIT to meet the needs of end users is one of the primary determinants of the project's success, therefore identifying these needs and continuing to engage end users throughout the AXO-SUIT design and development processes are core elements of the project.

End users are defined in three categories within the AAL programme [8], as follows:

- Primary end users are the persons who actually use an AAL product or service. This group directly benefits from AAL by increased quality of life.
- Secondary end users are persons or organisations directly in contact with a primary end user, such as formal and informal care persons, family members, friends, neighbours, care organisations and their representatives. This group benefits from AAL directly when using AAL products and services (at a primary end user's home or remote) and indirectly when the care needs of primary end users are reduced.
- Tertiary end users are such institutions and private or public organisations that are not directly in contact with AAL products and services, but who somehow contribute in organizing, paying or enabling them. This group includes the public sector service organizers, social security systems, insurance companies. Common to these is

that their benefit from AAL comes from increased efficiency and effectiveness which result in saving expenses or by not having to increase expenses in the mid and long term.

AXO-SUIT is dedicated to the engagement of end users throughout the course of the project, and will achieve this via the establishment of an end user group comprised of mainly primary, secondary and some tertiary end users from all four partner countries who will be actively involved in the specification, design, development, and testing and validation of the exoskeleton prototypes. A series of surveys of end user group members will be used to gather data concerning user requirements and gender differences throughout a number of European countries. These user requirements will be used to formulate functional specifications for the AXO-SUIT sub-systems needed for providing the individual support needed for mobility, reaching and handling. The user requirements will also inform the assessment metrics to be used in evaluating the solutions produced from technical, non-technical and users' viewpoints.

### *1.3. Questionnaire 1: Primary and secondary end user requirements*

The first in the series of questionnaire studies to be undertaken during the AXO-SUIT project – hereafter referred to as Questionnaire 1 – aims to determine the types of daily activities in the home and in the community for which end users require physical assistance. Specifically, Questionnaire 1 seeks primary and secondary end users' views on the lower-, upper-, and full-body activities with which they would like to receive assistance, and the results will be used to inform the design and technical specifications for realizing the AXO-SUIT lower-body and upper-body prototypes to be developed.

As an on-going study, this paper will describe the methods being employed to implement Questionnaire 1 and will report on some preliminary data obtained to date. The implications of these preliminary results and future directions of the AXO-SUIT project will also be briefly discussed.

## **2. Methods**

A cross-sectional questionnaire study of primary and secondary end users is being undertaken across several European countries, namely Belgium, Denmark, Ireland and Sweden. The projected total number of participants is expected to be 80 i.e.  $n=20$  in each country. Primary end user participants are adults aged 55 years and over. Secondary end user participants are individuals who have direct contact with a primary end user, such as family members, friends, neighbours, formal and informal care providers, care organisations and their representatives. Exclusion criteria are cognitive impairment which limits the individual's capacity to provide informed consent to participate and/or to complete the written questionnaire, and severe vision and hearing impairments, since the questionnaire will be administered in written format and/or verbally. Participants are being recruited primarily via residential care and assisted living facilities, older peoples' groups and other community groups, personal contacts as well as the end user group set up for another AAL Call 4 project EXO-LEGS ([www.exo-legs.org](http://www.exo-legs.org)) to ensure a variety of individuals of varying functional capacities are included.

The questionnaire was designed in English and has been translated to Danish, Swedish, Flemish, French and German to enable distribution across all partner countries. Questionnaires may be completed via email, post, or face-to-face according to the preference of the participant. Approval is being obtained from the relevant ethics committees in each country in which the questionnaire has been administered; it has already been obtained in Ireland and Sweden for the EXO-LEGS project and the initial results reported here are based on completed questionnaires via these sources. All participants provide written informed consent prior to completing the questionnaire.

### 2.1. Questionnaire 1: Description of content

Questionnaire 1 is composed of four sections. Sections 1-3 utilize ranking systems to seek participants' opinions on the importance of sample upper-, lower- and full-body motions to the performance of their usual daily activities. Examples of common tasks in which each motion may be performed are provided based on technical complexity of the assistive exoskeleton needed to support them. In each of these sections, participants may also add additional key motions which are not listed, including their rankings.

Section 1 asks participants to rank a list of 15 lower-body motions in terms of their importance in helping with their personal mobility (1 being most important, 15 being least important). The motions listed have previously been ranked in order of importance by older adult end users in a European survey carried out within the EXO-LEGS project (AAL Call 4 Project); therefore the present study will further validate these results in samples from additional European countries.

Section 2 asks participants to rank a list of 14 upper-body motions in terms of their importance in facilitating their usual daily activities. Participants are instructed to assume that the motions are performed standing still or in a seated position, so that only the upper-body demands of the task are considered. The list of upper-body motions was compiled by the AXO-SUIT team, and classified according to the type of upper-body exoskeleton required to assist the motion, namely, 1) an arm exoskeleton, where the shoulder, elbow and wrist joints may be assisted, and 2) an arm and hand exoskeleton, where all the arm joints as well as the hand (including finger) joints can be assisted to allow gripping and detailed manipulation of objects.

Section 3 asks participants to rank 10 full-body motions i.e. coordinated upper- and lower-body motions, in terms of their importance in the performance of their usual daily activities. The list includes motions of varying technical complexity in terms of exoskeleton usage, with lower-body, arm and hand assistance being required in various combinations.

Section 4 asks participants basic details about their age, gender, height, weight, residential status, interest in and knowledge of technology. This section also asks participants to rate their current status on a five-point Likert scale in four health-related domains: mobility, self-care, usual daily activities, and pain, as per the EQ-5D-5L instrument [8]. The questionnaire concludes with an open question allowing participants to provide comments or additional relevant information.

### 2.2. Data analysis

As this study is on-going, preliminary data only are available and therefore detailed statistical analysis is not appropriate at this time. Thus, the present paper provides an overview of the current sample characteristics and reports the top three lower-body, upper-body and full-body activities identified by current participants. The specific order and weighting of these activities will not be listed, as the small sample size does not allow for meaningful interpretation of these rankings as yet.

## 3. Preliminary results

Preliminary data from 16 participants have been obtained to date – ten in Ireland, and six in Sweden. The basic characteristics of this preliminary sample are summarized in Table 1.

Table 1. Characteristics of Questionnaire 1 participants to date (n=16). Data presented as median (range).

Variable	Primary (n=13)	Secondary (n=3)
Age (years)	72 (62-86)	29 (27-29)
Gender (% females)	84.6%	66.6%
Height (cm)	163 (155-180)	170 (169-179)
Body Mass (kg)	75 (70-79)	60 (58-75)

Table 2 summarizes the residential and health-related functional statuses of all participants. Data from both primary and secondary end users are included in Table 2, as secondary end users answered in relation to a primary end user with whom they have direct contact.

Table 2. Residential and functional statuses of participants (n=16).

Variable	% of Total Sample
<b>Residential Status</b>	
Alone	25%
With a spouse	44%
With other relatives	13%
In a nursing home	6%
With other residents in residential/shared living	12%
<b>Mobility</b>	
No problems	81%
Slight problems	6.3%
Moderate problems	6.3%
Severe problems	6.3%
<b>Self-care</b>	
No problems	94%
Moderate problems	6%
<b>Usual activities</b>	
No problems	88%
Slight problems	6%
Severe problems	6%
<b>Pain/Discomfort</b>	
None	44%
Mild	38%
Moderate	19%

### 3.1. Activities requiring assistance

The main lower-body activities which participants cited as requiring assistance to perform were 'Sit to stand', 'Standing', and 'Bending down to the floor'.

The top ranked upper-body activities were 'Lifting/dropping without grasping' e.g. lifting/lowering an object from the floor, 'Pushing/pulling horizontally' and 'Carrying an object in front with both arms'. 'Reaching to the side overhead/opposite shoulder' was closely ranked with these activities also.

In terms of full-body activities, the current sample reported a desire for assistance in 'Bending over/stooping to the floor/ground', 'Getting up from kneeling' and 'Getting up from a squatted position'.

## 4. Discussion

Preliminary data from potential AXO-SUIT end users indicate that the current highest priority tasks for which assistance is required are gross motor functions which bring about vertical displacements of the body's center of mass. These functions are necessary for essential mobility tasks, such as sit-to-stand and stand-to-sit transfers, and more challenging tasks such as getting up from kneeling and squatting positions. These functions were also ranked

highly when combined as coordinated upper and lower limb motions for tasks such as bending, lifting and lowering from floor/ground height.

These findings have multiple potential implications for the design of AXO-SUIT. Since lower limb strength in sagittal plane movements are key determining factors in sit-to-stand performance [9], the AXO-SUIT lower-body subsystem will need to assist these motions, while avoiding design features that may impair peripheral sensation and balance, as these are also major sit-to-stand performance determinants [10]. The design must also cater for sufficient mobility and comfort to allow the wearer to attain squatting and kneeling positions. In addition, the design of trunk-worn components of AXO-SUIT must meet similar criteria in order to facilitate bending, stooping and lifting/lowering tasks.

In terms of the upper-body subsystem, the current data indicates that assistance with upper-body power (e.g. pushing/pulling) and strength endurance (e.g. carrying) activities are the main priorities for end users. This is unsurprising, given that muscle strength and power decline with age [11]. The activities listed by the current sample primarily require assistance in the sagittal plane, thus these motions must be prioritized in AXO-SUIT upper-body subsystem design. Mobility must also be highly prioritized for the upper-body subsystem, particularly in the shoulder region, to facilitate the performance of overhead activities and those that cross the midline of the body e.g. reaching behind the head or over the opposite shoulder.

Load carriage tasks also feature prominently among the preliminary list of functions for which assistance is required by older adults. Carrying objects while walking is a complex dual-task which presents both motor and cognitive challenges, particularly in real-world situations where environmental factors further increase physical and cognitive demands, and such dual-task performance frequently declines with age [12]. Coordinated AXO-SUIT upper- and lower-body subsystems will be required to assist users' gait, balance, and upper- and lower-body strength to reduce the physical demands placed upon the end user when performing such tasks.

The primary limitation of the present study is the small current sample, which precludes in-depth analysis of the data obtained and the drawing of precise conclusions at present. Due to its size the current sample also presents a degree of bias in that it largely represents primary end users with high functional capacity levels, as evidenced by the fact that the majority of participants reported a lack of problems with mobility, self-care and usual activities (Table 2). However, the present study is on-going, and further data from end users in Ireland, Sweden, Belgium and Denmark will be obtained. It is anticipated that approximately 80 responses will be obtained from a combination of primary and secondary end users, which will provide a more representative indication of the needs of this end user group in relation to an assistive exoskeleton.

In summary, the present paper provides useful preliminary data on end user requirements, most notably for complex full-body tasks requiring coordinated upper- and lower-body assistance. The main activities for which end users express a desire for assistance may potentially change as the study progresses and the sample broadens to include older adults with greater functional impairments (and secondary end users reporting on such individuals). Despite this, the preliminary results reported can be used to inform the technical requirements and initial design considerations for an assistive exoskeleton for older adults as part of the AXO-SUIT project. Further questionnaire studies to determine end user opinions the design and aesthetics of prototype exoskeletons, as well as factors influencing commercialization potential, are planned.

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