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ORIGINAL RESEARCH

Assistive robots to improve the independent living of older persons: results from a needs study

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ABSTRACT

Background: More than 70% of elderly people age 80 and older are experiencing problems in personal mobility. Assistive robotics can represent a concrete support providing also a support for caregivers, clinicians and nurses by reducing their burden.

Methods: A total of 20 older people and 34 caregivers (formal and informal) were interviewed in Italy and the Netherlands to investigate and prioritize their needs concerning the personal mobility domains and their attitudes towards assistive robots. The data were analysed from a user point of view by means of thematic content analysis by underlying recurrent topics.

Results: The results revealed four categories of needs from the perspective of the older individuals: instrumental needs, rehabilitation needs, personal safety and indoor activities of daily life. Additionally, the results underline how personal mobility issues influence different aspects of daily life. Complementarily, three categories of caregiver needs were also distinguished: instrumental needs, rehabilitation monitoring needs and checkup needs. The highest percentage of participants showed a positive expectation towards assistive robotics.

Conclusions: The results were clustered according to the robot abilities (i.e., motion, interaction, manipulation, decision support and perception abilities) as a list of functional and technical requirements that should be developed to address all the needs related to the personal mobility. Robotic developer teams that work in this context could take advantage of this research. Additionally, this work can be used as a basis for clinicians and nurses working in geriatric units to understand how the robots can support and enhance their work.

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KEYWORDS
Personal mobility; assistive robots; technical and functional requirements; needs study; elderly people

➤ IMPLICATIONS FOR REHABILITATION

- The incidence of personal mobility limitations affects 35% of adults age 70 and older and 72% of people over 80 years of age.
- Assistive robots can support elderly people during daily tasks: they could promote their personal mobility acting as a supporting tool.
- The results of the needs analysis revealed four categories of needs from the perspective of the older individuals: instrumental needs, rehabilitation needs, personal safety, and indoor activities of daily life.
- Three categories of caregiver needs were also distinguished: instrumental needs, rehabilitation monitoring needs, and check-up needs.

Introduction

The increase in the number of elderly people is transforming the shape of the European age pyramid, challenging governments and public institutions. According to a recent statistic, in 2017, nearly one fifth (19.4%) of the EU population was aged 65 and more. It is important to notice the increase of 0.2 percentage points compared with the previous year and an increase of 2.4 percentage points compared with 10 years earlier. Additionally, the old-age dependency ratio for the European population the EU-28 was 29.9% on 1 January 2017; this ratio is destined to increase because of the low birth rate and the increase in life expectancy [1]. This statistic will lead to a growing demand for nurses and clinicians [2]. Ageing in place is a policy in most countries [3–5], which also impacts the network around an older person: the informal caregivers [6,7].

It is clear that we are living a socio-demographic challenge that we need to face to guarantee an adequate ageing in place with an acceptable quality of life (QoL). QoL is a broad-range

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concept which means to "*incorporate objective and subjective evaluations of physical, material, social, and emotional well-being together with the extent of personal development and purposeful activity, all weighted by a personal set of values*" [8]. The QoL of elderly people consists of multiple dimensions, including physical health, psychological state, level of independence, social relationships and their relationship with salient features of the environment [9,10]. Particularly, the incidence of personal mobility limitations affects 35% of adults age 70 and older and 72% of people over 80 years of age [11]. Concerning the "level of independence", personal mobility is one of the key aspects, and it is influenced primarily by the following main factors:

- The *physical environmental context* where the older person has to live and move around, such as the distance among the rooms, the "space planning", the electricity and the noise [10]. The independence of the elderly depends heavily on the facilities of their housing, particularly the indoor areas of individual flats. The relative distances of different functional rooms (e.g., bedrooms, bathrooms, toilets, kitchens and living rooms) will affect their daily activities, such as resting, having dinner and participating in social gatherings [12]. Outside the home, older people are even more affected if they have mobility problems, which limit their ability to go shopping, visit family and friends, or participate in recreational activities [13].
- The *age-related changes* such as impairments in vision and/or reaction time may be incongruent with specific challenges presented by environmental conditions, making mobility hazardous in certain circumstances (i.e., walking on a slippery surface or on uneven pavement tiles). Furthermore, older persons experiencing a decrease in motor and cognitive abilities, which could affect the personal mobility in indoor environment [14,15].

On the other hand, the World Health Organization [16] underlines that the cooperation between care professionals and informal caregivers should be the basis of primary care for older people. Indeed, informal caregivers are crucial partners in the care of elderly individuals and may help them to stay at home longer [17]. Sometimes informal caregivers perceive a burden from their role, which is related to complex and multidisciplinary factors such as the patient and the caregiver characteristics (i.e., demographics, educational level, cohabitation), the psychological factors and the disease related factors among others [17,18]. These negative consequences can affect the QoL and the quality of care perceived by the older individuals.

Recent researches [19–22] underline that assistive robots can support elderly people during daily tasks; additionally they could promote their personal mobility acting as a supporting tool. Indeed the added value proposition for these assistive robots is the physical interaction, when the robot provides functional assistance to walking tasks to humans with mobility problems [23]. It is worth to mention that assistive robots could support informal caregivers, nurses and clinicians during their working task by leveraging them from tedious or physical tasks [24].

Over the last years, several prototype robots were developed to keep people independent as long as possible. These prototypes include, among others, DoRo [25] from the Robot-Era project, Care-o-Bot III [26], Kompaï from Mario Project [27], GiraffPlus [28], the robot assistant from RAMCIP project [29] and Growmu from GrowMeUp project [23]. These robots are mainly devoted to the promotion of social inclusions and the well-being, so few assistive robots focused on the support of personal indoor mobility. Only five out of 10 project were founded on this topic between 2011 and 2015 [30]. The literature related to assistive robots universally stresses the importance to include the end-users from the initial stage of the developmental process to improve the fit between the user needs and robot services and thus the acceptability by the market. The co-designing with users, which can have different levels of intensity (from drafting the initial concept together, to asking feedback on a prototype), has proven to enhance the usability and the acceptability of products [31,32]. Interestingly, only few studies focused on the inclusion of formal and informal caregivers, in addition to elderly people, in the development process [30]. Formal and informal caregivers are, however, important stakeholders which should be included in the development chain [33]. The informal caregiver, for example, a husband or other family member adds a relevant perspective because they are also affected by the mobility problems of the elder, either because they help the older person to move in and around the house, or because they take over tasks. A robot might also relieve their burden. In the same way, formal caregivers play an important role, because they have expert knowledge on mobility issues, and they potentially could be the final end-user of a robotic service for the patients they are treating for mobility problems.

In this paper, we address the following research questions: *What are the personal indoor mobility needs of older persons, also from caregiver point of view? What are the technical and functional requirements for social robotics solutions that address these needs?* To answer these questions, we use data from the "Agile Co-Creation of Robots for Ageing (ACCRA) project" [30]. This project aims to design and develop – among others – an assistive robot able to support older people in indoor mobility tasks. In the design of the robotic service chain in ACCRA, which is based on co-design, both older persons and caregivers are the principal investigators.

First, this paper presents and discusses the mobility needs and attitudes towards robotics, collected through semi-structured interviews in a population of elderly individuals and their informal and formal caregivers. Then, the paper presents and discusses the needs from a roboticist point of view to define the technical guidelines that can be used from technical developers to define the future steps in the development process of robot functionalities. This study was executed in two European countries: Italy and the Netherlands.

Methods

This study on the needs of older people and the translation of the needs into technical requirements took a qualitative approach. We wanted to gain an in-depth understanding of the types of mobility issues older people face and the consequences for the technical requirements of an assistive robot to be used by these older people independently at home or as part of mobility rehabilitation or training at a care facility. Moreover, we sought to take into account the attitudes of the elderly individuals and their formal and informal caregivers towards robotics.

Recruitment

The study was performed in two countries: Italy and the Netherlands, both participated in the ACCRA project for the mobility use case. In the Netherlands, the participants were recruited from WVO Zorg, a long-term care organization in Vlissingen. The elderly people were recruited from a home care service, daily activities service and rehabilitation service, while the formal caregivers were working in the care facility or in the community. In Italy, older people and formal and informal caregivers were contacted by the Alzheimer's Evaluation Unit of Geriatrics Unit – IRCCS "Casa Sollievo della Sofferenza" in San Giovanni Rotondo. Inclusion criteria were that the older person was aged 60+, had mobility problems assessed with the Elderly Mobility Score (EMS). We excluded people in wheelchairs and with cognitive problems. The formal and informal caregiver recruitments were based on their daily assistance for older patients or family members with mobility issues.

The recruitment and study procedures conform to the requirements of the Declaration of Helsinki. The local Research Ethics Committees in both countries approved the study. All participants were informed that their participation was based fully on their free will, and that they were free to withdraw their participation at any time. The participants were not compensated. Informed consent was obtained from all participants prior to entry into the study.

Data collection

To gain insights into the needs and attitudes, we performed semi-structured qualitative interviews in the homes of the elderly or informal caregiver, or in the care facility, between March and July 2017. The interviews with older people lasted 60–120 min, and with formal/informal caregivers 20–60 min. All interviews were audio recorded with permission of the respondents.

A detailed interview guide for the semi-structured interviews in both countries was developed for both respondent groups: elderly people and (formal and informal) caregivers. The topic list in the interview guide (Supplementary Appendix) was based on a literature search into common mobility problems and attitudes of (older) individuals towards robotics. The interview guide was created in English and translated to Italian and Dutch after finalization. This assured that the data collection in the two countries would be comparable.

The interviews were performed to obtain an understanding of the context and the way of life of the person with regard to their mobility issues in order to identify their needs in terms of daily activities, and to measure early indications of the robot's attractiveness and its main functionalities (which we conceptualized as attitudes). The interview consisted of two parts. Examples of starting questions for the first part of the interview with the older persons are: *Could you describe the problems that you have experienced in your daily life caused by your limited mobility? How do you feel about having mobility problems? What do you currently do to solve your mobility issues?* The interviews with the caregivers contained question such as: *"Which mobility problems affect independent living of your loved one/patient one the most?* The second part of the interview began with questions about the current experience with technology in general and how the respondent felt about robots. Then, a demo of a robot, ASTRO, was shown via the computer of the researcher, (https://www.youtube.com/watch?v=cx9n9zCxA1g&t=59s) demonstrating some services this robot can perform. This two-part structure was chosen to have an open approach to collect the needs of the older people, not steering them to any feature ASTRO does or does not offer.

ASTRO (Figure 1) is an assistive smart robotic platform dedicated to mobility and user interaction. It was designed to move within the home and nursing home environments [34] and to accomplish several daily task such as the walking support, the communication and the reminder. ASTRO is based on the Scitos G5 robotic platform (Metralabs GmbH, Ilmenau, Germany), whereas the design was defined with an user centre design approach within Astromobile project [31]. ASTRO robot is equipped with a laser sensor (Laser SICK 30B-2011BA) mounted on the front for the perception of the surrounding environment and obstacle avoidance. Additionally, it has a passive handle on the back to support the seniors during the indoor walking activity. On the front, it has a big screen that the user can use to access to the interfaces and manages the services. The respondents were encouraged to express their first impressions about the services ASTRO can perform, and link them to the mobility issues they expressed in part one of the interview.

Figure 1. Older individual uses ASTRO robot as a mobility support.

Data analysis

First, the recorded interviews were transcribed and analysed using thematic content analysis [35]. The first level of coding was meant to identify themes and units of meaning. Here, we stayed close to the wording used by the respondent. In the second level of coding, we used more theoretical words. Finally, the third level of coding was the actual analysis: looking for recurring themes, coherence and unique cases. The codes were placed in tables with relevant quotes from the interviews. The analysis of the data from the first part of the interview resulted in categories of needs, and the analysis of the data from the second part of the interview presented corresponding services a robot could perform to meet the needs. These services were partly connected to the demo of the ASTRO robot, for which the respondents indicated whether or not these services were considered important. Priority ranking of the needs took place based on the frequency a certain need was expressed during the interviews. In the analysis for the second part of the interview, regarding attitude towards robotics in general, and first impressions of the ASTRO robot specifically, the quotes were coded as either positive, neutral or negative.

The analysis of the data was conducted in the Netherlands and in Italy. To assure that the data analysis in both countries would follow the same procedure, we used the same template to report on the analysis and had several written and oral exchanges in the multidisciplinary research team, which consisted of geriatricians, psychologists, health scientists, health service researchers, robotics engineers and biomedical engineers. The last step of the analysis was to bring the data from the two countries together and perform a cross-country synthesis. We aimed to identify the commonalities and differences between the two countries regarding mobility needs, related priority services and attitudes towards robot services. For this, we looked at both quantitative differences (e.g., the type of mobility support needed, the number of older people positive about the robot) and qualitative differences (e.g., the type of arguments in favour of robots).

Definition of technical requirements

The prioritized needs categories were analysed from a technical standpoint according to the robot functionality described within the Robotic Multi-Annual Roadmap (MAR) [36] to cluster the robot abilities and functionalities [36] since this document constitutes the official document of the partnership for robotics in Europe (SPARC) and gives guidelines for future development in robotic fields. Robot functionalities and abilities are transversal and they are not related to a specific application field.

The MAR distinguishes between manipulation, interaction, decisional autonomy, motion and perception, among other abilities. In particular, for each needs category and related robotic service identified in the previous phase, the robotic abilities involved were defined. It is worth mentioning that to accomplish a requested service, sometimes more than one robotic ability is needed, and different categories could require the same robotic ability.

Each "need" and "robotic service" from the analysis of the interviews led to the identification of themes and specific technical and functional requirements (e.g., the robot should be able to avoid crashing into "dynamic" obstacles; the robot should be able to do laundry and hang, fold and put clothes away) that should be developed. Finally, the themes and the requirements were grouped according to the related MAR abilities thus generating guidelines for future developments in this field.

Results

Mobility needs

In the interviews, people expressed that mobility problems limited their lives in many ways. These needs are reported in Tables 1 and 2 (elderly needs and caregiver needs respectively), and grouped according to whether they are primarily bound to mobility itself (the instrumental needs) or to the consequences for daily life of having mobility problems. For each needs category, the services considered as priorities by the interviewees are listed, and quotes from the interviews are added as an illustration. A distinction is made between needs for the older individuals themselves (expressed by the elderly *and* caregivers during the interviews) and needs for the caregivers themselves that refer to the support they need in their care for people with mobility problems (expressed only by caregivers).

Older individuals experience problems when walking around, standing up and moving to different locations within their homes or moving to different locations in the care facility. They are afraid of falling as well. Moreover, mobility problems also have an effect on many other daily activities: when getting dressed, carrying items or performing housework-related activities. For all these needs, older people may need help. They use technologies such as walking rollators, or more often, they depend on help from others.

When discussing how robots could meet these needs, older people expressed that a robot could motivate them, give them instrumental support, and call for help in case of an emergency (e.g., a fall). Some people also expected that a robot could perform activities for which normally the respondent needed to move, such as going to the kitchen for coffee, or taking care of a pet. We did not find any difference in needs between older

Table 1. Needs expressed by elderly people grouped into categories.

Needs category	Description	Service which the robot could perform	Requested robot abilities
Instrumental needs	Getting up or sitting down in a chair, getting out of bed, walking inside the house or inside the care facility	The robot could provide balance and leaning support "If you have troubles getting out of bed, then he can help. You can also walk behind him instead of using a walker" (Respondent 7, NL) "It is huge! But on the other hand, that is an advantage maybe, so that it can help people get up. Because that's the most difficult thing." (Respondent 5, NL)	Motion
Rehabilitation needs	Doing physical exercise aimed at maintaining or improving mobility	The robot could suggest exercises and monitor how the elderly perform them "I believe that this robot is useful to help us in physical exercises and in moving in hospital" (Respondent 3, IT). "The exercises I would find useful. That the physiotherapist does not have to come to my house, and I do not have to go there." (Respondent 4, NL)	Interaction Decisional autonomy Perception
Personal safety	Being able to walk safely, with a minimum risk of falling; Being able to warn a caregiver in case of an emergency, such as a fall	The robot could keep an eye on the elderly, could detect obstacles on the floor, could detect falls, could send a message to a caregiver. "I like the alarm function of the robot. I know of people who fell and who have been lying on the floor for hours because they could not reach their social alarm." (Respondent 10, NL)	Motion Perception
Activities of indoor daily life	Being able to fetch and carry items, doing housework	The robot could also perform some activities independently such as bringing a glass of water "A tray would be great, so I can put some stuff on it, and the robot can put it in the closet." (Respondent 7, NL)	Manipulation

Table 2. Needs expressed by caregivers, grouped into categories.

Needs category	Description	Service which the robot could perform	Requested robot abilities
Caregiver instrumental needs	Being able to lift or carry the elderly without physical discomfort for the caregiver	The robot could lift or carry people "It would be nice if the robot could lift people, or help them turn over in their bed. That would really ease our work, because now we have to ask a colleague." (Respondent 8, NL)	Motion
Rehabilitation monitoring needs	Being able to monitor health status and whether physical exercises have been performed (well)	The robot could automatically collect and store data "The robot could assess and manage the gait, in way to reduce the risk of fall and personalize the care" (Respondent 5, IT).	Perception
Checkup needs	Being able to check up on an elderly without going to their home	The robot could visit the elderly regularly to check if everything is all right and support them in going to bed and using the toilet "What I would find useful is that you can call the robot to help when someone has to go to the bathroom, or has to go from one room to the other. That will save me time that I can use for other people." (Respondent 7, NL)	Perception Interaction

Table 3. Characteristics of the older individuals.

	Italy	Netherlands	Total
Gender			
Male	4	3	7
Female	6	7	13
Age			
Average	76.1 ± 6.8	80.0 ± 8.9	78.1 ± 7.9
Housing situation			
Rehabilitation ward	0	3	3
Nursing home	4	0	4
Senior residence/home	6	7	13
Living situation			
Living alone	1	8	9
Living with partner or children	9	2	11
EMS score			
<10	0	1	1
10–13	10	2	12
13–16	0	3	3
>16	0	4	4

Table 4. Characteristics of the caregivers.

	Italy	Netherlands	Total
Gender			
Male	12	0	12
Female	18	4	22
Age			
Average	54.1 ± 15.7	41.0 ± 9.6	52.9 ± 15.6
Role			
Formal			
Nurse	3	4	7
Geriatrician	12	0	12
Informal			
Relative	14	0	14
Volunteer	1	0	1

individuals depending on the specific characteristics of the Italian and Dutch group (depicted in Tables 3 and 4).

Caregivers expressed the same needs as the older people themselves. However, they also have additional needs when taking care of elderly individuals with mobility problems, because they spend a lot of time monitoring to ensure that elderly people perform enough exercises. They also experience physical challenges when they mobilize an elderly person from a chair or bed. When discussing how robots could meet these needs, the caregivers express that a robot could physically support them, collect and store data for them, and keep an eye on the older individuals.

Attitudes towards assistive robots

At the beginning of the second part of the interview, ASTRO robot was shown to the respondents, using videos (with subtitles in native languages) and photos. Most of the older respondents expressed a positive attitude towards ASTRO (13 respondent out of 20) as summarized in Table 5. It is important to notice that the dominating positive attitude (see Figure 2) stems from the belief that ASTRO will improve independency, feelings of security, and lessen the burden of formal or informal caregivers: older individuals also deem themselves capable of controlling the robot properly, even if they are not very experienced with other technological devices, such as computers, tablets or smartphones. For the participants, ASTRO can be used for rehabilitation therapy procedures, such as gait training, to help patients with mobility issues during the hospitalization. By dynamically adjusting user control weight according to different user control efficiencies and walking environments, ASTRO can improve the user's degree of comfort when using the device and automatically adapt to the user's behaviour.

However, some older people still have to be convinced of the added value of robotic solutions such as ASTRO because they are unsure if ASTRO would be beneficial for them. This more neutral position was expressed primarily in the Dutch respondents. For example, they say they think the robot can be beneficial for other people, not for themselves, because they are still very independent. They also think they might become more dependent as they will remain passive unless ASTRO assigns them a task. The elderly people also fear that the little social contact they have with the caregivers will diminish, as ASTRO will take over the guidance and support they receive from them. Some are also afraid that ASTRO will attract unwanted attention, as it is a large robot and a new and unknown device. They do not want to be part of gossips or stand out. One elderly person was even explicitly negative as the human aspect of care would vanish in his view.

Caregiver

The caregivers in both countries are also positive about ASTRO, indeed 22 respondents out of 34 had a positive attitude, but their opinions differ considerably. Dutch caregivers seem to be less positive, because at this point in time, they find that the functionalities of ASTRO are still too limited to solve mobility issues. They do believe that the robot could help older people with some of their mobility problems in the future, but they find it difficult to imagine how the robot would function in their daily practice. They have a "wait and see" attitude and would like to see how ASTRO performs before fully rejecting or accepting the robot. Similar to the older individuals, they also feel that the use of robots might diminish social contacts and endanger the needed warmth of human contact. Finally, the caregivers state that social assistive robots must be easy to use. Complicated menus or

Table 5. Perception towards robot.

Country	Positive	Neutral	Negative
Elderly			
IT	8	1	1
NE	5	4	1
Subtotal	13	5	2
Quotes	"I believe that is quite positive. People are able to move around without help." (Respondent 8, NL)	"If I need more help, this thing would be ideal" (Respondent 7, IT)	"I do not believe that a robot can help us in mobility issues". (Respondent 9, IT) "I don't see it with this robot. I am not so technical." (Respondent 6, NL) "If you are in the situation where you have to live with a robot, then your quality is life is almost zero." (Respondent 4, NL)
Caregiver			
IT	22	3	5
NE	0	4	0
Subtotal	22	7	5
Quotes	"This robot can surely improve the patient's quality of life" (Respondent 13, IT) "If people miss human contact, this would be a good addition" (Respondent 2, NL)	"Actually, I have to wait and see how it works, this robot with the elderly. I don't know if it will work or be a failure" (Respondent 3, NL)	"I do not see much potential in a robot. It is not human, everything is done by a machine" (Respondent 6, NL)
Total	35	12	7

Occurrence of answers for each group (elderly people and caregiver) and country (Italy or The Netherlands).

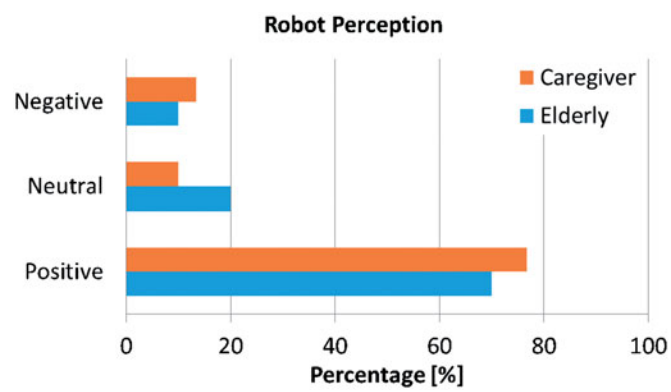

Figure 2. Attitude of elderly people and caregivers towards robots. This graph reports total occurrence of the answers (positive, neutral and negative). The results were expressed in percentage of the total (20 elderly subjects and 34 caregivers) to easily compare the feedback of the two groups.

instructions will demotivate them from using ASTRO. The Italian caregivers see more potential in ASTRO. The main safety needs resulting from the interviews were mobility dysfunctions (with emphasis on risk of falls). A caregiver reports how beneficial it would be when robots predict the likelihood of falls by measuring gait and pace length of patients.

Technical and functional requirements

The results underline and prioritize a set of needs in the context of personal mobility. In particular, they point to several key themes for the technical and functional requirements for assistive robots. These themes were grouped according to MAR abilities (see Table 6). Particularly, the results show the main requirements concern the motion, manipulation, perception, decisional autonomy and interaction abilities of the assistive robot.

The first group collects all the functional requirements related to the *motion*, which is the ability of a robot to move. This is a complex ability that implies also the planning and perception, sensing, and localization and mapping abilities. In this context, the main identified theme is autonomous navigation (AN) since the results clearly indicate that the robot should be able to autonomously move in indoor environments in a safe manner (AN1), avoiding obstacles (AN2). The AN is an issue that has been heavily investigated in the current state of the art, and recent results reveal a high level of maturity of AN technologies [37]. Nevertheless, further issues should be investigated to achieve a dependable and acceptable AN. As concern the first aspect related to the dependability, future development of assistive robots should consider the dynamic variations in the environment that could occur on long-term evaluation. Although this aspect has been investigated in recent works [38,39] and EU-projects (i.e., SPENCER, STRANDS), a cloud-based approach can be used to go beyond the state of the art, enabling the sharing and managing of information on the environment among multiple platforms and, above all, over longer periods of time [40]. As concern the other aspect related to the acceptability, the social navigation represents the field of research that studies the implementation of navigation solutions able to incorporate not only "robotic issues" (as obstacle avoidance) but also "social issues" that involve the comfort of user experience [39]. Considering differences in cultural background, the navigation should be modelled based on a learning approach which will be able to deal with several differences in cultural aspects (as mentioned in the Lewis models [41]).

From the analysis of needs (Tables 1 and 2), it is clear that interaction with the environment (in the specific scenarios this includes furniture and common-use objects) is an ability needed to perform the desired tasks (APP, MM). *Manipulation capabilities* were historically investigated for industrial purposes in highly structured environments, but manipulation in domestic areas requires high adaptability and perception abilities to manage a large variability of objects and situations (APP1 and MM1).

Another group concerns the *perception ability*, which is defined as the ability of the robot to perceive its surrounding environment. As remarked from the results, older people need to feel independent, which underlines the necessity to have support in their daily mobility tasks (theme SPM). In this context, future efforts should promote the implementation of a reactive control on the mobile platform, which can be adapted on the personal needs (SPM1 and SPM2), based on: (1) sensors on the robot (e.g., pressure and force sensors on the handle, laser scanner pointing at user's legs). (2) Physiological sensors on the user; (3) *a priori* and personalized knowledge gathered on previously performed tasks (desired speed, acceleration, etc.). (4) Clinical diagnosis and status of the end-user (e.g., the robot is aware that the user can use only one arm due to an injury). Another theme that arises mainly from results of the caregivers' interviews regards the

Table 6. Technical and functional requirements.

Robot abilities	Theme	Code	Technical and functional requirements "The robot should be able to … "
Motion	Autonomous navigation (AN)	AN1	Have "Safe guidance"
		AN2	Avoid crashing into "dynamic" obstacles
		AN3	Consider the "social" aspect of the navigation
		AN4	Identify the user's position
		AN5	Move in narrow spaces
Manipulation	Autonomous pick and place (APP)	APP1	Pick up a known object, location and orientation not pre-defined.
	Manipulation motion (MM)	MM1	Manipulate ad hoc end-effectors/tools on unknown surfaces
Perception	Support to personal mobility (SPM)	SPM1	Implement a personalized physical human robot interaction
		SPM2	Adapt robot mobility on user status
		SPM3	Activity and posture recognition
		SPM4	Detect falls and other anomalies
		SPM5	Consider usability issues
	Key indices of mobility and well-being (KIMW)	KIMW1	Identify the motor parameters correlated to the clinical status
		KIMW2	Monitor activity
		KIMW3	Send daily feedback on the users' mobility performances
		KIMW4	Analyse large amount of data
	Data management (DM)	DM1	Privacy
		DM2	Data storage of "sensitive data"
		DM3	Be connected to an infrastructure able to storage large amount of data
Decisional autonomy	Robot reaction (RR)	RR1	Model the navigation considering also the cultural aspects
		RR2	Implement a reactive control
		RR3	Alert family or experts in case of anomalies
		RR4	Have a personalized behaviour
		RR5	Suggest proper mobility exercises
Interaction	Advances multimodal human-robot interaction (AHRI)	AHRI1	Easy to use
		AHRI2	Offer a choice between feminine and masculine Voices
		AHRI3	Recognize the users (face detection)
		AHRI4	Recognize users' emotions
		AHRI5	Multimodal user interface to access the services

health indices that the robot could monitor to support their work (KIMW). Thus, while the user is walking, the assistive robot should be able to analyse these outputs simultaneously to provide information on the physical performance. According to the results, formal caregivers would like to receive daily feedback on the performance of users' mobility tasks, and they would like to store health data. A scientific challenge could be to understand *which* motor parameters can be associated with a particular clinical status and, from a more technical point of view, *how* these parameters could be measured during the robot's typical usage. Another theme to consider is related to the infrastructure needed to manage the huge amount of data gathered by heterogeneous sensors and systems addressing (also) the issues of security, personalization and data allocation of the medical and related records (DM). Additionally, since different types of sensitive and personal data were acquired during the interviews, to highlight the needs of elderly individuals, a well-structured research data management process is needed as a cornerstone to regulate knowledge discovery, integration and reuse.

A fourth group concerns the *decisional autonomy* ability, which is the ability of the robot to act autonomously. For instance, the robot could autonomously plan a reaction (RR) according to the external perception of the static and dynamic environment. Today, much information from personal devices is available; therefore, a personalized approach should be investigated to deal with inter-subject variability and cultural aspects (RR1) as well. Future development should lead to create a novel way of managing physiological and environmental data able to autonomously monitor the status of older users (KIMW2) and to identify critical and anomalous situations to properly react to by calling the relatives/caregivers (RR3) or suggesting a specific exercise (RR5). The scientific challenge would be the integration of all these heterogeneous information pieces collected by the robot (i.e., emotion, activity, physiological and clinical data) that will lead towards an assistive robot with personalized behaviour able to deal with differences among single users (RR4).

The last group is related to the *Human-Robot Interaction Ability*. Assistive robots need to be able to identify and properly react to emotions to accomplish successful social interaction with humans. Smart actuators can be used to provide sensorized multi-modal feedback to the users and thus to reinforce the communication according to the preferences and the residual abilities of the older users (AHRI5). Additionally, concerning the user interface, the assistive robot should envisage multi-modal interaction interfaces to guarantee an easy access to the service to people with limited residual abilities.

Discussion

A multidisciplinary team, including geriatricians, psychologists, health scientists, health service researchers, robotics and biomedical engineers conducted the analysis to identify the most common needs so they could present a list of needs and requirements which can be used in the future for the development of specific assistive robotic applications that support personal mobility. For the best of our knowledge, the finding of this need studies is important, because it could shed light on the current ways elderly cope with mobility issues, such as the informal and formal caregiver, and what is the expected role of assistive robots.

In this study, we focused on (indoor) mobility needs, but the interviews also revealed that mobility problems have huge impacts on many other aspects of life. This finding is aligned with the state of the art [42,43] that demonstrate a direct association between decreased mobility and decreased health-related QoL. Some of the mobility needs expressed in the interviews can be met with existing technologies such as rollators, but others rely on more intelligent solutions that service-assistive robotics can deliver. Indeed, these people might also have problems with their memory, their psychosocial status or their feelings of safety. As a result, a robot that only provides physical assistance would be of less value for them than a socially assistive robot. In other words, these results suggest that future development in this field should move towards assistive robotics able to provide also physical assistance which requires high social and interaction capabilities. Indeed, as highlighted from the results, the users (older person and caregiver) would like to have a robot able to adapt to their abilities and behaviour (Tables 1 and 2). Robotics solutions that aim to support independent living should be adaptable to a broad range of needs, and not focus too much on only one aspect of daily life. To date, high-quality research into effects of assistive robotics for health and well-being of older persons is limited, but the indications that assistive robotics can support independent living and contribute to QoL are strong [44].

Currently, a significant amount of information comes from personal devices [45]. These sensors can be worn by the users or mounted on the robot: for instance, inertial measurement units can be worn by the users to estimate their gait parameters [46], or their signals can be fused with odometer information measured by laser scanners which are usually placed on the robot [47]. Additionally, to achieve human-like interaction the robot is required to have competence in decoding emotions and showing advanced interaction abilities. Assistive robots would need to measure and quantify the same sensory cues that are processed by humans, such as linguistic, facial, body movement and physiological features [48]. In this context, innovative cloud-based solutions, such as the Affectiva Emotion or Microsoft Azure APIs, have recently opened new scenarios of research, enabling the possibility to introduce, among others, additional information concerning the “basic” emotions of older individuals (i.e., “sadness”, “joy”, “disgust” and “anger”) [49]. For instance, the most advanced affective model specifically developed for robots is the TAME architecture [50], which considers the four categories of personality traits, attitudes, moods and emotions. In this sense, future researchers should focus their investigative efforts on how to combine this information to reach the goal.

It is worth to mention that caregivers would like to have a robot able to support them during the work and that can continuously monitor the status of the older individuals (Tables 1 and 2). This result is aligned with the state of the art, indeed experts [51] underlined that sarcopenia has been associated with geriatric syndromes, morbidity and mortality and is related to different aspects of muscle mass, muscle strength and physical performance. Furthermore, frail elderly people are more at risk of adverse health outcomes (disability, falls, hospitalizations, institutionalizations and death) [52]. Additionally, several clinical studies support a relationship between daily behaviour and cognitive and physical health and how they change over time [53]. In this context, the definition of anomalous situations should be generated in a behavioural analysis of older users based on autonomous recognition of daily activities. This requires going beyond the state of the art to where detection of critical situations is usually performed without an *a priori* knowledge, as in the work described in [54] focused on fall detections, or as in the study presented in [55].

As concern the attitude towards robot, the presented analysis did not find differences in needs between older people from Italy and the Netherlands, even though the two groups differed in current level of mobility. Generally, the respondents in Italy were on average more positive about the ASTRO robot than the Dutch respondents and Dutch older respondent have more neutral impression than the Italian group. Also, there were no significant differences between the Dutch and Italian caregivers, but the needs expressed by the Italian formal caregivers seemed to be more oriented to clinical application of robots. These differences can be explained by the context of the research (community care versus hospital care) and the role of the respondents (nurse or geriatrician) (Tables 3 and 4). It is unlikely that this is caused by differences between countries. Due to the small sample size, there are differences in the number of respondents in both countries and the different settings. Future studies should be planned to enlarge the sample size and collect data in different settings.

The findings presented in this paper about the attitude of older people towards technological solutions such as robots, are aligned with the state of the art. Also other research has shown that older people tend to be positive about technology in general, but they do not want to have the technology themselves [23,56]. However, we know from other studies that family plays an important role in the acceptance [57], so they need to be positive about the robots as well. Moreover, there is a difference between having a positive attitude and actually using technology [58], so the results of this study are only an early indication that assistive robots will be accepted by their intended users. Conclusions about the actual level of adoption would require a real-life experiment.

Finally, it is worth to remark that most of the technological products developed for the elderly are not specifically designed for them, i.e., taking into account their specific needs. Therefore, although considered useful, technology is perceived as too demanding for the majority of elders, often too intrusive, complex and rarely disruptive. To optimize the fit between need and service, and to support the acceptability of robotics by older persons, they should be included in the design and development. The approach in the ACCRA project is an example how this could be done. In this project, we apply the principles of agile technology development and co-creation methodology [59]. During so-called co-creation sessions, health scientists and marketing scientists facilitate discussions between robotics engineers and potential users of the robot (older people, formal and informal caregivers), using creative techniques to collect input such as mind mapping, role playing and prototype testing. In between two co-creation sessions, the engineers work in small cycles on the feedback received. This approach has been very useful for the development of ASTRO [60].

Conclusions

The aim of this study was to present the needs of elderly people and caregiver related to the personal mobility needs and the technical requirements for assistive robotics. The results of the needs analysis revealed four categories of needs from the perspective of the older individuals: instrumental needs, rehabilitation needs, personal safety and indoor activities of daily life. Complementarily, three categories of caregiver needs were also distinguished: instrumental needs, rehabilitation monitoring needs and checkup needs. Although some respondents were more hesitant towards robotics, overall both the older people and the caregivers were positive about the ASTRO robot presented to them.

The results of this paper can be used by the assistive robotic researchers’ community as a guideline of functional requirements for future development in the fields of applied gerontology and service-assistive robotics. Moreover, the results of this mobility needs study make it possible to prioritize the functionalities of robots to be implemented in order to improve the aging well-being of older people in loss of autonomy.

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Ethics approval and consent to participate

In Netherlands, the study protocol was approved by the Medical Ethical Committee of the Erasmus Medical Center in Rotterdam, The Netherlands, under number: MEC-2017-536. In Italy, the study protocol was approved by the Ethical Committee of "Fondazione Casa Sollievo della Sofferenza" in San Giovanni Rotondo, Italy, under protocol number: N 112/CE. Written informed consent to participate in the study and to use the data for research purpose was obtained from the participants.

Authors' contributions

ES, DG, LF, MT, MM, GDO, IF, RL defined the guidelines for the methodology. LF, MM, GDO planned the study for the mobility application. FG prepared the module for the informed consent and the ethical approval. AG and FG made the recruitment for the Italian pilot site and MT made the recruitment for the Dutch pilot site. GDO, DS, and AV conducted the needs analysis of the Italian pilot site. MT, MM and IF conducted the needs analysis of the Dutch pilot site and made the synthesis of the two-countries. LF, RL, FC and AV analyzed the technical requirement and discussed the results. LF and RL wrote the technical requirements and the discussion. MT, MM, IF and GDO wrote the needs analysis results. AV and FG analyzed the data protection and related discussion. All the authors approved the final version of the manuscript and are accountable for all aspects of the work.

Disclosure statement

The authors declare that they have no competing interests.

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