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Co-creation of an assistive robot for independent living: lessons learned on robot design

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Abstract

To increase the usage of assistive robots into daily life it is important to include end-users in early development stages. This paper propose an iterative co-creative method to refine the design of an assistive robot called ASTRO. Three co-creation sessions were organized involving a total of 102 individuals. This paper presents the feedback collected and provides the results from an evaluation of the final prototype. The results underline that the robot's design was perceived in a positive way (attractiveness and stimulation domains). Even though the co-creation results show that the function of the robot are also valued, the survey provides a more nuanced view on these aspects of robot design by showing a neutral evaluation of perspicuity, efficiency and dependability.

Keywords Creative design · Design technology · Assistive robot design · User participation · Case study

1 Introduction

The European population is getting older [1], and this demographic shift could lead to an increase in the demographic old-age dependency ratio from the current 28% to 50% in 2060. In Italy, 11% of the total population was over the age of 65 in 1970 and by 2017 it will almost double to 21%. Population aging is often associated with a decline in physical, cognitive and emotional capacity and difficulties in personal mobility [2]. Particularly, the limitation of personal mobility incidence is equal to 35% of older adults aged over 70 years, and to 72% of elderly aged over 80 years [3]. Additionally, care issues and costs associated with an increasing elderly population are becoming a major concern for many countries.

Recently, assistive robots have been suggested as possible care solutions which could improve independent living and promote the well-being of an ageing population [4]. For example, psychological needs such as interaction and companionship typically shown by elderly people can be fulfilled by such robots as they provide opportunities for human–robot interaction [5]. The development of assistive robots was born from the need to maintain social contact and psychological well-being, especially when the physical and cognitive functioning of elderly declines. Assistive robots include remote telepresence and companion-type robots [6]. Such robots will be available in residential facilities, hospitals and private homes to help older people in daily life activities (e.g. reminding of medicine and appointments, promoting social inclusion, proposing cognitive games, supporting in mobility tasks, and so on). Additionally, these robots could also help family and friends by reducing their burden of care, since they can promote a connection with other relevant actors in the care process [7].

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The International Federation of Robotics (IFR)[1] projected that the sales of service robot (professional and domestic/assistive use) will increase in the next 3 years. It is worth to notice that there is a difference in the size and in the projections of the market of robots for entertainment, and the market of robots for personal assistance. For example, about 218,000 robots for education and research are expected to be sold in 2017 and another 994,000 in the period 2018–2020, while the sales of robots for elderly and handicap assistance will be about 32,900 units in the period of 2018–2020. However, the latter market is expected to increase substantially within the next 20 years.

To create successful products, systems or services it is necessary to ensure that the product has a sufficiently high user experience, which is defined as "persons' perceptions and responses that result from the use or anticipated use of a product, system or service" (ISO 9241-210). It is evident that the concept of user experience is wide, holistic and multidisciplinary; indeed it is more than the sum of acceptability and usability, it includes also concepts related to the hedonistic, attractive and aesthetic quality of a product, system or service [8]. Additionally, literature findings highlight that there is a dependency between aesthetic impression of a user interface and its perceived usability [9].

To achieve high user experience, user centered design (UCD) is an appropriate approach. UCD promotes the involvement of users in different stage of development [10]. For example, end-users can work in synergy with developers by testing robots and their improvements, and in some cases they can even be an active partner in development to co-create solutions together with developers [10]. This involvement of users as active partners in development is critical because it reduces the gap between research about the assistive robot and its market implementation (see e.g., [11]. Over the last years, UCD methods were applied in the development of assistive robots [12, 13], however these studies have limitations that need to be addressed in future work. Namely, until present too often robotic platforms were evaluated using videos or photos without direct interaction between users and the robot [12, 13]. Indeed, the co-creation of assistive robots is not common yet.

Therefore, this paper aims to present the results and discuss the lesson learned achieved with an iterative and multi-step co-creation method for the development of an assistive robot which aims to support elderly in independent living. The proposed approach involves older persons, formal and informal caregivers at different stages of robot development of the assistive robot. Particularly, three co-creation sessions were organized in Italy and in the Netherlands. During these sessions, the involved persons had the possibility to test the robot and its services, and give general feedback about them which were collected and clustered. Additionally, at the end of the third session, we collected feedback on the user experience through the User Experience Questionnaire (UEQ) to measure the attractiveness, perspicuity, efficiency, dependability, stimulation and novelty of the robotic assistance. In this paper we focused on the results of one transversal issues, namely robot design, which participants highlighted and prioritized as urgent and important in both countries.

2 Related work

According to the state of the art, there are commercial and research assistive robot prototypes, which aim to improve the independent living of the older population by supporting them during their activities of daily living. Indeed, over the past years several projects on assistive robotics for ageing well were initiated by the European community [14–16].

According to their main application domain, the robots developed in these projects can be clustered into six domains: support to the caregiver, promote health, promote social inclusion, promote well-being, physical support, and safety at home [17]. It is worthwhile to underline that only few of these assistive robotic project are devoted to the support of personal *indoor* mobility, which is one of the major aspects which influences the level of independence of elderly. Recent findings underline that elderly users prefer to walk with a robot rather than walking alone; furthermore, they enjoy walking with a robot because of its novelty and the feeling of companionship it provides [18].

Personal indoor mobility is mainly influenced by environmental factors such as the presence of stairs, distance between rooms, usage of carpets [19], and by age-related decline such as the reactivity of the individual or his or her vision loss [20]. Assistive robots can support elderly's walking activity in two ways. In the first way the robots act as a walking coach by accompanying users in the activity, walking side-by-side with them [18, 21]. They will indicate the path to the user by monitoring their gait but only light physical contact is allowed [22]. Indeed, without a handle or similar tools provided, these robots are not suited to support and guide aging persons during walking, but they are able to alert them on obstacles and generate interactive content during the day. Alternatively, the robot could act as a smart-walker by acting as a physical support tool. For instance, the Kompaï robot (height: 1.33 m), developed by Robosoft [23], has a small handle to help users to rise from a chair. However, the payload of the robot (45 kg) is most probably be not adequate to balance the force of elderly during the walking activity. The ASTRO robot (height: 1.55 m), developed within the ASTROmobile project [24], has a handle

[1] International Federation of Robotics (IFR) official website: https://ifr.org/.

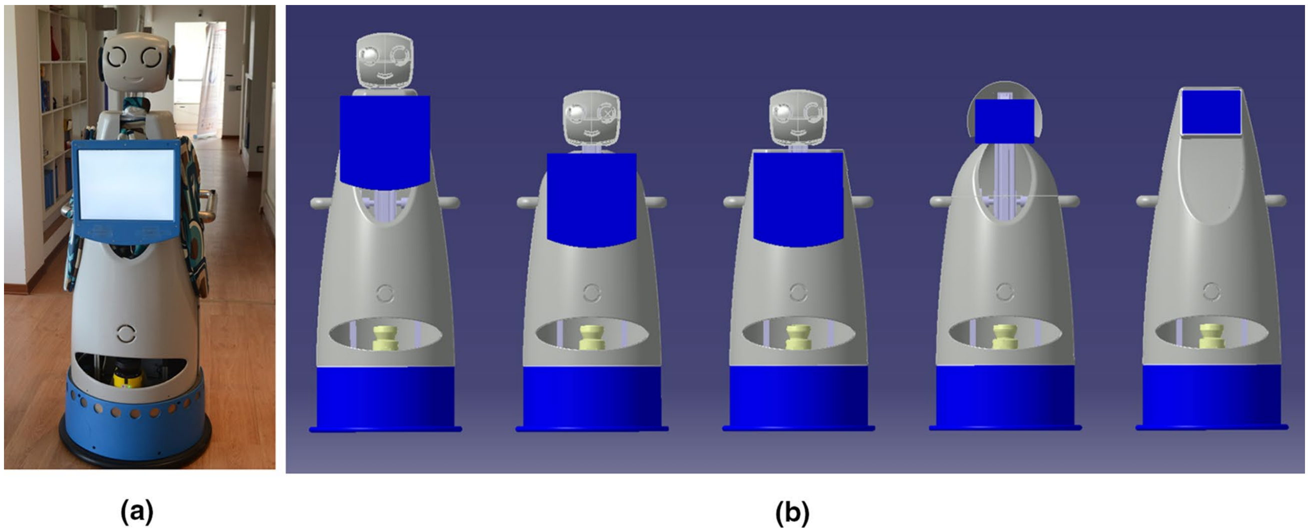

Fig. 1 **a** ASTRO robot at the beginning of the co-creation meeting, **b** prototypes of the new ASTRO design

to support mobility and, in respect to Kompaï robot, it has a bigger payload (60 kg), thus it can balance higher forces (Fig. 1b). The elderly user can use this handle to hold on to the robot with both hands during the walking task. Also the DoRo robot, developed under Robot-Era project, has a small passive handle on the back which can be used to support indoor mobility [25].

Over the past years, different assistive robots, not only those used for indoor mobility, were customized and tested with older users [4, 25–28]. Burke et al. [4] developed a co-learning system namely "Teach Me" on the Care-o-Bot 3 robot which promotes health and well-being. Particularly, Teach Me was developed to allow the 20 individuals involved in the study to define and test the robot's behaviour based on both house sensory activities and on basic robot actions. At the end of the test, the users were asked to compile the SUS questionnaire to rate the service. Another project uses the KOMPAÏ robot, and the experience of users with the KOMPAÏ was evaluated after 1 month of experience with the robot [28] by eleven older adults in a living lab. After an initial presentation, the users were asked to perform some daily task with the robot to assess if the robot is able to support the safety at home and to promote the health monitoring. Hereafter, questionnaires were used to collect feedback and evaluate the KOMPAÏ, and a focus group was held. During the Robot-era project, the DoRo robot was developed with an UCD approach to deliver shopping service, to promote safety at home and to enhance the physical support [25]. After an initial needs analysis phase, a total of 45 elder users tested the robot in a living lab for 1 h to give their feedback on user acceptance and usability. Further on, a couple of older adults tested the Giraff robot able to promote the social inclusion thanks to the telepresence system developed during the ExCITE project in a long term trial of 1 year [26]. After the initial phases of set-up and system installation, the elderly could talk with their family members through the telepresence robot. Questionnaires were administered periodically to the participants. Latikka et al. [27] aimed to understand the association between robot use self-efficacy and acceptance of robots. Particularly, humanoid, pet, lifting, and telepresence robots were studied among care work staff. In this study the authors used commercial solutions and collected feedback without any kind of personalization of services.

As this overview shows, all these solutions were designed with a user-centred design approach but without an *active* involvement of end-users in the development phase, that is: not in-cocreation with these individuals. Common methods used by the authors include questionnaires [4, 26, 28], focus groups [28], tests in living labs or at other locations [4, 25, 28] and longer term trials [26, 28], in which users are the *subjects* of the development process rather than *partners* in it. In this context, this paper follows co-creation for the development of an assistant robot which can help to support the indoor mobility among elderly. The proposed approach aims to iteratively and actively involve individuals with different areas of expertise to define interactively the design of the proposed assistive robot.

3 Methods and instruments

3.1 The ASTRO robot

The ASTRO robot offers different services, the most important being the supporting of elderly in their indoor walking

Table 1 Topics of the co-creation meetings

Meeting	Description of the main topic	Method and tools
#1	Presentation of the ASTRO robot	Participants can try ASTRO and its related services and give spontaneous feedback. This feedback was analyzed to highlight "tops and flops", amongst other on robot design
#2	Presentation of the four new design prototypes of the ASTRO robot	On the basis of the results from the first co-creation, new prototypes of the robot design were presented to and evaluated by the participants. Additionally, other robots were also presented to collect spontaneous feedback on different design elements
#3	Presentation of the new design of the ASTRO robot	Participants could evaluate the new robot design of ASTRO and tried the services again. Additionally, UEQ survey was administrated

activity and proposing physical exercises. Additionally, family and caregiver can use ASTRO to remotely get in touch with the loved one. The ASTRO robot is based on SCITOS G5 (Metralabs, Germany). Its weight and payload are 60 kg and 50 kg, respectively; it is able to move at a rate of up to 1.1 m/s. A laser range sensor (SICK S300) is mounted on the front to allow safe navigation in the environment. Additionally, it has a handle on the back to support the elderly person during his or her walking activity [29]. ASTRO also has a tablet on the front to access the web-based graphical user interfaces (GUIs). It is made out of plastic and it has coloured textile on its side as depicted in Fig. 1a. The use of ASTRO is facilitated through two GUIs: one for the caregiver and the other for the elderly person.

3.2 Co-creation sessions

The proposed methodology is based on an iterative co-creation approach [10]. We conducted three separate co-creation sessions with elderly persons and caregivers in two different EU countries (Italy and Netherlands) for a total of six meetings to define the design of ASTRO, as well as its associated services. Each co-creation meeting had a specific outline as detailed in the following paragraph (see Table 1). Each of the three co-sessions was recorded on audio and video, and pictures were made. Throughout the sessions, we made sure that participants are not the subjects of development, but partners in the process by, for example, not only asking them for feedback on ASTRO but also asking them to create solutions for this robot such as interfaces, visualizations of important data, and so on. In this paper we focus on discussing the findings on the robot design of ASTRO, as this is an issue that was found important and urgent by the participants. We distinguish between three dimensions of robot design: the appearance, function and tools of ASTRO. These dimensions are closely related to the UEQ questionnaire [30] that participants were asked to complete at the end of the third co-creation session. UEQ assess the perceived attractiveness that is the overall impression of the product, the pragmatic quality related to the goal or task oriented aspects of a design, and the hedonic quality related to non-task oriented aspects of a design. Hedonic quality is related to the appearance dimension of robot design treated in the co-creation sessions, while pragmatic quality is related to the function and tools of robot design. This questionnaire has been used in previous research in several application domains including robotics [31]. The scale consists of 26 pairs of adjectives clustered in six scales (attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty) and is evaluated on a 7 point Likert-scale.

The UEQ subscale of attractiveness measured the overall impression of the product; it is composed of 6 items and it is a pure valence dimension. The UEQ subscales of perspicuity, efficiency, and dependability belong to the pragmatic quality of the robot, while the subscales of stimulation and novelty are related to the hedonic quality of the robot, all these sub-scales are composed of 4 items each. The perspicuity scale measures if it is easy to get familiar with the robot, whereas the efficiency subscale measures if the user can solve the issue without any external support and if the system promptly react to an external input. The dependability subscale measures if the user feels safe during the interaction and if he can predict the system behavior. The stimulation scale measures if the system is able to motivate the users, whereas the novelty scale gives a score about the innovativeness of the product and evaluates if it is able to catch the interest of the user. For all scales, the score ranges between -3 and $+3$, the standard interpretation of the scale means is that values between -0.8 and 0.8 represent a neutral evaluation of the corresponding scale, values > 0.8 represent a positive evaluation and values < -0.8 represent a negative evaluation [8].

3.3 Participants

In the Netherlands, participants were recruited by a manager from a long-term care organization in a rural area. The elderly people were recruited from the organization's home care service, daily activities service, and rehabilitation service, while the formal caregivers were recruited from the

Table 2 Participants involved in the co-creation sessions in the two countries

	First co-creation		Second co-creation		Third co-creation		Total
	IT	NL	IT	NL	IT	NL	–
Elderly	6	5	3	6	10	7	34
Informal caregiver/volunteer	7	1	3	5	2	1	22
Formal caregiver/managers	6	5	8	11	10	6	44
Sub-total	19	11	14	22	22	14	–
Total	30		36		36		102

organization itself or from the community. In Italy, older people and formal and informal caregivers were contacted by the Alzheimer's Evaluation Unit of Geriatrics department from a hospital in the region of Apulia. During the co-creation sessions, we involved a total of 102 participants with different backgrounds among the two countries as detailed in Table 2. Of these 102 participants, 89 were unique as some participants came to multiple sessions (34 unique participants from The Netherlands and 55 from Italy). All participants were asked to sign three consent forms before participation: consent for participation (signed by 31 from the Netherlands, signed by all participants from Italy), consent for sharing the recorded photo and video material with other consortium members (signed by 22 from the Netherlands, signed by all participants from Italy) and a consent form for using the recorded photo and video material for public purposes (publications, dissemination goals) (signed by 13 from The Netherlands, signed by all participants from Italy). The members that did not sign the consent form for participation were asked whether their contribution can be used for this and future academic papers, to which they agreed. As not all members gave consent for sharing and using the recorded photo and video material this paper does not make use of these recordings. The sessions were hosted in the native languages (Italian and Dutch) to ensure that the co-creation participants were able to share their experiences and ideas.

3.4 Data analysis

First, the data analysis approach as regards to the date from the co-creation sessions. The data analysis approaches were different for the Netherlands and Italy. In The Netherlands, points for improvement for ASTRO were written down and complemented with interesting quotes where possible, while in Italy, the data was transcribed and hereafter analysed using thematic content analysis [32]. As concern the analysis of UEQ survey, 30 participants gave us consent to be included in the analysis (14 were males and 16 were females). Thus, data from 15 older seniors aged over 60 years old (M = 10 and F = 5) were included (7 subjects were from Netherlands and 8 were from Italy). The remaining of data was collected from formal and informal caregivers with different backgrounds; of which 6 caregivers were from Netherlands and 9 were from Italy (M = 6 and F = 9). Mean values and standard deviations were computed for each items of the UEQ-subscales for the overall population and for the two groups (older persons and caregivers). The reliability of each subscales was evaluated with Cronbach's alpha. Many authors assume that a scale should show an alpha value > 0.7 to be considered as sufficiently consistent but its interpretation should be also compared with the sample size [33]. The effect-size, defined as the measure of a magnitude of the effect of independent samples [34], was verified using the d Cohen coefficient. Shapiro–Wilk test of normality was used to verify the normality of the distribution of the score of each item. Since all the scores were not normally distributed, the Mann–Whitney U test was used to evaluate if there are differences in the response between older persons and caregivers, and between males and females.

4 Results

4.1 First co-creation meeting: evaluate the first release of ASTRO

During the first co-creation meeting, the first release of the ASTRO robot (Fig. 1a) was presented to the participants (see Table 1). A total of 11 elderly (aged > 60 years old), 8 informal caregivers and 11 formal caregivers from both countries joined these meetings. The participants could try ASTRO and its services (i.e. the walking support and exercise services) highlighting *tops and flops* of its appearance, function and tools. The participants were set free to try the robot, to discuss and express their personal impressions. The results were presented per service (e.g. mobility support, exercises) and transversally in case of common feedback on, for example, robot design and ergonomics. As mentioned earlier, in this paper we focus on one transversal result; robot design in terms of appearance, function and tools.

The results on these topic underline that the participants had a positive view of ASTRO; they think it's robust ("It is Big! It seems to be massive and robust.", IT; "Sometimes when people put the brakes on their walker, it will still move. I believe that this will remain still and is more secure", NL)

Table 3 Results of the first co-creation meeting

ASTRO features	Verbatims	Requirements	Improvements for the second co-creation
Height	*It should be shorter otherwise you can't see in front of you. NL* *It's very tall, I can't see very well! IT* *It should be smaller. IT*	The robot should be shorter to allow the user to see in front of them or a camera should be installed	Reduce the height of ASTRO Add a camera on the front of ASTRO
Object storage	*A 'plank' to place items on. NL*	The robot should have a storage space to put items in during the walk	Add a storage on the back of ASTRO
Interfaces	*There should be a screen on the side you are walking. NL*	A screen should be placed on the "back-side" for deaf and other people for communication purposes	Add a tablet on the back of ASTRO to allow users to access the services

Table 4 Results of the second co-creation meeting

ASTRO features	Verbatims	Requirements	Improvements for the third co-creation
Face	*The face is needed, it looks less frightening. IT* *Without the face, the aspect of the robot is not so cute! IT* *The presence of the face gives it a more friendly aspect. IT*	The robot should have a face as it is perceived friendly in this way	Add a face to ASTRO
Camera	*You should be able to see what ASTRO is seeing. NL* *It looks very promising the possibility for caregivers to have a look during the exercises. IT*	The robot should have a camera so the user can see what is happening	Add cameras on the back and front of ASTRO
Frontal screen	*It could be fruitful have a mobile display to adjust the position.* IT	The height of the frontal screen has to be adjustable per person so everybody can set it at a height that allows them to read what is on it	Add a mobile screen of which the position can be adjusted

and it is perceived as a companion during the walking ("It could be my friend!", IT; "I actually think it looks cute", NL). However, the participants in both countries underline also some limitations in the appearance, function and tools of ASTRO which can affect the presented services as presented in Table 3. On the basis of this analysis, requirements and improvements for the second co-creation meeting were defined. These improvements take in consideration three main ASTRO features as related to the robot's appearance (height), function (object storage) and tools (interface).

4.2 Second co-creation meeting: evaluate the prototypes

In the second co-creation, a total of 9 elderly (aged > 60 years old), 8 informal caregivers and 19 formal caregivers from both countries were involved (see Table 2). In the meetings, we presented four different prototypes conceived to meet the requirements defined in the previous meeting.

In these prototypes, we reduced the height of ASTRO with 20 cm, we added a camera on his front and a screen on his back. Additionally, we proposed two solutions with a face and two solutions without a face to evaluate if the users prefer or do not prefer this human-like feature. Figure 1b shows the four prototypes. The participants discussed the design of the robots in two phases: first they looked at full size photos of ASTRO. Then, four mock-ups of the alternative designs of ASTRO were presented by means of 3D models to provide a realistic overview of the prototypes.

This time, the participants only had comments about the robot's appearance (face) and tools (camera and frontal screen). Indeed, the participants stated that the robot should have a "face" that makes it less "cold" (see also Table 4). Additionally the participants gave positive comments about the frontal camera. The elderly liked the fact that they could see what is in front of them, and the caregivers thought it was promising that they could have a look during exercises. Finally, the participants gave feedback on the height of the frontal screen. They prefer to have a "mobile display" to adjust the position according to their needs.

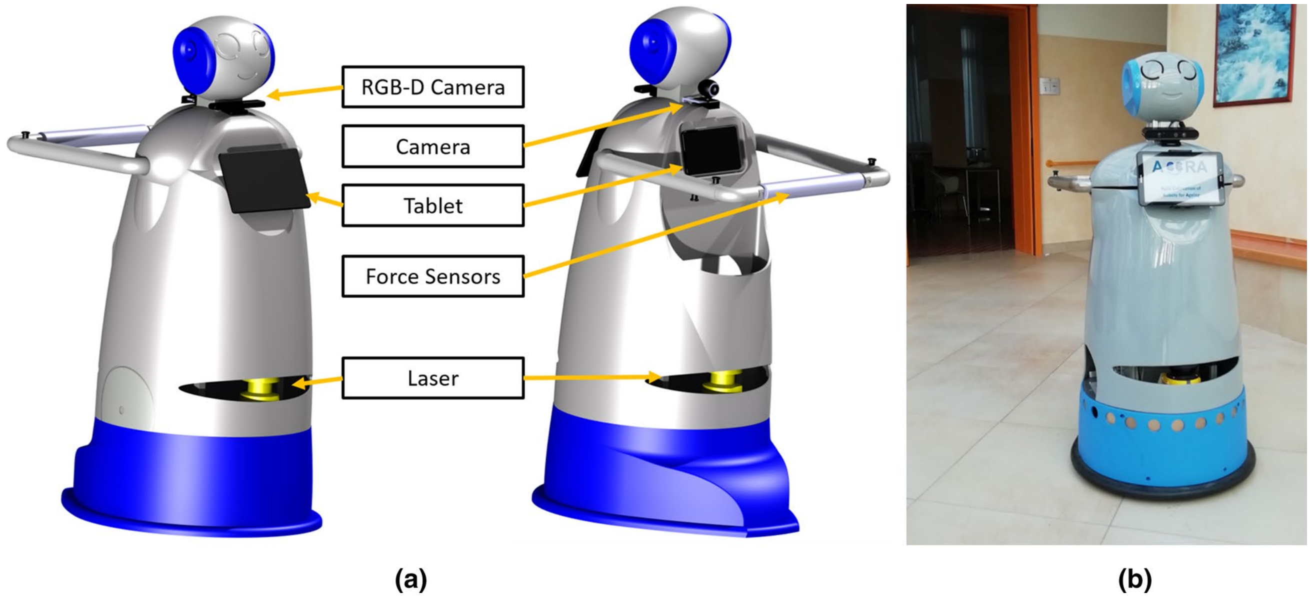

Fig. 2 **a** Technological tool integrated, **b** ASTRO Final prototype, the design was made out of 100% of recycled plastic

Table 5 ASTRO design elements included in the new design

#	Final features	Robot design element	Resulted from
1	ASTRO is 20 cm smaller than the previous version	Appearance	User feedback session 1
2	ASTRO has a face	Appearance	User feedback session 2
3	ASTRO can bring small object on the back	Function	User feedback session 1
4	A screen is mounted on the back	Tools	User feedback session 1
5	A RGBD-camera was added on the front	Tools	User feedback session 2
6	A camera was added on the back	Tools	User feedback session 2
7	The height of frontal screen can be adjustable	Tools	User feedback session 2

4.3 ASTRO: new appearance, function and tools

On the basis of the feedback collected during the first and the second co-creation meeting, a new ASTRO design was conceived. The design had to find also a balance between the user requirements and the technical constraints due to the size and the shape of commercial robotic platform (SCITOS G5) and the final height of the handle which should be comparable with the average height of human beings. The new ASTRO is 20 cm shorter than the previous version (Fig. 1). In this version, we maintained the smiling face to propose a friendly robot and the same grey colour. The 10″ frontal tablet (Samsung, Korea) is mounted on a flexible support with a spherical joint, thus the user is free to adjust the screen. A R-GBD camera (ORBBEC, USA) was mounted in correspondence of the neck to mimic a bow-tie. On the back we added a 7″ tablet (Samsung, Korea) mounted in the plastic cover and a small camera (NGS, Spain) to monitor the user while he or she is walking. Additionally, force sensors were mounted on the handle to monitor the user force [29] (Fig. 2a). Finally, ASTRO can bring small objects on his back. This new design of ASTRO was realized with a 3D printer and was made out of 100% of recycled plastic,[2] and all the soft textiles were removed. Table 5 summarizes the final features of ASTRO, clarifies which design element they address and how these elements resulted from the previous sessions.

4.4 Third co-creation meeting: evaluate the final version

A total of 22 persons joined the meeting in Italy and 14 persons joined the meeting in Netherlands; of these 36 individuals, 17 were elderly (age > 60), 3 informal caregivers and 16 formal caregivers (Fig. 3).

During the third co-creation meeting the new ASTRO was presented to the participants and they had the possibility

[2] Cresco Lab Website: https://crescolab.jimdo.com/.

Fig. 3 Third co-creation session. The new ASTRO robot was introduced to caregivers

to observe the robot and try the walking service as they did during the first meeting. The participants were free to discuss the new design of ASTRO (appearance, function and tools). As mentioned before, at the end of the session the participants completed the UEQ questionnaire. Below, we discuss the qualitative (co-creation session) and quantitative results (survey) from the third co-creation separately.

The participants from all sessions were asked, after presenting the new ASTRO, for things they liked about the robot and things they disliked about it (points for further improvement). From Italian participants' point of view, the added value of ASTRO in terms of appearance were its materials ("environmentally sustainable and good, IT"), dimension, and in terms of tools the caregiver interface since they were considered by all as appropriate, safe and well executed. It is worth to underline that the participants noticed significant improvement from the first release of the robot. The Dutch participants mostly liked the shape of ASTRO (friendly, beautifully and recognizable appearance) and various gadgets such as the object storage (tools). As regards to the things that can be improved in the future, the Italian and Dutch participants had several remarks. The first two remarks were related to the appearance of ASTRO. About the color of the robot, several of the participants have reported that it is too gloomy and needs colors that are more vivid and intense. Moreover, the platform of ASTRO should be smaller to facilitate walking behind it comfortably. Further on, there was one remark regarding the function of ASTRO, and the handle in particular. Namely, the participants suggested to improve the design with an adjustable handle which can be adapted along the vertical dimension to be more functional. Finally, as regards to the tools, the back screen could be enlarged to facilitate easy viewing of its content by elderly. The points for improvement for the future are summarized in Table 6.

4.5 Survey

We first evaluate the scale consistency using the Cronbach alpha. As shown in Table 7, the Cronbach alpha's are higher than 0.50 for all scales except novelty, and two are higher than 0.70 (attractiveness and stimulation). As regards to the novelty scale, especially the elderly measure has a low value (0.13), which also seems to have an effect on the overall measure (0.44). Removing the item (innovative-conservative) with a low correction with the remain ones did not result in a sufficiently high Cronbach alpha, so we decided to refrain from analysing the results from these two subscales scales as their interpretation can be questioned. As the Cronbach alpha for the caregiver novelty scale is good (0.79), we do include it in the results below.

Now, we move on to the descriptive statistics of the UEQ subscales (see Table 7 and Fig. 4). As shown in Table 7, the perceived attractiveness of ASTRO is well evaluated both overall and for the two groups with mean values ranging from 1.06 to 1.41, showing a medium effect size for the overall scale (<0.80). On the other hand, the evaluation of pragmatic quality of ASRO is neutral. Indeed, perspicuity, efficiency and dependability have mean values between -0.80 and 0.80 (0.48, 0.67, 0.29 overall, with similar scores

Table 6 Results of the qualitative evaluation of the new prototype

ASTRO features	Verbatims	Requirements	Improvements for the future
Colour	*Boring color, should be more expressive, but not too much. NL* *Opaque color and too dark, better more vivid and bright colors. IT*	The colour of ASTRO should be more attractive	Create a version of ASTRO in a more vivid and intense colour
Platform	*There is little space to walk behind. NL.* *The shape of the platform don't help me to walk. IT* *Too wide. NL.* *Too big for room elderly. NL*	Creating a comfortable space behind ASTRO so that elderly can walk behind him without bumping into things	Reduce the size of the platform of ASTRO
Navigation bar	*The navigation bar can't be adjusted vertically. NL.* *It is better to place the hands differently on the bar. IT*	The bar has to be at a height that is comfortable for a person	Improve the handle so it is adjustable to each person's height
Back screen	*Display on the client side is very small. NL* *Elderly would probably needs my help to use the interface. IT*	The screen should be big enough so that elderly can read what is on it	Enlarge the back screen

Table 7 Average scores of the UEQ subscale questionnaire for the entire population (overall), older persons and caregiver

UEQ subscales	Overall (average ± std)	Older persons (average ± std)	Caregiver (average ± std)	d Cohen (average)	Alpha overall	Alpha older persons	Alpha caregiver
UEQ attractiveness	1.06 ± 1.41	0.96 ± 1.45	1.40 ± 1.07	0.75	0.89	0.88	0.82
UEQ perspicuity	0.48 ± 1.26	0.30 ± 1.42	0.68 ± 1.14	0.38	0.70	0.76	0.66
UEQ efficiency	0.67 ± 1.11	0.80 ± 1.20	0.63 ± 1.02	0.60	0.63	0.81	0.57
UEQ dependability	0.29 ± 1.26	0.32 ± 1.16	0.31 ± 1.42	0.23	0.59	0.59	0.70
UEQ stimulation	0.99 ± 1.59	0.88 ± 1.80	1.33 ± 1.10	0.62	0.87	0.91	0.73
UEQ novelty	1.26 ± 1.08	1.34 ± 0.90	1.27 ± 1.25	1.10[a]	0.44	0.13	0.79

Cronbach alpha and d Cohen are also reported

[a]d Cohen for the UEQ Novelty is calculated based on the caregiver population only. For all other scales, the whole population is used

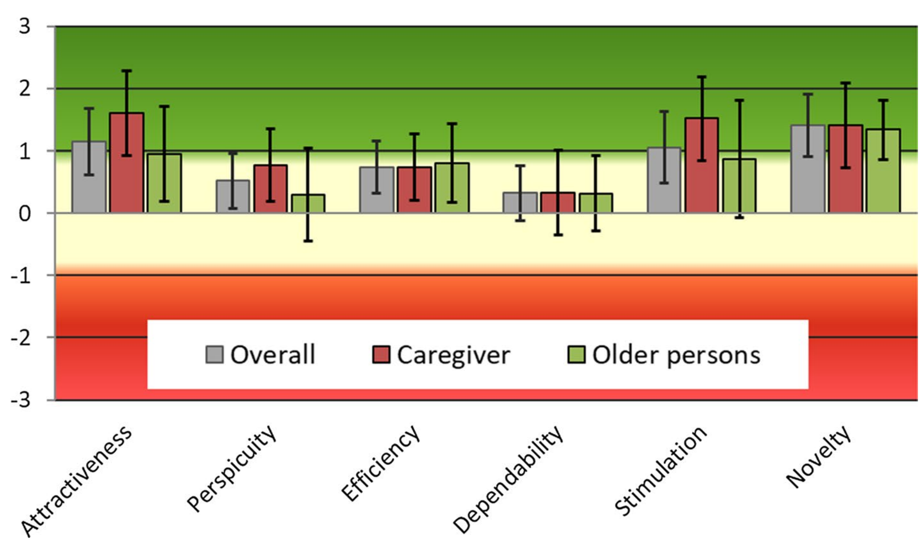

Fig. 4 UEQ mean values and confidence intervals for the overall population (grey), the caregiver (red) and the older person cohort (green)

for elderly and caregivers) [8]. Additionally, perspicuity and dependability subscales have a small effect size (<0.5), whereas efficiency has a medium effect size (<0.80). Last, the results show a positive evaluation of the ASTRO robot for hedonic quality (stimulation and novelty). The stimulation scale has a mean of 0.99 overall, with scores of 0.88 and 1.33 for the elderly and caregivers respectively, and shows medium sized effect for the overall scale. As mentioned earlier, we only interpret the results of the caregiver for the novelty scale due to the low Cronbach alpha of the other two. The novelty scale for the caregiver is the highest of all scales with an evaluation of 1.26, and the effect size is very high (>0.80). The report of the score at item level is reported in the Supplementary Material.

Concerning the effect of socio-demographic factors, no significant differences have been found between older persons and caregivers and sex for each scale ($p > 0.05$) (see Supplementary Material). Additionally, no significant differences have been found for each scale between people which used Skype or have a Smartphone.

5 Discussion

The goal of this work was to design the ASTRO robot using an iterative and iterative co-creation approach with end-users such as elderly, formal and informal caregivers. This paper presents a guidelines which can be used in the future for the design of specific robotic applications that support indoor mobility.

Namely, using an iterative co-creation method, not only do we discuss the design of ASTRO several times test robot and its services with end-users and, the users can also propose their own ideas for the design of ASTRO starting early in development. Our approach differs from prior research as users are active partners in development as opposed to completing questionnaires [4, 26, 28], engaging in focus groups [28], participating in tests in living labs or at other locations [4, 25, 28] or joining in longer term trials [26, 28].

According to the co-creation sessions' results, the robot is generally perceived in a positive way. Indeed, the suggested improvements about appearance, function and tools in the first and second co-creation sessions allowed participants to stress the positive features of ASTRO in the third co-creation. Features related to the appearance of ASTRO that were perceived as valuable were his materials, size and the fact that he comes across as friendly, beautiful and recognizable. Moreover the elderly appreciated the object storage, a function that was added after the first co-creation, and caregivers valued the interface as it was considered an appropriate, safe and well executed tool.

The survey partially confirms the positive results from the co-creation session as its results suggest that the ASTRO robot meets the expectations of its target population in terms of perceived attractiveness and hedonic quality in terms of stimulation and novelty. The overall scores for the perceived attractiveness, stimulation and novelty) as evaluated for ASTRO suggest a high perceived user experience because the average values for the considered subscales are higher than 0.8 and, according to Laugwitz et al. [30] a UEQ score higher than 0.8 indicates a positive evaluation. These results are aligned with recent findings [18] that emphasize people enjoy walk with a robot and they would like to use it for walking task because of the novelty and they are stimulating for this new idea. It is worth to underline that generally older persons have great expectation of an assistive robot due to the comics and film that can influence the experience with ASTRO. The results for novelty, although positive, have to be interpreted carefully as they are based on the mean values of the caregiver.

The survey results as regards to the perspicuity, efficiency and dependability of ASTRO are evaluated neutrally, as shown by mean values between -0.80 and 0.80. Thus, the user experience of the ASTRO in terms of the extent to which it is easy to understand, fast to use and can be controlled is neither bad nor good. This finding slightly differs than the one resulting from the co-creation sessions, as there we found that aspects of the design that enable users to reach their goals (such as the function and the tools of ASTRO) were also valued by participants. From this we can conclude that using a co-creation approach to design a social assistive robot is most useful to achieve positive user experience in terms of perceived attractiveness, and to a lesser extent in hedonic quality in terms of stimulation and novelty.

Pragmatic quality in terms of perspicuity, efficiency and dependability may be better achieved through other user-centred design methods. This may be explained by the fact that to evaluate pragmatic quality, which is related to the extent to which a product enables users to reach their goals, require experience with using the product in question and co-creating this usage may not be enough.

The perceived user experience can be influenced by multiple inter- and intra-factors [35] such as age, sex and previous experience with technology. As we have tested whether our results differ for different age groups, and for males and females and we have found no differences between groups, this results could suggest that people could use ASTRO even if they don't have any experience with technology which is a positive value.

Of course this paper present some limitations. The first limitation is related to the low Cronbach alpha of the novelty scale, in particular for the elderly. Elderly may not be as familiar with assistive robots as caregivers and as a result it may be difficult for them to estimate their novelty. On the other hand, as prior research states, low Cronbach alpha values may also result from a low sample size [33]. Future research should address this limitation by evaluating the user experience of assistive robots, and novelty in particular, with a larger group of elderly so the influence of sample size on robot evaluation can be excluded when interpreting results. Indeed, the low sample size, and relating small and medium effect sizes, is the second limitation of the study. Also to address this limitation, further studies should be focused on the increasing of the number of participants thus to increase the effect size. Lastly, it would be good to evaluate whether studying robot design by involving users in an active way in development has indeed a positive effect on the time to market and market acceptance of such solutions.

6 Conclusion

This paper presents and discusses the design of the ASTRO robot in terms of its appearance, function and tools, and user experience in terms of appearance, perspicuity, efficiency, dependability, stimulation and novelty as developed with end-user in a co-creation approach. The objective of these paper was to realize an assistive robot able to support older persons in their mobility and to help the clinicians and caregivers in their daily tasks. The results are promising and suggest that ASTRO robot could be used to sustain older persons in their mobility but also caregivers in their work since they showed a general positive view of ASTRO.

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Compliance with ethical standards

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

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