Original Paper

# Acceptance of Robot-Era system: results of robotic services in smart environments with older adults

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## Abstract

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**KEYWORDS**

social robotics; active and healthy ageing; acceptability models

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## Conflicts of Interest

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# Acceptance of Robot-Era system: results of robotic services in smart environments with older adults

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## Abstract

**Background:** In Europe, the population of older people is increasing rapidly. Many older people prefer to remain in their homes, but living alone could be a risk for their safety. In this context, robotics and other emerging technologies are increasingly proposed as potential solutions to this societal concern. However, one-third of all assistive technologies are abandoned within one year of use because the end-users do not accept them.

**Objectives:** The aim of this study is to investigate the acceptance of the Robot-Era system, which provides robotics service to permit older people to remain in their homes.

**Methods:** Six robotic services were tested by 35 older users; the experiments were conducted in three different environments: private home, condominium, and outdoor sites. The Appearance questionnaire was developed to collect the users' first impressions about the Robot-Era system; while the Acceptance was evaluated through a questionnaire developed ad-hoc for Robot-Era.

**Results:** A total of 45 older users were recruited. The people were grouped in two samples of 35 subjects, according to their availability. Participants had a positive impression of Robot-Era robots, as reflected by the median score of 71.67 for DORO's appearance, 75.00 for CORO, and 76.67 for ORO. Men gave ORO's appearance an overall score higher than women ($P$ = .02). Moreover, participants under 75 years old understood more readily the functionalities of Robot-Era robots, compared to older people ($P$ = .007 for DORO, P = .001 for CORO, and $P$ = .046 for ORO). Concerning the results of the Ad-hoc questionnaire, the mean overall score is over 80 out of 100 points for all Robot-Era services. Older persons with a high educational level gave Robot-Era services a higher score than those with a low level of education (*shopping* $P$ = .04, *garbage* $P$ = .047, *reminding* $P$ = .04, *indoor walking support* $P$ = .006, and *outdoor walking support* $P$ = .03). Moreover a higher score was given by male older adults for *shopping* ($P$ = .02), *indoor walking support* ($P$ = .02), and *outdoor walking support* ($P$ = .03).

**Conclusions:** Based on the feedback given by the end users, the Robot-Era system has the potential to be developed as a socially acceptable and believable provider of robotic services to facilitate older people to live independently in their homes.

## Introduction

Longevity is one of the biggest achievements of modern societies, and people that are age 65 or older will account for 28.7% of the EU-28's population by 2080, compared with 18.9% in 2015 [1] . Moreover, in 2011, 28.5% of Europe's population, greater than 65 years of age, were living their own homes, while for people over age 85, the percentage was 49.5% for women and 27.8% for men [2]. Furthermore, 17.7% of Europe's older citizens live in rural areas [2] where access to healthcare services can be limited. However, older people generally prefer to remain in their homes [3], but as older people, they often are affected by multimorbidity [4], falls [5], loneliness [6], and the risk of malnutrition [7]. Considering these risk factors, the odds of institutionalizations grows, thereby increasing the costs for healthcare services.

Considering all that, the World Health Organization and the Global Health Workforce Alliance are developing a strategy to plan effective human resources for health for the period 2016-2030. Although the healthcare labour market is growing, it is not clear if the number of health workers will be able to meet the demand for older assistance [8]. In particular, in Europe by 2030, health assistance supply will fall short of demand to meet the health needs of an ageing population [9].

In this context, robotics and other emerging technologies, such as ambient intelligence, are increasingly proposed as a potential solution to this societal concern [10]. In Europe, several research projects were founded under the ICT strand of the seventh research framework programme (FP7) [11] and EU Horizon 2020 Research and Innovation programme [12], as discussed in [13].

Despite the growing interest in developing this type of technology for supporting older people, the target user must accept robots for them to be effective assistive technology tools for older people. Unfortunately, one-third of all assistive technologies are abandoned within one year of use [14]. For this reason, the design and acceptability of service robots that interact with individuals and coexist in environments inhabited by humans are crucial aspects to overcome the resistance toward service robotics [15]. Furthermore, the concept of "trust" in the adoption of intelligent assistive technologies to assist aging in place by older adults is very important [16]. In this context, this paper shows the results achieved within the Robot-Era project, funded by the European Community's Seventh Framework Programme (FP7/2007-2013), that aimed to investigate and demonstrate, among other things, the usability and acceptability by end-users of a plurality of complete advanced robotic services, integrated into smart environments and experimented in realistic experiments.

## Related works

The concept of robots that most people have is shaped by movies and science fiction, provoking a mismatch in what the robots of today can accomplish and what the movies portray [17]. For this reason, in recent years, many studies have been conducted to evaluate the acceptance of robots by older users [18-29]. In this section, the studies, showing older adults' feedbacks about robots, are presented focusing on works comparable to Robot-Era project.

Some of these studies were done involving older adults to explore their attitudes toward possible tasks that robots, in general, could perform in the home, but no robot was used in these studies [18,19].

Prakash et al. studied how human-likeness of the robot's face influences the perceptions of robots by humans, involving thirty-two older adults. Data were collected using interviews and questionnaires; the outcomes showed a higher preference for the human-looking appearance of robots by older adults. However, no real robot was used in the study because participants' imaginations were stimulated by pictures of robots such as Pearl nursebot, Nexi MDS, NAO, and Kobian [18].

Wu et al. involved twenty older persons with mild cognitive impairments to investigate their perceived attitudes toward an assistive robot. The main outcome was that participants considered a robot as useful for themselves in the future, but not for the present; they also deemed a robot to be useful for older people affected by frailty, loneliness, and disability. However, the limitation of this study was that older adults did not interact with a robot because their feedback was obtained by showing video clips and pictures of robots [19].

In other studies, a robot was presented to older people, but they did not have the opportunity to directly interact with it and their feedback was obtained after viewing a video clip or a live demonstration showing the potentialities of a robot [20–21].

Pino et al. presented the RobuLAB 10, a robotic mobile platform that provides seven robotic services for the cognitive and social support of older people. Ten older adults with mild cognitive impairments and eight healthy ones were involved in the study to evaluate the acceptance of robots. The study employed a semi-structured focus group and questionnaires. The results showed that participants positively perceived the potential benefits of the robot to support older adults at home, even if the intention to use was low. However, participants attended to a live demonstration performed by a researcher and the robot was controlled remotely [20].

In a more recent study, on the basis of a demonstrative video of tele-presence Kubi and Beam robots, Stuck et al. interviewed 14 older adults with mobility impairments who perceived the benefits of a robotics system for communication service. However, they mentioned some concerns about damage to themselves or the environment [21].

Other studies evaluated the acceptance of a service robot by older adults after they interacted with it in a controlled laboratory setting [22–24].

Fischinger et al. developed the Hobbit PT1 robot that could perform six tasks to support older adults. The acceptance was evaluated by 49 older users who interacted with the robot in a laboratory decorated as a living room. The outcomes of the survey showed a positive reception by users because more than half of the sample could imagine having the robot at home for a longer period even if approximately half the participants were skeptical about its helpfulness. However, during the controlled laboratory user studies, the robot was not autonomous because a researcher remotely controlled it [22].

In another study, 33 older users interacted with a robot as a physical exercise coach that was appreciate as exercise motivator by most participants [23]. Furthermore, a study with 16 healthy older adults was conducted tin a controlled laboratory environment. The aim was to investigate their acceptance of robots for partner dance-based exercise. The results showed the robot was perceived as useful, easy to use, and enjoyable [24].

Cavallo et al. developed and tested an enhanced robotic platform, called ASTROMOBILE, which was integrated into an ambient intelligent infrastructure to provide a favorable independent living. Sixteen older users were involved. The robot was autonomous, and experiments were conducted in a domestic house. The ASTROMOBILE system provided three functional capabilities. The study was conducted as a focus group and live demonstration, but each participant tested at least one robotic capability. The results demonstrated a positive impression by older users because the utility of robotic services was appreciated [25].

Finally, other studies focused on robot acceptance were conducted in actual environments [26–29]. Koceski et al. developed an assistive tele-presence robot that was tested by 30 older adults in a nursing home. The results show that the functionalities provided by the tele-presence robot system were accepted by potential users, but the robot was not autonomous because it was tele-operated by the user, both for navigation and for fetch and carry of a small object, and only three robotics services were provided. In addition, although the experiments were conducted in the real environment, it was a pilot study, and the robotic system was not integrated into the daily routine of the nursing home [26].

Broadbent et al. investigated the effectiveness of iRobi robot delivering telehealth care to increase adherence to medication and home rehabilitation, improve quality of life, and reduce hospital readmission compared with a standard care control group. 25 older persons, with the chronic obstructive pulmonary disease, used the robot and the results showed that a homecare robot can improve adherence to medication and increase exercise; even if there were no significant differences in quality of life [27].

Finally, Kristoffersson et al. assessed the robustness and validity of the mobile robotic telepresence system Giraff as a means to support older persons and to foster their social interaction and participation [28]. In particular Cesta et al. evaluated the acceptance of Giraff robot by two older persons in a long-term trial, getting positive results [29]. In "Multimedia Appendix 1 : [Overview Related Works]"  an overview of the related works is shown.

### Goal of this study

As stated above, the acceptance of robots by older users has been examined in many studies, but here some limitations can be summarized. First, in some studies, older individuals have expressed an opinion without interacting with a robot. Feedback was collected from users based only on pictures of robots [18,19], or a video clip showing the robot's capabilities [21], or live demonstration performed by a researcher [20]. Second, some studies involved a small number of participants [21], and those studies conducted with many older adults had some limitations because users attended a single live demonstration without direct interaction with a robot [20]. In some studies, the experiment was conducted with a "Wizard of Oz" methodology (experiment in which subjects interact with a system that they believe to be autonomous, but which is controlled by a hidden person) [22], or the robot was tele-operated by the user [26]. Third, in some cases the robot was not autonomous [22,26] or was a stationary robot . Finally, in all considered studies, only one robot, working in a single environment, was used.

In this research, some of these limitations were overcome: (a) a total of forty-five older adults extensively interacted directly with three robots to accomplish tasks, (b) three autonomous robots were used to cooperate between them in smart environments, (c) the experiments were conducted in three different environments: domestic, condominium, and outdoor areas, (d) six robotic services were provided by the Robot-Era system, and (e) each Robot-Era service was tested by 35 older users.

## Methods

### Robot-Era architecture

The Robot-Era system (Fig. 1) implements six robotic services that involve three different environments: outdoor, condominium, and indoor. The agents involved in this system are the DOmestic RObot (DORO), COndominium RObot (CORO), Outdoor RObot (ORO), lift, wireless sensor networks (WSNs), GUI, and speech interactions. All these agents are managed by a Cloud platform based on elastic computing models, in which resources are dynamically allocated from a shared resource pool in the cloud to support task offloading and information sharing in robotic applications [30].

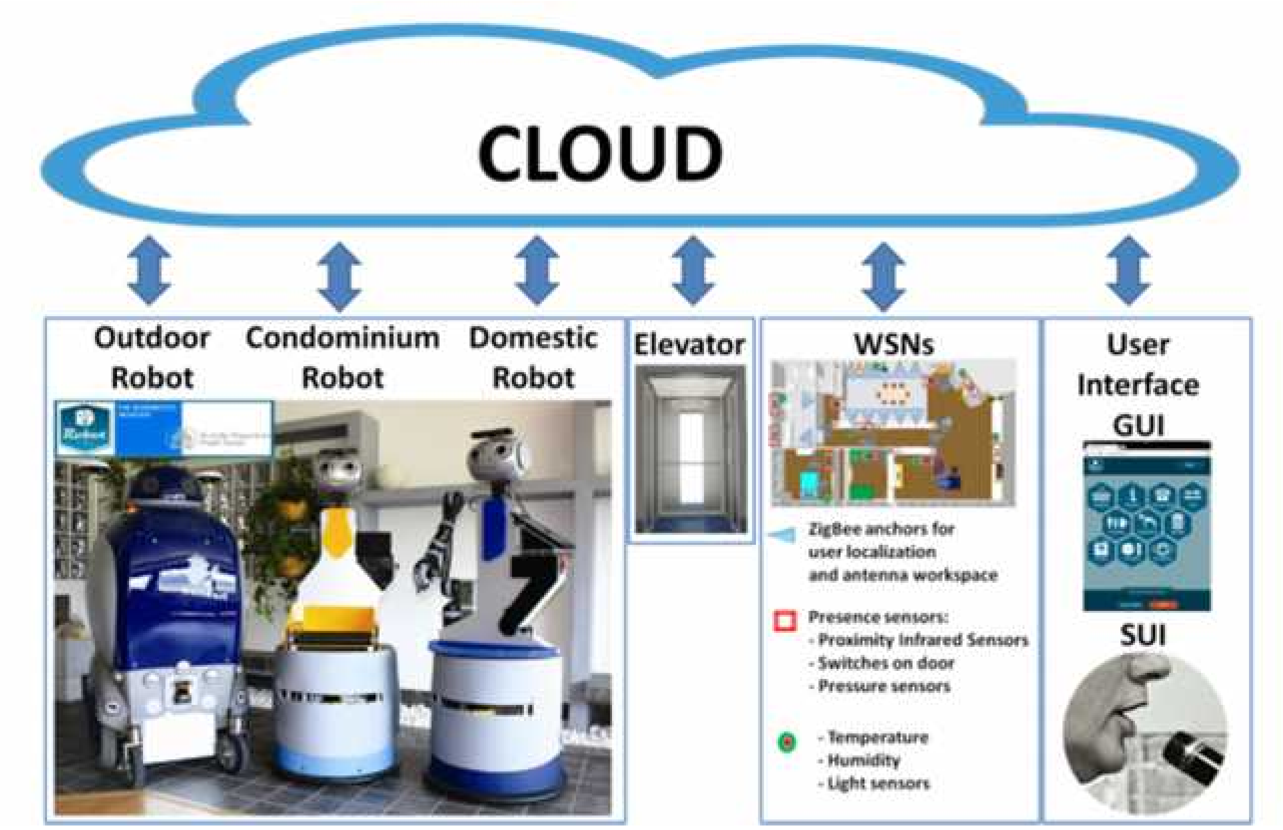


Figure 1 Robot-Era architecture

*DORO* – This robot was developed upon a SCITOS G5 platform (Metralabs, Germany) and safely navigates in a domestic environment. Doro can provide support to older individuals with its integrated robotic arm for object manipulation, a tray for the transportation of objects, and handle for walking support. Furthermore, both visual and auditory feedback is provided to the user via multicolor LEDs, mounted on the robot's eyes; speakers; and graphical user interface (GUI) on a removable tablet.

*CORO* – The CORO robot works in the condominium environment and can navigate between floors using the elevator. It is equipped with a roller mechanism to exchange goods with ORO, and it provides feedback to users in the same manner as DORO.

*ORO* – This robot was designed on the DustCart platform [31] and is an autonomous mobile robot for goods transportation in the urban environment by means of a container to carry the objects. ORO has a head with multicolor LEDs in the eyes, a touch screen on the left side, and speakers reproducing acoustic signals to provide information to the user.

*Elevator* – The elevator, already present in the environment, is embedded in the Robot-Era system through a Phidget input/output digital board used to control it remotely.

*Wireless sensor networks (WSNs)* – Two Zig-Bee WSNs are included in the Robot-Era system. The first network is designed for multiple user localization inside the domestic environment, by observing the received signal strength (RSS). The second network was developed for home monitoring and passive localization of people. It comprises Passive InfraRed (PIR) sensors; pressure sensors placed under a chair or bed; switches on doors or drawers; gas and water leak sensors; and sensors for temperature, humidity, and light.

*The Graphical User Interface (GUI)* – A web GUI (Fig. 2), which runs on the robot's tablet, is the GUI. A main menu index page allows the user to navigate between the different Robot-Era service pages that compose the GUI. The users can employ the GUI to call the robot, select a service, and perform the service [32].

*Speech user interface (SUI)* – Using the Bluetooth connected wearable microphone, the user can ask for, and perform, a robotics service. Specifically, the robot can recognize certain keywords when a user is speaking, corresponding to the commands or the services that the robot can perform. The robot can perform speech synthesis through the speakers to interact with the user [33].


Figure 2 Robot-Era GUI

More details about Robot-Era architecture are explained in [34].

The Robot-Era system can provide six advanced robotic services that were tested by real older users in Peccioli (Italy) to evaluate the usability and the acceptability of the system. The Robot-Era experiments were organized into two sessions. In the first session, the *shopping*, *garbage collection,* and *communication* services were tested. In the second session, the *reminding*, *indoor walking support,* and *outdoor walking support* services were examined.

## Robot-Era services

*Shopping service* – The older participant had to imagine they were sick and could not leave their home, but they needed several items to eat and drink. Bearing in mind this presupposition, the participants had to create and send a shopping list with five products using the GUI; and wait for the shopping delivery. In this scenario, all three Robot-Era platforms were involved, working in three different environments.

*Garbage service* – The older user wanted to dispose of garbage. The participant had to call the domestic robot to select the "garbage collection service". Speech interaction or GUI could be used to accomplish this service.

*Communication Service* — This scenario consisted of two parts: warning alert case and phone call case. A gas leak inside the home was simulated and detected. The domestic robot went to the user to inform them about this dangerous situation. Immediately following the notification, an incoming call, by a possible caregiver, was visualized on the tablet, and the user had to accept it. In the phone call case, the participant used the robot to call a family member via Skype. Users could use speech interaction and GUI to perform this service. Even if the communication service was composed of two parts, it was analyzed as a single service.

*Reminding service* – The older user wanted to set a date on the Robot-Era agenda. The user called the domestic robot to perform the task, and then he/she moved to another room inside the home. The robot reached the user to remember the date. The speech and graphical interface interaction were necessary to perform this service.

*Indoor walking support* – The older user had to imagine that they had a temporary mobility problem, so they used the domestic robot as a walking support. The participant drove DORO using two buttons mounted on the handle.

*Outdoor walking support* – The user moved from point A to point B following a preset path and then returned. The individual used the joystick to drive the robot and then tried to open and close the robot bin, pushing the icon on the screen. In this scenario, only ORO worked in the outdoor environment.

## Participants

To recruit the needed older users, associations and groups working with senior people were contacted. Furthermore, the municipality of Peccioli sent an instructive brochure about the Robot-Era experimentation to all citizens over 65 years of age. At the end of the recruitment phase, 45 older persons, between 65 and 86 years of age, were involved in the Robot-Era experimentation on a voluntary basis, and an informed consent was signed by each participant. To be enrolled in the study, the participants had to (a) be over 65 years old, (b) have a positive evaluation of mental status at the Short Portable Mental Status Questionnaire (SPSMQ) (cut-off errors ≤ 3) [35], and (c) have a minimum required autonomy in performing daily activities, evaluated with the Instrumental Activity of Daily Living Questionnaire (IADL) (cut-off score >2) [36]. However, all participants made maximum two errors in answering to SPSMQ and 0-2 errors mean normal mental functioning. Those who agreed to participate received a socio-demographic questionnaire. Given that the Robot-Era experimentation was organized in two sessions, older volunteers were grouped into two samples of 35 subjects according to their availability. However, two participants did not complete the second experimental session, so they were eliminated from the study. Moreover, 23 subjects participated both in the first experimentation session and in the second one three months later. The first sample was composed of 22 women and 13 men. Their mean age was 74.97 ± 5.70 and their achieved educational level was primary education for five subjects, junior high school for five, high school for 20, and university for five. The second sample was composed of 22 women and 11 men. Their mean age was 73.45 ± 6.27 and their achieved educational level was primary education for 10 subjects, junior high school for five, high school for 14, and university for four.

Figure 3 Participants in Robot-Era experimentation

## Procedure

The experiments were conducted in Peccioli, Italy, and the overall system was used in three different environments: *domestic, condominium, and outdoor*.

Each recruited participant was invited to the premises of the DomoCasa Lab, and the following experimental session was performed:

a. The Robot-Era project was introduced to the user by a researcher.
b. The user was free to gain confidence with the three robots, touching them and asking questions to clear up any confusion.
c. A questionnaire was given to the user to collect their first impressions about Robot-Era platforms.
d. A video tutorial, in which a researcher assumed the role of an older user, was shown to facilitate the understanding of the functioning and potentialities of the Robot-Era system.
e. The researcher announced the tasks of each Robot-Era service that the participant should fulfill via the robots. Subsequently, the user was asked whether they understood the tasks. If not, the action was repeated, and the tasks were explained again.
f. A written description of the tasks of each robotic service was given to the participant for them to refer to if needed, as they tested the Robot-Era services.
g. The user performed each Robot-Era service.
h. The usability and acceptability of each robotics service were evaluated by the user through questionnaires.

During the experimental session, the older adult performed the test without assistance from the researcher to avoid any influence or bias. However, a researcher was present during the experiments for security issues, and the experimental session was video recorded.

## Evaluation tools

One of the most important goals of robotics is to be able to give the robot the highest degree of acceptability. This concept plays a significant and delicate role in the industrial design, and in the context of robotics, this is even more pronounced. For this reason, a specific "Appearance questionnaire", "Multimedia Appendix 2 : [Appearance Questionnaire]" , based on a 5-point Likert scale, was developed to evaluate the impact of the robot's appearance on the user. This questionnaire is designed to investigate:

- Positive or negative feelings that could be evoked upon seeing the Robot-Era robots for the first time (Items A1-A2)
- Robot-Era robots' ability to arouse feelings of familiarity in the user thanks to their formal aspect, colors, and size. (Items A3-A8)
- The perceived robustness of Robot-Era robots (Items A9-A10)
- Robot-Era robots' ability to make their functions evident (Items A11-A13)
- Robot-Era robots' ability to establish a positive emotional relationship with the user (Items A14-A15)

The Appearance questionnaire was administered for each robot (DORO, CORO, and ORO).

For the services evaluation phase, an ad-hoc questionnaire was developed, consisting of 14 items to be rated on a 5-point Likert scale (from totally disagree to totally agree) ("Multimedia Appendix 3 : [Ad-Hoc Questionnaire]") and based on the following contents:

- Disposition about the Robot-Era services (Items Q1-Q3)
- Feelings of anxiety, enjoyment, and trust evoked using the robotics platforms (Items Q4-Q8)
- Perceived ease of use of the graphical user interface (GUI), during the performance of Robot-Era services (Items Q9-Q11)
- Perceived ease of use of the speech user interface (SUI) during the performance of Robot-Era services (Items Q12-Q14)

The choice of developing an original set of questions is motivated by the literature in the field of acceptability evaluation [37], which suggests the need of personalization of the tools to adjust the instrument to the specific technical features of the platform and the issues of interest for the project. Moreover, the development of an ad-hoc tool represents a common practice for the psychosocial research. The psychometric proprieties of the Appearance Questionnaire and Ad-Hoc one were assessed as detailed in the paragraph below.

### Statistical analysis

The first step was to estimate the reliability of the Appearance questionnaire and the Ad-Hoc one. Reliability was assessed in reliability over time and internal consistency reliability. Reliability over time of the Ad-Hoc questionnaire was measured applying Test-Retest, because this tool was administered twice to 23 same subjects who were involved both in the first experimentation session and in the second one three months later. Regarding the Appearance Questionnaire, the Test-Retest was not applicable because this tool was administered once time. For this reason, the Split-Half method was applied dividing the tool into even and odd questions. The two halves of a measure were treated as alternate forms (same mean and standard deviation). Therefore, the correlation between the two halves was calculated as estimating of the test-retest reliability. Finally, reliability estimate was stepped up to the full tool length using the Spearman–Brown prediction formula. The internal consistency reliability was assessed calculating the intra-class correlation coefficient (ICC) and Cronbach's Alpha.

Then for each questionnaire, the basic descriptive statistics were calculated: mean scores, standard deviation, and mode to obtain a first impression on the scores. Moreover, to obtain an overall score for each questionnaire, the sum of the item score contributions was rescaled from 0 to 100 because the 0 to 100 scale is more intuitive to understand. Furthermore, non-parametric tests, were applied to compare different conditions and users. The choice of non-parametric statistics is necessary when the sample size is not large, and data is not normally distributed. The Mann-Whitney U test was used to compare men vs women, users under 75 years old vs over 75 years old while the Kruskal-Wallis test to compare different conditions in educational level and technology skill. Finally, the correlation among Appearance, Ad-Hoc and SUS questionnaires was investigated calculating the Person correlation.

## Results

As shown in "Multimedia Appendix 4: [Questionnaires Reliability]" about the Appearance Questionnaire administered for DORO, CORO and ORO robots, the Split-Half reliability, adjusted using the Spearman–Brown prophecy formula, is higher than .60 and *P*<.001 and reliability over time higher than .4 is considered acceptable [38]. Regarding internal consistency reliability, ICC is higher than .4 and ICC value between .40 and 0.75 is good [39]. Moreover, Cronbach's Alpha value higher than .60, which is considered acceptable for short instruments with a small number of items [40–42].

Considering the Ad-Hoc questionnaire ("Multimedia Appendix 4: [Questionnaires Reliability]"), Test-Retest reliability value (r=.68 and *P*<.001) is acceptable [38] and also internal consistency reliability is well estimated because ICC is higher than .4 [39] and Cronbach's Alpha higher than .60 [40–42] for all Robot-Era services

In conclusion, the Appearance and the Ad-Hoc Questionnaire can be considered reliable.

### Appearance questionnaire outcomes

Figure 4 reports the boxplot of the overall score: the mean values are 73.04 ± 11.80 for DORO, 76.85 ± 12.01 for CORO, and 75.93 ± 11.67 for ORO.

In Table 1, descriptive statistics regarding the appearance questionnaire are reported. The results show that the items that are phrased negatively have a mean score lower than 3 and a mode value equal to 1, except for Item A8, related to DORO, with a mode value equal to 3. Conversely, the items that are phrased positively have a mean score greater than 3 with a mode value equal to 4 or 5. The only exceptions are items A3 and A10 with a mode value of 1 and 3, respectively.

Concerning the effect of gender factor, male participants gave ORO an overall score higher than female participants ($P = .02$). The appearance of ORO inspires more confidence in men than in women (Item A2: $P = .03$). In addition, male participants have a higher propensity for touching and interacting with ORO than female participants (Item A15: $P = .048$).

Regarding the impact of the age factor, individuals under 75 years of age readily understood the functionalities of Robot-Era robots, more so than older people (Item A11: $P = .007$ for DORO, P = .001 for CORO, and $P = .046$ for ORO).

Moreover, older users with a high educational level expressed willingness to interact with DORO (Item A15: $P = .007$) and CORO (Item A15: $P = .047$) more than volunteers with a low level of education.

Finally, older adults who were able to use a PC and the Internet gave CORO and ORO a higher overall score than those who were not able to use such technologies ($P = .03$ for CORO and $P = .01$).

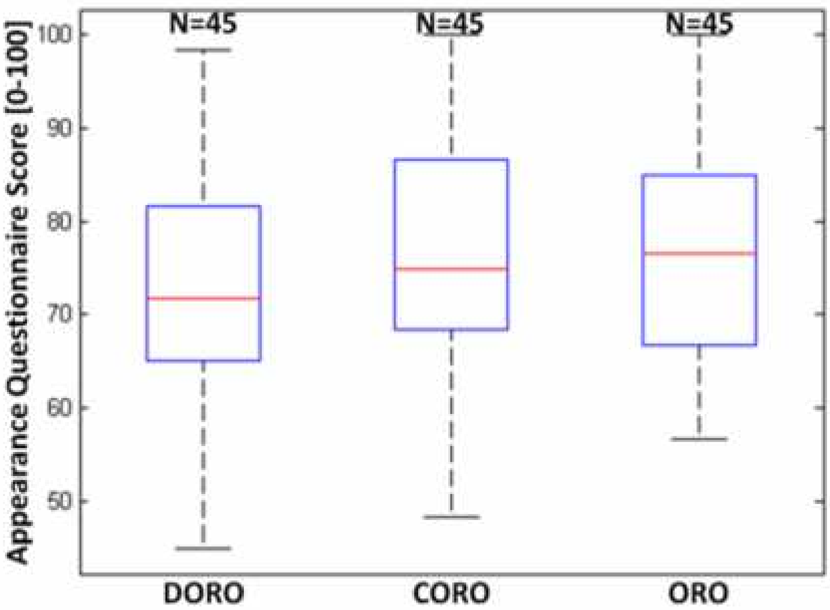


Figure 4 Boxplot of the overall score for the Appearance questionnaire

Table 1 Descriptive statistics of Appearance questionnaire

| | | μ[a] | σ[b] | Min[c] | Max[d] | Mo[e] |
|---|---|---|---|---|---|---|
| **DORO[f]** | | | | | | |
| | ItemA1 | 1.18 | 0.49 | 1 | 3 | 1 |
| | ItemA2 | 4.33 | 0.88 | 1 | 5 | 5 |
| | ItemA3 | 2.98 | 1.54 | 1 | 5 | 1 |
| | ItemA4 | 4.09 | 0.95 | 1 | 5 | 5 |
| | ItemA5 | 4.27 | 0.86 | 2 | 5 | 5 |
| | ItemA6 | 2.02 | 1.27 | 1 | 5 | 1 |
| | ItemA7 | 4.22 | 0.79 | 2 | 5 | 5 |
| | ItemA8 | 3.07 | 1.37 | 1 | 5 | 3 |
| | ItemA9 | 4.18 | 0.81 | 1 | 5 | 4 |
| | ItemA10 | 3.73 | 1.03 | 1 | 5 | 3 |
| | ItemA11 | 2.62 | 1.37 | 1 | 5 | 1 |
| | ItemA12 | 3.82 | 1.11 | 1 | 5 | 5 |
| | ItemA13 | 2.22 | 1.68 | 1 | 5 | 1 |
| | ItemA14 | 1.49 | 1.08 | 1 | 5 | 1 |
| | ItemA15 | 3.82 | 1.25 | 1 | 5 | 5 |
| **CORO[f]** | | | | | | |
| | ItemA1 | 1.11 | 0.32 | 1 | 2 | 1 |
| | ItemA2 | 4.31 | 0.95 | 1 | 5 | 5 |
| | ItemA3 | 2.76 | 1.43 | 1 | 5 | 1 |
| | ItemA4 | 4.24 | 0.80 | 2 | 5 | 5 |
| | ItemA5 | 4.64 | 0.48 | 4 | 5 | 5 |
| | ItemA6 | 1.67 | 1.15 | 1 | 5 | 1 |
| | ItemA7 | 4.33 | 0.88 | 1 | 5 | 5 |
| | ItemA8 | 2.11 | 1.34 | 1 | 5 | 1 |
| | ItemA9 | 4.22 | 0.79 | 1 | 5 | 4 |
| | ItemA10 | 3.84 | 0.98 | 1 | 5 | 3 |
| | ItemA11 | 2.69 | 1.33 | 1 | 5 | 1 |
| | ItemA12 | 4.11 | 0.83 | 2 | 5 | 4 |
| | ItemA13 | 2.16 | 1.64 | 1 | 5 | 1 |
| | ItemA14 | 1.49 | 1.08 | 1 | 5 | 1 |
| | ItemA15 | 3.87 | 1.18 | 1 | 5 | 5 |
| **ORO[f]** | | | | | | |
| | ItemA1 | 1.24 | 0.61 | 1 | 3 | 1 |
| | ItemA2 | 4.24 | 0.96 | 1 | 5 | 5 |
| | ItemA3 | 2.56 | 1.39 | 1 | 5 | 1 |
| | ItemA4 | 3.93 | 0.94 | 2 | 5 | 5 |
| | ItemA5 | 4.42 | 0.87 | 1 | 5 | 5 |
| | ItemA6 | 1.89 | 1.27 | 1 | 5 | 1 |
| | ItemA7 | 4.53 | 0.66 | 3 | 5 | 5 |
| | ItemA8 | 1.73 | 1.34 | 1 | 5 | 1 |
| | ItemA9 | 4.40 | 0.81 | 1 | 5 | 4 |
| | ItemA10 | 3.84 | 0.98 | 1 | 5 | 3 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | ItemA11 | 2.78 | 1.43 | 1 | 5 | 1 |
| | ItemA12 | 4.16 | 0.80 | 3 | 5 | 4 |
| | ItemA13 | 2.20 | 1.69 | 1 | 5 | 1 |
| | ItemA14 | 1.53 | 1.10 | 1 | 5 | 1 |
| | ItemA15 | 3.84 | 1.15 | 1 | 5 | 5 |

[a]mean value
[b]standard deviantion
[c]minimun value
[d]maximum value
[e]mode
[f] Multimedia Appendix 2: Appearance Questionnaire

## Ad-Hoc questionnaire outcomes

Regarding the results of the Ad-hoc questionnaire, the mean overall score is 84.59 ± 10.32 for *shopping*, 87.30 ± 10.84 for *garbage*, 86.73 ± 9.11 for *communication*, 86.58 ± 14.68 for *reminding*, 85.93 ± 11.05 for *indoor walking support,* and 84.69 ± 11.93 for *outdoor walking support.* Figure 5 shows the boxplot of the overall score.

Moreover, standard descriptive statistics present a high rate of agreement, characterized by a high mean score for positively formulated items and a low mean score for negatively formulated items for all Robot-Era services (Table 2).

Concerning the effect of socio-demographic factors, participants with a high educational level gave Robot-Era services a higher score than those with a low level of education: specifically, for *shopping* (*P* = .04), *garbage* (*P* = .047), *reminding* (*P* = .04), *indoor walking support* (*P* = .006), and *outdoor walking support* (*P* = .03). Moreover, a significant difference was found between genders, because a higher score was given by male older adults for *shopping* (*P* = .02), *indoor walking support* (*P* = .02), and *outdoor walking support* (*P* = .03).

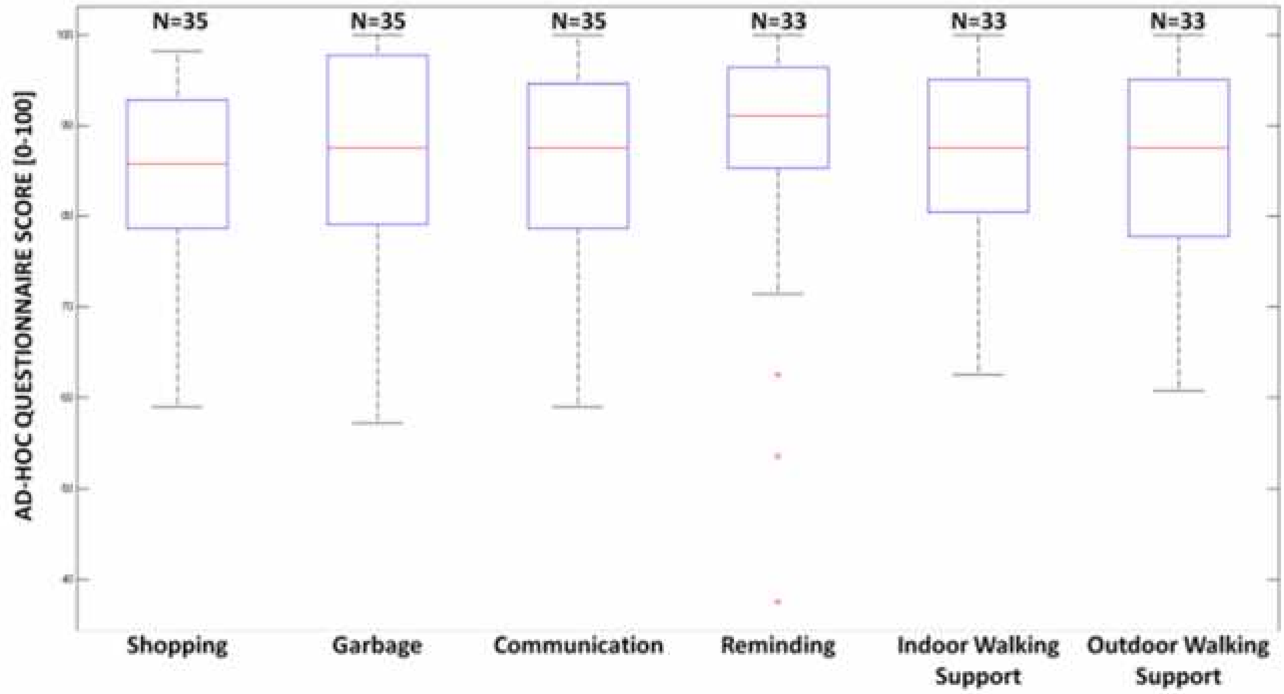


Figure 5 Boxplot of the overall score for Ad Hoc questionnaire

Table 2 Descriptive statistics of Ad-Hoc questionnaire

| | | Item Q1 | Item Q2 | Item Q3 | Item Q4 | Item Q5 | Item Q6 | Item Q7 | Item Q8 | Item Q9 | Item Q10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Shopping Service**[f] | | | | | | | | | | | |
| | μ[a] | 4.66 | 4.49 | 3.69 | 1.2 | 1.14 | 4.46 | 4.54 | 1.09 | 3.49 | 3.86 |
| | σ[b] | 0.94 | 1.07 | 1.53 | 0.68 | 0.69 | 1.04 | 0.66 | 0.37 | 1.34 | 1.35 |
| | Min[c] | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 1 |
| | Max[d] | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 3 | 5 | 5 |
| | Mo[e] | 5 | 5 | 5 | 1 | 1 | 5 | 5 | 1 | 3 | 5 |
| **Garbage Service**[f] | | | | | | | | | | | |
| | μ[a] | 4.69 | 4.54 | 4.14 | 1.14 | 1.11 | 4.46 | 4.74 | 1.2 | 3.94 | 4.17 |
| | σ[b] | 0.9 | 0.98 | 1.33 | 0.69 | 0.68 | 1.07 | 0.56 | 0.76 | 1.19 | 1.07 |
| | Min[c] | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 2 |
| | Max[d] | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | Mo[e] | 5 | 5 | 5 | 1 | 1 | 5 | 5 | 1 | 5 | 5 |
| **Communication Service**[f] | | | | | | | | | | | |
| | μ[a] | 4.63 | 4.34 | 3.91 | 1.17 | 1.14 | 4.57 | 4.43 | 1.26 | 4.09 | 4.23 |
| | σ[b] | 0.91 | 0.97 | 1.34 | 0.62 | 0.49 | 1.01 | 0.88 | 0.95 | 1.22 | 1.26 |
| | Min[c] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Max[d] | 5 | 5 | 5 | 4 | 3 | 5 | 5 | 5 | 5 | 5 |
| | Mo[e] | 5 | 5 | 5 | 1 | 1 | 5 | 5 | 1 | 5 | 5 |
| **Reminding Service**[f] | | | | | | | | | | | |
| | μ[a] | 4.55 | 4.48 | 4.27 | 1.12 | 1.24 | 4.3 | 4.55 | 1.33 | 3.76 | 4.61 |
| | σ[b] | 1.09 | 1.23 | 1.21 | 0.55 | 0.66 | 1.24 | 1.03 | 1.08 | 1.39 | 0.79 |
| | Min[c] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max[d] | 5 | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 5 | 5 |
| | Mo[e] | 5 | 5 | 5 | 1 | 1 | 5 | 5 | 1 | 5 | 5 |
| **Indoor walking support Service**[f] | | | | | | | | | | | |
| | μ[a] | 4.45 | 4.55 | 3.58 | 1.03 | 1 | 4.61 | 4.61 | 1.42 | 3.76 | 4.61 |
| | σ[b] | 1.23 | 1.12 | 1.58 | 0.17 | 0 | 0.79 | 0.83 | 1.06 | 1.39 | 0.79 |
| | Min[c] | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 2 |
| | Max[d] | 5 | 5 | 5 | 2 | 1 | 5 | 5 | 5 | 5 | 5 |
| | Mo[e] | 5 | 5 | 5 | 1 | 1 | 5 | 5 | 1 | 5 | 5 |
| **Outdoor walking support Service**[f] | | | | | | | | | | | |
| | μ[a] | 4.48 | 4.33 | 4.03 | 1.27 | 1 | 4.48 | 4.36 | 1.76 | 3.76 | 4.61 |
| | σ[b] | 1.23 | 1.24 | 1.31 | 0.91 | 0 | 0.87 | 1.06 | 1.35 | 1.39 | 0.79 |
| | Min[c] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 |
| | Max[d] | 5 | 5 | 5 | 5 | 1 | 5 | 5 | 5 | 5 | 5 |
| | Mo[e] | 5 | 5 | 5 | 1 | 1 | 5 | 5 | 1 | 5 | 5 |

[a]mean value
[b]standard deviantion
[c]minimun value
[d]maximum value
[e]mode
[f]Multimedia Appendix 3: Ad-Hoc Questionnaire

*Shopping Service* — Concerning the comparison between different conditions and users, men have more trust in the robot's ability to perform the shopping service than women (Item Q7: $P = .007$). Regarding the age factor, the participants under 75 years of age would use the robot for shopping if necessary (Item Q1: $P = .04$) and if it could reduce the family/caregiver's work burden (Item Q2: $P = .04$), more so than those over 75 years of age. Moreover, participants with a high educational level think that the proposed system could help the caregivers work less, more so than people with a low educational level (Item Q2: $P < .001$). However, higher educated users have more trust in the robot's ability to perform the shopping service (Item Q7: $P = .03$) than less educated users.

*Garbage Collection Service* — There is a significant difference on gender factor regarding the benefits that could lessen the family/caregiver's work burden: men gave a higher score than did women (Item Q2: $P = .02$). Furthermore, more educated participants are more skeptical than less educated ones about the help provided by the robotics system to caregivers (Item Q2: $P = .01$). The more educated participants perceived the robot as less intrusive for privacy (Item Q8: $P = .03$).

*Communication Service* — Men think their independence would be improved using the communication service (Item Q3: $P = .03$) more so than women. Furthermore, the robot is perceived as not intrusive (Item Q8: $P$ = .006) by men more so than by women. Furthermore, more males report that it is easy to speak to the robot (Item Q12: $P$ = .047) than do females. The vocal commands to interact with the robot are understood (Item Q13: $P$ = .048) better by men than by women. Moreover, more participants under 75 years of age would use the Robot-Era system in case of need (Item Q1: $P$ = .04) than those over 75 years of age. The younger group also felt the system could reduce the caregiver's work burden more so than the older group did (Item Q2: $P$ = .04). Finally, individuals with a high educational level had a more positive attitude (Item Q2: $P$ = .001) and felt the robot was less intrusive (Item Q8: $P$ = .03) compared to the less educated individuals.

*Reminding Service* — Participants' independence could be increased by this service (Item Q3: $P$ = .047), to a larger extent for men than for women. Moreover, males recognized the icons to press on the tablet to perform the reminding service (Item Q11: $P$ = .03) better than the females. Furthermore, more participants under 75 years of age reported that it is easier to use the speech commands (Item Q12: $P$ = .04, Item Q13: $P$ = .02) compared to those over 75 years of age. Regarding the educational level, more individuals with a high educational level think this service could reduce the caregiver's burden (Item Q2: $P$ = .02) and believe that the system is more reliable (Item Q7: $P$ = .02) compared to participants with a low level of education.

*Indoor walking support Service* — Men had a more positive attitude toward this robotics service (Item Q1: $P$ = .04; Item Q3: $P$ = .004) than women. Furthermore, more educated participants had more trust in the ability of the Robot-Era system (Item Q7: $P$ = .04) than those with a lower level of education.

*Outdoor walking support Service* — More men felt that their independence could be improved by this service (Item Q3: $P$ = .03) than women.

Moreover, investigating the correlation among the questionnaires, there are significant results between the Appearance one related to DORO and the Ad-Hoc one for Shopping (r=.35 and $P$=.04), Communication (r=.41 and $P$=.02), Reminding (r=.35 and $P$=.04), and Indoor walking support (r=.35 and $P$=.04) services; while there is not significant correlation between the Appearance questionnaire and SUS. Finally the Ad-Hoc questionnaire and SUS are correlated for all Robot-Era services: Shopping (r=.65 and $P$<.001), Garbage (r=.43 and $P$=.01), Communication (r=.41 and $P$=.001), Reminding (r=.71 and $P$<.001), Indoor walking support (r=.37 and $P$=.04), and Outdoor walking support (r=.39 and $P$=.03)

## Discussion

New technologies are increasingly impacting the entire society, but older adults often have difficulty accepting them. This reluctance could be due to the fear of trying something new, not perceiving the need for the technology, and the lack of training to use new technologies [43–45]. Moreover, many older individuals have never experienced such technologies, or at least they benefit from them to a lesser extent than younger people [46]. In this study, participants were free to become familiar with the Robot-Era robots before starting the experiment session, in order to feel more confident in testing them. A video tutorial was shown to illustrate all Robot-Era services, and older volunteers could touch the robots and ask questions about their functionalities to become confident with them. In fact, an adequate training can increase the level of acceptance [47].

### Principal results regarding robot's appearance

Participants had quite a positive impression of Robot-Era robots, as shown by the median score of 71.67 for DORO's appearance, 75.00 for CORO, and 76.67 for ORO. Furthermore, there is an upward trend in median score related to the workplace environment of the robot, as confirmed by the increase of the minimum value of the overall score (see Fig. 4). Looking at these data, older adults tend to express a more positive opinion about CORO and ORO, which usually do not live in the domestic environment with humans, but work in condominium and urban areas respectively. Having said that, a conscious and total acceptance of a robot in a domestic environment could reflect the successful diffusion of robots within society, starting from the outdoor environment, and progressing to their incorporation in the private house. This hypothesis finds a confirmation in the fact that older volunteers, able to use a PC and Internet, gave a higher score to CORO and ORO than those individuals who were not able to use the technologies. The older adults, with technology experience, were aware that these technologies can connect the outside world and their own homes, such as CORO and ORO are able to do. Moreover, ORO received a higher score by men than women because more male participants reported that the outdoor robot has a masculine aspect than women participants.

The appearance of a robot is a factor that may impact on human-robot interaction and acceptance by older adults even if older people did not express any preferences regarding the robot's appearance [48]. Furthermore, a human-like robot can confuse older individuals, so in the Robot-Era project, the choice is a mixed appearance between the anthropomorphic and machine features since all robots are equipped with a motorized head. The head is characterized by blinking colored eyes, a stylized mouth, and two small, soft disks on the side that resemble ears. Watching the Robot-

Era robots for the first time, all participants said something like, *"They have a nice face"*, *"They are smiling",* or *"They are welcoming"*. These sentences confirm that the older volunteers were positively impressed, and, in effect, that facial features of the robots, especially nose, eyelids, and mouth can influence positively the acceptance [49]. As matter of fact, 40 of 45 older adults think that the presence of a head on the robot promotes the interaction with it (Table 1, Item A14).

Furthermore, the Robot-Era robots are developed with a height of 1.50 m, which is shorter than an average human adult's height, for the user to perceive having control over the robot without feeling dominated by it. Thanks to this choice and to the presence of a head, DORO, CORO, and ORO do not evoke negative reactions in older users because they are judged not dangerous and they inspire confidence, as confirmed respectively by the low average score of Item A1 and the high score of Item A2 (Table 1). Moreover, the acceptance of new technologies increases if they are familiar with something known by end-users. For this reason, the shape of Robot-Era robots is designed to remind a domestic worker for DORO, a janitor for CORO, and a delivery man for ORO. Unfortunately, this goal has not been reached as shown by the low score of Item A3 (Table 1). However, the low familiarity may not always imply disliking or rejection, because if it does, it will mean that people do not ever like innovations or creativity.

Moreover, Robot-Era robots have to share and coexist with humans, so they have to integrate themselves in the real environments from an aesthetic and functional point of view. Investigating this issue, the survey outcomes show that DORO's appearance is pleasing for 34 out of 45 older adults, CORO's for 37 users, and ORO's for 34 (Table 1 Item A4). Additionally, the colors of the three robots are appropriate as confirmed by the high average score of Item A5 (Table 1). Considering that, it is reasonable to think that Robot-Era robots could fit well with a domestic, condominium, and outdoor environment as demonstrated by the positive results of Item A7 (Table 1). Furthermore, the size of a robot is an important perspective because it has to give the impression to work efficiently without damaging the environment. According to older individuals' feedback, CORO and ORO are not perceived as too big or bulky compared respectively to a condominium and outdoor environment (Table 1 Item A8). However, the participants assumed a neutral position regarding DORO's size (Table 1 Item A8) because most of them lived in a small house, but they were open to changing their minds after watching it move in a domestic environment.

Moreover, the appearance of a robot should be perceived as robust to people who should have trust in it. Investigating this issue, Robot-Era robots and their various components seem sufficiently robust according to the positive feedback from older individuals for Item A9 and Item A10 (Table 1).

However, all participants reported that they were not competent to judge this point, and they gave a high score, saying they trusted the developers.

Furthermore, a robot should be clearly understandable and easy to use to be accepted by end-users. According to the survey outcomes, all Robot-Era robots can successfully communicate their functions as confirmed by Item A11 (Table 1), and colored lights in the eyes of the robots are judged useful to communicate (Table 1 Item A13).

Individuals under age 75 readily understood the functionalities of Robot-Era robots, more so than older individuals, likely because the younger volunteers lead a more active life, so they are more familiar with new technologies, such as tablets and smartphones, which are achieving market and society penetration. Furthermore, the high score of Item A12 confirms that the position of the tablet is perfect for its use for all robots.

Finally, according to the results for Item A15, the appearance of the Robot-Era robots invites the user to touch and interact with them. Moreover, older users with a high educational level expressed a greater willingness to interact with DORO and CORO, possibly because they are open, due to their educational background, to perceiving the robot as a social entity.

### Principal results of Ad-Hoc questionnaire

Looking at Fig. 6, Robot-Era services are acceptable by older adults because the majority of the sample gave an overall score higher than 75 points, and the high degree of acceptance is also confirmed by the positive results shown in Table 2. The acceptance of robots by older people is related to their attitude toward robots because attitude is an important factor to understand the intention to use any technology [50]. In this study, the outcomes of the survey show a positive attitude toward Robot-Era services because the mean scores of Item Q1 and Item Q2 are higher than 4, and the mode is equal to 5 for all services. As matter of fact, all participants reported that they would share their life with a robot if the time would come when they would not be able to perform their daily tasks. Moreover, many volunteers said they would prefer to be assisted by a robot to avoid burdening their sons and daughters with their care. Furthermore, Robot-Era services have the potential to improve the independence of older people, as confirmed by the high mean score and mode equal to 5 for Item Q3. Many older adults reported that the Robot-Era system could prevent them from having to do boring tasks such as taking out the trash. Moreover, most of the participants said they would feel safer in their own homes using the Robot-Era services because DORO is able to communicate alert messages such as "*There is a gas leak*" or "*The door is open*" and because the robotics system can call a caregiver automatically in the event of dangerous situations.

Furthermore, the capabilities of DORO, to locate the user in the house and to remind them to take their medicine, were much appreciated by older adults who would no longer need to worry about forgetting to take their medications thanks to this robotics service. According to the feedback from older users, the *indoor walking support* service is useful to move safely in the home thanks to the robot's handle. However, the mean score of Item Q3 is not too high because the participants did not have mobility impairments. Nevertheless, they would use DORO to transport objects or laundry from one room to another, taking advantage of the robot's capabilities to navigate autonomously, because older users said they would feel safer if the robot would do that task for them, so they would avoid the risk of falls during this task. The same arguments are valid for the *outdoor walking support* service. In addition, the older participants would like the social capability of the outdoor robot to be improved. Furthermore, according to participants, the taking care of shopping needs is not perceived as a burdensome task, but as a socialization means; however, they said that this service is useful in the case of temporary mobility impairments or bad weather.

Moreover, anxiety toward robots is an important issue to be faced, and often older adults have negative feelings toward the idea of having a robot assistant, particularly in a home environment [51]. Conversely, the Robot-Era system did not evoke anxious or negative emotional reactions in older participants during the experimentation, because almost no one was embarrassed or nervous when interacting with the robots, as confirmed by a low score of Item Q4 and Item Q5. Furthermore, many participants expressed that, before starting the experiments, they were worried about appearing inadequate should they not be able to complete the test. However, they said they felt relaxed and comfortable thanks to the explanations provided by the researchers in the starting phase. In effect, the participants enjoyed using the Robot-Era system, as confirmed by the high agreement with Item Q6. Only two users did not get pleasure in testing the Robot-Era system because they claimed to see the robotics system as an appliance that is used for its usefulness and not for pleasure. Furthermore, the trust in the ability of the Robot-Era system to perform with integrity and reliability is a factor that affects the acceptance, and the participants expressed a high degree of trust in the Robot-Era system (Item Q7). The older adults justified their answers, saying that all provided robotics services had success during the experimentations. Moreover, the development of robotic systems working in daily living environments rises ethical issues such as privacy problems. However, according to older volunteers, the Robot-Era system was not too intrusive for their privacy, as confirmed by the low score obtained for Item Q8. Some participants said that their privacy would not be a concern since they can freely choose whether or not to use the proposed robotics services. Other older adults said that the Robot-Era system is not more intrusive than other technologies, while some male participants joked, reporting that a robot is less intrusive than their wives. Regarding the items related to the perceived ease of use of GUI, the feedback of participants was quite positive, and it should be considered that most of them did not have familiarity with the tablet and they had some starting difficulty because it was the first time they used it. In particular, the tablet was found easy to use (Item Q9), the messages on it were read without any major difficulties (Item Q10), and the icons to perform the services were identified (Item Q11). Therefore, at the end of the experiments, the older adults gave some suggestions to improve the GUI such as adding the captions to the icons. However, everybody reported a willingness to learn to use the tablet because it has widespread use in society. Finally, the speech interaction was well evaluated by older users, because they spoke to the robot easily (Item Q12), they understood the vocal commands to interact with the robot (Item Q13), and they heard without any major difficulties what the robot said (Item Q14). Moreover, the participants reported that they enjoyed speaking to the robot because it was seen as the more natural means to interact with it. Although the robot communicated in quite a sophisticated manner, it did not understand if a synonym of the keywords was used. For this reason, the participants suggested increasing the vocabulary of the robot, so that the user could speak in a natural way without having to remember the keywords to use. Moreover, the older adults suggested that the robot should give more feedback about its status, such as describing what it is doing, and the robot should communicate to the user if it understood a command.

Concerning the effect of socio-demographic factors, it seems that men have a more positive attitude toward Robot-Era services, and in effect, men are less skeptical in use of assistive robotic technologies than women [52], and they have a more positive attitude than women toward the possibility of using a robot in the future [53]. In effect, as shown in the previous section, the gender could have an impact on the acceptance of the technology. Examples of this in the study are that men would use the *indoor walking support*, in case of need, more than women (Item Q1) and regarding the *garbage collection service*, male participants thought that the Robot-Era system could reduce the caregiver's work burden (Item Q2). Furthermore, *Communication, Reminding, Indoor walking support,* and *Outdoor walking support* could improve men's independence more than women's (Item Q3). Moreover, the trust in the robot's ability to perform the *shopping service* (Item Q7) is higher in males than in females, who also think a robot would be too intrusive for their privacy (Item Q7, *Communication*). In general, men seem more willing to accept robotic technologies in their daily lives than women [54]. Furthermore, men perceived the interaction modalities (Item Q11: *Reminding, Indoor walking support,* and *Outdoor walking;* Item Q12 and Item Q13: *Communication)* as easier than women because males tend to be more task-oriented and motivated to achieve specific goals [55].

Regarding the effect of age on attitudes toward technology, the acceptance decreases with increasing age, and young older users are more likely to use technology [56]. However, if technology meets the older individuals' needs, the effect of age on the acceptance becomes less important [57]. In this study, the results show that older users positively evaluated Robot-Era services regardless of age, except for the *shopping* and *communication* services, in which the participants under age 75, more than those over age 75, would use the Robot-Era system in case of need (Item Q1) and if it could reduce the caregiver's work burden (Item Q2). Furthermore, the speech commands to perform the reminding service were evaluated as easier to use by young older users than older ones (Item Q12 and Item Q13). These results can be explained on the basis of cultural background because the sense of family ties is very strong for people over 75 years of age, who think they should be assisted by their sons and daughters. Moreover, younger people placed more trust in technology because they were more familiar with it, while the older individuals thought that the new technologies were far too complicated [52].

Concerning the factor of education level, it was found that people with a high education level expressed a positive attitude toward a robot [52]. However, in this study, the participants with a higher education level tended to have a less positive attitude toward the *shopping* (Item Q1, Item Q2) and *garbage collection* (Item Q2) services than those who had a low educational level. This could be explained by the fact that the participants with a higher education level tended to live in towns where they had more access to services such as home grocery delivery and curbside collection. Alternatively, participants who lived in rural areas where these services were less widespread needed a family member's help for transportation of goods, and for this reason, they would like to use robotics service to relieve the caregiver of these duties. However, in keeping with their familiarity with advanced technologies, older users with a high educational level reported more positive judgments about *communication* (Item Q2) and *reminding* (Item Q2) services. Furthermore, individuals with a higher education level had more trust in the robot's ability to perform *shopping* (Item Q7) and *reminding* (Item Q7) (Item 7: $P = .02$) and felt that the robot was not intrusive for their privacy.

However, even if some correlations between socio-demographic factors and ad-hoc questionnaire items were highlighted, the Robot-Era system could be considered acceptable by a large segment of the old population.

Finally, the significant correlation between the Appearance questionnaire related to DORO and the Ad-Hoc one for Shopping, Communication, Reminding, and Indoor walking support services, suggests that the acceptance by older users could be influenced and increased by the positive impression aroused by the aesthetics of a robot. However, it should be considered that DORO was the robotics platform with which older adults had interacted for more time during the experimentation.

## Strength and limitations

The strength of this study is that it reflects the real users' perceptions of acceptability of services provided by a robotics system. The rationale is that 35 older adults tested six robotic services in realistic environments; moreover, the individuals worked with three robots in a domestic, condominium, and outdoor environment, to guarantee the continuity of the robotic services from private houses to public areas and vice versa.

The study had some limitations. First, the Appearance and the Ad-Hoc questionnaires were developed specifically for the Robot-Era experiments, but they were not pilot tested nor validated before the trial sessions were started. However, the internal consistency was verified by applying the Cronbach's Alpha test, and all questionnaires have an Alpha value higher than 0.60.

Second, the Robot-Era experimentation was organized in two sessions, testing three services at a time. In this respect, the two samples were not composed of the same subjects because some of the subjects were not available to participate in both experimental sessions. Furthermore, the sample was not sex-balanced, but this is because, at the age of 65, women in Europe have a life expectancy higher than men.

Third, participants spent three hours in testing the Robot-Era system during which time they alternated the testing of each robotics service and the evaluation phase. This adopted experimentation format brought a lack of continuity that could have given an incomplete overview of robotic services and prevented its potential from being fully explored. In each case, this experimentation was positively used to gather feedback to improve the Robot-Era system. In the future, participants should interact with the robots for longer and in a more realistic setting, postponing the evaluation phase to the end of the trials.

Fourth, during the trial, some technical problems occurred, and this could have biased the user's perception of the robotic system. For further trials, the dependability of the Robot-Era system should be improved so that older adults can evaluate a reliable robotic system.

Finally, the recruitment was limited to older persons who lived in Peccioli Municipality, a small village in the Italian countryside, so the catchment area covered a small number of older citizens. For this reason, the randomization of the sample was not feasible. Furthermore, only participants without cognitive and physical impairments were recruited, because the Robot-Era system was conceived for frail older persons living alone at home without a formal caregiver's support. These recruitment criteria could lead to enroll basically positive inclination people towards the Robot-Era system.

## Conclusion

This paper presents the results of a realistic experimentation of a robotic system for supporting independent living of older people. The approach overcome some of the limitations of previous similar experiments. Six robotic services were tested by a total of 35 older users, who directly interacted with three autonomous robots, which cooperated between them in smart environments to accomplish everyday life tasks.

Looking at the proposed robotics system, interesting outcomes were found. In general, the Robot-Era robots' aesthetic and functionalities had a positive impact on the older adults, as shown by the high scores they gave to DORO, CORO, and ORO. Moreover, the results suggest that the positive perception of robots' aesthetics could play a role in increasing the acceptance of robotic services by older persons.

Finally, according to all aspects discussed in this work and based on the feedback given by the end-users, the Robot-Era system has the potential to be developed as a socially acceptable and believable provider of robotic services to promote the ability for older individuals to remain in their homes. Future works will foresee experimentations with the involvement of users with mild functional impairments.

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## Conflicts of Interest

None declared.

## Multimedia Appendix 1

Overview Related Works

## Multimedia Appendix 2

Appearance Questionnaire

## Multimedia Appendix 3

Ad-Hoc Questionnaire

## Multimedia Appendix 4

Questionnaires Reliability

## Multimedia Appendix 5

Video of Scenarios

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## Abbreviations

ICC: Intraclass Correlation Coefficient