# Human–Robot Interaction: Robots for Older Adults

**Wendy A. Rogers**
*College of Applied Health Sciences, University of Illinois Urbana-Champaign, Illinois, U.S.A.*

**Tracy L. Mitzner**
*School of Psychology, Georgia Institute of Technology, Atlanta, Georgia, U.S.A.*

**Abstract**
There is much potential for robots to support the needs of older adults. Older adults have been found to be quite open to the idea of interacting with robots, although they have preferences for the nature of the task they want the robot to do for/with them as well as what they want the robot to look like. These preferences are not set in stone but should be considered in the process of design and deployment. Moreover, it is crucial to involve older adults throughout the design process from formative to summative evaluation and even beyond to the integration of the robot into their everyday activities. The extant research provides valuable guidance regarding the capabilities and limitations of older adults that might influence their ability to interact with a personal robot. Additionally, much is known about the needs of older adults that might be met by a robot. Our goal in this entry was to provide a framework that can be used to guide the development of prototype robots that will be useful to and usable by older adults.

## INTRODUCTION

Robots have the potential to augment capabilities of older adults and enhance their quality of life. However, for such advancements to realize their full potential for supporting the needs of older adults, more detailed information is required about aspects of human–robot interaction (HRI) in this context. Specifically, robots could be more effective if robot designers understood the tasks for which older adults would benefit from technology support and the nature of the context in which these technologies would be used, in terms of the physical and structural environment and the users themselves. We have developed a framework to guide in the designing process of robots for older adults. The focus is on older adults as the interacting users of the robots (as opposed to passive recipients of care provided by a robot). The framework is based on an understanding of older adults' limitations and capabilities, their needs for everyday task support, their attitudes and experiences with technology and with robots, and research on HRI.

## OLDER ADULTS: A HETEROGENEOUS GROUP

In any design endeavor, the first step is to have a good understanding of who will be the users of your product/system/environment. Older adults—typically defined as those aged more than 65 years—are a heterogeneous group. They have different health needs and wellness goals; experienced varied life events; a range of capabilities and limitations; and a diversity of attitudes, opinions, and expectations. Thus, when thinking about design for older adults, it is critical to recognize that there is not a prototypical older person, but instead there may be groups of older adults that differ in these characteristics.

### World Demographics

Society is getting older, and this trend can be seen worldwide. Projections are that the proportion of older adults is going to rise substantially as illustrated in Fig. 1 for North America and Europe. It is imperative for designers to consider this growing demographic because more consumers of technology are considered "older" and bring their own demands to services and products.

Housing options for older adults have increased from the traditional (e.g., remaining in original home, moving in with relatives, or moving to a long-term care residence) to more recent options (e.g., downsizing, relocating, and continuing care retirement community). Although older adults' preferences vary, most prefer to remain in their own home as they age. Most live in private homes with a spouse; however, many live alone. The likelihood of living alone increases in women and the oldest old. Nevertheless, approximately 32% live with relatives, such as multigenerational households. This preference is more common in African American, Asian, and Hispanic seniors than in those who are Caucasian.

### Capabilities and Limitations

Individual differences in capabilities and limitations are prevalent. It is useful to think about older adults as two

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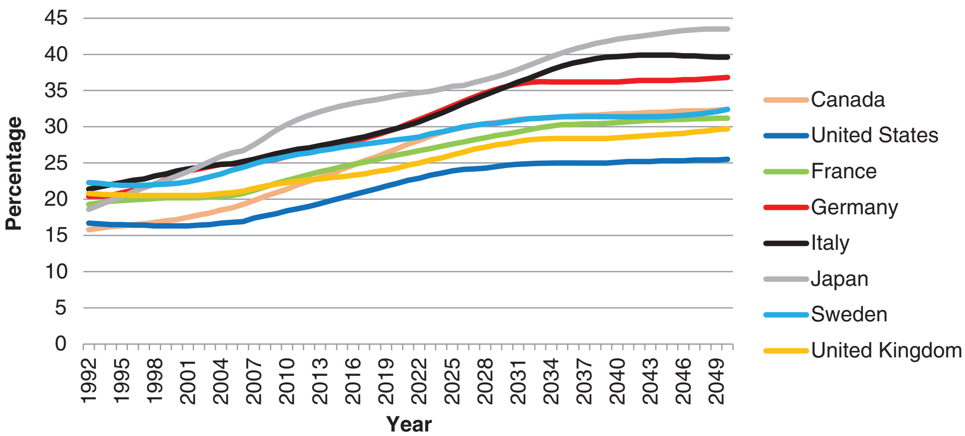


**Fig. 1** Past, current, and projected percentage of the population aged 60–99 years.
**Source:** From U.S. Census Bureau's International Database (http://www.census.gov/ipc/www/idb/)

major categories: 1) younger-old, comprising those older adults younger than 75 years of age and 2) older-old, comprising those aged more than 75 years. This simple categorization is useful because the capabilities and limitations of an individual who is 65 years are likely to be very different from those of someone who is 85 years.

Although there are individual differences, there are general changes that occur throughout the aging process. These changes transcend cohorts and can be largely categorized as changes in perception, cognition, and movement control. An overview of age-related differences relevant to technology design is provided in Table 1.[1] Chronological age is only a number, but it can be useful for a marker of corresponding age-related changes—the changes in Table 1 are evident for many adults aged more than 65 years.

## Health and Chronic Conditions

Needs for assistance managing chronic conditions vary as well. The most common conditions associated with aging are hypertension, stroke, heart disease, arthritis, cancer, and diabetes (National Center for Disease Control and

**Table 1** Age-related changes in perception, cognition, and movement control.

| Ability | Age-Related Changes |
|---|---|
| Perception | |
| *Audition* | • Declines in hearing are common for men, particularly for high-frequency sounds |
| *Haptics* | • Decreases in sensitivity to temperature and vibration make older adults susceptible to falls |
| *Taste and smell* | • Older adults show difficulty in distinguishing between different tastes and odors |
| *Vision* | • Declines in visual acuity begin around the age of 40 years |
| | • Glare is more problematic for older adults |
| | • Dark adaption slows |
| | • Breadth of visual field decreases |
| Cognition | |
| *Divided attention* | • Older adults show declines in coordinating multiple tasks (i.e., "multitasking") |
| *Selective attention* | • Declines in searching for information, especially in clutter |
| *Procedural memory* | • Well-learned procedures maintained with age and hard to inhibit |
| | • Older adults are less successful in acquiring new procedures |
| *Prospective memory* | • Older adults show decline in remembering to do things in the future, but this is less evident when strong cues or reminders are available |
| *Semantic memory* | • Knowledge acquired over time (e.g., vocabulary and historical facts) shows little decline with age but may be slower to retrieve |
| *Working memory* | • Older adults show difficulty in keeping active or manipulating new information in working memory |
| Movement control | |
| *Speed* | • Older adults take 1.5 to 2.0 times longer to respond than younger adults |
| *Precision* | • Older adults' motor control is less exactly reproducible and consistent |
| *Accuracy* | • Movements are less likely to reach the target |

**Note:** For a more detailed review, refer to Fisk et al.
**Source:** From Fisk, Rogers, et al.[1]

Prevention, http://www.cdc.gov/aging/index.html). Certain acute health conditions are also common such as falls and injuries, circulatory, and respiratory diseases in older adults. Approximately 80% of adults aged more than 65 years and older have at least one chronic health condition and 50% of them have at least two.

### Everyday Activities

Older adults have diverse needs for functional assistance (reviewed in Mitzner et al.).[2] To lead independent and healthy lives in their own homes, people must be able to perform a wide range of tasks related to daily living including self-maintenance activities of daily living (ADLs) and instrumental activities of daily living (IADLs). Self-maintenance activities of daily living are essential to maintaining independence and include the ability to toilet, feed, dress, groom, bathe, and ambulate. The Administration on Aging (www.aoa.gov) found that 37% of adults aged 65 years and older reported having a severe disability ranging from difficulty in hearing, vision, and cognition to difficulty with ambulation, self-care, and independent living, and this increased to 56% for adults aged more than 80 years.

Instrumental activities of daily living are more cognitively demanding and include the ability to successfully use the telephone, shop, prepare food, do the housekeeping and laundry, manage medications and finances, and use transportation. Approximately 2.2 million older adults require assistance with IADL tasks, such as cooking, shopping, or going outside of their house.

Enhanced activities of daily living (EADLs[3]) are lifelong learning, social participation, hobbies, and community engagement. These activities contribute to overall quality of life and well-being but may be impacted by financial, transportation, and other general challenges experienced by older adults.

### Technology Experience and Attitudes

Income, general technology experience, and education positively influence older adults' technology adoption.[1] According to the Pew Internet and American Life Project (www.pewinternet.org), 61% of older adults aged more than 65 years use the Internet, primarily for e-mail and searches.

In terms of experience with robots, a European survey found that 62% of those aged more than 55 years reported their attitudes toward robots as positive (https://ec.europa.eu/digital-agenda/en/news/robots-more-europeans-know-them-more-they-them), although their direct experience with robots was relatively limited. Older adults are open to robot support, although they have preferences for which tasks they want robot assistance[4] and for how they want their robot to look.[5] In addition, their perceptions of how useful, easy to use, and enjoyable the robot is in performing tasks around the home are all predictive of acceptance.[6]

Positive attitudes toward robotic technology are important, because positive attitudes toward technology predict intention and actual technology use, and the use of robots is predicted to increase. In 2011, approximately 2.5 million service robots were sold for personal and domestic use (International Federation of Robotics; www.ifr.org), and almost 15.6 million service robots were projected to be sold for personal use between 2012 and 2015.

## POTENTIAL FOR ROBOTS DESIGNED FOR OLDER ADULTS

Robots to be used by older adults have the most impact if they are designed to support the specific activities for which they need or want support. Any type of assistive technology is most useful when there is a match between the user's needs and the technology's functionality. The context in which the robot is to be used and the task demands are also important to consider. Moreover, given that most robot designers are likely to be under the age of 65 years, it is important to involve older adults in the design process—from the initial conceptualization through testing in the home environment.

### Support for ADLs, IADLs, and EADLs

Walking, getting in/out of bed/chairs, and bathing/showering are frequent ADLs with which community-dwelling older adults experienced limitations.[2] IADLs with which older adults experienced difficulty included housekeeping, meal preparation, and outdoor home maintenance tasks.[2] Older adults indicated that even leisure activities (EADLs) can be difficult or frustrating due to limited physical ability or limited technological knowledge.[3]

Different robots could purportedly support the range of activities of daily living for which older adults have difficulties; some robots may assist with multiple activities; e.g., robots could support ambulation by reducing the need to move or by supporting physical movements. Robots could perform housekeeping chores, cook meals, and provide reminders for medications. Robots might support social activities by being a social agent themselves or serving as a mediator for between-person engagement.

### Categories of Robots

We will focus here on the types of robots that are being developed for use by older adults. Two prominent categories are personal service and social robots. The International Federation of Robotics (http://www.ifr.org) defines a robot as follows: "A personal service robot or a service robot for personal use is a service robot used for a non-commercial task, usually by lay persons. Examples are domestic servant robot, automated wheelchair, personal mobility assist robot, and pet exercising robot." The *International Journal of Social Robotics* (http://www.springer.com/engineering/robotics/journal/12369) defines their scope as "the study of robots that are able to interact and communicate among themselves, with humans, and with the environment, within the social and cultural structure attached to its role."

Thus, a personal service robot for older adults might perform tasks for personally or around the house. One example is the personal robot 2 (PR2; developed by Willow Garage) which has been investigated for older adults in the home environment.[4] Personal service robots may have some social characteristics or people may impose a social aspect as was found for the Roomba.[7] However, other social robots may be more like the Paro, which was designed to elicit happiness and support socialization (http://www.parorobots.com/) or telepresence robots (e.g., Vgo, Double, and Beam), which support social engagement by enabling individuals to have a virtual presence at locations outside their home.

### The Design Process for HRI: Involving Older Adults

Successful robot design (i.e., robots integrated into the lives of people) will benefit from user-centered design (see Fisk et al.,[1] for more details). This process adheres to four broad principles:

1. Early focus on the user and the tasks the user will be performing, which often requires a task analysis.
2. Empirical measurement using questionnaires and surveys as well as usability testing studies that rely on observations and quantitative or qualitative performance data.
3. Iterative design and testing, which often requires the development of prototypes of products or system interfaces to support rapid development cycles and performing cost–benefit analyses to support trade-off decisions.
4. Integrated design, wherein all aspects of the usability design process evolve in parallel and are generally under the coordination of a single person.

These four principles roughly correspond to the following four phases of the design process: the gearing-up or front-end analysis phase; the initial design or usability testing phase; the iterative design and development phase; and the final test and evaluation phase.

A further extension of the idea of user-centered design is universal (or inclusive) design, whereby products or environments are designed that are flexible enough to be used by people with no limitations as well as by people with functional limitations related to impairments (e.g., those who are blind, cannot speak, cannot hear, or have learning disabilities) or due to circumstances (e.g., those whose hands are temporarily occupied and those cannot hear due to a noisy environment). In principle, good universal design benefits everyone.

## A FRAMEWORK FOR HRI DESIGN

Fig. 2 shows a representational framework of variables necessary to consider for successful HRI. There are four main components of the framework: 1) human characteristics; 2) robot characteristics; 3) task constraints; and 4) context of interaction. These general categories represent the breadth for variables that should be considered in the design of a robot intended to be used by older adults.

### Human Characteristics

The demographic characteristics of a person, such as their age, education, sex, ethnicity, and cultural background, can increase or decrease the likelihood of success of a robot. These individual differences primarily exert their influence through age-associated capabilities and limitations in abilities (e.g., motor, haptic, perception, and cognitive), psychographics (e.g., personality, and attitudes), experience, as well as an individual's personal situation. These characteristics are measureable and, therefore, predictable. Understanding how human characteristics influence HRI can inform the design of robots and the training that may be necessary when robots are deployed.

#### Demographics

Demographic characteristics, such as age, sex, and education, have been associated with technology acceptance, as well as the acceptance of robots.[6] For example, individuals who are younger, male, and more educated tend to be more likely to accept technology, in general, and robots, in particular. However, these demographic predictors are only markers for more direct predictors, such as an individual's abilities and psychographic characteristics.

Cultural differences would also be expected for robot use, just as cultural differences have been found for technology use, in general. Such differences are likely driven by differences in beliefs and attitudes (e.g., collectivist vs. individualistic cultures). Members of an individualistic culture (e.g., Americans, Dutch, and New Zealanders) focus on personal achievement at the expense of group goals, which builds a sense of competition, whereas members of a collectivist culture (e.g., Chinese and Japanese) focus on group goals above individual interests. These cultural differences in beliefs, attitudes, and goals would be expected to influence robot use and HRI.

#### Abilities

As indicated in Table 1, older adults, in general, experience age-related changes in abilities (see also Mitzner et al.).[2] These changes in motor, perceptual, and cognitive abilities

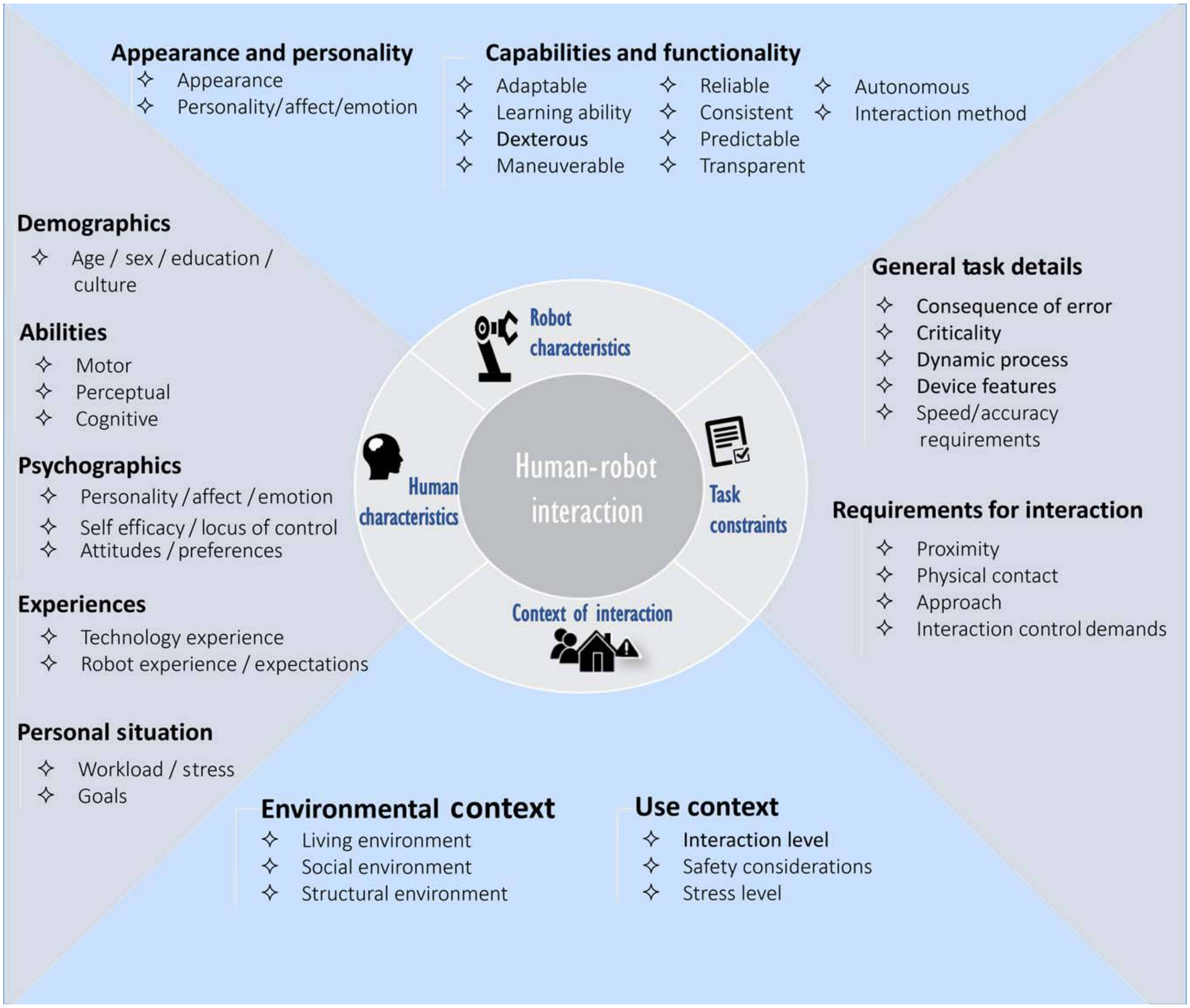


**Fig. 2** Representational framework of variables necessary to consider for successful human–robot interaction.

may impact HRI and must therefore be considered in the robot design process, as well as in the design of the related training programs.

***Motor.*** An individual's motor capabilities and limitations will impact how they interact with a robot particularly in terms of their ability to control and provide physical feedback; e.g., some robots require physical input from the user and some robots learn from demonstration and/or by being physically manipulated by the user (i.e., kinesthetic teaching). Age-related slowing and reduced precision of movement may cause older adults to be error-prone in their interactions with robots. Age-related slowing in motor movements can be particularly problematic for inputs that have time constraints. Allowing for more time, or having customization of input time constraints, would benefit older users in their interaction with robots.

***Perceptual.*** Perceptual abilities, including haptic, vision, and hearing, will impact HRI with respect to how well a user can control the robot and how much information can be exchanged between the user and robot. Robots often provide information via sight and sound; there is also a growing trend to incorporate haptic technology into robots. Age-related changes in haptic acuity, distance discrimination, and high-frequency vibration acuity may translate to older users having different needs than younger users for the quality and quantity of haptic information required for successful robot interaction. These issues might be especially relevant for domestic service robots designed to assist older adults with activities of daily living, including dressing and bathing. It is important to consider the amount of force these robots use on different parts of the body when bathing an individual. Too much force could cause pain, yet too little force could be unpleasant as well (e.g., ticklish).

With respect to visual declines, older adults may have difficulty interacting with a robot interface and/or perceiving subtle differences in expressions from social robots that have faces.[8] Age-related vision limitations would also make it difficult for older users to provide input and control robots with small buttons, keypads, displays, and other input devices. Visual search declines may create usability issues as well, particularly for certain types of robots, such as robotic telepresence systems. Older users may experience difficulty navigating a telepresence system around a home without damaging objects because of visual search limitations (e.g., scanning for obstacles while navigating the system).

Age-related hearing loss may limit older adults' interaction with robots, particularly those that output higher-frequency voices (e.g., women and children) and high-frequency beeps, pings, and alerts. To increase the success of HRI, visual and sound characteristics of the interface should be adjustable, and users with varying visual and hearing abilities should be involved early on in the design process.

***Cognitive.*** An individual's cognitive capabilities could impact HRI, particularly with respect to learning to use and remotely controlling a robot, as well as interpreting and understanding its visual interface, verbal communication, and feedback. For example, age-related changes in divided attention may make it difficult for a user to control a robot at the same time as interpreting verbal communication from the robot. In addition, selective attention declines would be particularly problematic for searching for information embedded in a cluttered interface. To increase the success of HRI, multitasking should be minimized, complex tasks should be divided into subtasks, and interfaces should be clean with non-essential graphical elements hidden. In cases where interface elements cannot be reduced, cues to orient the user to the relevant areas can be helpful for older users.

Due to working memory decrements and declines in learning new procedures, older users may need additional support when learning to use a robot (e.g., training materials such as quick start guides and manuals), and they may continue to need aids for newly acquired procedural memory tasks. Using cues and meaningful labels in an interface could facilitate older adults' use compared with arbitrary codes and icons. Furthermore, to compensate for age-related prospective memory declines, reminders should be used to help users remember to perform an action with the robot. Moreover, robots should be designed to take advantage of the relative preservation of procedural and semantic memory with age. For example, the robot interface characteristics and interaction methods should be compatible with a user's expectations and knowledge base.

By understanding potential users' abilities and designing a robot to compensate for declines and capitalize on strengths, HRI is more likely to be successful and users will be more likely to continue to use robots. However, regardless of abilities, and especially for those who have more limitations, it is important that robots are designed empower the user and facilitate their independence and autonomy rather than "taking over."

## Psychographics

Personality characteristics, and an individual's emotional state and affective response, as well as their interpretation of that of a robot should also be considered within the context of an HRI. Personality traits such as openness to experience and agreeableness may relate to positive perceptions of robots as they have been associated with positive perceptions of other technologies.[9] Aspects of the participant's personality, such as extroversion and conscientiousness, have also been shown to influence participants' task performance and preferences for interaction with a robot; when a socially assistive robot autonomously adapted to the user's personality, task performance increased.[10] An individual's emotion state and affective response may also influence their interaction with a robot, depending on how well a robot interprets their state and appropriately responds. Likewise, a robot's affective response can influence how well a user interprets the state they are attempting to communicate.

With age, one would continue to expect personality traits to impact robot use and interaction, as personality tends to be relatively stable over time. However, there are age-related changes in emotional state and affective response that may impact older adults' interactions with robots. For example, aging is associated with improvement in emotional regulation, as well as increased affective complexity.[11] These changes may translate to older adults expressing their emotions differently than younger adults. Therefore, the parameters used for a robot to detect a user's affective response or emotional state may need to be different depending on the user's age. This may be particularly important for social robots given their potential to provide support to isolated older adults. With respect to users' interpretation of a robot's expression, older adults have lower recognition rates for emotions expressed by a virtual agent compared with younger adults[8] and thus may require different (e.g., more intense) parameters to accurately interpret a robot's intended emotion.

Self-efficacy (one's perception of control over his or her environment and behavior) is socioemotional construct that has been implicated in the use of technologies, such as computers and the Internet, and would be expected to influence HRI, as well. Individuals vary in general as well as in task- or context-specific self-efficacy. Self-efficacy for using/controlling the robot would impact how much a person uses the robot (i.e., low self-efficacy would be associated with less use). Self-efficacy for a task would also be expected to impact how much a person uses a robot, but in the opposite direction (i.e., low self-efficacy would be associated with more use). Aging is associated with lower computer self-efficacy and would also be expected to be associated with lower robot self-efficacy and would be less likely to troubleshoot independently. An individual who has lower self-efficacy is also more likely to perceive a technology as difficult to use.[9] Therefore, older adults who are learning to use robots for the first time might need additional training and ongoing help resources (e.g., technical support). At the same time, age-related declines in abilities could reduce older adults' self-efficacy for certain tasks (e.g., physically demanding household tasks), and they might be more likely to want to use and depend on a robot for those tasks.

Attitudes and preferences about robots and the tasks they should perform will impact how users interact with robots. Users are also likely to hold attitudes about the level of autonomy robots have for different tasks.[12] As individuals age, they may change their preferences for what types of tasks they would want robot assistance. Despite indicating openness to robots and robotic assistance, older adults may prefer robot assistance for certain tasks such as chores, manipulating objects, and information management.[4] Robots should be designed to meet preferences to facilitate adoption and use and the task requirements for HRI for these types of tasks (e.g., housework, yard work, and cooking) be carefully considered.

### Experience

Prior experience appears to be a stronger influence on robot acceptance than on demographic variables. However, given the emergence of robotics, most people have limited experience with robots. Nevertheless, people have seen robots in popular media, and these experiences do influence their expectations of what a robot looks like and what it can do. These expectations will impact how users will try to interact with a robot and also their perceptions of a robot's performance. Given that older adults have less technology experience in general, they will have less experience to draw from in terms of how advanced technologies work. Providing education and training to older users to ensure that their mental model of the robot is as accurate as possible will facilitate their interactions with robots.

### Personal Situation

A person's current situation with regard to workload and stress may impact the types of tasks they want a robot to perform. For example, high workload in people's lives (e.g., work and childcare demands) may prevent them from regularly taking care of household activities. They might prefer a robot to assist with such activities or perform them all together (i.e., autonomously). High workload conditions for a user may also influence how well the user controls or monitors the robot. For instance, high workload has been associated with users being less accurate at detecting automation errors for younger and older adults.[13]

High stress in an individual's life might also influence the types of tasks the robot should be designed to assist with. Social robots may reduce stress by providing companionship. Many older adults live alone and may be at a risk of social isolation, which is associated with negative health outcomes.[14] There is some evidence that social robots can benefit older adults with dementia,[15] and healthy older adults may benefit as well.[16] Additionally, robots may benefit individuals under stress by monitoring their vitals and reporting concerning levels of stress to a healthcare provider who can then intervene.

The goals the user has for their interaction with a robot will also influence which tasks they want robot assistance with and what level of assistance they want or need. Successful aging has been proposed to be a process including the selection of personal goals, the optimization of time or energy to meet the selected goals, and the compensation for a loss in ability.[17] Robotic assistance may be one way for older adults to select, optimize, or compensate for age-related decrements. An older adult may choose to cook their own meals because they enjoy cooking even though aspects of the cooking process are difficult for them. A robot could assist by offering suggestions for new recipes that are easy to prepare (select) or healthier versions of favorite foods (optimize) while the older adult is cooking, or the robot could assist with the physical aspect of the task, such as moving a heavy pot off of the stove (compensate). Furthermore, the robot could adapt as a user's goals changed over time.

## Robot Characteristics

Robots vary in their appearance and their functional capabilities. The robot characteristics will influence the success of the HRI because certain appearances may be preferred—and for certain tasks. Moreover, the specific capabilities of the robot will influence the effectiveness of the interaction.

### Appearance and Personality

There may be differences among people in the assessment of robot appearances depending on their age, health, gender, personality, need, and so on. Most research on robotic appearance has involved only young participants, and there are limited data on older adults' attitudes toward robot appearance. Nonetheless, in a review of the literature relevant to older adults, the following trends have been observed. Older adults have concerns about robot size and weight.[18] Older adults want their robot to be small in size (preferably not taller than an average human); therefore, it could fit well into their homes and could also be stored when it is not in use. There is also variability in older adults' attitudes toward humanoid vs. mechanical appearance of robots.[5,18]

With respect to the personality of the robot, this has been less studied. However, individuals do seem to attribute personalities to robots, even if the robots are not explicitly designed to be social.[4,7]

### Capabilities and Functionality

The specific capabilities and functionality of a particular robot will depend on the purpose of use for which it was designed. Mataric's[19] *The Robotics Primer* provides an excellent overview of the dimensions on which robots can vary as well as the range of functionality they can have. Some robots are very specific, single-function robots (e.g., Roomba and PARO), whereas others are intended to perform a variety of tasks and are hence multifunction robots (e.g., PR2).

The framework in Fig. 2 lists the various characteristics that could influence the success of a HRI. Most of the variables have a positive, beneficial aspect, but it is important to consider also potential unintended consequences. For example, a robot that is adaptable to the individual or has the ability to learn about the person with whom it is interacting (e.g., Simon) may positively influence the HRI but may also result in unexpected behaviors as the robot capabilities change over time. Robots that are dexterous and maneuverable will be able to perform a broader range of tasks in the home environment, but a robot that moves around the home might also result in potential trip/fall hazards for older adults.

The reliability of the robot and how accurate it is in performing tasks influence how accepting older adults will be of the robot.[4] That does not mean that the robot must be perfect but instead that the users understand the limits of the capabilities of the robot. This relates to the ideas that the robot actions should be predictable and transparent to the users. Older adults should be able to understand what the robot is doing (and what it will do next) and also why particular actions are carried out by the robot. Much like people like to know what other people are going to do next, similar predictability and transparency will influence HRI.

Robots can range in their level of autonomy, from being completely controlled by a human to being completely self-controlling. If the robot is to be controlled in some way by the user, then the interaction method becomes a key design consideration. Consider a telepresence robot; if an older person is going to be navigating a telepresence robot in another space (e.g., a friend's apartment), then it is crucial to ensure that the control interface is easy to use, that the display is visible and comprehensible, and so on. The issues of autonomy and interaction methods with respect to older adults are detailed in Beer and Rogers.[12] They reported that older adults are open to a variety of input methods such as voice control as well as remote controls, touchscreens, and laser pointers. However, different control methods might be more feasible at different points in an older adult's life; e.g., physical manipulation may not be a preferred input method if older adults thought they might lack the strength to move the robot, especially in later older adulthood. Older adults' capabilities and limitations—in terms of perceptual, motor, and cognitive capabilities—must be considered in the context of the level of autonomy of the robot as well as the method(s) selected for interacting with the robot.

## Task Constraints

Given that older adults are diverse, have a variety of needs and preferences, and vary in their capabilities and limitations, robots designed to support them will likely have to perform different tasks.[2] These task variations will influence the design of the robot and the success of the overall HRI. Two relevant categories are the general details of the task and the specific requirements for interaction.

### General Task Details

Consider a robot that is assisting with ADLs—bathing, mobility, transfer from wheelchair to toilet, and so on. The consequence of an error with such tasks could be very serious for older adults, e.g., a fall leading to broken bones or other injuries. As such the design of the robot will have to be as error-proof as possible, with appropriate backups for safety concerns. Likewise, a robot that assists with IADLs such as medication management is performing potentially life critical tasks, and the need for assurances and high thresholds of reliability will be greater than for less critical tasks. Thus, the consequence of an error and the criticality of the task impose additional constraints on the design of the robot.

Additional constraints may be imposed by the details of the task; e.g., the human and the robot might be performing a dynamic task wherein one action influences another action, and there is a need for continuous adjustments on both sides. An example is a telepresence robot that a human is navigating through a complex environment that contains objects as well as other people or perhaps animals. The human must be able to react to the demands, and the changes in the environment and the robot must be able to react accordingly, given the control inputs from the human. Another example is a robot assisting with a medical procedure such as taking a person's temperature or monitoring blood pressure. In these cases, the human is actively moving, and the robot will need to be able to adjust to the dynamic nature of the task.

In some cases, the robot will have to use a device, as in the medical procedure examples That is going to impose demands on the dexterity and maneuverability of the robot; e.g., if the robot has to hold an electric razor to assist a human with shaving or a thermometer to take a temperature. Imagine that the robot is assisting with transfers—it may need to have the capacity to lock the wheels on the wheelchair. Examples of these types of interactions, and the constraints imposed by the nature of the task, are well illustrated in the Robots for Humanity project (http://r4 h.org/).

Tasks also impose certain requirements for speed and accuracy. It may be critical for a task to be done quickly (e.g., protecting a person from a fall), with less consideration for accuracy (e.g., some range is allowable for the robot to support the person); or the reverse may be true (e.g., exact placement of a needle in a procedure is more important than the speed of the placement); or the level of accuracy for the item might be crucial, but the accuracy of delivering it to a person within a certain spatial area may be less important (e.g., selecting the correct medicine vs. handing it to a person so that it is at least within reach).

### Requirements for Interaction

The interaction level between the human and the robot will be necessary to consider for determining the design features of a robot. The robot and the human may be operating in the same physical space, and the robot may need to get within a foot or maybe even a few inches for certain tasks (e.g., to hand off a medication), but for other tasks, the human will have to physically touch the robot—and vice versa. The level of physical contact will guide the need for sensors on the robot, as well as the structure of the robot (e.g., skin that is reactive to touch, soft grippers so as not to scratch a person). If the robot is lifting or supporting the person, then factors such as payload, stability, and maneuverability will be relevant.

For both proximal situations and contact situations, the approach of the robot will be a necessary consideration. Will it approach the person from the front or the side? Will the person be seated or standing? How quickly will the robot be moving when it nears the person? There are likely to be personal preferences to be considered in these contexts, in addition to what is technically feasible and necessary for the tasks being conducted.

Given the need for interaction (by definition this is necessary for HRI), an additional consideration is the interaction control demand imposed by the task being carried out. Fine movements of the robot would be needed for certain tasks such as medical procedures vs. gross motor movements for mobility in the environment. The need for precision and the demands imposed on the human (perceptual, motoric, and cognitive) would thus differ across tasks and contexts.

## Context of Interaction

The context of interaction has implications for the design requirements of robots, including the environmental context (i.e., living, social, and structural environments), as well as the context of use (i.e., interaction level between the user and robot, safety considerations, and stress level). These aspects are critical for successful HRI and should be addressed early on in the design process.

### Environmental Context

With respect to personal or home robots (vs. industrial robots), the living environments in which they may be used include private homes (e.g., single-family and multifamily), communal living environments (e.g., dormitories for younger adults, independent living, and long-term care residences for older adults), schools, clinics, and hospitals. Depending on the environment, the user characteristics and social dynamics may vary. For example, some households are multigenerational. In these environments, the users would be of different ages and would likely have different levels of technology experience and attitudes about robots. There might also be multiple robots or multiple robot roles (e.g., assist a child with homework and a grandparent with ambulation). In public environments, such as clinics and hospitals, users might vary on multiple dimensions such as age, abilities, native language, and ethnicity, in addition to experience and attitudes. In these different environments, it is also possible that users will vary in the types of tasks for which they are using the robot, as well as the methods they use to control and interact with it. Furthermore, robot use can influence social relationships in an environment, such as new social activities centered on the robot.[15]

The structural differences between private homes, communal living residences, and public environments have implications for interaction with robots; e.g., environments such as long-term care residences, hospitals, and clinics tend to have wider open hallways than private homes, which allows for easier autonomous robotic navigation. In addition, group living environments often have a standard floor plan with similar room furnishings, which might allow the robot to do more autonomously (less need to customize code significantly for each living space), which may reduce the amount of controlling required by the user. In contrast, private homes vary in size, number of rooms, dimensions of rooms, and number of floors, and they likely do not have an elevator. Robots must be designed with the physical environments in which they will be employed in mind. Lack of compatibility (e.g., a robot not being able to navigate into some spaces or colliding with the physical environment) could cause frustration on the part of the user, which could lead to disuse, and could also damage the environment.

### Use Context

The use context includes the interaction level between the user and robot, safety considerations, and stress level. The interaction level refers to the degree of coordination between the user and the robot and includes the frequency of HRI in a specified time frame as well as the type of interaction taking place.[12,19] Five interaction roles have been proposed for HRI (i.e., supervisor, operator, mechanic, teammate, and bystander) with each role's interactions with the robot differing.[20] The supervisor monitors and controls the overall situation to keep the robot on track for goal completion. The operator modifies software internal to the robot but cannot change the overall goal of the robot. The mechanic fixes behavior of the robot through physical modification and testing. The teammate (or peer) gives robot commands within the overall goal but cannot change the goal. The bystander coexists in the environment with the robot (e.g., a person walking by the robot) and may not realize what actions are available for him or her to interact with the robot. For older adults, the role selected might be driven by the user's abilities, preferences, and goals as described in earlier sections; e.g., an older adult might prefer a supervisor role for a cleaning task if they are physically not capable of or do not like performing the task. For the human, each role differs in the knowledge and expertise users are required to have, their permissions with the robot, their goals, proximity to the robot, and their level of interaction with the robot.[20] Interaction level can require different things not only from the human, but also from the robot. For instance, the robot has to provide appropriate information and feedback to the human depending on their role.

Regardless of interaction level, ensuring safety in HRI is critical. In a healthcare environment, such as an assisted living facility, there would be multiple caregivers or nurses operating the robot, and they would be expected to have a system in place for ensuring safety. In communal living and public environments, multiple people would be available to intervene to avoid an unsafe interaction or particular people could be designated to ensure safety as well as maintenance. In contrast, if a robot performs an undesired motion in a private home, additional demands would be placed on a single user to stop the robot using a run–stop mechanism. Robots designed to assist older adults should incorporate available safety standards and, in general, limit the robot's speed and force of contact as well as utilize intrinsically safe compliant actuators to reduce the effects of unwanted contact between an older adult and a robot.

In addition to considering safety in robot applications, designers should consider the stress level of the environment. Some contexts of interaction will be of inherently high stress and are often also associated with high cognitive load. In a home environment, an example of a high-stress context would be an older adult returning home after a hospital stay. A robot could be beneficial if it were able to measure vitals, assist with the management of newly prescribed medication(s), provide emotional support, and facilitate social connectedness with family and friends. Given the relationship between social connectivity and health outcomes, the ability to provide social support is a potentially critically important role that robots have the potential to fill, especially for older adults who live alone.

## CONCLUSION

Good design of robots is going to follow the same basic principles and processes for good design of any technology with which a human will interact: identify the needs of the user, design in an iterative manner to correct problems, follow good human factors principles, and involve the target user group from start (formative evaluation) to finish (summative evaluation). What is important to recognize is that older adults represent a unique population in terms of their needs, preferences, experiences, and lifestyles.

What is the best way to design robots for older adults? First, designers must understand the user population—that is, follow the maxim of know thy user. We do not mean to imply in any way that all older adults are the same. In fact, we emphasized the reality that older adults do not represent a homogeneous group. There are differences in rates of change, patterns of changes, life experiences, compensatory strategies, motivations, attitudes, and more. However, there are normative age-related changes that tend to occur, and designers who understand these general patterns will develop robots that are more easily usable by older adults and probably by other user populations as well.

Second, the tools and techniques of human factors should be used to develop prototypes that can then be tested with representative users, doing representative tasks, in representative contexts. The design guidelines herein provide a starting point for the development of prototypes. Rather than starting from scratch, designers should be able to restrict the solution space for features of the design based on what older adults' capabilities, needs, and preferences are. Using this knowledge as a base to develop initial prototypes should yield more useful and usable robots, but appropriate user testing is invaluable and very necessary for successful deployment.

Lastly, it is important to recognize the complexity of HRI. In Fig. 2, we provide a very broad framework of the many potentially relevant variables. There are characteristics of the human, the robot, the task itself, and the context of the interaction. This list is not exhaustive, but it is illustrative of the considerations that can and should guide robot design for successful HRI.

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