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SURVEY

# Identifying the Potential for Robotics to Assist Older Adults in Different Living Environments

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**Abstract** As the older adult population grows and becomes more diverse, so will their needs and preferences for living environments. Many adults over 65 years of age require some assistance (Administration on Aging in A profile of older Americans: 2009, U.S.D.o.H.a.H. Services, 2009; Ball et al. in J. Aging Stud. 18:467–483, 2004); yet it is important for their feelings of well-being that the assistance not restrict their autonomy (Barkay in Int. J. Nurs. Pract. 8(4):198–209, 2002). Not only is autonomy correlated with quality of life (Bowling in J. Epidemiol. Commun. Health 65(3):273–280, 2011), autonomy enhancement may improve functionality (Ball et al. in J. Aging Stud. 18:467–483, 2004; Greiner in Am. J. Publ. Health 86(1):62–66, 1996). The goal of this paper is to provide guidance for the development of technology to enhance autonomy and quality of life for older adults. We explore the potential for robotics to meet these needs. We evaluated older adults' diverse living situations and the predictors of residential moves to higher levels of care in the United States. We also examined older adults' needs for assistance with activities of daily living (ADLs), instrumental activities of daily living (IADLs), and medical conditions when living independently or in a long-term care residence. By providing support for older adults, mobile manipulator robots may reduce need-driven, undesired moves from residences with lower levels of care (i.e., private homes, assisted living) to those with higher levels of care (i.e., skilled nursing).

**Keywords** Aging · Assistive technology · Robotics · Aging in place · Long-term care · Assisted living · Nursing homes · Design

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**Abbreviations**

ADLs: Activities of daily living
CCRC: Continuing care retirement community
COPD: Chronic obstructive pulmonary disease
IADLs: Instrumental activities of daily living
NORC: Naturally occurring retirement community
SNF: Skilled nursing facility

## 1 Introduction

In 2000, 12 countries had more than 10 million people aged 60 or over and 5 were comprised of more than 20 million older adults: China (129 million), India (77 million), the United States (46 million), Japan (30 million) and the Russian Federation (27 million) [6]. Over the first half of this century, the global population 60 or over is projected to grow more than three times to reach nearly 2 billion in 2050 [6]. The world is not prepared for the shifting population needs that follow from this societal ageing trend, including provision of support for age-related declines and housing requirements. In this paper we focus on these issues in the context of the United States population.

Housing options for older adults living in the United States have increased in recent years, 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., moving to a retirement community, an independent or assisted living residence, or a continuing-care retirement community). Furthermore, within each of these housing types there is often a wide range of care needs. Individuals may be living in their original home with very little need for assistance or with needs for substantial assistance from informal and formal caregivers [7]. Likewise, individuals residing in a skilled nursing residence may be requiring various types and levels of assistance.

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Technology has the potential to augment the capabilities of older adults and enhance their quality of life. Robotics is an emerging technology that may hold particular promise, especially mobile manipulator robots that are multi-functional, adaptable, and intelligent. In fact, a European survey found that 62 % of those aged 55+ reported their attitudes toward robots as positive [8]. However, for such advancements to realize their full potential for supporting the needs of older adults, more detailed information is required about aspects of older adults' challenges and characteristics of their environments. Specifically, robots could be more effective if robot designers understand 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, structural environment and the users themselves. A small number of studies have explored design issues for assistive robots for older adults [7, 9–17]. However, currently large-scale survey data reflecting these characteristics and needs are not integrated in the literature making it challenging to determine what accommodations for older adults should be made as a function of living environment.

Robots would also be more likely to be accepted if they are designed to meet older adults' needs. The most prominent model describing the acceptance of technology is the Technology Acceptance Model (TAM; [18]). The TAM is suggested to be robust across technologies, persons, and times [18, 19]. One of the most prominent predictive variables in the model (and the most replicated in other studies) is Perceived Usefulness. Perceived Usefulness (PU) is defined as the extent to which a technology is expected to improve a potential user's performance [19, 20]. And would, therefore, be expected to be directly related to how well the technology meets users' needs. In general, Perceived Usefulness increases the acceptance of technologies [21] for all three levels of acceptance, that is, for attitudinal acceptance, intentional acceptance, and behavioral acceptance. Within the specific context of older adults' acceptance of robotics, Perceived Usefulness has been found to be predictive of intention to use [22].

Our goal for this paper was to assess the defining features of the different types of environments where older adults live (e.g., private homes, assisted living, skilled nursing), as well as to explore the predictors of need-driven (vs. choice-driven) moves to residences with higher levels of care. In conjunction, we have identified the facets of older adults' everyday tasks for which they are likely to need functional and medical assistance, across these different living environments. Moreover, we provide a detailed assessment of the considerations that robot developers must understand to create robots that will be useful and usable for older adults.

## 2 Older Adults' Needs and Preferences for Different Living Environments

Older adults' diverse needs for functional assistance are one of the factors driving housing market changes for older adults. About 2.2 million older adults in the United States require assistance with only instrumental activities of daily living (IADL) tasks, such as cooking, shopping or going outside of their house [23]. Moreover, approximately 37 % of adults 65 and older reported having a severe disability (e.g., three or more activities of daily living (ADL) dependencies or severe cognitive impairment), ranging from difficulties with vision, hearing, and cognition to difficulties with ambulation, self-care, and independent living [1]. Furthermore, the percentage of people who report a severe disability increases to 56 % for adults over 80 years of age. Often needs for assistance can be met where older adults choose to live, but in some cases older adults' needs for assistance necessitate relocation to a long-term care residence.

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 [24]. Certain acute health conditions are also particularly common for older adults. In one study of hospital discharges, 20 % of the acute condition diagnoses were falls and injuries, 18 % were conditions related to diseases of the circulatory system, and 15 % related to diseases of the respiratory system [25]. The prevalence of health conditions is high for older adults. About 80 % of adults 65 years of age and older have at least one chronic health condition and 50 % have at least two [26].

Older adults vary in their preferences for housing environments, although most prefer to remain in their own homes as they age [27]. Yet, some older adults voluntarily relocate to independent or assisted living residences [28], in anticipation of future needs of assistance or for the convenience of the available amenities. Ethnic differences in housing preferences have also been noted. An AARP [29] survey found that African American, Asian, and Hispanic seniors are more likely to live in multigenerational homes as compared to Caucasian seniors. Given that the older adult ethnic population is growing, these findings suggest that the percentage of older adults living in multigenerational homes may increase in the future.

Regardless of where older adults live, research suggests they prefer to preserve their autonomy. The preservation of autonomy has substantial benefits, including a higher quality of life [30]. Autonomy refers to the "experience of choice" [31] and is related to perception of control. Policies in nursing home that support autonomy are associated with higher resident well-being, less reliance on supportive services, and more participation in social activities [3, 32]; contrarily, autonomy-restricting policies have been associated

with mental and physical declines [33]. Taken as a whole, findings from experimental, cross-sectional, and longitudinal studies on autonomy present a clear message that losses in autonomy may have detrimental consequences, including increased mortality [34], whereas enhancements in autonomy may improve activity level, psychological well-being, and health status [35].

Even people who reside in assisted living facilities have been shown to value their autonomy and prefer to have their personal autonomy facilitated [2]. Yet, some older adults may not prefer to preserve their autonomy [32] and some may not benefit from autonomy enhancement. One research study found that greater autonomy was only associated with reduced rates of hospitalization and mortality for nursing home residents who had little functional impairment; those who had some functional impairment did not experience the same benefits [36]. Hence, while the majority of older adults may prefer to maintain their autonomy, there appears to be a subset of older adults whose needs for assistance surpass or reduce their preference for autonomy. Note that for the remainder of this article, we will refer to older adults' autonomy as their independence to avoid confusion with robot autonomy.

## 3 Robotics: An Assistive Technology for Older Adults

A wide variety of assistive technologies are commercially available to meet the various physical, cognitive, and perceptual needs of older adults. Research suggests that use of such technologies is associated with improvements in quality of life, particularly for older adults who have higher needs for assistance [37]. Examples of assistive technologies include walkers to aid in ambulation, large button telephones to assist with vision and dexterity, hearing aids, and pill dispensers with a timer for reminding. Home modifications can also be made using assistive technologies, such as grab bars and adjustable counter tops. However, most of these technologies have very specific task applications and are therefore limited in the amount of support they provide and their adjustability to a user's changing needs.

Robotics has the potential to assist older adults across several categories of need and can be adaptable to an older adult's varying needs. As an intelligent form of assistive technology, robots may have the capability of providing needed assistance while enhancing older adults' feelings of independence [38]. Perhaps most promising are human-scale mobile-manipulator robots, which are similar in size and height to a human and have the capability to sense and manipulate objects as well as navigate around in human environments. As such, mobile manipulators may have more potential to improve quality of life for older adults than currently available assistive technologies. An example of a mobile manipulator is Willow Garage's PR2 robot [www.willowgarage.com], which includes a sensorized head to perceive objects and people, grippers and compliant arms to manipulate objects, and an omnidirectional wheeled base that enables the robot to move around on flat floors. Some robotic technologies have been developed to assist with various activities of daily living, but are not general-purpose mobile manipulators, and can only perform a few limited functions [39, 40]. Mobile manipulators have already been developed to assist people with motor impairments [41–44] and may be extended to assisting older adults. Given that mobile manipulators have the ability to be flexible to assist under a broad range of circumstances, there is a need to understand the nature of the environments and related assistance needs for which they need to be designed.

In the past, researchers have focused on several categories for the design of personal and service robots. These categories include the level of structure of the environment, the level of robot autonomy, safety, cost, emotional factors, anthropomorphism [16], and acceptance [17, 45, 46]. Similarly, Kawamura, Pack, et al. [47] established three design categories for service robots: robot intelligence (including level of robot autonomy), environmental modification, and user training (including communication between the robot and user). Kawamura breaks down these categories even further into type of locomotion, hand dexterity, natural language communication, and aesthetic [48]. Defining these categories in terms of the needs for any user who requires assistance, including older adults, directly impacts the subsequent design of mobile manipulators.

Throughout this paper we will be using mobile manipulator robots (referred to generally as "robots" from here on) to illustrate the considerations that need to be made for assistive technologies to accommodate the living environments of older adults in addition to their needs and the importance of independence. These findings can provide guidance for developing robots that support older adults' needs, but may also be generalized to other types of assistive technologies.

## 4 Where is Home?

Adults 65 years of age and older reside in diverse types of housing arrangements (see Table 1). Most live in private homes, with a spouse, yet many live alone (approximately 30 %). The likelihood of living alone is greatest for the oldest age group (i.e., 38.7 % of those 85 and older) and for women. Approximately 50 % of women 75 and older live alone. Approximately 32 % of adults 65 and over live with relatives, such as in a multigenerational household [49]. Almost 11 % of adults 65 and older live in the private homes with informal care [50] and nearly 5 % live in private homes with formal care [23].

Table 2 provides an overview of the various types and definitions of residential housing options for older adults in the United States. It is noteworthy that there are a variety of names for the same type of living environment. This variability may lead to some confusion for designers thinking about the potential for robotics, for example. It is useful therefore to categorize the different environments to provide some clarity of this space and to operationalize the context of our discussion.

**Table 1** Living arrangements for older adults in the United States (% of the U.S. population)

| Age | Private home alone[a] | Private home with spouse[b] | Private home with other relatives[b] | Long-term care (institutional living)[c] |
|---|---|---|---|---|
| 65–74 | 21.9 | 63.0 | 10.9 | 1.3 |
| 75–84 | 31.2 | 48.2 | 13.4 | 3.8 |
| 85+ | 38.7 | 27.3 | 23.0 | 15.4 |

Source: [a]Pew [49], [b]US Census [51], [c]Administration on Aging [1]

Note: Rows do not equal 100 because living arrangement categories are not comprehensive and table includes data from multiple sources

Typically, assisted living residents function more independently than nursing home residents and have greater independence in daily living tasks. However, most older adults who live in long-term care facilities live in skilled nursing residences. There are an estimated 36,399 assisted living residences nationwide with more than 910,486 beds [2]. As a point of comparison, it is estimated that there are 1.8 million nursing home beds nationwide [54]. These residences can be in freestanding facilities, congregate housing units, or continuing care retirement community housing units. Research has shown that assisted living residents are at a high risk for further functional decline and subsequent nursing home placement [55, 56]. In fact, it is estimated that 24 % to 40 % of assisted living residents are discharged to a skilled nursing long-term care residence annually [57]. However, findings show that older adults may make multiple moves

**Table 2** General definitions of different categories of living environments

| Residence type (alternative names) | General definition |
|---|---|
| Private Home | Private residence in the community |
| Naturally Occurring Retirement Community (NORC) | "An initiative for connecting elders to community-based eldercare services while remaining in their own homes and staying connected to neighbors and community institutions." (Bookman, p. 113 [52]) |
| Independent Living Facility (Retirement Communities; Congregate Living; Senior Apartments) | "These facilities are designed for seniors who are able to live on their own, but who desire the security and convenience of community living. Independent living facilities may offer housekeeping services, laundry facilities, linen service, meals or access to meals, local transportation, and planned social activities." (Bookman, p. 59 [52]) |
| Assisted Living Facility (Residential Care; Board and Care, Community Based Retirement Facility; Congregate Care; Adult Care Home; Adult Group Home; Alternative Care Facility; Sheltered Housing; Supportive Care; Domiciliary Care) | "Unlike nursing homes, which are subject to extensive federal regulations, assisted living facilities generally have considerable flexibility to determine the resident populations that they serve and the services they provide. As a result, assisted living facilities vary widely on both of these dimensions. Nevertheless, most [assisted living] facilities provide housing, meals, housekeeping, laundry, supervision, and assistance with some ADLs and other needs, such as medication administration." (GAO, p. 4 [53]) |
| Skilled Nursing Facility (SNF) (Nursing Home; Rehabilitation Facility; Convalescent Home; Care Home; Rest Home) | "A nursing home providing services for residents whose general condition tends to be unstable, and requires close observation and care given by professional staff over a 24-hour period. Some SNFs have rehabilitation programs that help people maintain their ability to function." (Bookman, p. 116 [52]) |
| Continuous Care Retirement Community (CCRC) (Life Care; Life Care Facility; Life Care Community) | "An alternative housing option designed to accommodate the needs of elders who can no longer live alone. CCRCs offer a full continuum of care, ranging from fully independent units, to assistance with personal care in assisted living apartments, to long-term care in a skilled nursing facility." (Bookman, p. 107 [52]) |
| Living with Relatives | Living in the same household with parents, siblings, children, or extended family members who can assist and provide care when necessary. |

prior to moving to more supportive residential settings [58]. For example, an older adult may move from one assisted living residence to another before moving to a skilled nursing residence.

One notable trend in Table 1 is that the probability of living in a long-term care residence increases significantly for those 85 years of age and older. Adults 85 and older are almost 12 times more likely to reside in a skilled nursing residence as compared to those less than 85 years of age. The implication of this trend is noteworthy given that those 85 years of age and older are the most rapidly growing age group of older adults [59, 60]. As noted earlier, a growing trend is that older adults are choosing to live in assisted living residences. In 1999 it was estimated that 811,000 individuals 65 and older resided in assisted care residences [50], an increase of more than 37 % from 1990 [61].

Some older adults move out of their private home into a long-term care residence, such as one that offers assisted living, skilled nursing, or continuous care. However, it is important to note that some of these moves may be temporary until the individual is strong enough or receives the assistance necessary to regain independence [62]. Assisted living residences offer less assistance than skilled nursing residences. The specific services offered at assisted living residences vary but typically include congregate meals, housekeeping, and personal care assistance. Skilled nursing residences typically offer these same services, in addition to skilled nursing and rehabilitation services.

## 5 Understanding Need-Driven Moves to Higher Levels of Care

Older adults move for a variety of reasons, both choice-driven and need-driven. Moves that are not by choice can have negative consequences and can negatively impact older adults' level of functioning [63, 64]. Furthermore, as the level of care increases, so do the monetary costs. For example, the average cost of a private room in an assisted living residence is estimated to be 35 % to 43 % less than a private bed in a nursing facility [53]. Therefore, it is important to understand the triggers of these moves.

Residential mobility patterns reflect older adults' moves that are required to meet their higher needs for care. A widely used framework proposed by Andersen et al. [65], suggests the mechanisms driving utilization of formal health services are as follows: (1) predisposing variables, (2) enabling conditions, and (3) need variables. Predisposing variables consist of person characteristics associated with greater use of health services (e.g., age, race). Enabling conditions consist of variables that increase the accessibility of health services (i.e., income). Need variables consist of impairment (e.g., ADL and IADL limitations) and illness-related factors that necessitate the use of formal services. Research has been conducted in this space, primarily exploring the significance of different predictors of nursing home placement. Below we review the evidence to date showing significant predictors of nursing home placement and moves to assisted living. We also discuss in greater detail the roles of (1) functional need for assistance, (2) medical needs for assistance, and (3) informal caregivers.

### 5.1 Nursing Home Placement

In a systematic review of 36 studies, Luppa and colleagues [66] examined existing evidence for predisposing and need variables predicting nursing home placement. The authors found strong evidence (i.e., consistent findings in at least 75 % of reviewed studies and in at least three studies rated as high quality) for the following predisposing variables: Increased age, housing (not having one's own home), ethnicity (White American in US studies). Moderate evidence (consistent findings in at least 75 % of studies and in at least two high quality studies) for predicting nursing home placement was found for unmarried persons (single, widowed or divorced), unemployed persons and those with a poor social network. The evidence was weak for marital status (married persons being more at risk for nursing home placement) and inconclusive for male gender, living alone, low education and low income predicting nursing home placement. Therefore, with respect to predisposing characteristics, older adults who do not own their own homes and who are Caucasian/White are the most likely to move to a nursing home.

Need characteristics are often the significant predictors of the utilization of formal health services [67] and the transition from assisted living to skilled nursing [56, 68]. The need variables for which Luppa et al. [66] found strong evidence of predicting nursing home placement were low self-rated health, ADL or IADL functional impairment, cognitive impairment, dementia diagnosis, prior nursing home placement, and number of prescriptions. Although many nursing home residents have medical conditions, these diagnoses did not contribute independently to nursing home placement, rather chronic diseases affected nursing home placement almost entirely by the associated functional impairment. Also, the availability or presence of informal care did not independently influence the risk of nursing home placement, but instead was predictive by the association with existing cognitive and functional impairment. That is, cognitive and functional impairments were larger risk factors than whether a person had assistance from family or friends. Moreover, predisposing variables interact with need characteristics. For instance, in one study a dementia diagnosis for an individual receiving publicly funded home and community-based services was associated with a 50 % increased risk of nursing home placement [69].

### 5.2 Assisted Living Placement

Less research has explored the predictors of assisted living placement. However, just as older adults who live independently often require assistance with IADLs from caregivers, IADL needs can also precipitate moves to assisted living. For instance, difficulties doing heavy housework and laundry, as well as walking outside and going shopping may be predictors of moves to assisted living [70]. Medication management difficulties have also been found to be a significant predictor of older adults' moves into assisted living [71]. This finding is not surprising given that on average assisted living residents take approximately six medications and 25 % take nine or more [72]. Therefore, assistance needs for performing IADLs may impact the likelihood that a person moves to an assisted living residence. However, there is a clear need for more systematic, empirical research to determine the relative contributions of various need characteristics to assisted living placement.

### 5.3 Functional Needs for Assistance

Whereas moves to assisted living may be precipitated in part by IADL assistance needs, moves to skilled nursing facilities are frequently predicted by additional needs for ADL assistance. The data in Fig. 1 are consistent with this idea in that assistance with all ADLs is more frequently provided in skilled nursing as compared to assisted living. In fact, the percentage of nursing home residents with complete or partial ADL function dependence may be as high as 97 % [73]. Moreover, research suggests that moves from assisted living to skilled nursing are instigated by needs for assistance with ADLs [57], in particular the inability to independently bathe [73].

Other findings suggest that the need for assistance with IADLs may be a stronger predictor of nursing home placement than the need for assistance with ADLs. In a study of 4,066 older adults, bowel incontinence and IADL dependence independently predicted admission to a skilled nursing residence; yet number of chronic conditions, behavioral disturbances, urinary incontinence, ADL deficits, poor cognitive status, and duration of program operation were not significant predictors [74]. IADL dependence may be more likely to predict skilled nursing admission for older adults who live alone [75]. That is, these older adults may be unable to live alone before their ADLs become significantly impaired. Overall, these results suggest that ADL and IADL assistance needs are closely tied to moves to long-term care facilities, and therefore may be a significant opportunity for robot assistance.

Given these findings, it would be informative to know more about the pattern and order of these declines. Jagger and colleagues [76] conducted a longitudinal study of individuals 75 years of age and older ($N = 1{,}344$) to explore such declines. Of those who reported no difficulty with ADLs at an initial assessment 47.6 % reported some loss in ability to perform ADLs independently at a later assessment (approx. every 20 months). This pattern reflects the well-documented trajectory of decline for ADLs associated with age. The order of decline in activities, across both gender and age groups, was bathing, mobility, toileting, dressing, transfers (from bed and chair), and feeding. The authors noted that declines in lower-extremity strength (e.g., bathing, mobility, toileting) preceded declines in upper-extremity strength (e.g., dressing, feeding). These findings provide some specifics about temporal order of the tasks for which older adults may need support. It would be beneficial to have additional information about the specific nature of the ADL and IADL limitations that predict long-term care placement. Unfortunately, as noted by Luppa et al. [66], the operationalization of functional impairment was lacking in most studies investigating predictors of nursing home placement. Future research would benefit from specifying the ADL and IADL limitations that are most predictive of nursing home placement.

### 5.4 Medical Needs for Assistance

With respect to chronic and acute medical conditions, cerebrovascular diseases were the strongest disease predictor of skilled nursing admission, and fractures of the ankle or

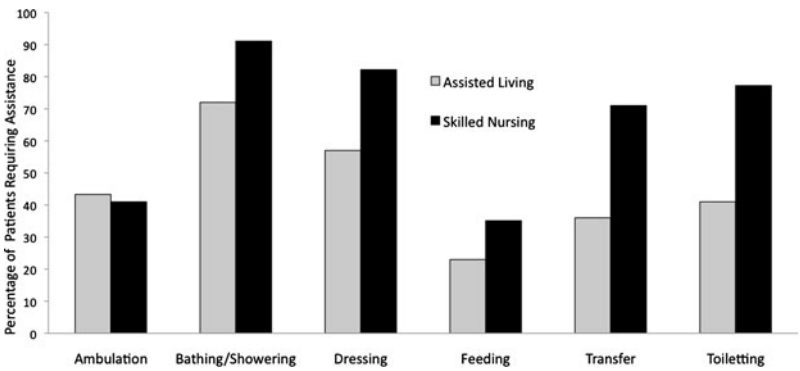


**Fig. 1** Distribution of support across caregiver type. Percentage of patients requiring assistance with Activities of Daily Living

lower leg were also strong determinants of admission [77]. In another study, stroke, incontinence, dementia, and functional impairments predicted nursing home admission [78]. Other research has found that cognitive impairment and incontinence were strong factors, in addition to functional decline, in whether someone entered a skilled nursing residence [79–81].

### 5.5 The Role of Informal Caregivers

The relationship between functional impairment and nursing home placement is mediated by the predisposing variable of having an informal caregiver. Qualitative research provides some insight into this relationship. For instance, in interviews about their relocation to assisted living, residents spoke of worsening caregiver health and the strain on their spouses as reasons for their moves [82]. Caregivers may also have knowledge about the difficulties the care recipient is having and that knowledge drives their perception that the care recipient cannot live alone. Alternatively, an individual living alone may be having the same difficulties yet there is no one there to make those observations. Furthermore, some older adults may move to long-term care residences because of a desire to not be a burden on their caregivers. A person living alone without a caregiver would not have the same concern.

## 6 Assistance Needs for Different Living Environments

### 6.1 Private Homes

Examining the provision and utilization of assistive services can help to elucidate older adults' needs for assistance in various living environments. To explore the needs of older adults who reside in private homes, we explored survey findings regarding assistance from informal caregivers (e.g., spouses, children, other relatives, friends, neighbors) and formal caregivers (i.e., subsidized or fee-paid professionals). In the U.S., approximately 40 % of adults 65 years of age and older report having some type of disability [83]. About 96 % of those who are disabled (i.e., difficulty in vision, hearing, cognition, self-care, ambulation, or independent living) report receiving some type of assistance from informal caregivers for an average of approximately 29 hours a week [23].

Informal caregivers typically provide assistance with ADLs and IADLs. ADLs include bathing, eating, dressing, and getting around inside the home, whereas IADLs include tasks such as doing housework, preparing meals, driving, shopping, managing medication, managing finances, and using the telephone [84]. Needs for ADL and IADL assistance increase with age. In one national survey, 1,002 informal caregivers were asked to identify the ADLs and IADLs for which they provide assistance to older adults living in private homes [85] (see Table 3). Some respondents (30 %) reported assisting with three or more ADLs. The ADLs that respondents reported assisting with most frequently included dressing, transfer (in and out of bed or chairs), ambulation (walking across the room), and bathing/showering. The IADLs that respondents reported assisting with most frequently included errands, transportation, housework, making phone calls, preparing meals and managing medications. The pattern of responses in this survey suggests that informal caregivers assist with IADLs more frequently than with ADLs, a finding that is consistent with other studies as well [86].

Approximately 35 % of disabled older adults who live in private homes also utilize formal home care, although only 5.4 % rely entirely on formal caregivers. The use of formal caregivers (i.e., home health providers) is greater among older adults with moderate to severe levels of disability (i.e., those requiring assistance with one or more ADL). In fact, approximately 50 % of older adults who require assistance with three or more ADLs rely to some degree on assistance from formal caregivers. About 44 % of home health care patients received assistance with personal care, including ADLs and IADLs [87]. About half of these patients received assistance with at least one ADL (51 %). Older

**Table 3** Provision of assistance by informal caregivers and utilization of assistance from formal caregivers for older adults living in private homes

| | | Provision of assistance by informal caregivers[a] | Utilization of assistance from formal caregivers[b] |
|---|---|---|---|
| ADLs | Dressing | 42 % | 45 % |
| | Transfer (in and out of bed or chairs) | 40 % | 34 % |
| | Ambulation (walking across the room) | 34 % | 27 % |
| | Bathing/showering | 26 % | 45 % |
| | Feeding | 17 % | 14 % |
| | Managing incontinence/Toileting | 17 % | 26 % |
| IADLs | Errands | 85 % | 13 % |
| | Transportation | 76 % | 2 % |
| | Housework | 71 % | 37 % |
| | Making phone calls | 59 % | <1 % |
| | Preparing meals | 59 % | 22 % |
| | Managing medications | 39 % | 19 % |

[a]The percentage of caregiver respondents who reported providing assistance with each task [85]

[b]The percentage of home health care patients who reported receiving assistance with each task [87]

**Table 4** Robot assistance opportunities for older adults living in private homes vs. long-term care

| Activity | Private home | Long-term care (assisted living and skilled nursing)* |
|---|---|---|
| Activities of Daily Living | Ambulation | Ambulation |
| | Bathing/showering | Bathing/showering* |
| | Dressing | Dressing* |
| | Transfer | Feeding |
| | | Transfer* |
| | | Toileting |
| Instrumental Activities of Daily Living | Errands/shopping | Errands/shopping |
| | Housework | Housework |
| | Making phone calls | Making phone calls |
| | Managing medications | Managing medications |
| | Preparing meals | Preparing meals |
| Chronic Health Conditions | Heart disease | Heart disease* |
| | Diabetes | Diabetes* |
| | Cerebral vascular disease | Stroke* |
| | Chronic obstructive pulmonary disease (COPD) | COPD/emphysema* |
| | | Mental illness (e.g., depression, dementia)* |

*Activities in critical need of support in both assisted living and skilled nursing residences; all others in this column are in critical need of support in skilled nursing residences only

adults most frequently received assistance with the following ADLs: bathing/showering, dressing, transfer, and ambulation (see Table 3). The most frequent IADL for which assistance was received was housework. These data suggest a differentiation between the types of caregiving tasks provided by informal caregivers (i.e., more often provide IADL assistance) versus formal caregivers (i.e., more often provide ADL assistance).

Formal caregivers are also more likely to be utilized for assistance with medical conditions. For formal care recipients, medical/skilled nursing services are primarily needed for treating and managing chronic health conditions, particularly heart disease (11 %), diabetes (8 %), cerebral vascular disease (7 %), chronic obstructive pulmonary disease (COPD; 5 %), malignant neoplasms (5 %), congestive heart failure (4 %), osteoarthritis and allied disorders (4 %), fractures (4 %), and hypertension [3 %; DHHS, 2000]. In addition, older adults with depression are more likely to use formal care services than those without depression with similar physical conditions [88, 89]. Hence, not only do older adults who live in their homes often need assistance with ADLs and IADLs, they need assistance with managing and treating chronic health conditions as well.

Although the efficacy of robot assistance in private homes is in need of further exploration, our review suggests that robots that assist with the activities we have listed in Table 4 could be of benefit to a large number of older adults. Our literature review shows that not only do a substantial percentage of older adults require assistance for these activities, those needs can translate into unwanted moves to environments that offer higher levels of care. To deploy a robot to provide assistance with these tasks in a person's private home, several technical challenges would need to be overcome. First, the robot would need to be robust enough to require little maintenance or troubleshooting, especially if it were to be in the home of an older adult living alone. Second, the robot would need to be able to negotiate the navigation environment of the home such as dynamic and static obstacles, uneven floors, stairs, varying lighting conditions, door thresholds, clutter, and pets, to name a few. Third, the designers of the robot would need to carefully consider who would be interacting with it and in what roles. Informal caregivers, formal caregivers, older adults who require care, as well as remotely located robot operators might all interact with the robot in different ways.

For a robot to assist with ADLs, IADLs, and chronic health conditions, the appropriate sensing, information processing, decision making, and actuation aspects for these particular tasks must be carefully designed with older adults in mind. For example, each of the ADLs in Table 4 would involve the robot making physical contact with the older adult's body. Hence, haptic sensors such as force, pressure, contact sensors may be especially relevant. For example, haptic sensing could help a robot better control the mechanics of contact with a person's body as well as provide information for safety monitoring while assisting with ADLs.

Assisting with some ADLs may only require that the robot move a lightweight object with respect to a person's

body. However, some ADLs would likely require that the robot be able to apply large forces and handle large payloads, such as when moving a person's body. As has been noted by other researchers (e.g., Chris Atkeson), manipulating lightweight household objects has distinct design implications for a robot versus manipulating the human body. For example, manipulating large and heavy objects tends to result in larger robots. Methods to visually perceive and physically manipulate the human body and deformable objects, such as clothing, could also be useful to robots assisting with ADLs. Assisting with ambulation and transfers come with additional challenges, such as the robot moving through an environment while maintaining physical contact with the older adult's body. The robot might benefit from simultaneously monitoring the environment for obstacles in the desired navigation path while monitoring the safety of the physical interaction with the older adult. Assisting with bathing/showering would involve the robot operating in wet conditions and interacting with potentially slippery surfaces. If the robot were providing assistance for these ADLs for the older adult without any other informal caregiver around, then implementing appropriate safety mechanisms would be especially important. Regarding IADL assistance, depending on the type of housework the older adult would want the robot to perform, the robot may need to have high payload capacity (e.g., moving furniture or heavy groceries) or fine dexterity (e.g., screwing in a light bulb or manipulating mail envelopes).

A mobile manipulator could potentially assist with medication delivery, and there has research on human-robot object hand off and object delivery [41, 90–93]. However, assisting an older adult with medication could entail numerous complexities beyond giving the older adult the medicine, such as preparing and bringing a drink, providing motivation to adhere, providing information about the medicine, and deciding whether or not to interrupt a person. Furthermore, given the potential consequences of a medication error, there may be barriers to older adults' acceptance and regulatory hurdles. Assisting with the management of chronic health conditions could involve related challenges, and would likely require specialized capabilities to monitor appropriate health conditions and provide care. For example, to care for diabetes, the robot might sense and manipulate the diabetes test strips, glucose monitor, and the older adult's body to take a blood sample. Doing this task involves a combination of accurate localization, fine dexterity, and haptic safety monitoring. Managing COPD might involve the robot managing an oxygen tank or other breathing equipment. To develop these systems, roboticists would likely work closely with medical professional.

There has also been some work on creating robots, such as Paro [94], that reduce stress and encourage socialization. Telepresence robots have been used to encourage communication with other people. Companion and telepresence robots have the potential to reduce older adults' feelings of loneliness and disconnectedness from the world [95]. Some researchers have enabled humans and robots to communicate using verbal and non-verbal modalities, such as gaze, gestures, and body language. Socializing with a robot might also impact socializing with other people and feelings of isolation for older adults living at home.

### 6.2 Long-Term Care Residences

To assess the needs of older adults who are living in long-term care residences, we examined data on the provision of assistance in skilled nursing and assisted living residences. Assisted living is typically conceptualized as a special type of housing (not licensed as a skilled nursing home) that offers supportive and health care services for individuals requiring help with daily activities. Other terms that are similar in meaning to assisted living include personal care and residential care homes, both of which offer assistive services in a homelike environment [96]. As a combination of housing and services, assisted living residences aim to support residents' independence [2, 97], whereas skilled nursing residences offer more medical and rehabilitation services.

The average number of ADL limitations for assisted living residents is 2.8 [98], and survey findings have identified bathing/showering and dressing as most commonly requiring assistance [99]. Most assisted living residents were ambulatory; some used mobility aids, such as walker (30 %), a wheelchair (15 %), and a cane (11 %). The assistance needs of assisted living residents were more equally dispersed for IADLs. Figures 1 and 2 show a sustained shift toward greater provision/need for ADL assistance as the level of care increases in long-term care environments (i.e., assisted living versus skilled nursing). Assistance with ambulation is an exception to this trend given that the need of assistance for ambulation is comparable across assisted living and skilled nursing residents.

In addition, assisted living residents are in need of medical/skilled nursing services for conditions including bladder incontinence (33 %), heart disease (28 %), and bowel incontinence (28 %) [99]. In another report, which documented the diagnoses of assisted living residents, it was found that the most common diagnoses were heart disease (24 %), diabetes (22 %), stroke (14 %), and COPD/Emphysema (13 %) [100]. Cognitive/mental conditions were also found to be common diagnoses in assisted living residences: depression (38 %), dementia (33 %), and other mental disorders [9 %) [100]. Additional research has documented similar findings of a high prevalence of cognitive impairment in assisted living residences with estimates ranging from 34 % to 71 % [101–103]. Moreover, the prevalence of dementia in dementia-specific assisted living residences has been found to be much higher, at 83 % [104].

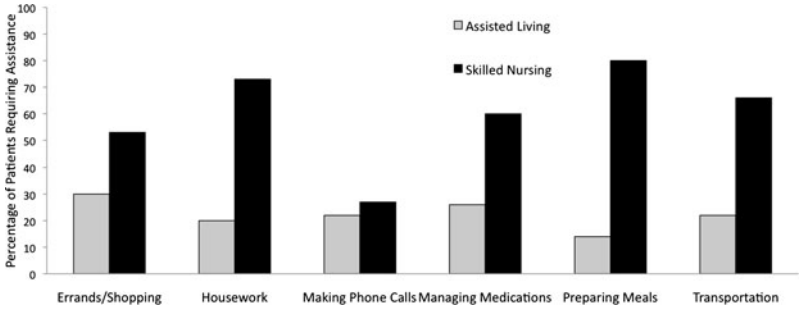


**Fig. 2** Distribution of support across caregiver type. Percentage of patients requiring assistance with Instrumental Activities of Daily Living

The average number of ADL limitations increases for skilled nursing residents to 4.7 [98], and they most frequently included bathing/showering, dressing, using the toilet room, and transfer (in and out of bed or chairs). Needs for assistance in IADLs increase for residents in skilled nursing residences compared to those in assisted living residences, as well. The most frequently reported IADLs for which assistance was needed in skilled nursing residences were preparing meals, transportation, medication management, shopping/errands, and housework. Making phone calls was the only IADL for which less than 40 % of nursing home residents reportedly had limitations.

The 2004 National Nursing Home Survey found that the most common skilled nursing home diagnoses were heart disease (38 %), diabetes (24 %), stroke (24 %), COPD/Emphysema (15 %) [105]. Cognitive/mental conditions were also found to be prevalent: depression (37 %), dementia (23 %), and other mental disorders (26 %). Moreover, other research has documented even higher prevalence of cognitive impairment (71 % had moderate to severe cognitive impairment), more than double that found in assisted living homes [106]. These data reflect the increase in medical and cognitive support needs and/or service provisions for skilled nursing residents.

In the immediate future, it may be more economically feasible to deploy robots in long-term care residences than in private homes. The communal living nature of long-term care residences could allow a single robot to provide assistance to multiple care recipients, as well as to assist multiple caregivers. The data from assisted living and skilled nursing residences show disparate needs in these two types of long-term care residences. Overall, older adults' needs for assistance with ADLs tend to increase as level of care increases (moving from assisted living to skilled nursing), particularly for bathing, dressing, transferring, and toileting. The majority of older adults in assisted living residences did not require assistance with IADLs; the activity for which most assistance was needed was doing errands and shopping. In comparison, most older adults in skilled nursing residences required assistance with all IADLs, except making phone calls. Although individuals residing in assisted living may currently have more limited needs than those in skilled nursing, it would be advantageous to design robots that have the capability to provide greater levels of assistance to adjust to changing needs. In this manner, robots may be able to support older adults sufficiently to enable them to continue residence in assisted living rather than having to move to a skilled nursing residence.

The critical needs of assisted living residences are combined with those of skilled living residents in Table 4. Note, there is significant overlap with the needs of older adults living in private homes. An exception is that of the toileting ADL. That is, assistance with toileting is a more critical need of older adults living in long-term care residences than those living in private homes. Some of the technical challenges of robots assisting with medical conditions would also be similar to those of robots assisting in private homes, as would the types of medical services, although there is a greater prevalence and higher severity of health conditions for older adults who live in long-term care residences. Long-term care residents may require assistance with monitoring and managing medical conditions, particularly heart disease, diabetes, stroke, and COPD/emphysema. Such assistance may include biophysiological monitoring (e.g., blood pressure, blood glucose) and medication management. However, special considerations do need to be made for robots designed for long-term care residences given the high rate of mental illness (e.g., depression, dementia). In fact, the older adults who require the greatest levels of physical assistance, may be the most cognitively impaired [107]. Therefore, robot developers should consider the possibility of providing assistance in the form of cognitive support and research is needed to understand use and acceptance of robots by older adults who are cognitively impaired.

The environmental differences, however, between private homes and assisted living or skilled nursing residences could have distinct implications for the design of robots (see Table 5). For example, long-term care residences tend to have wider open hallways than a private home, which allows for easier autonomous robotic navigation. Also, long-term care residences typically have a static floor plan with duplicate furnishings across each bedroom and across floors. A group living environment also allows for one robot to be shared among multiple users at one site without the need to customize code extensively for each individual's living space.

**Table 5** Robot design attributes specific to private homes vs. long-term care residences

| Robot design attribute | Private home | Long-term care residence |
|---|---|---|
| Footprint | Smaller than ADA-compliant | As large as ADA-compliant |
| Navigation | Narrow hallways and doors (i.e., not necessarily ADA-compliant) | Wide hallways and doors (i.e., ADA-compliant) |
| | Stairs | Elevators |
| | Uneven floors/thresholds/rugs | Flat floors |
| | Clutter | Routinely cleaned spaces |
| Specialized knowledge | Medical knowledge | Medical knowledge |
| | | Dementia care |
| Users | Few older adults | Several older adults |
| | Few formal/informal caregivers | Several nurses |
| | Naïve users outside the home | |
| Users who will perform maintenance | Older adults in the home | Nurses |
| | Formal/informal caregivers | Maintenance workers |
| | Maintenance workers | |
| Safety: Initiating run-stop due to undesired robot behavior and asking caregiver to initiate run-stop | More reliance on older adult, autonomous algorithms, | More reliance on nurses to initiate run-stop |
| Safety: Monitoring (e.g. falls, undesired contact, robot restart, medical emergency) | More reliance on older adult, autonomous algorithms, and asking caregiver to recognize and resolve emergencies | More reliance on nurses to recognize and resolve emergencies |

Also, long-term care residences allow for multiple caregivers or nurses to help operate the robot, which might aid in safety monitoring and maintenance of the robot. Deploying a robot in a long-term care residence could serve as a valuable test bed for evaluating these care tasks in an institutional environment with many users. There exist standards that are used by the United States, Europe, Japan, and Korea for the safe design of industrial robots and reduction of risks associated with industrial robots [108, 109]. The International Organization for Standardization (ISO) notes that these standards can be used for non-industrial robots such as medical, healthcare, and consumer robots. Furthermore, an ISO standard for "Safety requirements for personal care robots" (ISO/FDIS 13482) is under development, and the ISO subcommittee/working group that is overseeing its development (TC 184/SC 2/WG 7) will soon publish the completed standard [110]. Also, creating standards for personal care and service robots has been an ongoing discussion among the international robotics community [111, 112]. Robots designed to assist older adults would incorporate the safety standards for personal care robots once they are available. In general, limits on the robot's speed and force of contact as well as utilization of intrinsically safe compliant actuators will reduce the effects of unwanted contact between an older adult and a robot. Living in a private home may place additional safety requirements on older adults to stop the robot themselves using a run-stop mechanism if the robot performs an undesired motion. In contrast, nurses in a long-term care residence could be available for emergency situations that require the robot to be stopped or repositioned (Table 5). Table 5 presents design attributes that vary as a function of environment (i.e., single care recipient versus multiple care recipients; individual living versus communal living), including footprint, navigation, specialized knowledge, users, users who will perform maintenance, and safety.

## 7 Conclusions

Around the globe the older adult population is growing at a dramatic pace [6]. The growing aging population has diverse needs, including requirements of assistance with chronic disease management, ADLs, and IADLs. Data that we have presented here show that in some cases these needs necessitate a move to a living environment offering greater levels of assistance. However, survey data from the United States suggests that most older adults prefer to age in place and research has shown that there may be significant benefits from

delaying or avoiding moving to skilled nursing residences. Research suggests that moves to skilled nursing residences may be anxiety-provoking [63], place older adults at risk for developing depression and suicide ideation [64], and be a threat to quality of life and loss of independence [2, 113]. Quality of life has also been shown to decrease with growing level of dependence and institutionalization [28].

Older adults need support for everyday activities. Support needs vary by individual and include both functional and medical needs. Successful assistive technology must consider the environmental context, which includes both the physical structure and the users. Our assessment examined older adults' housing options in the United States, as well as their preference and need for independence regardless of living environment. We clarified and classified housing terminology to facilitate our analysis of older adults' needs as a function of where they live. Predictors of moves to higher levels of care (e.g., skilled nursing) included assistance needs for specific ADLs, IADLs, and the management of certain chronic conditions. Much more research is needed, particularly converging evidence given the complex nature of ADL and IADL functioning and the wide variation in support services available and required across different living contexts.

Findings, such as those we discussed, detailing assistance needs as a function of environment provides insights into how declines progress in independent functioning. Jaggar and colleagues' [76] findings are consistent with the data we presented regarding ADL and IADL assistance needs in different living environments. Bathing, dressing, toileting, and transfer (often a component of toileting) appear to be the ADLs that require the most assistance to perform, especially when greater levels of care are necessitated. Most of the IADLs appear to require some type of assistance to complete, especially for individuals who reside in a private home with informal caregivers and for those who reside in skilled nursing. Even though assistive devices are available for these activities, they may not be adopted universally, the reason for which is an area in need of exploration. Lastly, we found a need for assistance for persons with particular chronic health conditions (e.g., heart disease, diabetes, COPD) and cognitive impairment [114].

By providing needed assistance, robots have the potential to support older adults' preference for independence and aging in place. Robots may also be able to alleviate some of the caregiver burden. Over seven million Americans provide 120 million hours of informal care to approximately 4.2 million functionally disabled older adults every week [23]. If the work of these caregivers were to be replaced by formal caregivers, the cost has been estimated to range from $45 billion to $94 billion dollars a year [23]. Not only does informal care substitute for formal care, it also facilitates professional care when both informal and formal caregivers are involved [115]. There is a substantial amount of data on the emotional and physical toll of informal caregiving [23]. Moreover, caregiver-related needs, such as depressive symptoms and activity restriction, are a significant predictor of long-term care utilization [67]. By supporting older adults' needs for ADL, IADL, and medical assistance, robots have the potential to improve the quality of life of older adults, as well as that of their caregivers.

Our needs assessment integrated data from various literatures and studies to the degree that has not been done previously. Our review provided insight into where older adults' needs for assistance are the greatest and what the nature of their need is. A comprehensive needs assessment, such as this, is a valuable step in understanding where robot assistance would be most beneficial in difference contexts. Moreover, this needs assessment can directly inform a requirements analysis from which to guide the design of future mobile manipulators, as well as other assistive technologies [116].

Although most of the data we presented was collected in the United States, we would expect to find similar patterns in other countries given that most needs result from fundamental age-related declines. Alternatively, housing patterns may be less consistent across different countries because they would be predicted to be driven more so by cultural norms and economics. For example, Japan has a history of adult children caring for their aging parents, rather than providing government provision for the aged. Recently, these expectations about who will care for the aged have been changing, with fewer adult children able (e.g., because of their own advanced age) or willing to care for their parents [114]. This shift has implications for the living environment of future older adults, as well as for the work force that will be needed to care for them. Public policies are changing as a result and Japan is also implementing community-based support systems [115]. Furthermore, the critical growing need for aged care workers has facilitated the interest in robot assistance for older adults in Japan [114].

Understanding user needs is critical for gauging user acceptance. User needs are likely related to their perception of usefulness, which is a significant predictor of technology acceptance [19]. More research is needed, however, to understand users' acceptance of robots. We need to understand more about older adults' attitudes and expectations of robots [17, 46]; we also need to understand the tasks for which older adults are accepting or not accepting of robot assistance and the reasons for their attitudes [12–15]. Attitude data, such as this, together with the assistance needs data presented here, can provide the necessary science-based guidelines for the development of prototype robots that will be useful to and usable by older adults. We also need to examine informal and professional caregivers' acceptance of robot assistance, such as their opinions about ethics of care,

quality of care, and acceptable task parameters when robots perform caregiving tasks.

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