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Towards a Holistic Approach to Studying Human–Robot Interaction in Later Life

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Abstract

Background and Objectives: Implementation of robotics technology in eldercare depends on successful human–robot interaction (HRI). Relying on a systematic literature review, this article proposes a holistic approach to the study of such interaction.

Research Design and Methods: A literature search was carried out in five databases. A Boolean phrase search included the term robot and at least one term referencing older age, leading to an initial corpus of 543 articles. Articles were included in this review if they described older adults' interaction with robots. Exclusion of articles that did not meet this criterion, as well as duplicate material, led to a total of 80 articles, that were then subjected to quantitative and qualitative analyses.

Results: Studies tended to focus on older users, typically community-dwelling adults, without sufficient consideration of the users' characteristics and the physical, social, and cultural context of the HRI. Using a variety of methods, many studies were snapshot inquiries. The chief topics explored were use patterns, the resulting outcomes thereof and factors that constrain use. Commonly, however, these topics were examined separately. In addition, most studies lacked any theoretical framework.

Discussion and Implications: Additional studies are needed to more fully understand what makes HRI successful. The model presented here suggests scholars to conduct theory-driven research, and distinguish among various segments of older users, different types of robots, and group and individual HRI. It also proposes paying greater attention to the users' cultural, physical and social environment, and application of longitudinal and simultaneous examination of uses, outcomes, and constraints.

Keywords: Eldercare, Robotics technology, Quality of life, Systematic review

Background and Objectives

Population aging is expected to be the most significant demographic transformation of the 21st century, with implications for nearly all sectors of society. Globally, the population aged 60 years or over is growing faster than all younger age groups. Recent forecasts suggest that the number of individuals in that age group is expected to more than double by 2050 and to more than triple by 2100, rising from 962 million globally in 2017 to 2.1 billion in 2050 and 3.1 billion in 2100 (United Nations, 2017). This trend, which has no equivalence in the history of humanity, yields numerous social and economic challenges related to health and quality of life and the achievement of healthy aging in general, and a healthy life expectancy in particular.

To reduce the social and economic impact of the projected demand for eldercare, technological solutions are required, wherein robotics technology is expected to play a significant role (Beer et al., 2012). Indeed, in the past decade, a variety of robotic technologies designed specifically for older people or adapted to their needs was suggested. These technologies can be classified according to their degree of perceived intelligence and abilities as well as their design, proactivity, and motion capabilities. Most simply, however, assistive robots for the older adults can be grouped into service-type or companion-type robots. This classification was originally suggested by Broekens, Heerink, and Rosendal (2009) to describe social robots, namely, assistive robotics designed for social interaction with humans, but it can be adapted to all robotics technologies including the ones that do not have "social" skills.

Service-type robots are typically designed to assist frail older people with specific activities of daily living (ADL), such as bathing, dressing, and eating. Other salient robots of the service-type are communication and transportation robots. The first are remotely controlled mobile, human-height devices with videoconferencing systems, offering users an augmented communication channel that can also be used by caregivers for monitoring the older adults and their environment. Transportation robots are one-person robot vehicles with built-in navigation systems and environmental monitoring censors that may be used in hospitals or nursing homes to move persons to destinations within the facility.

Companion-type robots are used primarily to improve the user's wellbeing and may have a humanoid (i.e., human-like) or animal-like form. In addition to offering friendly and enjoyable interaction, many of these robots also include personal assistance applications. They have the ability to access online information (e.g., weather conditions and news) from a variety of sources and assist users in managing their calendars and to-do lists. In addition, they can access entertainment content (e.g., music), assist in interpersonal communication, and perform concierge-type tasks. To some extent, these robots are gradually becoming service-oriented, but unlike service-type robots, they do not focus on a specific task but rather offer a variety of services.

All robot types have great potential to promote autonomy and quality of life among older adults. To achieve acceptable robotics technologies offering natural, ethical, safe, and efficient human–robot interaction (HRI), however, an in-depth understanding of what makes interaction between robots and older adults successful is necessary. The purpose of this article, therefore, is twofold. First, it aims to describe the existing body of knowledge related to HRI in later life based on a systematic literature review. Second, by portraying the strengths and weaknesses of previous research, it aspires to present a holistic approach to studying older adults' interaction with robots.

Research Design and Methods

Literature Search

The PRISMA statement for reporting systematic reviews (Liberati et al., 2009) guided this study and the writing process. Articles published in English in peer-reviewed journals and conference proceedings between January 2000 and June 2017 were included in this review if they described older adults' interaction with robots. A systematic literature search was carried out in five databases: EBSCO Academic Search Complete, PsychInfo, Sociological Abstracts, PubMed, and the Association for Computing Machinery (ACM) Digital Library, to include sources from a variety of disciplines. A Boolean phrase search included the term *robot* and at least one term referencing older age (*aging/ageing*, *elder**, *later life, old age*, *older adults*, *retire**, *senior*) in the article's title and/or abstract and/or keywords. Books and book chapters, dissertations and theses, and practice-oriented articles were beyond the scope of this analysis.

Overall, the initial search yielded 543 articles, which were reduced to 492 after screening out duplicates. These publications were reviewed by the research team and were included in the review according to the following criteria: (a) described users' experience with robots at least to some extent (i.e., did not focus on technological and design issues only), and (b) users were individuals aged 50 years and older or included a subset of persons aged 50 years and older. This choice of age group resulted from the wish to explore HRI across the later life course. Its rationale lies in the perception of aging as a continuous process rather than a life stage (Neugarten, 1979). Excluding articles that did not meet both criteria led to a total of 80 articles. Figure 1 presents the flow chart of the screening process (for more information and the complete list of publications included in the systematic review, see Supplementary Data).

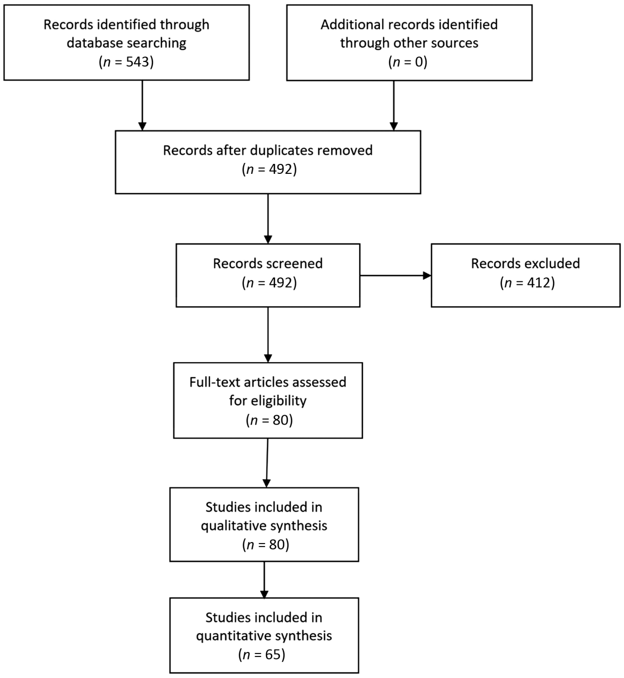

Figure 1. The articles screening process (PRISMA flow chart).

Analysis and Synthesis

Of the articles included in this review, 65 were empirical and 15 were conceptual or review papers. Empirical articles were systematically coded according to the following characteristics: Year of publication, country and place of study (laboratory, senior home, older adults' residences, other), theoretical framework (yes/no), type of robot (service-type: ADL, communication, or transportation robots; companion-type: humanoid or animal-like), number and type of study participants (community-dwelling adults, senior home residents, formal caregivers such as physicians, nurses and staff, and informal caregivers such as family relatives and/or friends). Additional codes referred to the older study participants' age and health condition (physical, cognitive and psychological), the study's duration (in days) and number of contacts with each participant, methodologies applied (experiments, observations, focus groups, in-depth interviews, scenario-based design, and survey instruments), and the main topics explored (uses, outcomes, and constraints). Analysis was supported by the Statistical Package for Social Science (SPSS)® IBM, version 22, and descriptive statistics were used to portray the reviewed articles.

Next, the insights arising from each article were summarized. Conceptual and review papers were included in this phase, as they could clarify and expand on topics briefly described in empirical articles. To ensure reliability, summaries were conducted simultaneously by the first author and a PhD student, and then reviewed by the second author vis-à-vis each article. Summaries were then integrated to describe the principal insights related to older adults' interactions with robots. Memo writing and team discussions were conducted in parallel to the analysis and integration, creating a source of reflexivity and documentation alike.

Results

Characteristics of Examined Studies

Analysis of the 65 empirical publications indicated that since 2010 scientific interest in older adults' interaction with robots has been increasing, as reflected by the number of publications per year (Figure 2). This finding can be explained by the growing number of new robotics technologies designed for older persons during this period, as well as by the relatively new and developing situation of HRI research. Examining the place in which each study was conducted showed that 82% were carried out in Western Europe (N = 26) or North America (N = 27). Hence, the existing body of knowledge is based primarily on insights from the Western world.

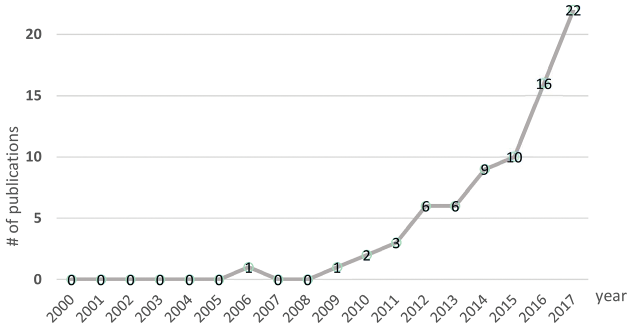

Figure 2. Number of publications per year.
Note: The data for the last 6 months of 2017 were estimated according to the first 6 months of the year.

Exploration of the use of theoretical frameworks (i.e., structured and validated models, not just concepts and definitions) revealed that about 90% of the publications (N = 58) in this review did not use any theory on which to base their rationale and/or with which to interpret their results. Only seven articles relied on theories, of which the Technology Acceptance Model (Davis, 1989)—an information systems theory that describes factors influencing users' acceptance of new technology such as perceived usefulness and ease of use—was the most commonly used, and only one study (Beer et al., 2012) used a theory originating in gerontology literature. The latter applied the Selection and Optimization with Compensation (SOC) model (Baltes & Baltes, 1990) according to which it is adaptive and healthy to respond to limiting factors in old age by being selective about activities of choice, abandoning those that are less personally meaningful and compensating in whatever way necessary to optimize the more restricted number of alternatives. Beer and colleagues (2012) explored older adults' willingness to use a service-type robot for home upkeep tasks. They applied the SOC model both in the design of their study as well as in their interpretations of the findings, which led to the conclusion that older adults are willing to accept robots as a "technological compensatory method" (p. 340). Following this conclusion, they even developed a list of recommendations for the design of home robots for seniors. Their study may thus serve as a good example of the practical value of theories (Eaton, 1921).

Characteristics of Study Participants

The number of study participants in each study ranged from 3 to 379 (mean = 63). Yet, in two thirds (66.15%) of the studies, the number of participants reached up to 30. Studies in which numerous persons participated were based on survey instruments. Sixty-three of the 65 studies involved older adults, with community-dwelling adults more commonly researched than senior home residents (N = 38 vs 31). Forty-one studies (63%) examined only one of the four populations (community-dwelling adults, senior home residents, formal or informal caregivers), and 20 (31%) simultaneously examined two populations. Typically, these studies explored senior home residents and their formal caregivers (N = 8) or compared community-dwelling adults with senior home residents (N = 5). Only four studies (6%) concurrently examined three different populations. Moreover, only six studies involved informal caregivers.

As the definition of "old age" is arbitrary, the reviewed articles used varying classifications. Some (e.g., De Graaf, Allouch, & Klamer, 2015) used the age of 50 as the lower limit, whereas others (e.g., Hebesberger, Koertner, Gisinger, Pripfl, & Dondrup, 2016) only explored individuals aged 70 years and older. Most studies, however, set minimum age limits of 60 or 65 years, that are consistent with official definitions of old age (e.g., United Nations, 2017; World Health Organization, 2002). Forty-five publications (70%) reported the average age of participants. This figure ranged from 59 to 91 years (mean = 75.5), indicating that the range of ages was well distributed from a probability point of view.

It should be noted, however, that in 15 (24%) of the 63 empirical publications examined in this review that explored older adults, the age group of the study participants was not mentioned. Readers could only figure out participants' ages according to verbal hints (e.g., "senior home residents"). In addition, five of the studies that reported the participants' age group did not mention the average age. Moreover, many studies lacked basic information related to the participants' cognitive, psychological, and/or physiological conditions. Twenty-four percent (N = 15) of the 63 publications that explored older adults did not report the participants' cognitive condition, 40% (N = 25) did not report their physiological condition, and 52% (N = 33) did not report their psychological condition.

Methods

Seventy-five percent of the studies used one (N = 21) or two (N = 28) methodologies, 21% (N = 15) applied three methodologies, and one study (Beedholm, Frederiksen, & Lomborg, 2016) used four. There was no particular methodology prevalent among studies that used only one (experiment = 4, observations = 5, focus groups = 3, in-depth interviews = 4, survey instruments = 5). By contrast, studies that used two methodologies often combined in-depth interviews and survey instruments (N = 12, 43%).

Most studies (N = 34, 52%) took place in a laboratory setting, whereas the others were conducted at senior homes (N = 24, 37%) or the residences of community-dwelling adults (N = 13, 20%). Seven studies were conducted in more than one location. In accordance with the prevalence of laboratory studies, in 54% of the studies (N = 35), there was only one contact with each study participant. Most studies conducted in senior homes and/or in participants' residences, however, applied multiple contacts up to a maximum of 30. Similarly, exploration of the studies' duration showed that the majority lasted one day (N = 25, 55% of the 45 studies that reported and/or implied this information according to methodology). Only nine studies took 30 days or more to perform. Eight of them were conducted at senior homes or community-dwelling adults' residences.

Topics

The studies explored older adults' interaction with a variety of robots. The most common were service-type robots (N = 38, 58%), and in particular ADL assistants (N = 18) and communication robots (N = 17). Interaction with companion-type robots was examined in 26 studies (40%) and general concepts of robots in three. Only two studies simultaneously examined HRI with more than one type of robot. Summarizing all articles examined in this systematic literature review led to the identification of three major topics explored with regard to HRI in later life, namely: Uses, outcomes and constraints. Each category comprised various subcategories, as detailed below. Most of the articles (N = 50) examined uses, about half of them (N = 35) explored the outcomes resulting thereof, and about one third (N = 20) addressed factors that constrain older persons' use of robots. Almost half of the studies (N = 31, 48%) examined only one of these topics, and while others explored more than one aspect, there were only six studies that simultaneously examined uses, outcomes and constraints.

Principal Insights

Uses

The *uses* category included explorations of (a) users' acceptance of new robotics technology, (b) processes of adaptation to such technologies, and (c) factors affecting user experience. Many studies suggested that although older adults and their formal caregivers were interested in robots and even excited about them, their *acceptance* of robotics technologies was somewhat ambivalent (Hebesberger, Koertner, Gisinger, & Pripfl, 2017). For example, whereas older adults saw robotics as a future extension of existing communications technologies such as the Internet and smartphones, and expected robots to be widely adopted, they were also concerned that such technologies would replace and even control humans sooner or later (Walden, Jung, Sundar, & Johnson, 2015). People with Alzheimer's disease (AD) also demonstrated such ambivalence. Expressing prospects for robot support in daily life activities, such individuals stated that they did not want to use robots (Wang, Sudhama, Begum, Huq, & Mihailidis, 2017). Similarly, formal caregivers reported both enthusiasm about robots (Lewis et al., 2016) and dislike of sharing their work space with them (Hebesberger et al., 2017). In fact, according to the reviewed articles the only audience that was purely positive about robots was that of the informal caregivers, who demonstrated openness to robotics technology, understanding of its benefits, and a desire to use it (Wang et al., 2017).

Some studies revealed that people often attribute human traits to robots and expect them to exhibit human behavior and intelligence even though they know clearly that they are dealing with machines (Frennert, Eftring, & Östlund, 2017). Among persons with AD, this subject-machine duality led, in some conditions, to agitation, rejection, and displeasure (Klein, Gaedt, & Cook, 2013). In addition to humanizing the robots, older adults often compared them to humans. One study, for example, reported that older adults were discerning in their approval of support for different tasks, and preferred robots for tasks related to manipulating objects, chores, and information management, but sought humans for tasks related to leisure activities and personal care (Smarr et al., 2014). In another study, participants favored the robot instructor for physical exercise training, although they displayed strong inclinations towards humans for information delivery (Shen & Wu, 2016). Users also compared robots with pets (Lazar, Thompson, Piper, & Demiris, 2016), that were more valued thanks to the reciprocity inherent in caring for them and the relationships they form, as well as with other technologies such as those of tablet computers (Mann, Macdonald, Kuo, Li, & Broadbent, 2015) and smart home technologies (Johnson et al., 2014), that were typically perceived as inferior and less enjoyable than robots.

Direct experience with robots appeared to lessen ambivalence and promote acceptance. This impact was evident in snapshot studies that enabled interaction with robots (Mehrotra et al., 2016; Shen & Wu, 2016), as well as in longitudinal studies that explored *processes of adaptation* to robotic technologies. The latter demonstrated that giving robots a function in the older adults' daily routines may lead to greater approval and appreciation (De Graaf et al., 2015), which, in turn, leads to increased intensity of use (Šabanović, Bennett, Chang, & Huber, 2013). If users did not ascribe specific functions to the robot, they gradually lost interest, enjoyed the interaction less (Torta et al., 2014) and eventually returned to their previous routines and habits without the robot (Frennert et al., 2017).

Reports of adaptation processes among people with cognitive impairments were somewhat different. Facing more constraints to independent use of the robots and frequently relying on their caregivers to operate them (Hebesberger et al., 2016), such users demonstrated willingness to interact with the robots that increased over time (Chang, Šabanović, & Huber, 2013). They tended to treat robots as children, and exhibited growing emotional attachment to them that was often expressed by various physical gestures, such as petting and hugging (Chang et al., 2013).

The differences in adaptation among people with varying cognitive functioning suggest that user experience depends on the individual's characteristics. Indeed, many of the reviewed studies reported *factors affecting user experience*, which could generally be divided into two types: User and robot attributes. User attributes significantly affecting user experience included personal factors such as age, cognitive condition, level of education and computer experience (Wu et al., 2016), and interpersonal factors such as perceived amount of social support (Baisch et al., 2017). Some review papers (e.g., Kachouie, Sedighadeli, Khosla, & Chu, 2014; Klein et al., 2013) also pointed to the effects of older persons' cultural backgrounds on their attitudes towards robots. Cross-cultural studies of HRI in later life are scarce, however, and the few multinational studies included in this review (e.g., Jenkins & Draper, 2015; Mehrotra et al., 2016; Torta et al., 2014) focused on similarities among users rather than differences.

Robot attributes that affect user experience were studied extensively as well, including the robots' appearance, behavior, and functionality. Whereas users expressed preference for clear distinction between humans and robots in terms of physical appearance (Walden et al., 2015), they tended to favor those who looked more like humans (Khosla, Chu, Kachouie, Yamada, & Yamaguchi, 2012), or displayed human-like features and gestures (Caleb-Solly, Dogramadzi, Ellender, Fear, & Heuvel, 2014). In terms of behavior, users wanted robots to be social, intelligent, and spontaneous (Frennert et al., 2017), although there was some incongruity with regard to the robots' playfulness. Hedonic features did increase users' willingness to interact with robots, but serious demeanor added credibility and appreciation (De Graaf et al., 2015). Similarly, users tended to like "young" robots but perceived "older" ones as more competent and safe (Marin Mejia, Jo, & Lee, 2013). Finally, the robots' perceived functionality seemed to play an important role. This term describes a host of valued robot attributes such as safety, reliability, control, efficiency and satisfaction (Begum, Wang, Huq, & Mihailidis, 2013; Padir, Skorinko, & Dimitrov, 2015). Users expected the robots to be useful and adjustable to their needs (Pripfl et al., 2016; Tsardoulias et al., 2017).

Noticeably, while all studies described in this review referred to HRI, the importance of the interaction methods was rarely discussed. Studies showed that older adults tend to appreciate communication methods that resemble human–human interaction as well as multimodality, namely, multiple interaction possibilities (Fischinger et al., 2016; Khosla et al., 2012). For example, a study that applied Matilda (a companion-type humanoid robot embodied with a range of multimodal attributes such as voice, music, gestures, movement and touch panel) in a nursing home setting showed that its multimodality was highly valued by the residents (Khosla et al., 2012). The manners in which older people and robots interact and the effects of the interaction methods, however, require further exploration.

Outcomes

The reviewed publications described a variety of outcomes resulting from HRI in later life, mostly divided between (a) benefits and (b) risks. Overall, the studies reported *positive effects* of HRI on older adults' psychological wellbeing and functioning (Broekens et al., 2009), and provided solid evidence that these effects can indeed be attributed to the HRI. Interacting with robots was experienced as a cognitively stimulating (Khosla et al., 2012; Neven, 2010, Tsardoulias et al., 2017; Wu et al., 2016) and enjoyable activity (De Graaf et al., 2015; Fischinger et al., 2016; Lazar et al., 2016) and had beneficial effects on users' psychological wellbeing, including better and more intensive communication with family and friends (Tsardoulias et al., 2017), elevated mood (Khosla et al., 2012), positive affect (McGlynn, Kemple, Mitzner, King, & Rogers, 2017) and decreased frustration, stress, and relationship strain (Wang et al., 2017).

In addition, the robots proved efficient as a therapeutic means in long-term care settings. Often using the pet-like robot Paro (a robot that was designed to mimic movements and sounds of a baby harp seal in response to petting, complete with white fur) in recreation and/or occupational therapy sessions, studies showed that interactions with robots are a powerful projective screen as well as a site for working through personal and social concerns (Turkle, Taggart, Kidd, & Dasté, 2006). The interactions also had a positive impact on session participants' mood (Lane et al., 2016), communication and interaction skills, and activity participation (Šabanović et al., 2013). Therapists felt that the robots are good social mediators in group sessions, but thought that they were even more appropriate for one-on-one interaction (Chang et al., 2013). Only one of the reviewed publications, however, explored both individual and group HRI.

Functional benefits primarily included the robots' contribution to older persons' independence and quality of life (Bedaf et al., 2014; Neven, 2010, Padir et al., 2015; Smarr et al., 2014; Tsardoulias et al., 2017), as well as their role in relieving the burden for caregivers (Broadbent, Stafford, & MacDonald, 2009; Jenkins & Draper, 2015). Furthermore, the robots were found useful in supporting physical exercise and/or rehabilitation thanks to their ability to correct the users' position and movements (Tsardoulias et al., 2017) and enhance motivation, group coherence, and mood (Hebesberger et al., 2016). One study even showed that physical exercise sessions led by robots were significantly more effective than those with human instructors (Shen & Wu, 2016). Another study, however, revealed no positive influence on exercise behavior (Mann et al., 2015).

Besides describing the benefits accruing from older persons' use of robots, the literature also addressed its *risks* and/or negative impacts insofar as both psychological wellbeing and functioning are concerned. It should be noted, however, that such risks were hypothetical. They were only expressed as concerns by scholars and/or study participants, but have not been examined empirically to date. With regard to psychological risks, concerns related primarily to robot applications in long-term care settings. One of the conceptual articles argued that robots lack emotions that are integral to the provision of such care; consequently, they cannot accord residents with essential recognition and respect (Sparrow, 2016). They may thus make care receivers feel like "problem carriers" (Beedholm et al., 2016). Another conceptual article discussed ethical ramifications including invasion of privacy and feelings of a loss of control (Kernaghan, 2014). Furthermore, it was suggested that the robots may create tension between older people and their formal and informal caregivers. For example, robots used for monitoring formal caregivers may weaken the residents' trust in the care they receive, while robots programmed to report nonadherence to treatment may cause humiliation and anger (Jenkins & Draper, 2015).

Concerns regarding older adults' functioning were often associated with issues of safety and reliability (Ng, Tan, Wong, & Kiat, 2012). Some study participants, for example, worried about potential damage or harm to themselves or their environment (Beer et al., 2012). Furthermore, although one major justification for incorporation of robots in older people's lives is their potential to support autonomy, it was claimed that the robots may actually threaten autonomy by replacing users in tasks they would be better off performing themselves, rendering seniors dependent on robots (Beer et al., 2012; Jenkins & Draper, 2015).

Constraints

The reviewed publications also pointed to a variety of constraints on robot use. This category comprised explorations of (a) antecedent constraints, namely, factors that reduce or limit motivation to use robots, and (b) intervening constraints that come between the desire to use robots and the actualization thereof. Among the salient *antecedent constraints* were uneasiness with the new technology (Wu et al., 2014), and perceiving it as no more useful and/or having no added value than existing technologies (Caleb-Solly et al., 2014; Wu et al., 2014; Wu et al., 2016). It appears, however, that the most dominant antecedent constraint is the stigma associated with using a robot in old age. Trying to dissociate themselves from negative stereotypes of old age as a period of frailty and dependency, healthy older adults tended to perceive the prospective robot user as someone older, lonelier and more in need of care (Neven, 2010; Pripfl et al., 2016). Interestingly, however, even people with dementia did not think that they could benefit from using an assistive robot. At most, they could imagine themselves using one down the road if their cognitive condition worsens (Begum et al., 2013; Wu et al., 2016).

Prominent *intervening constraints* described in the literature were affordability and usability. Concern over robot costs was expressed often (Ng et al., 2012; Padir et al., 2015). Community-dwelling adults were doubtful about buying a robot, but could imagine renting one for a short period if needed (Fischinger et al., 2016), while senior home residents, who considered robots vis-à-vis human caregivers, thought it would be more reasonable for both financial and functional reasons to hire more staff than to acquire a robot (Compagna & Kohlbacher, 2015).

As many of the reviewed publications tested new devices and applications, usability was of major interest. Accordingly, various operative difficulties were reported. Some studies, for example, described users' dissatisfaction with the robots' verbal skills, comprehension of instructions, and response speed (Begum et al., 2013; Fischinger et al., 2016; Pripfl et al., 2016). Shortcomings in robot performance led to frustration (Pripfl et al, 2016), and some users were annoyed by the conversations that companion robots initiated autonomously (De Graaf et al., 2015). Usability was even more challenging among cognitively impaired individuals, as the robots were often unable to match the interaction abilities and speed of such users (Begum et al., 2013).

Scholars also noted various reasons for usability problems, the first being the extensive heterogeneity characterizing the older population (McGlynn et al., 2017; Šabanović et al., 2013). Bedaf and colleagues (2014), for example, tried to identify which daily activities pose the greatest threat to independent living as they become more difficult for the older individual to perform. They concluded that it was often a combination of activities rather than a specific activity, and that the threat was largely specific to the person studied. Hence, a single perfect robotics technology for older adults is unlikely, and designers should develop flexible and customizable solutions (Broadbent et al., 2009; Caleb-Solly et al., 2014). Another problem is the gap between the technology developers and its users, rendering Participatory Design (PD) highly challenging. PD methods aim to develop a socially robust and responsible robot design by building on mutual learning between researchers and participants, and the active participation of older adults and/or their caregivers as "designers." Often, however, the participants' understanding of technology is limited and their expectations from the robots unrealistic (Compagna & Kohlbacher, 2015; Mehrotra et al., 2016).

Discussion and Implications

Our systematic review suggests that the literature on older adults' interaction with robots is still in its infancy. Providing many important insights, which laid the groundwork for future research and development, the existing literature has many weaknesses, of which the most dominant are lack of theory, cultural bias, and relatively little attention to the characteristics of users and to their informal caregivers. Studies also tended to consist of snapshot inquiries incapable of exploring processes of assimilation and adaptation to robotics technology and changes in HRI over time, and typically focused on one aspect of the interaction only. Without discounting the value of previous studies, we call for future research based on a holistic approach that is built on the following five principles:

Theory-Driven Research

Theories, defined as "the construction of explicit explanations in accounting for empirical findings" (Bengston, Rice, & Johnston, 1999, p. 3), offer lenses through which we can understand what we observe in research. Moreover, they enable knowledge building in a systematic and cumulative manner, so that each new empirical effort simultaneously adds to what is already known and guides us towards what is yet to be learned. The absence of theory in most previous research on older adults' interaction with robots therefore renders this research rather sporadic and limited, and does not enable systematic and cumulative knowledge building.

Moreover, the few studies that were theory-driven mostly referred to technology-related theories, completely ignoring the vast corpus of gerontological theories related to wellbeing in later life (for a review, see Bengston & Settersten, 2016). A potential explanation for this phenomenon may be that many previous studies were conducted by robotics experts, who have no academic background in gerontology. As promoting quality of life is the chief motivation for developing robotics technologies for older individuals, however, future studies should use such theories to explain their findings, develop existing theories, and/or suggest new ones related to successful HRI in later life.

Differentiation Among Various Segments of Older Users

Gerontology literature provides solid evidence demonstrating increases in physical, sociological and psychological variability with age (Wolfe & Snyder, 2003; Yang & Lee, 2010). Older adults may thus constitute the most heterogeneous population of all. Nevertheless, many of the studies reviewed did not distinguish among the various segments of older adults. Moreover, many did not report (and perhaps not even gather) the most basic information about the study participants, such as their physical, psychological and cognitive condition. In addition, the researchers' definition for old age was rather fluid, and 24% of the studies did not report the participants' age at all. The absence of these data is rather limiting, as age and health are key factors in explaining older adults' acceptance and use of technology (Anderson & Perrin, 2017). Implying a wrong perception of older people as a homogeneous population, this approach may also lead to misleading generalizations. For example, seniors with motoric and/or cognitive impairments may be more receptive to robotic assistance than healthy individuals. Unless these segments are differentiated from one another, however, all studies of technology acceptance hinder such insights. Future research should therefore take users' characteristics into account and offer many more comparisons among segments of the older population than did previous research.

Greater Attention to Users' Cultural, Physical, and Social Environments

As 80% of previous research was conducted in North America and Western Europe, it may be argued that the existing literature is culturally biased. Considering the significant impact of culture on technology acceptance and use (Leidner & Kayworth, 2006; Nistor, Lerche, Weinberger, Ceobanu, & Heymann, 2014), this also means that one cannot generalize from existing studies to other, non-Western cultural contexts. Moreover, whereas studies were carried out among both senior home residents and community-dwelling adults, very few of them simultaneously studied both audiences. Consequently, current understanding of the impact of the physical environment and residence type on users is very limited. Similarly, while some studies simultaneously explored older people and their formal caregivers, fewer than 10% explored informal caregivers such as family and friends, and only one (Jenkins & Draper, 2015) examined all three groups simultaneously. The effects of the care triad on HRI were thus largely neglected. To increase our understanding of how seniors' environments influence their interaction with robots, studies should be conducted in additional cultural contexts and include cross-cultural comparisons, according greater attention to the immediate physical environment, and simultaneously exploring the older adults and their formal and informal caregivers.

Differentiation Among Various Types of Robots and HRI

Most previous research explored HRI using one type of robot, such as a companion robot, communication robot, or ADL assistant. As many aimed at examining topics such as acceptance and usability of specific technological developments, such focus was obviously necessary. Nevertheless, simultaneous study of two or more types of robots may have constituted a considerable contribution to research. Such exploration may shed light on associations between individual needs (e.g., when physically constrained) and willingness to accept various types of robotic assistance, as well as the correlation between one's objective condition and subjective experience. People with mild cognitive impairment, for example, may enjoy interaction with pet-like robots, whereas their cognitively intact peers may display greater appreciation for ADL assistance. Similarly, it would be valuable to explore the differences and associations between individual and group HRI that have hardly been addressed to date. Group dynamics may be a powerful means of facilitating technology use (Sykes, Venkatesh, & Gosain, 2009). Hence, group HRI may increase use legitimacy and sense of relevance that may later affect individual HRI. Such insights may ease the transition from research to practice and promote beneficial use of robotics technologies by the older population.

Longitudinal and Concurrent Investigation of Uses, Outcomes, and Constraints

While previous studies used a variety of methodologies, often applying a mixed-methods approach, many were not conducted in real-life conditions and the majority relied on snapshot inquiries. Although they are more complex to perform and analyze, and typically more expensive, studies that follow how older adults interact with robots over time in their natural environment are of great importance. Only such studies can reveal how the interaction changes according to users' experience, to what extent HRI is integrated in their daily lives, what factors affect frequency of use and the benefits so accrued, and what constrains beneficial use and/or leads to decreased frequency of use or even cessation thereof. Furthermore, simultaneous exploration of uses, outcomes (including both positive and negative effects), and constraints, rather than focusing on one or two of these issues, may explain how they correlate with one another. Only six studies in the corpus examined in this article, however, extended over more than 30 days and simultaneously examined uses, outcomes, and constraints. More studies of this type, which will also apply the above principles and combine components of interpersonal communication research (i.e., explore *how* people and robots interact and the effects of the interaction methods), will yield significant insights capable of guiding theory and technology development alike.

Adoption of most or all of the suggested principles in future research may be regarded as a holistic approach to HRI in later life, because it takes all relevant aspects into account. Effective application of this approach is highly dependent on interdisciplinary research and greater collaboration between engineers and social scientists focusing on aging studies. Such application should contribute substantially to the development of our understanding regarding successful interaction between robots and older adults, and assist in the design of acceptable robotics technologies that offer natural, safe and beneficial assistance to the global aging population. There is no doubt that the future of humankind will heavily rely on robots, and that this will "have a major impact on all aspects of our society and industries, ranging from manufacturing and consumer devices to medical applications and wearable technology" (Rossiter & Hauser, 2016, p. 17). To make this future a bright one, especially for the older people, it is our responsibility to conduct thorough, informative and useful research that will direct this inevitable technological revolution cautiously.

Supplementary Data

Supplementary data are available at *The Gerontologist* online.

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Conflict of Interest

None reported.

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