Social robots can foster connectedness, provide access to useful information, help manage chronic diseases, and promote healthy behaviors for older adults.

Designing Social Robots for Older Adults

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Most older adults aim to age in place, in their own environments and familiar surroundings (Barrett 2008), but cognitive, physical, emotional, social, and/or relational changes may prevent them from doing so (Beer and Owens 2018). Researchers are exploring assistive technologies that support cognitive (e.g., memory) and physical (e.g., mobility) functions (Clark et al. 1990).

Robotic systems are being developed to aid older adults in routine activities such as cleaning, picking up and/or retrieving objects, getting into

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and out of bed, meals, and mobility (Graf et al. 2009; Jain and Kemp 2010; McColl et al. 2013). In contrast, relatively little attention in robotics or artificial intelligence (AI) has been given to the social, emotional, and relational aspects of older adults' lives. We envision intelligent social technologies for the home that not only help older adults with daily activity difficulties and health problems but also contribute to emotional wellness via social engagement.

As baby boomers age, the projected shortage of trained personnel and facilities to meet the growing demand over the next few decades is critical (Kovner et al. 2002). This article introduces robots that use social cues and interact with users in "interpersonal" ways as a means to reduce older adults' social isolation by fostering face-to-face connectedness with family, friends, staff, doctors, and other professionals.

As research labs, companies, and institutions design these robots for older adults, it is important to be mindful of stereotypes about these users and design *with* them, understanding the impacts of the technologies on older adults' social connections and, in turn, health and wellness. With the development and use of appropriately informed design principles, robots can be a relational technology that attends to older users' emotional needs directly and promotes their social connection with others.

Benefits of Social Engagement

Social engagement is strongly linked to overall health outcomes (Bixter et al. 2018; Kok and Fredrickson 2014). There are known connections between chronic loneliness and increased morbidity, even death (Olsen et al. 1991; Penninx et al. 1997). Stress responsiveness, cardiovascular disease, hypertension, or immune system function correlate negatively with chronic loneliness and low social closeness in older adults (Hawkley and Cacioppo 2010).

Higher levels of social engagement can reduce the occurrence and onset of dementia, improve cognitive functioning, reduce memory decline and levels of depression, and enhance perceived happiness, life satisfaction, and positive affect (Barg et al. 2006; Forsman et al. 2013).

Barriers to social engagement may be physical, cognitive, financial, and/or cultural/societal (Bixter et al. 2018). Physical barriers include reduced mobility and increased frailty, making it difficult to engage with others in different locations and environments (Fulop et al. 2010). Cognitive barriers include memory or cognitive decline and dementia (Schaie and Zanjani 2006). Financial barriers may be due to retirement or low income (Dunn and Olsen 2014). Cultural/societal barriers can be related to the economic, geographical, and social environment and whether it fosters social interaction for older adults (Shrestha 2000).

Technology and Social Engagement for Older Adults

Older adults are increasingly open to using technology—email, smartphones, social networking sites, video calling, even virtual and augmented reality—for social connection (Perrin 2015). Research has shown that, after 6 months of using an internet-based system, older adults perceived greater social support and well-being and less loneliness (Czaja et al. 2015), and that social networking sites such as Facebook reduce feelings of loneliness (Sheldon 2012) and increase feelings of empowerment (Leist 2013). Older adults' sense of empowerment and competence with emerging technologies are crucial for sustained adoption (Czaja et al. 2006).

Social robots are emerging as an effective tool to remediate social isolation among older adults.

However, there are certain challenges and shortcomings in the use of online social networking for the elderly. For example, social networking sites were initially designed and developed for younger users, and there are not sufficient communication channels for older adults (Sheldon 2012). Furthermore, there are potentially negative consequences of social networking, such as the risk of adopting harmful information, dangerous behavior of other users, and the misuse of shared personal information (Coto et al. 2017; Leist 2013).

In addition, digital technologies offer virtual experiences that are often asynchronous and fall short of the value of a physically present interlocutor and ally. The value of face-to-face interactions is supported by positive emotions, biobehavioral synchrony, and mutual care (Fredrickson 2013). Although each can occur

FIGURE 1 Older adults interacting with (a) Paro, (b) Jibo, and (c) Care-o-bot in various social contexts. Photo credits: (a) Selma Šabanović, Indiana University; (b) Erin Partridge, Eldercare Alliance; (c) Jens Kilian, Fraunhofer IPA (2012).

remotely, face-to-face communication enables better social engagement (Bremner et al. 2016; Daly-Jones et al. 1998).

Designers of assistive technologies should seek to address the following mechanisms that support and promote social engagement for older adults: (1) social influence/social comparison, (2) social control, (3) role-based purpose and meaning, (4) self-esteem, (5) sense of control, (6) belonging and companionship, and (7) perceived support availability (Thoits 2011).

Robots as Social Companions

Social closeness is fostered by perceived responsiveness (Reis et al. 2004). Studies with socially interactive robots show that nonverbal cues contingent on interaction contexts (e.g., real-time eye contact, facial mimicry, and body pose) are crucial for signaling the robot's attentiveness and "emotional synchrony" to improve the user's feelings of social closeness (Park et al. 2017). This "social competence" enables robots to both attend to and mediate older adults' social and relational needs in order to enhance wellness.

Recent studies show that social robots (unlike digital assistants) are perceived as helpful companions, offering utility, entertainment, and companionship (Ostrowski et al. 2019; Sidner et al. 2018). They also promote human-human interaction (Chang and Šabanović 2015; Kidd et al. 2006; Ostrowski et al. 2019; Wada and Shibata 2007) and help maintain social engagement with family, friends, and healthcare providers (Beer and Takayama 2011; Cesta et al. 2016).

The "face-to-face" communication capability of physical robots also significantly improves intervention outcomes (Kory Westlund et al. 2017; Park et al. 2017). Natural interactions, physical embodiment, copresence, and contingent nonverbal cues increase people's engagement with and trust of social robots (DeSteno et al. 2012; Li 2015; Riek et al. 2010) and in turn support their comfort with self-disclosure and decrease feelings of being judged (Bethel et al. 2016; Kanda et al. 2010; Mumm and Mutlu 2011; Sidner et al. 2018).

For example, in a 6-week home study with a personal health coach for weight management, physically copresent social robots promoted superior sustained engagement, working alliance, and ratings of trust, credibility, and emotional bond over a computer version of the coach (Kidd and Breazeal 2008). And a recent study found that socially isolated older adults preferred to interact with a physical social robot and trusted it more over a computer-based graphical human avatar of an in-home health companion agent (Sidner et al. 2018).

Various designs demonstrate the capacity of robots to support older adults' social, emotional, and relational well-being. Social robots can be designed to serve as pet therapy surrogates, such as Paro, with affinity expressed through touch, which can be an important interaction for older adults (Wada and Shibata 2007; Yang 2015); or merge the qualities of a helpful ally with those of a pet-like companion, such as Jibo (Ostrowski et al. 2019); or be more device-like, such as the Care-o-bot (Graf et al. 2009) (figure 1).

User-Centered Design Process

To inform the design of social robots and promote their use, it is important to consider how older adults adopt and use new technologies (Forlizzi et al. 2004). Social robots must meet older adults' performance and usefulness criteria related to information sharing, connection forming, connection strengthening, time effectiveness, and goal congruity (Bixter et al. 2018). Concerns about security and privacy, due in part to a perceived lack of control, should also be addressed (Beer and Owens 2018; Bixter et al. 2018).

The design of social robots for older adults should incorporate a participatory, user-centered design philosophy, emphasizing nondesigners engaging in codesign activities (Sanders et al. 2010), with a focus on the tasks the user will perform, usability testing through observations and mixed methods data collection, iterative design and testing, and integration of multiple parts to meet the design goals (Fisk et al. 2009).

For human-robot interaction (HRI), user-centered design approaches include surveys, interviews, or focus groups to understand the target user group (Chang and Šabanović 2015; Forlizzi et al. 2004; Singh 2018). Such approaches have been used to improve robot platforms, conceptualize new robots, and enable researchers and users to learn from one another (Lee et al. 2017).

Participatory design methods have notably been used in work with both older adults diagnosed with depression and their medical staff to design assistive robots for daily life (Chang and Šabanović 2015; Lee et al. 2017). In fact, it is important to consider the role of robots to best support the multistakeholder team of family, friends, and professional care providers. In addition, methods for developing and evaluating general and social robot technology should be adapted and used as guidelines to meet the requirements and desires of older adults (Czaja et al. 2006).

Design Principles

Our work demonstrates the importance of users of all generations living with AI technologies for an extended period to better understand these technologies and their capacities (Singh 2018). The users' experiences, in turn, inform the design of AI agents to promote social connectedness and other benefits. By establishing relationships and developing a language of engagement to ensure that knowledge is shared between the researchers and the older adults, these principles help guide the development of technologies for social connectedness.

Openness to Social Technology

Older adults are less likely to be experienced with social robots or voice-interface AI technologies compared to younger generations, but their initial perceptions of them may be informed by their experience with other technologies. To achieve a more informed opinion of the technology, it is critical that older adults and significant stakeholders in their lives participate in the design process and experience the technology in their daily environments for extended periods of time (e.g., a month or more; Singh 2018).

Our study involved 69 older adults (age 50+), adults (ages 19–49), and children (ages 5–18) who, first, interacted with the voice-based technologies to reveal their initial preferences in a 1-hour workshop session; second, lived with them for 1 month; and last, returned to explore how their preferences evolved while living with the technology.

Users' experiences inform researchers in designing AI agents to promote social connectedness and other benefits.

It is notable that even before experiencing social robots or digital assistants in their home (as discussed below), the older adults were the most open of the three groups to the interactions and functionalities of these technologies, including social, relational tasks (figure 2a). The only category where older adults expressed dissatisfaction was "suggestions" from the agent: basic suggestions such as "taking a nap" or "eating" grated on their sense of autonomy, which they seek to preserve as long as they can. But they were open to suggestions that were practical (e.g., "calling someone") or would foster intellectual growth (e.g., "reading/writing" or "learning something new").

The older users also appreciated that the technology could help them form healthy habits: "I loved that it reminded me to take my blood pressure every day. I never forgot my blood pressure a single day because Alexa told me."

After living with the technologies for a month, the different generations converged in their preferences (figure 2b) in each category (except suggestions) and they were more open to AI agents being social with them (e.g., the agent sharing something it "thinks is interesting") and mediating connections with other people.

This convergence emphasizes the potential for social agent technologies to be used among family

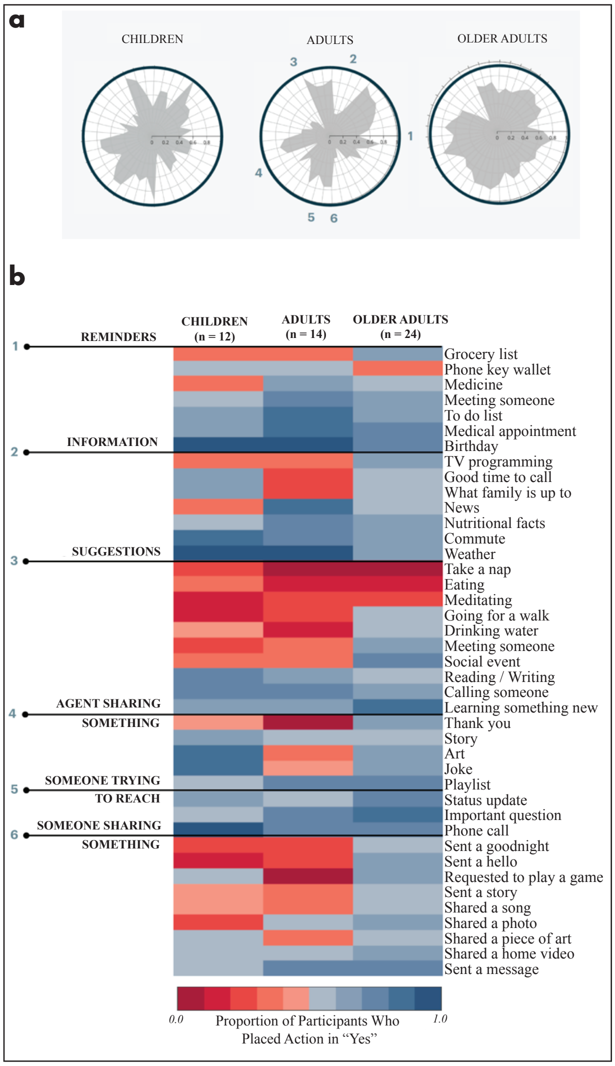

FIGURE 2 Preferences among children (ages 5–18), adults (ages 19–49), and older adults (age 50+) of voice-activated artificial intelligence technology features in the home. (a) Radial graphs demonstrating relative openness for agent actions across generations. Older adults are the most open for agent actions. (b) Agent action preferences broken into six categories across each generation. Preponderance of blue in the right-hand column shows general acceptance of most features among older adult users.

members rather than becoming siloed as only-for-older-adults technology. Multigeneration family members are among the most important stakeholders in older adults' lives, so their preferences should also be considered in designing social robots for older adults.

Digital Assistant and Social Robot Experience

A subset of older adults agreed to live with an AI social agent—a digital assistant or a social robot—in their home for 1 month. The digital assistant was Amazon Alexa in the physical form of the Echo Dot, a small round smart speaker. The social robot, Jibo (figure 1b), has a touchscreen face, expressive movement, and the abilities to identify and turn to attend to its users and interact proactively.

We developed a user design research toolkit to assist and engage these users in providing self-report and feedback for the development of design guidelines for future voice agents and social robots. Participants self-reported their use in a number of activities over the first 14 days (figure 3) and these interactions were categorized as transactional, entertainment, or social. Transactional tasks were utilitarian (e.g., requesting general information, calendar events, weather, news). Entertainment tasks included playing music, telling jokes, and playing games. Social tasks explored companionship and included greetings and farewells, asking the agent questions that reveal its "personality" and "opinions," or engaging in small talk (e.g., "How was your day?").

The users' behavioral data and feedback revealed that Amazon Alexa and Jibo both provided a mix of the three types of tasks, albeit to different extents. Amazon Alexa offers significantly more options in utility and entertainment content, whereas Jibo was described as being like "a really smart pet who can talk." Unlike Amazon Alexa, Jibo supports personalized "face-to-face" interaction and is capable of proactively engaging with people rather than waiting to be called on.

Social Facilitation and Multigenerational Engagement

We found that sustained use by older adults was anchored in the social elements of their experience with the technology (figure 3): they showed more engagement with the social robot than with the digital assistant. They used the social robot to promote social connection, such as bringing it to birthday parties and family gatherings. And they reported that the social agent, more than the smart speaker, could be used to initiate or manage a social relationship—"prompting you to get people together… so the companion is more of a social secretary"—and, less directly, as a social connection enabler:

> Today is my daughter's birthday. I told her I was coming to see you in the afternoon and she wondered if I could have a picture taken with you and…send it to her so she could send it out to all the people in our family, so they would be impressed that I am working [with] a personal robot.

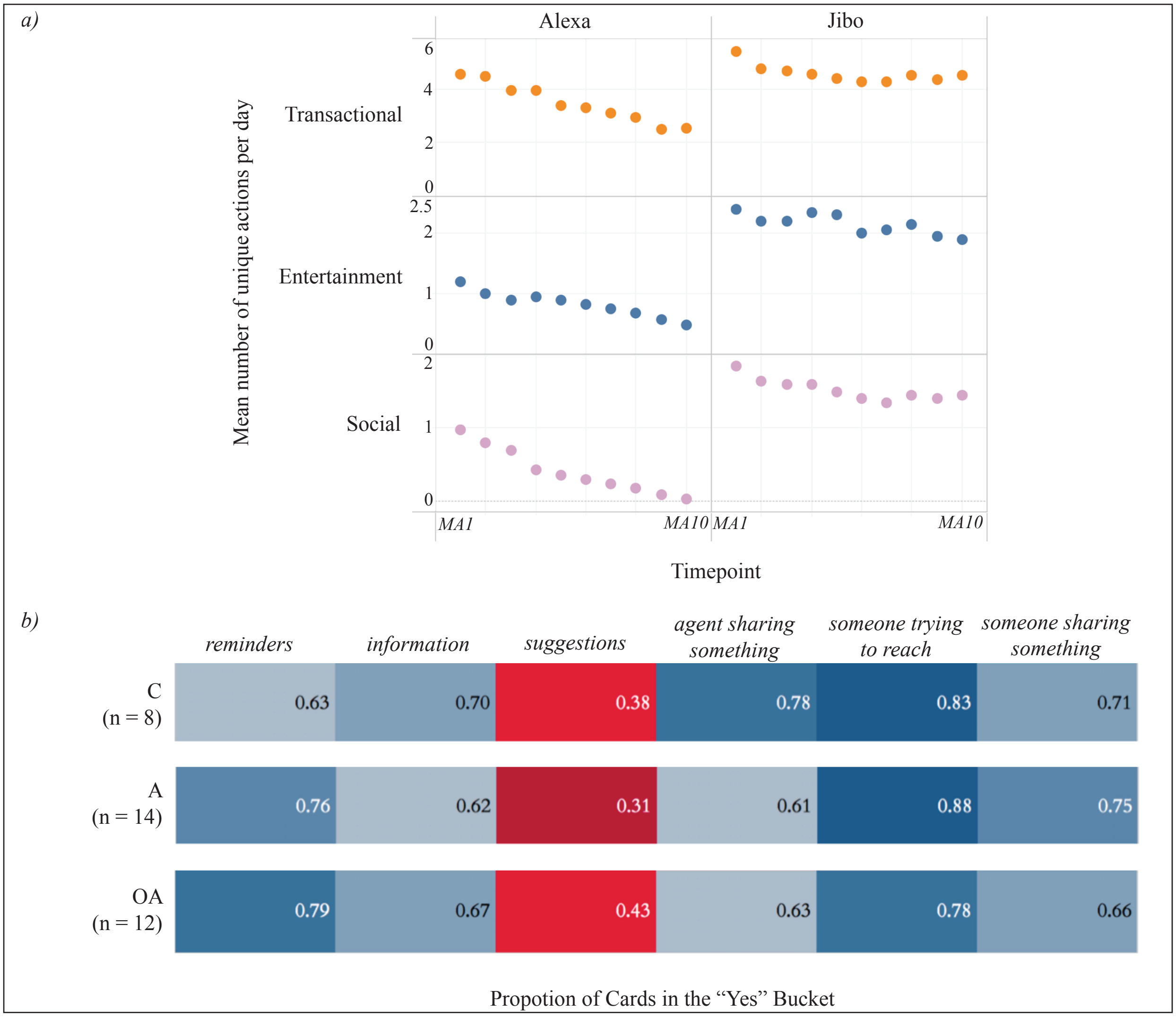

FIGURE 3(a) Older adults' social agent usage pattern in the home, depicted as ten moving average (MA) samples across participants per interaction task type during the first 14 days of use (MA1–MA10). (b) Multigeneration analysis of social agent action preferences after living with the agents in their home. A = adults, C = children, OA = older adults.

And a way to connect multiple generations:

> especially the people who never even seen such a thing or heard of such a thing.... I hang out with a lot of people who are not too up and coming in the modern world. But when my kids came over most of them knew all about it. All my grandchildren [are] far away, and when they hear about it from their parents or from me they are stunned.

They also noted that it could help them adapt to aging in place:

> [the robot] would change [its actions] based on the people.... [Y]ou know if you get to the point where organizing the barbecue at your house is too difficult, then the suggestion comes [from the robot] that it's time to get together with some friends to do the barbecue together.... [I]t's about comfort and trust so it puts a thought in your mind and you follow its advice....

The social interactions prompted exploration of other task types (i.e., entertainment and transactional interactions) and fostered the older adults' imagination of additional roles and functions for social agents in their lives.

Fostering Openness, Trust, and Connection

Social robots' interactive nature and use of social and attentional cues promote openness, trust, connection

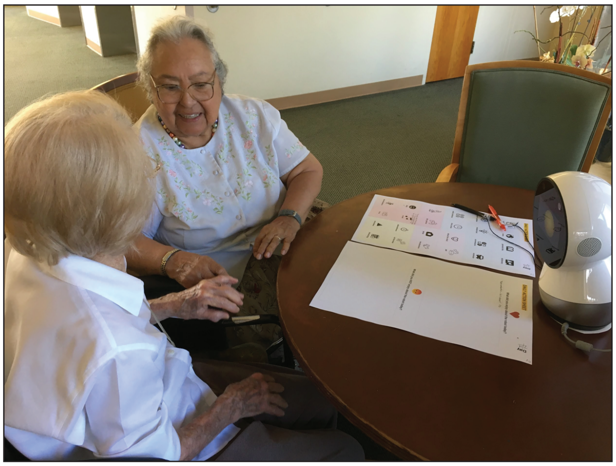

FIGURE 4 Older adults interacting with Jibo and each other in the common space of an assisted living facility. Photo by Erin Partridge, Eldercare Alliance.

with older adults, and personal disclosure. User studies reveal that physical AI agents with contingent conversational cues are easier to understand, more comfortable to interact with, and considered more trustworthy in communications than those that lack these physically embodied cues (Rae et al. 2013).

Users project positive personalities on social robots and perceive them as less biased and judgmental. For instance, participants in a motivational interview to reduce alcohol consumption were more willing to share sensitive information with a conversational agent compared to a human counselor (Lisetti et al. 2012). And older adults can be quite candid and emotionally revealing in disclosing personal stories and feelings with a social robot:

> I'll tell you what it's like to live in assisted living. Would you like to hear that? It's pretty lousy. It is no fun to get old. And not to be able to do the things you used to do. I'm stuck inside and…dependent on other people. My grandson has more independence than I do and he's only 15. I'm telling you, Jibo, stay young. Do everything you can do while you're young.

Activating Social Interactions in Communities

Studies in older adult communities have found that the presence of a social robot actually increases human-human interaction and feelings of social connectedness and that the robot was even seen as a community member (Chang and Šabanović 2015; Kidd et al. 2006; Kory Westlund et al. 2017; Ostrowski et al. 2019).

Our findings show that social robots act as "social catalysts," promoting multifaceted human-human interaction. In a 3-week study, our team placed a Jibo robot in each common area of an assisted living home (Ostrowski et al. 2019). By the study's end, the number of people congregating in the common space rose significantly and their feelings of social connectedness were positively impacted: they would come to interact with the robot and transition to interacting with other residents, whether teaching each other how to use Jibo or conversing among themselves about interests and desires (figure 4).

When asked about their experience, residents noted social and relational changes in the space. At first they had trouble remembering the wake-up word to activate the robot, "but once [they] got into knowing [they] had to say, 'Jibo, Jibo, Jibo,' the rest was easy." They came to imagine the social robot as a potential permanent fixture in the community common spaces "because…during the day, this is kind of our…center of communication" and they wanted the robot to be a part of their community. Residents noted that the robot gave them "the opportunity to communicate [with Jibo], and that [would] help with…communication skills [to interact with other residents]."

Conclusion

Social robots are an emerging relational AI technology whose copresent, physical embodiment and verbal and nonverbal social modalities have several advantages over other digital social networking mediums in engaging elderly users to attend to their social, emotional, and relational needs. Social robots can foster connection with those who are remote, assist access to useful information and digital services, and provide coaching support for managing chronic diseases and promoting healthy behaviors (Fasola and Matarić 2013; Kidd and Breazeal 2008; Rabbitt et al. 2015). By mediating social connections and activating interactions, they support companionship and engagement to decrease social isolation.

In developing social robots for aging, engineers and designers must collaborate with older adults as design partners to ensure that these users' desires, preferences, and boundaries are considered in the design of these robots. Long-term, real-world HRI studies are needed to enhance understanding of how people respond to robots in complex social settings and how robots affect social dynamics (Jung and Hinds 2018). Finally, care must be taken to design intelligent technologies that are part of human-AI teams to support and improve the ability of *all* stakeholders to work together to help people flourish at all stages.

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