Clinical Interventions in Aging

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REVIEW

Home-Based Cognitively Assistive Robots: Maximizing Cognitive Functioning and Maintaining Independence in Older Adults Without Dementia

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Abstract: Promoting health and prolonging independence in the home is a priority for older adults, caregivers, clinicians, and society at large. Rapidly developing robotics technology provides a platform for interventions, with the fields of physically and socially assistive robots expanding in recent years. However, less attention has been paid to using robots to enhance the cognitive health of older adults. The goal of this review is to synthesize the current literature on home-based cognitively assistive robots (CAR) in older adults without dementia and to provide suggestions to improve the quality of the scientific evidence in this subfield. First, we set the stage for CAR by: a) introducing the field of robotics to improve health, b) summarizing evidence emphasizing the importance of home-based interventions for older adults, c) reviewing literature on robot acceptability in older adults, d) highlighting important ethical issues in healthcare robotics, and e) reviewing current findings on socially assistive robots, with a focus on translating findings to the CAR context. With this foundation in place, we then review the literature on CAR, identifying gaps and limitations of current evidence, and proposing future directions for research. We conclude that CAR is promising and feasible and that there is a need for more methodologically rigorous evaluations of CAR to promote prolonged home-based independence in older adults.

Keywords: aging, cognitive status, healthy aging, autonomy, successful aging, technology

Plain Language Summary

Most older people prefer to remain healthy and active in their homes rather than moving into assisted living centers. Technology is being used to help with this goal and one example of this is robots in the homes of older adults to assist them with their cognitive functioning. This paper reviews research on robots to help older adults stay cognitively healthy in their homes. We discuss robots in general, the importance of placing robots in the home rather than in nursing homes, ethical issues, and robots to help people remain socially engaged and mentally active. Finally, we conclude that robots to improve cognitive functions is a promising area of research and we provide suggestions for scientists to continue to make headway in this area.

Introduction

In light of the aging population, one approach to enhancing quality of life in older adults capitalizes on ongoing developments in the field of healthcare technology to support independence in the home.[1,2] In particular, the subdiscipline of robotics is expanding and innovating at a rapid pace,[3] driven by advancements in hardware,

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artificial intelligence (AI), and internet connectivity.[4] However, empirical data on robots to promote healthy aging are still nascent,[5] and researchers from foundational disciplines (eg, engineering/robotics, psychology, geriatrics, biology) have only recently begun developing the requisite interprofessional collaborations.[6] Consequently, there is a great opportunity for scientific progress, and the movement to use robots to promote home-based health in older adults deserves our full attention.

One promising application of robotic interventions in older adults has occurred in the rapidly-expanding field of socially assistive robots (SAR),[7,8] where SAR represents the integration of assistive robots and socially intelligent robots leveraged to improve social health. However, despite the fact that cognitive skills such as language, memory, and executive functions are also integral to functional status and overall wellness,[9–11] less attention has been paid to using robots to enhance the cognitive health of older adults.[12,13] In order to delineate and then fuel this line of inquiry, we propose the construct of cognitively assistive robots (CAR) to refer to robots designed to support healthy cognitive functioning. Given the centrality of cognition to independence and quality of life in aging populations in particular, we aim to synthesize the available research pertaining to cognitive robotic interventions in older adults. Additionally, we emphasize robots specifically tailored to promote autonomy in the home, as this is a key objective of older adults themselves,[14,15] as well as secondary and tertiary stakeholders such as caregivers, physicians, and policymakers.[3,16] Consequently, we focus our conceptual review on older adults without dementia (ie, those who are cognitively healthy and/or those who have mild cognitive impairment [MCI]).[17] First, we set the stage with a brief discussion of older adults in home environments and then we transition to three core issues related to healthcare robots in older adults: a) acceptability, b) ethics, and c) efficacy/effectiveness of SAR in older adults. Finally, we review the available research in CAR and conclude with recommendations for future CAR investigations. Overall, we believe that the successful implementation of home-based CAR as we describe it could a) improve quality of life for older adults by allowing for prolonged independent aging in place, b) reduce demand on caregivers for older adults with cognitive decline, and c) attenuate healthcare costs by delaying institutionalization for as long as is safe and feasible.

In reviewing the literature in SAR and CAR, it became evident that the relevant studies are heterogeneous in terms of aims and scope of the publishing journal (eg, engineering/robotics, psychology, medicine), style of publication (eg, scientific article, conference proceeding, technical report), and type of data presented (eg, literature review, qualitative observation, single subject design, technical robot description, group-based quantitative evaluation). That is, the literature is scattered across disciplines, early data on CAR are embedded in papers on other topics (eg, SAR), and conventional search terms (eg, "cognitive robot") did not produce manuscripts on robotic interventions to improve cognition. Consequently, a systematic review and/or meta-analysis might omit important aspects of the literature (see, eg, Alnajjar et al)[13] and we believe that a conceptual review is the most appropriate method for presenting available research. In order to implement the review, we explored the SAR literature, with a focus on a wide array of search terms in multiple databases, as well as references from recent papers.

Home Environments

Most people prefer to age in place, remaining self-sufficient in their own homes rather than transitioning into assisted living facilities.[14] Aging in place is associated with better mental health and well-being,[18] as well as with lower healthcare costs.[16] Interventions to promote home-based autonomy can be as simple as hand rails in the shower and ramps leading into doorways,[19] although mild to moderate cognitive impairments would likely require more significant support. Older adults who do transition to assisted living environments frequently do so out of necessity rather than personal choice, often due to declines in cognitively mediated instrumental activities of daily living (IADLs) such as financial management.[15] Consequently, cognitive interventions to maintain independence in IADLs and allow older adults to age comfortably in place are highly desirable.[18]

Social robots offer a promising mode of service delivery for interventions targeting cognitive and functional abilities.[12,15,20] However, the majority of this research has been conducted in institutions such as skilled nursing facilities rather than older adults' homes,[12,21] likely because studies in home environments require more resources per participant.[22] Moreover, the significant differences in institutions compared to private homes have implications for the initial design of the robots, as well as for the eventual interpretation of research results;[15] consequently, studies conducted in institutional settings may not apply directly to home settings. Importantly, although the home-based older adult robotics literature is still growing, several publications on robots created for in-home care have provided early support. For example, Kidd and Breazeal[23] demonstrated success of a home-based robotic weight loss coach in 45 adults, Tsai et al[24] reported on the development of a telepresence robot designed to allow older adults to communicate easily with friends and family, and Orejana et al[20] showed that robots in the homes of four older adults reduced utilization of healthcare resources and enhanced quality of life. These studies provide preliminary evidence of feasibility in home environments and set the stage for more methodologically rigorous experimental work in the future.

Acceptability

Unfortunately, the idea of autonomous robots engenders fear and unease for many people, likely due in part to decades of media and science fiction portrayals of robots as malevolent entities.[25,26] Older adults in particular can be slow to adopt new technologies,[27] including robots,[28] and their reticence may be related to the concern that using an assistive device signals dependency and fragility.[29] Indeed, schemas related to helplessness and disability can become embedded in the morphology, functionality, and communication style of products, and robots that communicate ageist messages are likely to be met with resistance and/or rejection.[29–31] Consequently, we advocate for the rejection of a deficit model of aging in robot design, instead replacing it with evidence-based social models of aging, emphasizing appreciation of resilience and reserve over weakness and disability,[31] and likely enhancing the acceptance and ultimate success of robot-based interventions.

Although, on average, older adults are less apt to embrace new technology than are younger adults, a subset of older individuals are receptive toward and enjoy interacting with robots,[1,32] including in their homes.[33] Meanwhile, for those older people who are hesitant to adopt non-biased robots, real-world interactions can improve overall attitudes and interest in future use.[34,35] Moreover, we believe that embedding the creation of assistive robots into a well-supported engineering framework such as human-centered design[36] may further enhance acceptance. Finally, on a broader level, robot acceptability may increase over time, even in the absence of intervention, as newer cohorts of aging adults (eg, Generation X, Millennials) will have more life experience with computerized devices.[37]

When considering the design of acceptable robotic interventions in the near-term, existing literature provides several insights into the specific system characteristics that will be most appealing and effective in aging populations. First and foremost, older adults prefer devices that are easy to use and healthcare robots are more effective when designed in a simple, straightforward manner.[3,12,29,38] Second, robots should be personalized and adaptable.[3,6,28,29,39] No single physical shape or behavioral pattern will suit every user, and allowing for personalization and choice (eg, regarding color) is associated with more positive user experiences.[40] Third, regarding robot morphology, multiple investigators have reported that small size (eg, maximum height: 125cm in Broadbent et al;[29] maximum weight: 1.6kg in Hutson et al)[28] and moderately anthropomorphized features[41] are desirable to older adults. In contrast, large, fully humanoid robots are unappealing and tend to evoke a sense of unease, consistent with the "uncanny valley" hypothesis.[42] Fourth, with respect to personality, sociability (eg, initiating conversations spontaneously, exhibiting affect and humor) appears to engender positive reactions[28,43] and matching robot to user personality has received support as well.[44,45]

Ethical Issues

Above and beyond acceptability, there are important ethical concerns to examine prior to the implementation of healthcare robots such as SAR and CAR in older adult populations. Similar to other areas of rapid innovation (eg, gene editing),[46] scientific progress can quickly outpace philosophical deliberation, potentially leading to injustice and even outright harm to vulnerable groups such as older adults with cognitive impairments.[25] In the field of healthcare robots, there are a number of potential dilemmas to consider, including deception, feelings of objectification, a loss of personal freedom, feelings of emotional attachment to a robot, and the substitution of contact with robots for contact with people.[4,8,25,47] Additional ethical issues worthy of consideration include data privacy of the humans interacting with robots and liability from potential adverse events.[48,49] Although a detailed discussion of these issues is beyond the scope of the current review, researchers have begun responding to a number of these concerns; for example, Bogue[4] and Calo et al[47] highlight the fact that effective social robots are designed to promote human-human engagement rather than replacing it with human-machine contact. Additionally, a code of ethics for human-robot interactions has been proposed,[48] and a preliminary strategy to integrate ethics into robotics has been released.[50] Consequently, scientists and engineers have begun contemplating important ethical issues in healthcare robotics, and early recommendations can be used to approach CAR interventions in a responsible manner that avoids undue harm to older adult users.

SAR as a Model for CAR

Robots that can sense and synthesize social behavior have existed since the mid-20th century, but early systems were low in complexity due to limited computing power.[51] With advances in AI, current software can better model and respond to human behavior, thereby broadening the potential therapeutic scope of SAR. In terms of robot platforms, the landscape of social robots available for healthcare purposes continues to widen, and appearances can range from zoomorphic to anthropomorphic to mechanoid.[52] The current review will not detail available robot morphologies, as previous authors have addressed this issue extensively.[8,12,28] Instead, given that the available robots designed to address cognitive outcomes are currently embedded in the SAR literature, we will briefly review the state of the evidence on the impact of SAR on relevant outcomes in older adults.

Two systematic reviews of SAR for older adults in 86[22] and 13[53] investigations reported small, positive effects on engagement, interaction, medication use, and well-being, as well as reduced stress and loneliness. Moreover, many researchers make a conceptual distinction between companion-type and service-type SAR, where the former provide emotional support and the latter provide functional assistance.[31] Companion-type social robots are often described as similar to therapy animals, but without the need for food, water, or cleaning, and without the danger of allergic reactions or unpredictable behavior.[6,54] In contrast, service-type robots typically offer more practical assistance, which can be programmed with a high degree of adaptability and flexibility, and these features are integral when working with human partners.[38,51] One service-type robot that is particularly relevant to CAR is the behavior-change robot. This approach capitalizes on social influence to promote positive behavior change, as the robot can be viewed as a coach that helps to encourage and motivate users to work toward personal goals.[55] For example, three studies reported positive outcomes with respect to a) participants' preference for a robotic coach over alternative designs, b) enjoyment in interacting with the robotic coach, c) tracking of their own exercise behavior, and d) engagement in exercise.[23,55,56] Importantly, the behavior change platform is relevant in the context of evidence-based interventions designed to encourage the adoption of compensatory cognitive strategies[57,58] and other pro-cognitive behaviors such as aerobic exercise.[59]

CAR

Assistive robots are now recognized as a potential platform from which to launch cognitive assessments[60,61] and cognitive interventions[15] in older adults, with the latter ranging from prolonging functioning in people with dementia[32] to protecting cognition in healthy older adults.[12] Given the efficacy of cognitive training in older adults without dementia,[11] in contrast to impaired learning and retention of new information in people with dementia,[62] targeting independently-living, older adults without dementia may be a particularly efficient and effective approach. Specifically, we believe that CAR interventions will be capable of prolonging residence in the home and delaying the transition to an assisted living facility, without over-burdening caregivers. This emphasis is consistent with reports that older adults are interested in robotic assistance if it helps them maintain autonomy in home-based IADLs.[28,63]

Importantly, robots in particular, relative to virtual electronic devices, may be well positioned to provide cognitive assistance. An overt physical embodiment is integral to robots' overall effectiveness, and physically embodied platforms are both a) more preferred and enjoyable[64,65] and b) more effective in eliciting positive behavior change[56] than are intangible systems with comparable software. Additionally, robots' physical presence allows them to support many tasks that a virtual system cannot (eg, ambulation, reaching/grasping), which could be of use in the provision of assistance with IADLs.

Although there is currently no formal cognitive branch of healthcare robotics, insight may be gleaned from the limited CAR research embedded in the SAR literature. For example, Zafrani and Nimrod[5] argued that the SAR model can be utilized in assistive robots that are designed to affect outcomes other than interpersonal functioning. In this vein, while SAR is conceptualized as the integration of assistive robots and socially intelligent robots, we propose CAR as the synthesis of a) assistive robots, b) socially intelligent robots, and c) cognitive interventions.[66,67] CAR platforms could be designed to provide both compensatory cognitive training interventions[57,58,68,69] and restorative drill-and-practice interventions,[70,71] with the ultimate goal of maintaining independence in IADLs. Cognitive "prosthetics" (eg, a robot-delivered reminding system) could also be used to scaffold cognitive and instrumental tasks that would otherwise require assistance from a caregiver.[66] Moreover, although we are not aware of current research on the topic, CAR are theoretically well equipped to attenuate cognitive load, which can interfere with both intellectual and motor tasks. In this way, CAR is built upon and closely related to SAR, but with a distinct end goal (ie, improving cognition rather than increasing/enhancing social interaction).

CAR Interventions

Although formal cognitive training is uncommon in the robotics literature (but see Tsiakas et al[72]), there is broad interest in providing direct IADL assistance, often in the form of reminders to complete daily living tasks. For example, medication reminding systems have been used to address older adults' reported desire to receive robotic assistance with medication management.[29,33] One such system is Pearl, a home-based healthcare robot with software capable of storing a person's schedule and assisting with medication management.[67] Additionally, the robots Cafero and iRobiQ were specifically designed to target quality of life in older adults and include appointment and medication reminders.[34] At present, these robots are not commercially available, but they represent potential prototypes to inform future engineering projects. Finally, the European Union's ENabling Robot and assisted living environment for Independent Care and Health Monitoring of the Elderly (ENRICHME) project is designed to enhance autonomy in people with MCI by improving exercise, interpersonal engagement, and medication management.[4] In terms of direct empirical support, Pu et al[53] reported results from a conceptual review of the literature suggesting that robotic interventions can indeed improve medication adherence in older adults.

In addition to medication management, robots also have the potential to positively impact spatial navigation,[73] calendar organization,[12] and communication with friends and family.[34,74] Researchers have even reported on "memory games,"[20,30] often delivered via music.[75] For example, Tapus et al[64] described the task "Song Discovery" in a robotic test-bed platform. The game entails locating and pressing a button representing a song played over the speakers. In a subsequent paper, the authors presented the music game to ten people with dementia.[76] No inferential statistics were reported, but, based on a visual examination of individual-level data, improvements occurred in reaction times and error rates as a result of extended practice.

CAR Systems

Central to the success of CAR is the delivery method. There are several examples of robot platforms through which cognitive interventions could be implemented. For example, a range of non-mobile, tabletop robots provide activities such as conversational support, cognitive games, and positive social affect (eg, Companionbot).[32] Other platforms, such as the Scitos G3, are embedded within a smart home environment, and are designed for videoconferencing, schedule management, centralized control of smart appliances and utilities, and transmission of health data to appropriate professionals.[77] Scitos G3 tracks users' movements in the home and can approach them in order to initiate conversations; it also provides greetings and farewells when they enter or leave the home and suggests health behaviors (eg, exercising, nutritious snacks) when appropriate. Such technological advances provide the foundation from which cognitive interventions could be successfully delivered, but the current science is years behind the technology and the literature in robotic cognitive interventions is plagued by three major methodological limitations. First, the cognitive interventions that have been deployed are not evidence-based and, consequently, we cannot be confident that there will be positive therapeutic effects. Second, study designs are non-experimental with small sample sizes, thereby limiting causal inference. Third, most dependent variables are not standardized, psychometrically sound, or objective, thereby limiting interpretation of cognitive and functional improvements. Overall, similar to the Rabbitt et al[8] conclusion about the SAR literature, the current evidence for CAR is nascent. Importantly, while it is possible to program a cognitive intervention into an interactive robot, we do not yet know if the intervention effects are actually reliable and valid.[3] In Table 1, we highlight the six most promising CAR studies to date based on the quality of a) the robot hardware and software, b) the research methodology, and c) the cognitive intervention.[74,78–82]

Future Directions

Although the healthcare robotics literature is exciting and promising, much work remains to be done. Based on the evidence reviewed above, we present seven recommendations for future CAR researchers in order to propel the field toward the ultimate goal of widespread, real-world implementation of robotic interventions to improve cognition. First, conduct investigations in the real-world environment of independently-living older adults – ie, their homes (see, e.g., Schroeter et al[77]). This may include simulated lab-based home environments initially, in order to enhance internal validity and reduce cost.[83] Second, maintain and

Table 1 Promising CAR Studies

Authors	Robot	Robot Hardware/Software	Research Design	Cognitive Intervention	Outcomes/Results	Strengths/Limitations
Tanaka et al, 2012[74]	Kabochan Nodding Communication ROBOT	Both robots: 28cm and 680g. Communication robot: Morphology and communication resemble a 3-year-old boy. Included affective behavior and interacted by talking and nodding. Control robot: same morphology but did not communicate.	Randomized controlled trial: 34 healthy, independently-living older adult Japanese women were randomized to reside with either a communication robot (n = 18) or a control robot (n = 16) for 8 weeks. Assessments conducted at baseline, 4 weeks, and 8 weeks.	Daily communications with the robot.	Cognitive: Paper-pencil screening instrument and brief computer-based measure of attention, naming, verbal abstraction, judgment, comprehension, repetition, visuoconstruction, verbal memory, calculation, and orientation. Self-report: Standardized, validated measures of activities of daily living, depression, sleep, and appetite. Physiological: Cortisol and autonomic activation. Results: Sleep improved, cortisol decreased, and overall cognition, judgment, and verbal memory improved in the intervention but not the control group.	Strengths: Medium-sized sample; use of an experimental design and a control group; neuropsychological outcome measures; significant cognitive results. Limitations: Did not report on details of the intervention (e.g., number/type of daily communications in the experimental group); generalizability limited to women.
Anh et al, 2014[84]	iRobiS	45x32x32cm, 7kg. Intel Atom processor-based internal computer. Includes two arms, physical touch sensors, and a 7in touch screen.	Non-experimental design: 10 independently living older adults in New Zealand. Participants completed four brain training games based on paper-based exercises developed by a psychologist and a teacher.	Four brain training exercises developed for the current study. Cognitive domains targeted: working memory, verbal memory, non-verbal memory, short-term memory, face recognition, and prospective memory.	Self-report usability questionnaire: The tasks were reported to be high in usability, interest, and enjoyment and low in consistency across tasks. Task completion: Tasks were "passed" (sufficient performance to complete a level) at different rates, with one task being deemed too difficult.	Strengths: Focused on computer-based cognitive training; recruited independently-living older adults; usability, interest, and enjoyment of the treatment were high. Limitations: Small, unrepresentative sample; non-experimental design with no control group, no theory-based or empirically-based cognitive intervention, no standardized, validated neuropsychological outcomes.

Broadbent et al, 2014[79]	1. iRobiQ 2. Cafero	iRobiQ: 45x32x32cm, 7kg. Includes 7in touch screen, microphone, camera, speakers, and a face. Head, arms, and base move. Includes medication management software. Cafero: 4ft tall. Includes touchscreen, microphone, camera, speakers, and Skype calling. Also includes Dakim Brain Fitness software and calendar reminders.	Repeated measures randomized controlled cross-over trial: 29 older adults in a retirement village in New Zealand. Participants used robots in their apartments for 6 weeks and experienced a 6-week non-robot control in a randomized order. Assessments conducted at baseline, 6 weeks, and 12 weeks.	Both robots took blood pressure and pulse oximetry and produced music. iRobiQ assistant with medication adherence. Cafero provided cognitive training via Dakim Brain Fitness (http://www.dakim.com/), electronic calendar reminders, and allowed for Skype calls.	Outcome measures: Acceptability and feasibility of the robots assessed via unstructured interviews, questionnaires, and diaries. Health-related quality of life, depression, and medication adherence assessed via standardized, empirically-supported measures. Results: Reactions to the robots were mixed. No significant differences reported in quality of life, depression, or medication adherence.	Strengths: In-home design; experimental methodology; multicomponent intervention; standardized, empirically-supported outcome measures. Limitations: Small sample size; used two different robots with different capabilities; no neuropsychological outcome measures; no measurable impact of the intervention.
Kim et al, 2015[80]	1. Silbot 2. Mero	No details provided.	Randomized controlled trial: 85 healthy older adults in South Korea randomized to cognitive training (n = 48; traditional cognitive training = 24, robot cognitive training = 24) or no training (n = 37). Training consisted of 90-minute sessions once per day, five days a week, for twelve weeks total (60 sessions). Assessments conducted at baseline and post-intervention.	All participants completed 10 hours of dementia education. Both cognitive intervention groups underwent 2 training blocks targeting five domains: memory, language, calculation, visuospatial function, and executive functions. Two psychometricians assisted both groups. The cognitive intervention was designed by internally-based neurologists, neuropsychologists, and speech-language pathologists.	Magnetic resonance imaging: Changes in cortical thickness and structural brain networks. Neuropsychological measures: Standardized, validated neuropsychological measures of overall cognition, visual memory, working memory, executive functions, and attention. Results: Relative to the control group, both cognitive training groups showed less cortical thinning in frontotemporal association cortices. Relative to the traditional training group, the robot group showed less cortical thinning in the anterior cingulate cortex. The training group improved more on executive functions than the control group. General cognitive ability and visual memory improved more in the traditional training group than the robot training group.	Strengths: Large sample size; use of an experimental design and a control group; high dose of the cognitive intervention; standardized neuropsychological outcomes. Limitations: Robot hardware/software not detailed; no in-home measurement; no empirical support provided for the cognitive intervention used; no results supporting the utility of the robot in cognitive training.

(*Continued*)

Table 1 (Continued).

Authors	Robot	Robot Hardware/Software	Research Design	Cognitive Intervention	Outcomes/Results	Strengths/Limitations
Otake-Matsuura et al, 2019[81]	Bono	A "chair-robot" adept at time management and turn-taking moderation based on analysis of speech patterns. Capabilities facilitating a moderator role include head pitching, body rotation, left/right arm elevations, and audio prompting.	Randomized controlled trial: 65 community-living, non-demented Japanese older adults were randomized to either receive the Photo-Integrated Conversation (PICMOR) intervention delivered by the robot (n = 32) or an unstructured group conversation (n = 33) for 12 weeks. Conversations took place in groups of 4–5 participants for 60 minutes. Outcome assessments were conducted at baseline and immediately post-intervention.	The PICMOR intervention targeted preparation of conversation topics (e.g., "Favorite Food"), time management, turn-taking in conversations, and reflection on the topics using a group conversation support method (Coimagination) and a moderator robot. PICMOR included preparation, conversation, and reflection. The robot managed turn-taking by moderating the amount of time each participant spent speaking.	Neuropsychological measures: Standardized, valid neuropsychological measures of global cognition, attention, processing speed, language, and executive functions. Self-report: Physical and mental health status and quality of life. Process outcome measures: Conversational speech characteristics and memory for conversation topics. Results: Verbal fluency, improved in the intervention compared to the control group. Diversity of conversational speech was greater in the intervention compared to the control group.	Strengths: Medium-sized sample; use of an experimental design and a control group; multiple neuropsychological and linguistic outcome measures; significant cognitive and conversational results. Limitations: No follow-up outcome assessment; infrequent (1/week) study sessions; a lack of a non-conversation control condition; and a lack of a structured, moderated, non-robot control condition (so it is unclear whether structure or the robot explain group differences).
Sawami et al, 2019[82]	Conversation and dance-therapy robots (no name provided)	Communication robots that primarily intervened through conversation and cognitive dance therapy. No other details provided.	Pre-post, single-group design: 71 older adult non-demented Japanese participants completed 90 minutes of cognitive dance therapy once per week for 7 weeks. Outcome assessments were conducted at baseline and immediately post-intervention.	Participants attempted to learn ten words, practiced a choreography routine, recalled the ten words, recreated the choreography routine, danced and sang simultaneously, and then recalled song lyrics. Participants were able to support each other while completing the memory tasks.	Neuropsychological measures: Cognitive evaluation scale for National Police Agency of driver's licenses (orientation, visuoconstruction, memory). Self-report: Four items measuring comfort, satisfaction, stress, and vitality. Results: Objective cognitive performance significantly improved after cognitive dance therapy. There was also significant improvement in self-reported mood, satisfaction, and vitality. A correlation was found between cognitive functioning and mental state.	Strengths: Medium-sized sample; significant pre-post improvements in cognitive and self-report measures. Limitations: Non-experimental design with no control group; brief intervention; lack of standardized, validated, objective neuropsychological outcome measures; brief overall outcome assessment, no follow-up evaluation.

advance interdisciplinary research teams, including technical (engineering) and scientific (psychology, neuropsychology, geriatrics) collaborators. Third, closely adhere to ethical guidelines.[48,50] Fourth, prioritize models of social aging over a deficit model of aging[31] in design and implementation. Fifth, select a set of evidence-based robotic platforms and move forward with rigorous scientific investigation of each platform rather than introducing new robotic systems into the current market. Sixth, and relatedly, select a robot with the following evidence-based features for further investigation: a) ease of use, b) personalization and adaptability, c) small in size and moderately anthropomorphized features, and d) sociability and ability to be matched to users' personalities. Seventh, address methodological limitations from the SAR/CAR literature; that is, studies would benefit from a) a theoretical basis, b) recruitment of large samples, c) inclusion of evidence-based cognitive interventions, d) experimental designs with appropriate control groups, and e) administration of standardized, psychometrically-sound, objective neuropsychological and functional tests as dependent variables.

Consequently, we provide a broad framework for future researchers to use in ongoing investigations into CAR. However, the current review is limited by a dearth of literature on the topic, and so our recommendations remain broad. As the field progresses, we encourage future researchers to turn their attention to important nuanced topics such as the ideal method for CAR delivery in the home, the degree of technical assistance required by older adults for a successful intervention, the extent to which home-based robots benefit from augmentation by human therapists, and the initial costs and later healthcare savings associated with these interventions.

Conclusion

Aging populations across the globe are in need of creative, innovative treatments in order to support health and wellness in the later stages of life. There is a small but growing literature focused on healthcare robots stationed in the homes of older adults to promote wellness and independence. We propose that more resources be allocated to robots to improve cognitive health, as this is an area where there is a) potential for great benefit to older adults and to society, and b) little methodologically rigorous research. Ultimately, by capitalizing on interdisciplinary knowledge and skill, we are confident that CAR researchers will be equipped to produce high-quality scientific evidence that will support and enhance the aging process, leading to happier, healthier, more autonomous older adults all over the world.

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