Social Robots for the Care of Persons with Dementia: A Systematic Review

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Intelligent assistive robots can enhance the quality of life of people with dementia and their caregivers. They can increase the independence of older adults, reduce tensions between a person with dementia and their caregiver, and increase social engagement. This article provides a review of assistive robots designed for and evaluated by persons with dementia. Assistive robots that only increased mobility or brain-computer interfaces were excluded. Google Scholar, IEEE Digital Library, PubMed, and ACM Digital Library were searched. A final set of 53 articles covering research in 16 different countries are reviewed. Assistive robots are categorized into five different applications and evaluated for their effectiveness, as well as the robots' social and emotional capabilities. Our findings show that robots used in the context of therapy or for increasing engagement received the most attention in the literature, whereas the robots that assist by providing health guidance or help with an activity of daily living received relatively limited attention. PARO was the most commonly used robot in dementia care studies. The effectiveness of each assistive robot and the outcome of the studies are discussed, and particularly, the social/emotional capabilities of each assistive robot are summarized. Gaps in the research literature are identified and we provide directions for future work.

CCS Concepts: • **General and reference** → **Surveys and overviews**; • **Human-centered computing** → **User studies**; • **Computing methodologies** → Cognitive robotics;

Additional Key Words and Phrases: Social robots, assistive robot, dementia, emotions, quality of life

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1 INTRODUCTION

According to **World Health Organization (WHO)**, around 50 million people are currently living with dementia, and about 10 million new cases are diagnosed every year [79]. The number of people with dementia is predicted to reach 82 million in 2030 and 152 million in 2050. Dementia is reported to be the major cause of disability and dependency among older adults and can affect families emotionally, socially, and financially [79]. The health care and out-of-pocket caregiver costs were estimated to be US\$ 818 billion in 2015 [79]. **Intelligent Assistive Technologies (IATs;** i.e., “*devices that incorporate context into their decision-making process, which enables them to provide customised and dynamic assistance in an appropriate manner*” [18, p. 271]) that support people with dementia and their caregivers can significantly reduce these costs, improve independence of people with dementia, and improve quality of lives.

IATs can also act as companions and reduce loneliness, which has been reported as an issue by many people with dementia [48]. One category of the IAT is assistive robots (i.e., *robot “that gives aid or support to a human user”* [38, p. 465]), which have the potential to provide a highly flexible and portable platform on which to implement assistive services. Assistive robots might have the advantage of a physical presence that cannot be found in other types of IATs and could be an effective platform for implementing an assistive technology. Assistive robots have been shown to be beneficial in many application areas (e.g., [14, 98]) and have been shown to have a positive impact on many age-related challenges (e.g., physical, cognitive, emotional, and social challenges [94, 110]) that affect one’s independence and quality of life [64], for example, by reducing depression [30]. Due to multiple benefits and the flexibility of a robotic platform, this article focuses on evaluation of social robots (i.e., robots that “*are designed to interact with people in a natural, interpersonal manner*” [20, p. 1935]) specifically for the care of people with dementia.

Previous review articles have addressed different aspects of assistive technologies (i.e., “*the technologies or applications (hardware or software) that are specifically developed to assist individuals with disabilities in overcoming barriers*” [7, p. 41]) that support older adults and have identified many challenges and gaps in the literature. A recent review by Hung et al. [43] identified benefits and barriers of using one of the social robots, PARO, for the care of older adults to inform how PARO (or a similar social robot) could be effectively adopted in clinical settings. While focusing on dementia care and social robots, the article only studied one of the existing social robots, i.e., PARO. Abdi et al. [2] reviewed the literature on the use of socially assistive robots for the care of older adults and suggested that some of the existing studies might have methodological issues and limitations. This review was a scoping review with a general focus on the use of social robots for the care of older adults (including 33 articles presenting user studies with healthy older adults, as well as those with dementia). Furthermore, Leng et al. [56] reviewed the effectiveness of pet robot intervention for people with dementia and concluded that pet robot intervention could be a suitable and useful tool in clinical practice, but did not find significant improvements in cognitive function and quality of life of people with dementia. While being focused on dementia care, the review also only focused on a subset of the existing social robots, i.e., the pet robots. In another review by Whelan et al. [112], factors affecting the acceptability of social robots were investigated in older adults (including people with dementia). The article reviewed literature that studied acceptability issues related to social robots, and while including dementia care, focused on a more general audience (i.e., older adults). They concluded that acceptance was affected by multiple factors related to individuals, their significant others, or even society. The review proposed that human-like communication can improve acceptance of the robots and raised issues related to trust and control of the robot [112].

A different category of assistive technologies that received attention in previous reviews concerned electronic assistive technologies that support living environments of people with dementia.

Daly et al. [32] categorized electronic assistive technologies into six types: tele-care, light therapy, robotic companion, well-being and leisure, simulated presence, and to support orientation and **Activities of Daily Living (ADLs)**. They reported a variety of technical interventions and methods used to evaluate different technologies and found a lack of evidence for finding a technology intervention that might be most effective. The review studied a variety of different electronic assistive technologies, with a focus on the methodologies used, and did not focus on social robots or social capabilities of the technologies.

Another review of the existing assistive technologies for people with dementia by Asghar et al. [10] in 2015 concluded that the focus of the industry is mostly on health monitoring and software-based assistive technologies, and proposed that the communication and software-based assistive technologies need more attention. The review also targeted a larger range of technologies (assistive technologies), and their function (e.g., rehabilitation, mobility, etc.), and did not focus on social robots or the social capabilities of the technologies.

Tele-presence robots, which can be considered as a type of assistive robot (e.g., see [17]), were reviewed by Moyle et al. [69]. The review pointed out the potential benefits of telepresence robots for enhancing social connections in persons with dementia and concluded that more systematic feasibility testing studies were required that develop and assess the efficacy of telepresence robots for dementia care. In another review [15], the effectiveness of socially assistive robots was evaluated for the care of older adults. Four robots and 17 studies were reviewed and it was concluded that most studies reported positive effects of the robots, but future work was needed to study the effectiveness of the results. While focusing on persons with dementia, this article also included a subset of social (and non-social) robots, i.e., tele-presence robots.

Furthermore, Kachouie et al. [47] provided a review of socially assistive robots for the care of older adults and proposed that there was a need for understanding caregivers' expectations, multimodal interaction, and developing person-centered care. Robot therapy was another area that received attention in the reviews. While focusing on socially assistive robots, the article focused on a more general audience, i.e., older adults. Also, due to many advancements in developing social robots, many new studies have focused on socially assistive robots since 2014 (see Figure 2). In another article, Shibata and Wada [102] reviewed robot therapy for improving mental health of older adults and provided a brief review of its effects on people with dementia (focusing only on applications related to mental health and a more general audience, i.e., older adults). Further, Mordoch et al. [68] reviewed 21 studies on the use of social commitment robots in dementia care and concluded that there were few randomized clinical studies that evaluated the efficacy of robots (covering a subset of articles reviewed here, and the review did not address the social capabilities of the robots or other aspects other than the methodology of each article).

The above-mentioned reviews provide valuable information about the use of different types of intelligent technologies for the care of older adults, their effectiveness, and existing challenges. Some of them focused on dementia care and specific types of robots (e.g., pet robots and teleoperated robots) used in that context. The current review adds to the existing work by evaluating a larger range of studies and assistive robots with a focus on applications for dementia care. Unlike previous reviews, this article reviews literature focused solely on *assistive robots for dementia care*. Although many of the results related to the studies on older adults' care could be applied to dementia care, we believe that a focused review on dementia care would help better identify additional challenges associated with developing assistive robots for this specific group of users. Further, this review identifies the most recent work,¹ not covered in the previous reviews, and reviews all existing assistive robots, not limited to any particular application or type of robot. The

¹ Articles published up to September 2019 when this review was conducted.

purpose of this literature review is to identify (1) the tasks for which the assistive robots are developed to help persons with dementia, (2) the level of success for each task/robot, (3) the appearance and social/emotional capabilities of the existing assistive robots, and (4) directions for future work with the goal of developing new assistive robots or improving existing robots in a way that they can effectively assist persons with dementia and their caregivers.

In the following, we will first explain our methodology and decision criteria, and will then present the outcome of the review. We will conclude by discussing the results and proposing directions for future work.

2 METHODOLOGY

2.1 Terminology

In this review, we define a *social robot* as a robot that possesses social skills and is designed to interact with people in human-centric terms and to operate in human environments alongside people [33]. Social robots engage people in an interpersonal manner, communicating and coordinating their behavior with humans through verbal, nonverbal, or affective modalities [21]. Our criteria for considering a technology/machine a *robot* was (1) to have an embodiment and be physically present and (2) to be able to move and act upon its environment (even if the movement is very limited, cf. PARO [113]). We call a robot *intelligent* if it can take actions in a meaningful manner and make choices based on the interactions in its environment (i.e., information it gathers through its sensors) [8].² Finally, we call the robots in this review *assistive robots* as they are all designed for dementia care and to assist a person with dementia.

2.2 Scope of the Review and Inclusion/Exclusion Criteria

We reviewed articles that evaluated an assistive robot for the care of people with any type of dementia (e.g., Alzheimer's Disease). This comprises a review of different applications where the robots have been used in, as well as the identification of the robots' social and emotional capabilities. We have employed multiple inclusion and exclusion criteria as below:

Inclusion criteria: Articles that evaluated an assistive robot for the care of people with any type of dementia (e.g., Alzheimer's Disease). The proposed assistive robots should have been used for an application related to dementia care and tested by actual participants. We also included articles that proposed an initial evaluation of a robot designed for dementia care with a group of participants, who did not necessarily have dementia (e.g., the studies could have involved healthy older adults). All articles identified through our search queries and data collection approach (which is explained in the next section) were included, *unless* they were excluded as a result of meeting our exclusion criteria as below.

Exclusion criteria: The following articles were excluded:

- Articles that proposed an assistive robot but did not use it in a study
- Articles that used an assistive robot for older adults, but the robot was not specifically targeting **Persons with Dementia (PwDs)**
- Articles focusing on evaluating general robot architectures
- Articles proposing new robots without a user study
- Articles on robots that were solely designed to assist by increasing mobility (e.g., limb movement) and **Brain-Computer Interfaces (BCIs)**
- Articles written in any language other than English

²Note that robots are not limited to being assistive, social, or intelligent.

- Articles with results that have been completely covered in another related article by the same authors. This includes conference papers that were later expanded into journal articles. In these cases, we only included the journal article. Note that if the conference paper had any additional information that was not covered in the journal article, it was included in the review.

2.3 Data Search

Our search originally identified 164 publications with relevant titles. Google Scholar, ACM Digital Library, IEEE digital library, as well as PubMed databases and archives, were included in the search and a *snowballing* approach (looking for related articles that were cited in the identified articles and those that have cited them later on) was used to detect additional articles that would fit in our inclusion criteria. The keywords and phrases used in the search were “Assistive Robot,” “Social Robot,” “socially assistive robot,” and “Emotional Robot” used along with either “Dementia” or “Alzheimer” (i.e., “assistive robot | social Robot | socially assistive robot | Emotional Robot”+“dementia | Alzheimer”).

Data was gathered in September 2019.³ No exclusion was applied according to the date of publication. In total 110 articles on Google Scholar, 24 on IEEE digital library, 25 on PubMed, and 5 on ACM Digital Library (a total of 164) were identified. Mendeley was then used to detect duplicate articles. After removing the duplicates, 130 publications remained.

These remaining 130 articles were then checked manually. Two articles were removed for being in a language other than English. Seven were removed for presenting results that were similar to another article reviewed here (e.g., a conference article that was later expanded into a journal article). One article was removed for being focused on co-design and not mentioning the number of participants or who they were. Sixty-seven others were removed as they did not meet the inclusion/exclusion criteria. Note, 16 of the 67 were review articles, which were already discussed in the introduction and discussion sections of this article. Most of the others did not meet the inclusion/exclusion criteria because they did not present a study that actually evaluated a robot with participants.

A total of 53 articles were identified at the end, which met inclusion and exclusion criteria, published between 2002 and 2019, and included studies from 16 countries: Australia, Austria, Canada, China, Denmark, France, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Poland, Spain, United Kingdom, and the United States. Figure 1 summarizes the data collection process.

2.4 Categorization

The articles were categorized based on (1) the assistive robot’s application, (2) the type of the robot used in the study, (3) the robot’s social and emotional capabilities, (4) the robot’s function, (5) participants, (6) year of the study, and (7) results of the study. A more precise description of each category is given below.

Application: This category indicates the context for which the robot was designed. After consideration of existing literature and different applications, we decided on five main classes as below:

- ADLs: this class represents any robot that helps a PwD in completing an ADL, for example, washing hands or preparing tea.
- Companion: this class represents robots that are designed to be companions for PwDs, for example, by reminding them about tasks or medications, or by showing PwDs their favorite pictures, music, or videos.

³Data was gathered by one of the authors. All articles were checked carefully to ensure that inclusion and exclusion criteria were met.

Fig. 1. Diagram of the data collection process, conducted according to the PRISMA guidelines [67].

- **Engagement:** this class represents robots that are developed to increase engagement of PwDs with others, including family members, other residents at **Long-Term Care (LTC)** facilities, caregivers, or therapists.
- **Health Guidance:** this class represents robots that provide PwDs with information about healthy living styles, for example, by providing guidance about diet.
- **Initial Evaluation or Observation:** this class represents studies that have conducted a general, initial observation/evaluation of an assistive robot for PwDs, for example, articles evaluating PwDs' general attitude toward a specific robot.
- **Therapy:** this class represents robots used in the context of therapy for PwDs. It can range from assisting a therapist to providing music or pet therapy.

We decided on these categories after an initial scoping review of the identified articles. We used the same keywords that were used by the authors of those articles regarding the classification of the application areas. The articles were also checked in more detail to ensure that the mentioned application areas in the list of keywords or in the abstract accurately reflected the research done. This scoping review resulted in the above-mentioned categories, which overlap with the categories recognized in a review of the existing electronic assistive technologies (a scope wider than what is investigated in this article) by Daly et al. [32].

Social and emotional capabilities: this category contains information about the social and emotional capabilities of the robot in each study, for example, whether the robot showed specific emotions or understood PwDs' emotions (through facial expression recognition).

Function: this category provides more information about the function of a robot. For example, it could be "helping with washing hands," where the application is ADLs.

Fig. 2. Number of articles identified per year. Note that the search only includes articles published before mid-September 2019 and thus does not include all 2019 publications.

Fig. 3. Number of articles identified for each application.

Participants: this category contains information about the participant groups, location of the study, and duration of the study (if indicated).

Robot, year of the study, and results: these categories contain information about the robot used in the study, the year of the study, and a brief summary of the outcome of the study.

3 RESULTS

The number of articles identified per year and per application is shown in Figures 2 and 3, respectively. Table 1 provides a summary of all the reviewed articles. Table 2 shows the findings for each robot and summarizes robots' capabilities in general and the applications that each robot has been used in. Table 3 summarizes the number of articles on each robot based on each application. In the following, we will further discuss the success of each application, function, and robot, as well as the emotional and social capabilities of the robots.

3.1 Applications and Success

In this section we will first provide a general overview of the results and then discuss specific results based on the application areas.

As shown in Figure 3 and Table 1, assistive robots have been mostly studied in the therapeutic contexts or for increasing PwDs' engagement, whereas health guidance and ADL applications have received relatively limited attention. Also, while a range of different robots with different functionalities and appearances (e.g., human-like, animal-like, non-holonomic) were used across the reviewed studies, PARO was the most commonly used: it was included in 19 studies and in four different applications (see Table 3).

Most of the studies have emphasized the positive effects of assistive robots on PwDs and caregivers. In therapeutic contexts, the robots were shown to be successful in reducing many symptoms of dementia, such as agitation [46], anxiety [54], depression [46, 101], and night-time behavior disturbance [106]. Assistive robots also improved PwDs' task performance and cognitive attention [105], mood [108, 109], physical activity [41], and social engagement [31, 41, 74]. Further,

Table 1. Summary of the Reviewed Articles, Categorized Based on Application and Ordered by Date

Application	Robot	lit.	Emotion/Social	Function	Participants	Year	Results
Activity of Daily Living (ADL)							
ADL	Brian	[35]	Understands users' affective state (angry, happy, disturbed)	Meal-time assistant. Provides prompts.	6 healthy adults	2012	High recognition and success rates in prompting users to eat and in understanding their activities and affective states
		[66]	provides encouragement		8 PwDs living in nursing home/supported living (5 female, 3 male, 82–93 yrs). Mild to no cognitive impairment. 2 lunch-time meals.	2013	High recognition rates for utensil tracking, and main dish and beverage tracking. Successfully engaged participants. Participants had positive attitudes towards the robot and liked its human-like voice.
ADL	Ed	[111]	NM (teleoperated)	Teleoperated. Helps with washing hands in the bathroom and making a cup of tea in the kitchen	10 PwDs (mild to moderate; 59–88 yrs) and their family caregivers (36–78 yrs).	2017	Provided evidence that social robots are practical and have social benefits: they care for PwDs and help caregivers. Some older adults responded positively to the robot. Neither showed immediate desire to use one and did not perceive a need for it. Caregivers were more accepting and suggested more ADLs. Differences in the views of older adults with mild-to-moderate AD and their caregivers emphasized the necessity to understand PwDs' needs, preferences, and living situations to design a robot in context of ADLs. One PwD expressed concern about an assistive robot decreasing social contact or leading to neglect by family. Others saw it as a potential to function as a social companion.
ADL	RAMCIP	[6]	Capable of showing facial expressions	Co-design of the robot for help with ADLs (e.g., medicine). Outcome was not evaluated.	82 participants (20 MCI)	2019	Facial expressions and speech were co-designed with participants (neutral/calm, excited, sad, tired, sleeping, and focused)

(Continued)

Table 1. Continued

Application	Robot	lit.	Emotion/Social	Function	Participants	Year	Results
Health Guidance							
Health	Matilda	[49]	Recognizes emotion changes and adapts persuasive dialogues based on users' emotional state	Provides healthy living advice (diet)	34 residents (28 female, 6 male) with different medical conditions including PwDs. 3 nursing homes.	2012	Evaluations suggested that the robot could be effective for improving the quality of care of older adults.
Companion							
Companion	AIBO	[78]	Wagging tail and moving head and mouth to show feeling of "happiness"	NA. Observation study	24 older adults with cognitive deficits (avg. 76.6 yrs: 12 male, 12 female; MMSE>23)	2007	Good acceptability, especially in those with a good relationship with technology. AIBO was generally perceived harmless and friendly.
Companion	PARO	[58]	Pet-type reactions	Pet companion	30 PwD (67–98 yrs, 64% female) and caregivers (30–86 yrs, 96% female). 30-min group sessions in 2 dementia day-care centers 2–3 times a week for 6 weeks, and participants' homes for 6 weeks.	2017	Significantly improved facial expressions and interactions with staff at day-care center. Reduced anxiety and enhanced mood at home. PwDs with less cognitive impairment responded better to PARO
Companion	Ryan	[3]	Understands users' facial expression and spoken language. Shows facial expressions.	Engaged in social activities (e.g., playing games, conversations, showing family photo albums, etc.), reminded older adults about daily schedule)	6 older adults with moderate dementia/depression living in senior living facility	2017	Improved QoL by increasing engagement in activities. Improved level of depression.

(Continued)

Table 1. Continued

Application	Robot	lit.	Emotion/Social	Function	Participants	Year	Results
		[36]	Engages PwDs in conversation about specific photo contents leading to discussion of events	Engages PwDs in conversations with the help of multiple apps on robot's screen, such as music, myReminiscence, my	38 PwDs (14 M, 24 F), ages 55–93 yr.	2019	Improved participants' resilience score (significant). Improvements observed in their mood and focus. Improved QoL and decreased depression (not statistically significant). Some participants faced difficulty interacting with a touchscreen.
Companion	MARIO	[60]	that can bring back happy memories	calendar, game, news.	7 PwDs (4 female & 3 male, moderate to severe dementia) were observed.	2019	Four researchers (in engineering, nursing, and psychology) observed interactions with the robot. Music was reported as a key feature. Robot's physical & functional features facilitated its use. Younger family members' interactions with MARIO increased PwDs' engagement. Ability to use MARIO was influenced by severity of dementia and prior technology experience.
Engagement							
Engagement	PARO	[107]	Generated proactive behavior according to its internal state and desire	Pet robot to increase engagement between residents	12 participants, 67–89 yrs, 1 male. Healthy subjects and PwDs capable of taking care of self. 2 months (over 9 hours daily at a care center)	2007	PARO increased strong ties with other participants over 2 months for those who shaped strong or moderate tie with it. One participant complained about speech ability of PARO and changed interactions with it afterwards.
Engagement	Brian	[23]	Emotional (happy, neutral, and sad) and social (task assistance, encouragement, reinforcement, and celebration)	Engages PwDs in the cognitively stimulating card game of memory	6 healthy adult participants (23 to 40)	2010	Improved social interactions. Social interactions improved engagement.
		[24]			6 participants (21 to 35)	2011	Could reduce task-induced stress
		[26]			2 experiments, 10 healthy adults each (21 to 40)	2011	Participants worked on the control architecture of the robot to decide on assistive behavior: provide assistance, encouragement, and celebration.
		[25]	Emotions: Excited pleased, neutral stressed		10 participant (20–35)	2012	

(Continued)

Table 1. Continued

Application	Robot	lit.	Emotion/Social	Function	Participants	Year	Results
Engagement	Matilda	[49]	Gestures (nod) and expressions. User's body posture, visual and voice interaction, and facial expressions were used to control the pace of interaction	Engaging in card games	34 residents (28 female, 6 male) with different medical conditions including PwDs. 3 nursing homes.	2012	Enabled caregiver to personalize care. Robot could increase older adults' engagement in the activities.
Engagement and ADL	Brian	[65]	Robot changed assistive behavior, showed happy and sad emotions, and provided celebration and encouragement	1-meal-time assistant, 2-memory card game	40 older adults with and without dementia	2013	33/40 were engaged all the time. 7 were engaged some of the time. 35 complied with the robot all the time. 4 complied some of the times, and 1 did not comply. Impaired hearing led to challenges for those who used hearing aids.
Engagement	PARO	[93]	NM	Motivating engagement with the robot and increasing social interactions	10 PwD nursing home residents (3 excluded), 7 weeks, 7 sessions (30–45 min).	2013	PARO increased activity in different modalities of social interaction (e.g., visual, verbal, and physical). Some PwDs did not remember PARO from one session to the other. Consistent growth in interaction over time. Indirect benefit: increase in PwDs' interactions with others over time.
Engagement	Ed	[13]	NA	Robot got engaged in social conversations, gave task-related directions. Robot was controlled by researchers	5 family caregivers and 5 PwDs living in their own home	2013	PwDs and Caregivers involved in co-design of the robot and provided feedback through interviews.
		[12]	Social interaction	Robot got engaged in social conversations, gave task-related directions. Robot was controlled by researchers	10 participants, 55 yr or older, diagnosed with AD and who have difficulty completing sequences of steps	2015	Level of trust was not so high that PwDs turned to it for help. (1) Inability to properly communicate with the robot and convey necessary information, and (2) failure to develop a correct mental model of the robots were proposed as challenges in HR for dementia. Suggested penalization according to user needs.

(Continued)

Table 1. Continued

Application	Robot	lit.	Emotion/Social	Function	Participants	Year	Results
Engagement/ Guidance	Brian	[59]	Encouragement, celebration, help, joking and laughing	Assessing older adult's attitude in memory game, restaurant finding	46 older adults (37 female, 9 male; 62–91 yrs). At least a bachelor's degree.	2014	surveyed attitude of older adults toward Brian. Robot perceived easier to use by those who were less anxious toward it. Human-like communication was preferred over human-like appearance. Generally positive attitudes and minimal anxiety toward the robot.
Engagement	Matilda	[51]	Facial expression interpretation. Emotional recognition and penalization according to users' emotions. Emotion measuring to motivate positive emotional engagement (Uses Pleasure and Activity).	Engagement: Social (e.g., sing, dance), healthy living (e.g., walk, exercise), mental activity (e.g., quiz, reminders), and social reminders (e.g., phone calls, social event reminders)	7 households, 7 older adults living with a carer.	2014	Proposed and tested an architecture that facilitates assistance to PwDs in home-based care. The robot Eliminated barriers of use of technology by older adults. Positive impact on emotional well-being and engagement of PwDs. Could enhance QoL.
Engagement	Giraff	[72]	NA (teleoperated)	Teleoperated robot, increasing engagement between family and PwD in LTC	5 people with dementia, 6 family members, 7 staff. 6 calls over 6–8 weeks (average 23 mins). Total of 26 calls. 1 resident-family dyad removed due to technical issues with video recording	2014	Giraff was reported to be accepted and feasible to implement within LTC. Greatest positive emotion reported to happen at the beginning of calls. Families expressed that face-to-face interaction enhanced communication and reduced social isolation. They found Giraff to be useful for connecting to staff members as well. Cost of Giraff was reported as a concern.
Engagement	PARO	[104]	NM	Compared a stuffed toy (Lion) and PARO in persons with mild/moderate dementia versus severe dementia.	19 care facility residents with mild/moderate dementia and 11 with severe dementia	2014	PwDs talked more with PARO than the stuffed toy and showed more positive emotional expressions. Persons with severe dementia showed more neutral expression when interacting with the stuffed toy than PARO. Those with mild/moderate dementia touched/stroke the stuffed toy more and talked with staff less frequently when interacting with PARO.

(Continued)

Table 1. Continued

Application	Robot	lit.	Emotion/Social	Function	Participants	Year	Results
Engagement	AIBO	[75]	NA	Observation	care center residents including PwDs (number of participants is not mentioned)	2015	AIBO with the help of therapist increased residents' interest in each other's actions (when interacting with the robot).
Engagement	Pleo	[84]	NM	Evaluation of interactions and comparison with cognitive games	14 PwDs (12 female, 2 male, 69–92 yrs) with mild to moderate dementia.	2017	Pleo led to significantly more engagement and pleasure compared to cognitive games, but participants were less alert when interacting with Pleo compared to cognitive games.
		[85]	Robot showed its internal drives (e.g., hunger or sleep) and moods (e.g., happy, scared, curious)			2017	Participants' affect was observed through monitoring their face and hands. Cognitive games were perceived as significantly more difficult.
Engagement	Giraff	[73]	NA (teleoperated)	Evaluating attitude of participants toward a teleoperated robot	22 Participants, 5 PwDs and their caregivers (59–87 yrs), 12 professional caregivers (avg 36yrs). Conducted in a social robotics lab.	2018	Positive experience with presence of Giraff. More positive affect than negative on the I-PANAS-SF. Giraff was perceived authentic and engaging, having the sense of being in the same room. One PWD and two professionals reported it as unrealistic. Professionals expressed privacy concerns. Could help older adults live more independently and families be connected from distance. Participants suggested making it human-like and colorful.
Observation or Initial Evaluation							
Social Interaction/ Observation	PARO	[29] [27]	Simple pet-like interaction without evoking specific expectations from the interaction	Observational study on Participants' interest in PARO	Residents (majority with dementia), visitors, and staff ^a in a nursing home, 3 months, 35 sessions, average 49 participants per session ^b	2014, 2015	Gender, observation of interactions with PARO, staff/family-mediated interaction, and individual interpretations of PARO affected adoption of the robot. Few cases of interaction for more than 10 min. Majority of people ignored the robot. Indirect interaction (e.g., observing) was preferred over direct (e.g., touching PARO)

(Continued)

Table 1. Continued

Application	Robot	lit.	Emotion/Social	Function	Participants	Year	Results
All contexts	RobuLab 10 and images of 9 others	[88]	NA	Understanding robot's preferred appearance, potential applications, social ability, perceived usefulness, and intention to use	25 older adults, including 10 PwDs and 7 informal carers. 7 focus groups.	2015	Personalization was emphasized as important factor (appearance, behavior, social capabilities, and type of service). Participants mostly preferred a mechanical human-like robot, followed by a mechanical animal-like robot. Preference for task: (1) cognitive help (e.g., locating items), (2) communication help (e.g., video calls), (3) risk prevention and health application (e.g., fall detection), (4) supporting in tasks (e.g., online shopping).
All contexts	Pepper	[80]	NM	Initial evaluation	6 PwDs, 3 focus groups.	2018	Pepper in the future. Communication/contacts with others, recreational activities, avoiding dangers, and daily activities were recognized as most beneficial for a robot like Pepper. Drinking and eating were indicated to be least beneficial. Proposed a motivational framework called AMIGO for multimodal intervention strategies in the context of dementia.
Therapy							
Therapeutic	PARO	[109]	Generated proactive behavior according to its internal state, and desire	Robot assisted activity (details not mentioned)	26 older adults (73–93 yrs; 10 PwDs), 6 nursing staff. Day service center. 3 days a week for 5 weeks (individuals interacted with PARO 1–3 times/week.) 20–40 minute interactions.	2002	Face scale data was obtained from 12 participants. Mood was improved after interaction and over 5 weeks of study. Nursing staff's burnout (measured through burnout scale) results were lower after introduction of the robot.
Therapeutic	PARO	[108]	Generated proactive behavior according to its internal state and desire	Robot assisted activity (details not mentioned)	14 Participants (all female; 77–98 yrs; 13 PwDs). 1-hour sessions at LTC. 1 month.	2005	8 subjects' moods were tested based on face scale. Results were significantly lower after interaction compared to before. Scores also reduced over weeks; PARO improved moods after interaction and over the course of time.
Therapeutic	PARO	[62]	NM	mediate patient-therapist relation	1 PwD, moderate dementia	2006	PARO was able to support therapy sessions. PARO stimulated feelings, e.g., taking care, affection, tenderness, docility.

(Continued)

Table 1. Continued

Application	Robot	lit.	Emotion/Social	Function	Participants	Year	Results
Therapeutic	Bandit II	[105]	Positive and encouraging feedback regardless of performance	Music therapy and increasing cognitive attention	9 PwDs (4 male, 5 female) over 70 yr. living in senior care facility. Once (10–20 minutes) per week for 6 months.	2009	Tested adaptive behavior of the robot for individuals and different levels of disability. Improved users' task performance and helped maintain cognitive attention of PwDs.
Therapeutic	PARO	[101]	NM	Pet Therapy	14 PwD residents in Denmark and 14 in US. Many with depression and verbally/physically abusive behavior.	2012	Improved communication and sociability and reduced aggression and wandering. Depression reduced (13 to 6 cases) and behavioral problem decreased (20 to 10 cases). Use of medication was reduced.
Therapeutic	PARO	[28]	NM	Interactions in a therapy session. For calming and distracting residents	10 older adults over 65 yrs with mild to severe cognitive impairment. 8 weeks. 4–7 people/group.	2013	Physical activity and willingness to interact with PARO increased through the course of the study. Therapy sessions with one-on-one interactions and groups less than 3 may be better for PARO.
Therapeutic	NAO	[63]	NM	Language (numbers, days) and music therapy, storytelling, physiotherapy (exercises). For those with severe dementia: created animal sounds and walked toward/looked at PwDs	13 PwDs, age 74–91 yrs, 92% women. 30–45 min sessions, 2 days/week for 1 month	2013	Trends of improvement in neuropsychiatric symptoms, apathy, and QoL. No significant difference between baseline and follow up.
Therapeutic	NAO and PARO	[106]	NM	Comparing NAO, PARO, and dog therapy with conventional therapy.	2 phases 101 and 110 PwDs (58–101 yrs), nursing homes & day care centers. 2 days/week for 3 months. 9–15 PwDs per group.	2015	NAO group: impairment in delusions and improvement in apathy and total irritability score. PARO group: impairment in irritability and hallucination and disinhibition, improvement in night-time behavior disturbance.

(Continued)

Table 1. Continued

Application	Robot	lit.	Emotion/Social	Function	Participants	Year	Results
Therapeutic	PARO	[16]	Social, makes noises, moves its flippers, and looks at the participant. Shows emotional states such as enjoyment.	Providing comfort, increasing focus, relaxation, and fear reduction. User-specific interventions were implemented.	91 participants: 71 completed 14 men and 57 women	2015	PARO should be used as a tool, not a replacement for care. PARO can increase quality of care and QoL. Attention to hygiene is necessary in use of PARO. No significant difference between male and female participants.
Therapy, Exercise	Palro	[41]	NA	Motivated locomotion exercise by speaking and making action	Older adults (no details)	2016	Can induce physical activity and social communications
Therapy	PARO	[46]	NM	Robot assisted group activity (activity details not mentioned).	53 participant: 26 control, 27 participated in for 30 minutes twice a week over 12 weeks (24 sessions).	2016	Statistically significant effect on QoL, but only for participants with severe dementia.
		[45]	NM	Robot assisted group activity. Robot interactions involved stroking, cuddling, and petting	60 nursing home residents with dementia or cognitive impairment (62–95 yrs)	2015	Significant change on symptoms of depression and agitation. Intervention group's symptoms declined, control group's symptoms increased.
Therapeutic, Exercise	SCITOS	[42]	NA	Walking group assistance, music playing, and picture galleries.	10 residents with PwD, 74–95 yrs. 4 therapists, 26–33 yrs. 2 groups per week for 1 month.	2016	Potential to enhance motivation and also mood using the robot within the walking group. Therapists and PwDs with severe dementia had positive attitude towards the robot. PwDs could not initiate interactions; therapists mediated it. Use decreased over the sessions, probably due to its malfunctioning.
Therapeutic	PARO	[54]	NM	Pet Therapy	23 male veterans including PwDs (avg. 80 yrs, $sd = 10.6$). Residents of LTC.	2016	Significant decreases in negative behavioral states (e.g., anxiety, sadness). Significant increase in positive behavioral states (e.g., calmness, sleep behavior).

(Continued)

Table 1. Continued

Application	Robot	lit.	Emotion/Social	Function	Participants	Year	Results
Therapeutic	Sophie and Jack	[31]	Head and body motion as well as emotion expressions and gestures. Can make people smile and laugh as well as cause them to be open to talk and interact with robots	Diversion therapy. Engaging in activities: songs, games (bingo), stories	139 PwD with different levels of dementia, aged 65–90 yrs. In residential care, over 5 years	2017	Significant improvement in approaching robot and approaching others. Improved social engagement. Facilitated delivering diversion therapy based social activities
Therapeutic	PARO	[74]	NM	Observation - comparing PARO with a plush toy and usual care	28 LTCs, 415 participants >= 60 yrs. 9 LTCs with PARO (138 participants), 10 plush toy (140 participants), 9 usual care (137 participants).	2017	PARO increased engagement (greater verbal communication and eye contact (especially visual engagement)). PARO and plush toy reduced neutral affect compared with usual care. CMAI-SF test showed no significant difference among conditions. Effect of PARO and plush toy were short term (1–5 weeks).
Therapeutic	PARO	[86]	NM	Pet therapy, reducing dementia-related symptoms	61 PwDs (77% female, avg 83.4 yrs). Five dementia units, 12 weeks, 20-minute sessions with 6 PwDs.	2017	PARO decreased stress anxiety in the treatment group. Reductions in the use of psychoactive medications and pain medications was observed (not significant for sleep and behavior depression were controlled. Oxygen saturation, pulse rate, GSV, RAID, and CSDD and medication use were positively impacted.
Therapeutic	NAO	[91]	Robot was controlled through Wizard of Oz (WOZ) technique	Robot-Assisted Therapy (RAT)	9 PwDs (7 women and 2 men, mean age 86 yrs) in a geriatrics unit. 36 therapy sessions (mean 22.15 min, total: 770.19 min)	2017	No statistically significant difference between engagement in Classic Therapy (CT) and RAT (except for cognitive stimulation part). Significant increase in duration of pleasure in RAT. PwDs with symptoms of apathy and agitation responded well to RAT. PwDs were related in both CT and RAT. RAT improved well-being but not significantly. PwDs preferred RAT over CT. Robot was well accepted. Humanoid aspect personalizability of NAO helped with its acceptance.

(Continued)

Table 1. Continued

Application	Robot	lit.	Emotion/Social	Function	Participants	Year	Results
Therapy, Music	Pepper	[34]	NA	Listening to songs, switching between them, and creating a personal playlist.	7 PwDs	2018	PwDs talked more and linked conversation of memories associated with music. Increased emotional involvement. Challenges: volume of participants can cause problems. Reduced eyesight might cause challenges in reading screen. Human-like robot may raise expectations of understanding humans.
Therapeutic	PARO	[70]	NM	Observation - comparing PARO with a plush toy	20 care staff (20–75 yrs with 5–36 yrs work experience in aged care and 2–23 in current facility) from 9 centers. 10 in PARO group and 10 in plush toy group.	2018	Plush toy did not engage residents. PARO was identified as a potential to improve QoL. PARO could reduce agitation, improve mood and engagement, and help isolated residents. It could distract residents and reduced wandering and associated falls. PARO's limitations were identified as cost and staff training.
Therapeutic	Betty	[50]	Human-like communication modalities such as emotional expressions, head/body movements, and gestures in an emotionally engaging manner	Activities such as playing favorite music, audio books, family photo quiz, etc.	5 households, 5 PwDs between 75 and 85. Robot installed for 4 months.	2019	The robot helped maintain social engagement and encouraged interactions. Can improve quality of care for PwDs. Emotion engagement, visual engagement, and behavioral engagement are key components for designing social robots. Can provide caregivers with the time to do other domestic chores.

NA: Not Applicable; NM: Not Mentioned; PWD: Person with Dementia; LTC: Long-Term Care.
^a nurses, nurse assistants, housekeepers, social workers, general managers, and therapists.
^b 19% residents, 55% staff and 26% visitors.

Table 2. Robots Used in Research with Persons with Dementia in Alphabetic Order

Robot	Info	Lit.	Application	Description	Affect
AIBO	[4]	[75] [78]	Engagement	Dog like	NM
Bandit II	NA	[105]	Therapy	Humanoid torso mounted on a mobile base	Expressive eyebrows and mouth, capable of generating facial expressions
Batty ^a	[82]	[50]	Therapy	NA	Human-like communication modalities such as emotional expressions, head/body movements, and gestures in an emotionally engaging manner
Brian	NA	[23] [26] [24] [25] [59] [35] [65] [66]	Therapy, simulating social/cognitive training/engagement in activities, ADLs (meal-time)	Human-like demeanor, human-like waist up	Capable of showing human-like facial expressions, head gestures, and body language using arms
Ed	NA	[111] [13] [12]	Teleoperated assistive robot/ADLs	A screen as a face and a rectangular body	NA
Giraff	[40]	[72] [73]	Telepresence	Human height, remotely controllable with a screen on top	NA
MARIO	[61]	[36] [60]	Companion, general evaluation	Head with eyes on a robotic body	Limited social/engages in conversation about specific photo contents
Matilda ^b	[82]	[49] [51]	Social engagement, healthy living, activity engagement	Head with two eyes (baby face-like appearance), no neck, a robotic body	Emotion recognition and detects emotional state changes, has facial (head) expression and gestures
NAO	[76]	[63] [91] [106]	Therapy	Humanoid robot with head, neck, hands, body, and feet	Fully programmable; some positive, negative, and neutral moods (e.g., excited, happy, confused) are implemented; capable of emotion recognition from users' tone; multiple human-like emotions and gestures can be implemented as a result of its human-like capabilities and joints
Palro	[81]	[41]	Therapy/exercise	Human-like	NM
Pepper	[83]	[34] [80]	Therapy/music, assistive/ADLs	Human-like with head, neck, hands, body, and wheels instead of feet; touchscreen on the body	NM

(Continued)

Table 2. Continued

Robot	Info	Lit.	Application	Description	Affect
PARO	[113]	[16] [27] [29] [28] [46] [45] [54] [58] [62] [63] [70] [74] [86] [93] [101] [104] [106] [108] [107] [109]	Therapy, psychogeriatric care, social interaction/engagement, robot-assisted group activity, pet therapy, companion	Seal robot	Shows different behaviors, e.g., by moving its head and legs, making sounds, which can be adjusted based on the way that users interact with it
Pleo	[89]	[84] [85]	Engagement	Dinosaur-like	Capable of showing moods (e.g., happy, scared, curious)
RAMCIP	[90]	[6]	Assistive/ADLs	Two screens as a face and on the body; body consists of a rectangle and a square	Capable of showing facial expressions (on the screen face)
RobuLab 10	[37]	[88]	General observation/focus groups	Non-holonomic with wheels and a touchscreen on the body	NA
Ryan	[92]	[3]	Companion	Human-like robot with head, neck, hands, and a torso (a screen on torso); capable of showing facial expressions and generating speech; has the ability to recognize facial expression and speech	Yes, shows and understands facial expressions
SCITOS	[97]	[42]	Therapy	Non-holonomic with a bubble-like head and eyes; a touchscreen on the body	NM
Sophie & Jack ^c	[82]	[31]	Therapy	NA	Emotion and emotion change recognition; body language synthesis; designed for emotional and intentional communication and interaction

“Info” provides a reference where technical details of the robot are discussed. “Lit.” shows the articles that used the robot. NM: Not Mentioned. NA: Not Any. NA in the second column (Info) indicates that we did not find an article or a website introducing the robot, because the robot was developed by the authors of the same articles and no references beyond the articles provided in the third column were available (i.e., the robot was introduced in the same articles).

^a Although not indicated, this robot looks similar to Matilda, Sophie, and Jack. The robot that was found to be similar to these robots in looks and features is called PePero, a robot created by NEC. PePero is the robot that is provided in the Info column.

^b Although not indicated, this robot looks similar to Batty, Sophie, and Jack. The robot that was found to be similar to these robots in looks and features is called PePero, a robot created by NEC. PePero is the robot that is provided in the Info column.

^c Although not indicated, they look similar to Matilda and Batty. The robot that was found to be similar to these robots in looks and features is called PePero, a robot created by NEC. PePero is the robot that is provided in the Info column.

Table 3. Robots Used for PWDs and the Contexts in Which They Have Been Used

Robot	ADL	Companion	Engagement	Health Guidance	Initial Observation/ Evaluation	Therapy	TOTAL
AIBO	-	1	1	-	-	-	2
Bandit II	-	-	-	-	-	1	1
Batty	-	-	-	-	-	1	1
Brian	2	-	6	-	-	-	8
Ed	1	-	2	-	-	-	3
Giraff	-	-	2	-	-	-	2
MARIO	-	1	-	-	-	-	1
Matilda	-	-	2	1	-	-	3
NAO	-	-	-	-	-	3	3
Palro	-	-	-	-	-	1	1
Pepper	-	-	-	-	1	1	2
PARO	-	1	3	-	2	13	19
Pleo	-	-	2	-	-	-	2
RAMCIP	1	-	-	-	-	-	1
Robulab 10	-	-	-	-	1	-	1
Ryan	-	1	-	-	-	-	1
SCITOS	-	-	-	-	-	1	1
Sophie & Jack	-	-	-	-	-	1	1

companion robots were able to improve **Quality of Life (QoL)** [3] and reduce depression [3, 36] and anxiety [58]. One study showed that a companion robot was able to improve interaction of PwDs with younger family members [60]. Assistive robots also successfully improved engagement of PwDs with others (e.g., other PwDs or LTC residents) [23, 93, 107], reduced isolation [72], and improved engagement in activities [65, 84] and emotional well-being of PwDs [51].

Overall, the studies showed a variety of positive impacts of assistive robots on PwDs in many contexts. In the context of ADLs, however, despite positive attitude of both PwDs and caregivers, PwDs showed concerns about the negative consequences of using the robots [111] such as the possibility of decreasing social contact or causing neglect by family caregivers.

Below, we will provide a brief discussion for each application area. All of these findings will also be further discussed in the Discussion section.

Activities of Daily Living: Four studies investigated designing a robot that helps with an ADL. Out of these four, one did not actually focus on the ADL as such, but rather focused on the co-design of robot facial expressions, with the goal that it can be more effective in helping with ADLs in the future [6]. The second robot was teleoperated and helped with hand-washing, as well as preparing a cup of tea. This study provided evidence on the effectiveness of social robots, especially by helping caregivers [111]. The other two studies focused on a meal-time assistant robot that provided prompts related to eating a meal. The robot showed success in engaging participants and the participants' attitudes were reported to be positive [35, 66].

Companionship: Five studies were reviewed in this category. Two of the studies investigated the effect of having applications (games, news, calendar, etc.) displayed on a robot's screen to provide companionship, e.g., by playing music. While this was shown to be promising in terms of improving PwDs' mood and focus, the ability to use these applications was affected by the severity of dementia [60]. Another similar study (a pilot study) used a social robot that engaged in social activities with PwDs by playing games, showing family albums, etc., and demonstrated that such a social robot can be effective in improving the level of depression and increasing engagement with these activities [3]. The other study also suggested that PwDs have good acceptability of a pet robot [78], and that a pet robot with pet-type reactions can help improve interactions of PwDs with staff at day-care centers [58].

Health Guidance: This category is more common, including a wider range of healthy older adults and adults in general. The agents in this context provide guidelines for remaining healthy. While such health guidance could be valuable in dementia care, we could only find one social robot within this application domain, which provided diet-related advice to residents of a care home facility including PwDs. The study suggested that the social robot was effective in improving quality of care of older adults [49].

Therapy: Twenty-one articles investigated the role of social robots in a context related to therapy and this application area received the most attention in the literature. Here, social robots have been used in multiple situations such as in robot-assisted activities [31, 42, 45, 46, 108, 109], to mediate patient-therapist relations and support therapy sessions [62, 91], and even in situations in which the social robot provided therapy more directly, such as pet therapy [54, 86, 101], music therapy [63, 105], or playing audio books or using family photo quizzes [50]. The social robots in this category not only successfully helped PwDs in many different ways, such as by improving PwDs' mood [108], reducing depression [101], and increasing PwDs' social engagement [31], but also helped caregivers, e.g. by distracting residents and reducing wandering behavior [70, 101] (which can result in falls) and by providing caregivers additional time to do domestic chores [50].

Engagement: Engagement was the second application area that had received a lot of attention in the literature (18 articles were reviewed). Social robots have been used in studies (1) to increase engagement between residents of care centers [75, 107]; (2) in activities that could help with increasing social interactions, such as using games [23, 49, 65, 85], dancing, and singing [51]; (3) to improve PwD's engagement in social interactions [12, 84, 93, 104]; and (4) to increase engagement with others such as family members who lived at another location [72]. The studies reported positive effects of the social robots on engagement with others [23, 75], reduced stress [24], increased engagement in activities [49], and improved emotional well-being and quality of life [51]. The social robots also helped with connecting PwDs with family members [72]. Also, PwDs successfully engaged with the robots [65, 104], which can be important especially in the absence of other forms of social interactions.

Among the reported challenges that affected the success of social robots in this application area were participants' difficulties in appropriately communicating with the robot and conveying necessary information [12], a failure to develop a correct mental model of the robot [12], limitations in the general speech ability of the robot [107], participants' hearing challenges in understanding the robot's speech (e.g., by those who used hearing aids) [65], and privacy concerns [73].

Initial Evaluation/Observation: Four of the reviewed studies performed initial observations of the robots. Two studies observed interactions with the PARO robot and noticed that staff- and family-mediated interactions can affect adoption of the robot. Indeed, many participants seemed to either ignore the robot or prefer indirect interactions over direct interactions [27, 29]. Another study conducted focus groups to understand the preferred appearance for a social robot, as well as potential applications. While participants mostly preferred a mechanical human-like robot, followed by a mechanical animal-like robot, personalization was found to be an important factor [88]. Cognitive help (e.g., help with locating items), communication help (e.g., with video calls), risk prevention and health applications (e.g., fall detection), and support in tasks such as online shopping were the four application areas that were preferred the most [88]. The last study investigated potential application areas for the use of the Pepper robot and suggested assisting with communication/contacts with others, recreational activities, avoiding dangers, and support in daily activities as most beneficial applications for a robot like Pepper [80]. Drinking and eating were indicated to be the least beneficial [80].

3.2 Emotional and Social Capabilities

The reviewed studies varied widely regarding the robots' emotional and social capabilities. In some cases (e.g., teleoperated robots), the robots did not show any emotion or react to PwDs' emotions. In many other situations, the robots reflected basic social skills or understanding of PwDs' emotions. Examples were understanding users' basic affective states (angry, happy, disturbed) [23, 35], understanding and adjusting persuasive dialogue based on PwDs' emotion changes [49], expressing happiness by animal-like robots (e.g., wagging tail) [78], providing encouragement [105] and celebration [26], and showing proactive behavior according to the robot's internal state [107]. More advanced capabilities included understanding users' facial expressions and using facial expressions [3], or employing facial expressions to control the pace of interaction [49]. However, the accuracy and success of these capabilities were not assessed or reported in the reviewed articles. The general social/emotional capabilities of the reviewed robots as indicated by the studies are shown in Table 2, and Table 1 reports these capabilities in each study.

4 DISCUSSION

This article provided a review of the assistive robots that were designed for people with dementia and evaluated in a study with human participants. The review covered a range of applications and robots used across studies from different countries. The studies used robots with different levels of autonomy (e.g., from teleoperated robots that were fully controlled by another person to robots that were designed to work autonomously). The assistive robots helped in many situations, such as connecting PwDs with family members that were physically away, providing companionship, promoting health or therapeutic support, and helping with completing daily tasks.

The review suggested that assistive robots have been mostly studied in therapeutic contexts or for increasing PwDs' engagement. A major difference between the nature of these two tasks and the others (e.g., helping with ADLs or companionship) is that the robots have to be used in the presence of another person (i.e., a therapist or a caregiver), and PwDs might perceive the robots as a tool that complements a caregiver/therapist as opposed to a replacement for care [16]. Indeed, some PwDs raised concerns about applications in the area of ADLs possibly leading to more neglect and fewer interactions with family caregivers [111], which could reduce the motivation to use assistive robots in those situations. However, "dehumanizing care" [96] is mostly argued to be unjustifiable [44]. In fact, the goal of assistive technologies in the context of ADLs is to improve independence of PwDs and improve quality of life. That is to say, while decreasing interactions with caregivers might be a concern for PwDs, many positive consequences such as decreasing stress, relationship strain, and frustration are reported, which can actually improve social interactions [111].

Another important factor that could explain the lower number of studies in the context of ADLs as compared to the other applications is the complexity of designing a fully functioning assistive robot for ADLs. Many of the assistive robots used in contexts such as therapy were controlled by a caregiver or did not show advanced functionalities. However, there are multiple challenges involved in designing robots that can truly help with ADLs. For example, the existing robots' capabilities might limit the level of assistance with ADLs to just providing cues about the next step of the activity and delivering reminders; in such situations the assistive robots are not actually able to physically help PwDs, which might be needed in many ADL situations. Similarly, while there is an argument that physical robots can have a high level of authority and increase obedience in interactions with people (e.g., even when compared to other digital assistants or when being asked unusual, suspicious, or socially inappropriate requests, e.g., [9, 11, 19, 55, 57, 95]), if the robots are not able to provide actual physical assistance, then they might be substituted with

another type of intelligent system (e.g., a smartphone application), at a lower cost and higher robustness compared to physical robots. Emphasizing the importance of ADLs, a recent review by Ienca et al. [44] has categorized ADLs as one of the most common applications in Intelligent Assistive Technologies, robotic or otherwise. Another challenge is that to successfully help with this category, the robots need to have multiple functionalities, such as understanding of each step of the activities, recognizing humans' actions, understanding possible alternative options, using face and emotion recognition to understand when the situation becomes challenging for the users, and the capability of getting involved in a dialogue with the users about the task (which can be challenging as a consequence of impaired hearing [65] or impaired verbal communication abilities due to dementia).

One issue raised by the studies was that older adults with different stages of dementia and their caregivers have different views toward assistive robots and their use [111]. For example, initiating interactions was found to be challenging in one study [42]; PwDs also found it hard to use touchscreens on the robots due to not being familiar with such type of interaction (e.g., this led to applying hard pressure or not removing fingers from where they touched) [42]. This highlights the necessity of co-designing assistive robots and effective interfaces with people with dementia and their caregivers, as also emphasized by Ienca et al. [44].

Another issue brought up by the caregivers was related to the assistive robots' ease of use (cost of utility and learning how to interact with it) [88]. This is a valid concern as using an assistive robot typically requires more maintenance effort as compared to another type of intelligent system such as a virtual assistant (which can be checked or even upgraded remotely). For example, technical problems in one study were perceived to be tedious and annoying, especially because caregivers and therapists were busy with other responsibilities [42]. However, this can also be improved through co-design sessions, by designing user-friendly and personalizable robots [1], and by minimizing the need for external control/maintenance.

Cost was another issue raised by the caregivers [87]. Although the cost of an assistive robot can be an issue in some contexts, developing robots that maximize benefits (while minimizing costs) could help reduce other costs associated with dementia care in the long run. Further, robustness and reliability of the robots are shown to affect caregivers' perception of the usefulness of the robot [42]; therefore, the developed robots should be rigorously tested before being used by PwDs and caregivers.

Finally, although the focus of this article has been on technologies developed for PwDs, many of the proposed assistive robots can be beneficial for other groups of users as well, such as older adults, long-term care residents, and people with depression, cognitive disabilities, or anxiety.

5 RESEARCH GAPS AND DIRECTIONS FOR THE FUTURE WORK

Although the work on assistive robots is covered by researchers in many different countries (16 were identified and reviewed in this article), cross-cultural challenges and effects should be studied further to better understand personalization approaches. For example, [103] emphasized the importance of such factors (i.e., cross-cultural differences) and showed that some countries evaluate the robot highly in the first factor (i.e., impressions about the behavior of the robot, e.g., how lively and expressive the robot is and how comfortable the interactions are), while the other countries evaluate it in the second factor (i.e., the appearance and attraction to the robot, e.g., how cute the robot is). These factors can affect people's expectation from the robots, preference about the shape of the robot, and their preferred way of interaction.

Another important future direction would be developing assistive robots that are emotionally intelligent. Emotions and affective expressions have been shown to be important for developing

technologies meant to interact with people; they have improved people's cooperation with the technology, as well as their enjoyment and engagement [39, 77]. Further, many of the reviewed articles have also emphasized the importance of social and emotional interaction capabilities, arguing that these capabilities have positively affected trust and engagement [23], enjoyment, and reduction of stress [24, 25]. Emotional and behavioral engagement was proposed by Khosla et al. [50] to be key components for designing socially assistive robots. It is now well documented that despite cognitive decline, PwDs retain their sense of self (their "identity," or biographical interpretation of who they are) [53]. This sense of self has a strong emotional component. A robot's ability to adequately adapt to a PwD's identity and emotional state (or mood) and to express proper emotions in response to that state is key to persuade PwDs to perform activities, especially for applications related to ADLs.

Investigating long-term effects of social robots has also seen limited attention, which could be due to significant and multiple challenges and complications associated with running studies at long-term care facilities with social robots (e.g., the constant changes in the residents and residents' availabilities, as well as other challenges related to the environment and attitude of staff as pointed out in [71]). It is important to understand whether the effect will persist if assistive robots are deployed long term or even permanently, and what the optimal duration of their deployment should be. The existing research has shown positive long-term impact of social robots [107, 108], while one study found only little sustainability beyond the intervention period [74]. Šabanović et al. [93] investigated whether the interest in PARO was due to "novelty effects" or the impact persisted over time [93]. Although the results were positive, all PwDs had memory impairments and did not remember PARO from session to session. Therefore, future work should investigate the long-term impact of assistive robots and take into account the different factors that can affect their adoption over the course of time, as well as contextual, environmental, and cultural factors. Also, future work will benefit from studies that replicate the existing results in other situations and settings and with other groups and people with different levels of dementia.

Furthermore, assistive robots that help PwDs with ADLs have seen limited attention, perhaps due to the above-mentioned complexity and challenges. However, helping with ADLs could be an important application that can improve PwDs' and caregivers' quality of life by making PwDs more independent, decreasing relationship tensions, and freeing caregivers to do more valuable activities with PwDs [111]. Helping with ADLs can also be beneficial in situations in which a PwD prefers not to constantly ask for help from a caregiver [111]. Therefore, future research on designing/developing assistive robots in the context of ADLs can be highly beneficial.

While PARO has seen significantly more attention in the literature as compared to the other robots reviewed in this article, some of the other robots have functionalities and capabilities that might make them a better choice for other applications, such as ADLs. For example, one study reported that the participants preferred a mechanical human-like robot followed by a mechanical animal-like robot [88], while in another study the human-like communication capabilities were emphasized and it was considered to be more important than the human-like appearance [59]. Khosla et al. [51] also suggested that size and embodiment of human attributes have positive impacts on engaging older adults with technology. Therefore, future work should focus on understanding how such preference for appearance and behavior of the robots changes based on different personalities of PwDs, as well as the specific task (e.g., an animal-like robot might be more preferable in helping with more private ADLs, while a human-like robot might be preferred in other, non-private ADLs). Furthermore, while initial evaluations with healthy older adults and including caregivers in evaluation studies would be beneficial for the design of social robots for dementia care, it is important to understand PwDs' independent opinions and preferences, as it

is shown that the perception of/expectations from a robot for self can be different from those for others [52].⁴

Finally, future work would be beneficial to expand on the existing body of literature on the ethical implications and considerations for designing social robots (e.g., [5, 22, 99, 100]), as well as to understand the privacy and security concerns and considerations that need to be taken into account for developing social robots that can successfully assist caregivers and PwDs, while being safe and secure and maintaining users' privacy.

6 LIMITATIONS

Our review approach has the following limitations. First, although we attempted to be as comprehensive as possible in the review, some articles might not have been covered. For example, some related publications might have not been detected if they did not include dementia or Alzheimer as a keyword or only referred to it with terms such as "cognitive impairment." Also, there are reported issues related to replicability of searches in the IEEE Explore database, as the same search performed at another time may yield different results. Also, if only the name of a social robot is used in a related article (e.g., "PARO") without any indication of it being a robot, our search queries could have missed it. Second, we did not attempt to verify the validity of the methodology used in the reviewed studies: while the articles that did not provide information about the methodology or participants were excluded, we relied on the accuracy of the published articles. Further, the validity and consistency of the results might have been affected by multiple factors, such as the location of the study, selection of participants, and the culture and structure of care in the particular country that the study was conducted in. Such differences were not the focus of this review article and therefore were not investigated. Finally, although we checked the significance of effects for the claims made in the reviewed studies, we referred to the authors' interpretations for writing the summary of the results of each study.

Note that this review was conducted in 2019; therefore, the results and discussions are based on the articles reported in this review and do not include the articles published after September 2019 (i.e., the time during which the article was under review).

7 CONCLUSION

This article reviewed the existing work on assistive robots evaluated for dementia care. It provided a summary of (1) the effectiveness of each robot in five different applications, (2) the existing robots used in dementia care studies, and (3) the appearance and social/emotional capabilities of the existing robots in dementia care. Gaps were identified, which emphasized the importance of (1) understanding long-term effects of social robots, (2) personalization based on PwDs' emotional states and cultural backgrounds, (3) developing assistive robots in the context of ADLs, and (4) understanding the preferred appearance and functionalities for an assistive robot depending on the context. With the increasing number of PwDs, assistive robots that can be successfully adopted and effectively help PwDs can play an important role in increasing independence of PwDs, reducing costs, and improving quality of life of PwDs and caregivers.

REFERENCES

- [1] Joe Saunders, Dag Sverre Syrdal, Kheng Lee Koay, Nathan Burke, and Kerstin Dautenhahn. 2015. "Teach me—show me"—end-user personalization of a smart home and companion robot. *IEEE Transactions on Human-Machine Systems* 46, 1 (2015), 27–40.

⁴Note: While the future direction provided here was inspired by the discussion of the existing literature provided in the previous section, it also contains authors' opinions and their suggestions on future work.

- [2] Jordan Abdi, Ahmed Al-Hindawi, Tiffany Ng, and Marcela P Vizcaychipi. 2018. Scoping review on the use of socially assistive robot technology in elderly care. *BMJ Open* 8, 2 (2018), e018815.
- [3] Hojjat Abdollahi, Ali Mollahosseini, Josh T. Lane, and Mohammad H. Mahoor. 2017. A pilot study on using an intelligent life-like robot as a companion for elderly individuals with dementia and depression. In *2017 IEEE-RAS 17th International Conference on Humanoid Robotics (Humanoids'17)*. IEEE, 541–546.
- [4] aibo. 2020. <https://us.aibo.com>.
- [5] Farshid Amirabdollahian, Rieks op den Akker, Sandra Bedaf, Richard Bormann, Heather Draper, Vanessa Evers, Jorge Gallego Pérez, Gert Jan Gelderblom, Carolina Gutierrez Ruiz, David Hewson, et al. 2013. Assistive technology design and development for acceptable robotics companions for ageing years. *Paladyn, Journal of Behavioral Robotics* 4, 2 (2013), 94–112.
- [6] Margherita Antona, Danai Ioannidi, Michalis Foukarakis, Justyna Gerlowska, Konrad Rejdak, Carla Abdelnour, Joan Hernández, Natalia Tantinya, and Natalia Roberto. 2019. My robot is happy today: How older people with mild cognitive impairments understand assistive robots' affective output. In *Proceedings of the 12th ACM International Conference on Pervasive Technologies Related to Assistive Environments*. ACM, 416–424.
- [7] Ismahan Arslan Ari and Fethi A. Inan. 2010. Assistive technologies for students with disabilities: A survey of access and use in turkish universities. *Turkish Online Journal of Educational Technology-TOJET* 9, 2 (2010), 40–45.
- [8] Ronald C. Arkin. 1995. Intelligent robotic systems. *IEEE Intelligent Systems* 2 (1995), 6–8.
- [9] A. M. Aroyo, T. Kyohei, T. Koyama, H. Takahashi, F. Rea, A. Sciutti, Y. Yoshikawa, H. Ishiguro, and G. Sandini. 2018. Will people morally crack under the authority of a famous wicked robot? In *2018 27th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN'18)*. 35–42. <https://doi.org/10.1109/ROMAN.2018.8525744>
- [10] Ikram Asghar, Shuang Cang, and Hongnian Yu. 2015. A systematic mapping study on assitive technologies for people with dementia. In *2015 9th International Conference on Software, Knowledge, Information Management and Applications (SKIMA'15)*. IEEE, 1–8.
- [11] Wilma Bainbridge, Justin Hart, Elizabeth Kim, and Brian Scassellati. 2011. The benefits of interactions with physically present robots over video-displayed agents. *International Journal of Social Robotics* 3 (2011), 41–52. <https://doi.org/10.1007/s12369-010-0082-7>
- [12] M. Begum, R. Huq, R. Wang, and A. Mihailidis. 2015. Collaboration of an assistive robot and older adults with dementia. *Gerontechnology* 13, 4 (2015), 405–419.
- [13] Momotaz Begum, Rosalie Wang, Rajibul Huq, and Alex Mihailidis. 2013. Performance of daily activities by older adults with dementia: The role of an assistive robot. In *2013 IEEE 13th International Conference on Rehabilitation Robotics (ICORR'13)*. IEEE, 1–8.
- [14] Tony Belpaeme, James Kennedy, Aditi Ramachandran, Brian Scassellati, and Fumihide Tanaka. 2018. Social robots for education: A review. *Science Robotics* 3, 21 (2018), eaat5954. DOI: [10.1126/scirobotics.aat5954](https://doi.org/10.1126/scirobotics.aat5954)
- [15] Roger Bemelmans, Gert Jan Gelderblom, Pieter Jonker, and Luc De Witte. 2012. Socially assistive robots in elderly care: A systematic review into effects and effectiveness. *Journal of the American Medical Directors Association* 13, 2 (2012), 114–120.
- [16] Roger Bemelmans, Gert Jan Gelderblom, Pieter Jonker, and Luc de Witte. 2015. Effectiveness of robot Paro in intramural psychogeriatric care: A multicenter quasi-experimental study. *Journal of the American Medical Directors Association* 16, 11 (2015), 946–950.
- [17] Roberta Bevilacqua, Amedeo Cesta, Gabriella Cortellessa, Alessandro Macchione, Andrea Orlandini, and Lorenza Tiberio. 2014. Telepresence robot at home: A long-term case study. In *Ambient Assisted Living*. Springer, 73–85.
- [18] Jennifer Boger and Alex Mihailidis. 2011. The future of intelligent assistive technologies for cognition: Devices under development to support independent living and aging-with-choice. *NeuroRehabilitation* 28, 3 (2011), 271–280.
- [19] Serena Booth, James Tompkin, Hanspeter Pfister, Jim Waldo, Krzysztof Gajos, and Radhika Nagpal. 2017. Piggy-backing robots: Human-robot overtrust in university dormitory security. In *ACM/IEEE International Conference on Human-Robot Interaction (HRI'17)*. Association for Computing Machinery, New York, NY, 426–434. <https://doi.org/10.1145/2909824.3020211>
- [20] Cynthia Breazeal, Kerstin Dautenhahn, and Takayuki Kanda. 2016. *Social Robotics*. Springer International Publishing, Cham, 1935–1972. https://doi.org/10.1007/978-3-319-32552-1_72
- [21] Cynthia Breazeal, Kerstin Dautenhahn, and Takayuki Kanda. 2016. Social robotics. In *Springer Handbook of Robotics*. Springer, 1935–1972.
- [22] Christopher James Calo, Nicholas Hunt-Bull, Lundy Lewis, and Ted Metzler. 2011. Ethical implications of using the Paro robot, with a focus on dementia patient care. In *Workshops at the 25th AAAI Conference on Artificial Intelligence*.
- [23] Jeanie Chan and Goldie Nejat. 2010. Promoting engagement in cognitively stimulating activities using an intelligent socially assistive robot. In *2010 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*. IEEE, 533–538.

- [24] Jeanie Chan and Goldie Nejat. 2011. Minimizing task-induced stress in cognitively stimulating activities using an intelligent socially assistive robot. In *2011 RO-MAN*. IEEE, 296–301.
- [25] Jeanie Chan and Goldie Nejat. 2012. Social intelligence for a robot engaging people in cognitive training activities. *International Journal of Advanced Robotic Systems* 9, 4 (2012), 113.
- [26] Jeanie Chan, Goldie Nejat, and Jingcong Chen. 2011. Designing intelligent socially assistive robots as effective tools in cognitive interventions. *International Journal of Humanoid Robotics* 8, 1 (2011), 103–126.
- [27] Wan-Ling Chang and Selma Šabanovic. 2015. Interaction expands function: Social shaping of the therapeutic robot PARO in a nursing home. In *2015 10th ACM/IEEE International Conference on Human-Robot Interaction (HRI'15)*. IEEE, 343–350.
- [28] Wan-Ling Chang, Selma Šabanovic, and Lesa Huber. 2013. Use of seal-like robot PARO in sensory group therapy for older adults with dementia. In *2013 8th ACM/IEEE International Conference on Human-Robot Interaction (HRI'13)*. IEEE, 101–102.
- [29] Wan-Ling Chang, Selma Šabanovic, and Lesa Huber. 2014. Observational study of naturalistic interactions with the socially assistive robot PARO in a nursing home. In *The 23rd IEEE International Symposium on Robot and Human Interactive Communication*. IEEE, 294–299.
- [30] Shu-Chuan Chen, Cindy Jones, and Wendy Moyle. 2018. Social robots for depression in older adults: A systematic review. *Journal of Nursing Scholarship* 50, 6 (2018), 612–622.
- [31] Mei-Tai Chu, Rajiv Khosla, Seyed Mohammad Sadegh Khaksar, and Khanh Nguyen. 2017. Service innovation through social robot engagement to improve dementia care quality. *Assistive Technology* 29, 1 (2017), 8–18.
- [32] Jean Daly Lynn, Janeet Rondón-Sulbarán, Eamon Quinn, Assumpta Ryan, Brendan McCormack, and Suzanne Martin. 2017. A systematic review of electronic assistive technology within supporting living environments for people with dementia. *Dementia* 18, 7–8 (2019), 2371–2435.
- [33] Kerstin Dautenhahn. 2007. Socially intelligent robots: Dimensions of human–robot interaction. *Philosophical Transactions of the Royal Society B: Biological Sciences* 362, 1480 (2007), 679–704.
- [34] Roos De Kok, Joost Rothweiler, Lizzy Scholten, Max van Zoest, Roel Boumans, and Mark Neerincx. 2018. Combining social robotics and music as a non-medical treatment for people with dementia. In *2018 27th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN'18)*. IEEE, 465–467.
- [35] McColl Derek, Jeanie Chan, and Goldie Nejat. 2012. A socially assistive robot for meal-time cognitive interventions. *Journal of Medical Devices* 6, 1 (2012).
- [36] Grazia D'Onofrio, Daniele Sancarlo, Massimiliano Raciti, Megan Burke, Aimee Teare, Tanja Kovacic, Keith Cortis, Kathy Murphy, Eva Barrett, Sally Whelan, et al. 2019. MARIO project: Validation and evidence of service robots for older people with dementia. *Journal of Alzheimer's Disease Preprint* (2019), 1–15.
- [37] V. Dupourqué. 2009. RobuLAB 10, a service robot designed to Aging-in-Place. *Gerontechnology* 8 (2009), 183.
- [38] David Feil-Seifer and Maja J. Matarić. 2011. Socially assistive robotics. *IEEE Robotics & Automation Magazine* 18, 1 (2011), 24–31.
- [39] Moojan Ghafurian, Neil Budnarain, and Jesse Hoey. 2019. Role of emotions in perception of humanness of virtual agents. In *Proceedings of the 18th International Conference on Autonomous Agents and MultiAgent Systems*. International Foundation for Autonomous Agents and Multiagent Systems, 1979–1981.
- [40] Giraff. 2020. <http://www.giraff.org>.
- [41] Toshimitsu Hamada, Hiroaki Kawakami, Azumi Inden, Kyouhei Onose, Mitsuru Naganuma, Yoshihito Kagawa, and Tomomi Hashimoto. 2016. Physical activity rehabilitation trials with humanoid robot. In *2016 IEEE International Conference on Industrial Technology (ICIT'16)*. IEEE, 1592–1596.
- [42] Denise Hebesberger, Christian Dondrup, Tobias Koertner, Christoph Gisinger, and Juergen Pripfl. 2016. Lessons learned from the deployment of a long-term autonomous robot as companion in physical therapy for older adults with dementia: A mixed methods study. In *The 11th ACM/IEEE International Conference on Human Robot Interaction*. IEEE Press, 27–34.
- [43] Lillian Hung, Cindy Liu, Evan Woldum, Andy Au-Yeung, Annette Berndt, Christine Wallsworth, Neil Horne, Mario Gregorio, Jim Mann, and Habib Chaudhury. 2019. The benefits of and barriers to using a social robot PARO in care settings: A scoping review. *BMC Geriatrics* 19, 1 (2019), 1–10.
- [44] Marcello Ienca, Jottrand Fabrice, Bernice Elger, Maurizio Caon, Alessandro Scoccia Pappagallo, Reto W. Kressig, and Tenzin Wangmo. 2017. Intelligent assistive technology for Alzheimer's disease and other dementias: A systematic review. *Journal of Alzheimer's Disease* 56, 4 (2017), 1301–1340.
- [45] Nina Jøranson, Ingeborg Pedersen, Anne Marie Mork Rokstad, and Camilla Ihlebaek. 2015. Effects on symptoms of agitation and depression in persons with dementia participating in robot-assisted activity: A cluster-randomized controlled trial. *Journal of the American Medical Directors Association* 16, 10 (2015), 867–873.
- [46] Nina Jøranson, Ingeborg Pedersen, Anne Marie Mork Rokstad, and Camilla Ihlebaek. 2016. Change in quality of life in older people with dementia participating in Paro-activity: A cluster-randomized controlled trial. *Journal of Advanced Nursing* 72, 12 (2016), 3020–3033.

- [47] Reza Kachouie, Sima Sedighadeli, Rajiv Khosla, and Mei-Tai Chu. 2014. Socially assistive robots in elderly care: A mixed-method systematic literature review. *International Journal of Human-Computer Interaction* 30, 5 (2014), 369–393.
- [48] Martina Kane and Laura Cook. 2013. *Dementia 2013: The Hidden Voice of Loneliness*. London: Alzheimers Society.
- [49] Rajiv Khosla, Mei-Tai Chu, Reza Kachouie, Keiji Yamada, Fujita Yoshihiro, and Tomoharu Yamaguchi. 2012. Interactive multimodal social robot for improving quality of care of elderly in Australian nursing homes. In *Proceedings of the 20th ACM International Conference on Multimedia*. ACM, 1173–1176.
- [50] Rajiv Khosla, Mei-Tai Chu, Seyed Mohammad Sadegh Khaksar, Khanh Nguyen, and Toyoaki Nishida. 2021. Engagement and experience of older people with socially assistive robots in home care. *Assistive Technology* 33, 2 (2021), 57–71.
- [51] Rajiv Khosla, Khanh Nguyen, and Mei-Tai Chu. 2014. Assistive robot enabled service architecture to support home-based dementia care. In *2014 IEEE 7th International Conference on Service-Oriented Computing and Applications*. IEEE, 73–80.
- [52] Kheng Lee Koay, Dag Sverre Syrdal, Kerstin Dautenhahn, and Michael L. Walters. 2020. A narrative approach to human-robot interaction prototyping for companion robots. *Paladyn, Journal of Behavioral Robotics* 11, 1 (2020), 66–85.
- [53] Alexandra König, Linda E. Francis, Jyoti Joshi, Julie M. Robillard, and Jesse Hoey. 2017. Qualitative study of affective identities in dementia patients for the design of cognitive assistive technologies. *Journal of Rehabilitation and Assistive Technologies Engineering* 4 (2017), 2055668316685038.
- [54] Geoffrey W. Lane, Delilah Noronha, Alexandra Rivera, Kathy Craig, Christina Yee, Brent Mills, and Eimee Villanueva. 2016. Effectiveness of a social robot, “Paro”, in a VA long-term care setting. *Psychological Services* 13, 3 (2016), 292.
- [55] Kwan Min Lee, Younbo Jung, Jaywoo Kim, and Sang Ryong Kim. 2006. Are physically embodied social agents better than disembodied social agents? The effects of physical embodiment, tactile interaction, and people’s loneliness in human-robot interaction. *International Journal on Human-Computer Studies* 64, 10 (Oct. 2006), 962–973. <https://doi.org/10.1016/j.ijhcs.2006.05.002>
- [56] Minmin Leng, Peng Liu, Ping Zhang, Mingyue Hu, Haiyan Zhou, Guichen Li, Huiru Yin, and Li Chen. 2019. Pet robot intervention for people with dementia: A systematic review and meta-analysis of randomized controlled trials. *Psychiatry Research* 271 (2019), 516–525.
- [57] Jamy Li. 2015. The benefit of being physically present: A survey of experimental works comparing copresent robots, telepresent robots and virtual agents. *International Journal of Human-Computer Studies* 77 (2015), 23–37. <https://doi.org/10.1016/j.ijhcs.2015.01.001>
- [58] Amy Liang, Isabell Piroth, Hayley Robinson, Bruce MacDonald, Mark Fisher, Urs M. Nater, Nadine Skoluda, and Elizabeth Broadbent. 2017. A pilot randomized trial of a companion robot for people with dementia living in the community. *Journal of the American Medical Directors Association* 18, 10 (2017), 871–878.
- [59] Wing-Yue Geoffrey Louie, Derek McColl, and Goldie Nejat. 2014. Acceptance and attitudes toward a human-like socially assistive robot by older adults. *Assistive Technology* 26, 3 (2014), 140–150.
- [60] Arlene Mannion, Sarah Summerville, Eva Barrett, Megan Burke, Adam Santorelli, Cheryl Kruschke, Heike Felzmann, Tanja Kovacic, Kathy Murphy, Dymphna Casey, et al. 2019. Introducing the social robot MARIO to people living with dementia in long term residential care: Reflections. *International Journal of Social Robotics* (2019), 12:535–547. <https://doi.org/10.1007/s12369-019-00568-1>
- [61] MARIO. 2020. <http://www.mario-project.eu/>.
- [62] Patrizia Marti, Margherita Bacigalupo, Leonardo Giusti, Claudio Mennecozzi, and Takanori Shibata. 2006. Socially assistive robotics in the treatment of behavioural and psychological symptoms of dementia. In *The 1st IEEE/RAS-EMBS International Conference on Biomedical Robotics and Biomechatronics, 2006 (BioRob’06)*. IEEE, 483–488.
- [63] Francisco Martín, Carlos Agüero, José María Cañas, Gonzalo Abella, Raúl Benítez, Sergio Rivero, Meritxell Valenti, and Pablo Martínez-Martín. 2013. Robots in therapy for dementia patients. *Journal of Physical Agents* 7, 1 (2013), 48–55.
- [64] Maja J. Matarić and Brian Scassellati. 2016. Socially assistive robotics. In *Springer Handbook of Robotics*. Springer, 1973–1994.
- [65] Derek McColl, Wing-Yue Geoffrey Louie, and Goldie Nejat. 2013. Brian 2.1: A socially assistive robot for the elderly and cognitively impaired. *IEEE Robotics & Automation Magazine* 20, 1 (2013), 74–83.
- [66] Derek McColl and Goldie Nejat. 2013. Meal-time with a socially assistive robot and older adults at a long-term care facility. *Journal of Human-Robot Interaction* 2, 1 (2013), 152–171.
- [67] David Moher, Alessandro Liberati, Jennifer Tetzlaff, Douglas G. Altman, Prisma Group, et al. 2009. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Med* 6, 7 (2009), e1000097.
- [68] Elaine Mordoch, Angela Osterreicher, Lorna Guse, Kerstin Roger, and Genevieve Thompson. 2013. Use of social commitment robots in the care of elderly people with dementia: A literature review. *Maturitas* 74, 1 (2013), 14–20.

- [69] Wendy Moyle, Urska Arnautovska, Tamara Ownsworth, and Cindy Jones. 2017. Potential of telepresence robots to enhance social connectedness in older adults with dementia: an integrative review of feasibility. *International Psychogeriatrics* 29, 12 (2017), 1951–1964.
- [70] Wendy Moyle, Marguerite Bramble, Cindy Jones, and Jenny Murfield. 2018. Care staff perceptions of a social robot called Paro and a look-alike plush toy: A descriptive qualitative approach. *Aging & Mental Health* 22, 3 (2018), 330–335.
- [71] Wendy Moyle, Cindy Jones, Marie Cooke, Siobhan O'Dwyer, Billy Sung, and Suzie Drummond. 2013. Social robots helping people with dementia: Assessing efficacy of social robots in the nursing home environment. In *2013 6th International Conference on Human System Interactions (HSI'13)*. IEEE, 608–613.
- [72] Wendy Moyle, Cindy Jones, Marie Cooke, Siobhan O'Dwyer, Billy Sung, and Suzie Drummond. 2014. Connecting the person with dementia and family: A feasibility study of a telepresence robot. *BMC Geriatrics* 14, 1 (2014), 7.
- [73] Wendy Moyle, Cindy Jones, Toni Dwan, Tamara Ownsworth, and Billy Sung. 2019. Using telepresence for social connection: Views of older people with dementia, families, and health professionals from a mixed methods pilot study. *Aging & Mental Health* 23, 12 (2019), 1643–1650.
- [74] Wendy Moyle, Cindy J. Jones, Jenny E. Murfield, Lukman Thalib, Elizabeth R. A. Beattie, David K. H. Shum, Siobhan T. O'Dwyer, M. Cindy Mervin, and Brian M. Draper. 2017. Use of a robotic seal as a therapeutic tool to improve dementia symptoms: A cluster-randomized controlled trial. *Journal of the American Medical Directors Association* 18, 9 (2017), 766–773.
- [75] Mitsuru Naganuma, Eiichi Ohkubo, and N. Kato. 2015. Use of robotic pets in providing stimulation for nursing home residents with dementia. *Studies in Health Technology and Informatics* 217 (2015), 1009–1012.
- [76] NAO. 2020. <https://www.softbankrobotics.com/emea/en/nao>.
- [77] Heather L. O'Brien and Elaine G. Toms. 2008. What is user engagement? A conceptual framework for defining user engagement with technology. *Journal of the American society for Information Science and Technology* 59, 6 (2008), 938–955.
- [78] Luca Odetti, Giuseppe Anerdi, Maria Paola Barbieri, Debora Mazzei, Elisa Rizza, Paolo Dario, Guido Rodriguez, and Silvestro Micera. 2007. Preliminary experiments on the acceptability of animaloid companion robots by older people with early dementia. In *2007 29th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*. IEEE, 1816–1819.
- [79] World Health Organization. 2019. Dementia. Retrieved December 17, 2020, from <https://www.who.int/news-room/fact-sheets/detail/dementia>.
- [80] Lucas Paletta, Maria Fellner, Sandra Schüssler, Julia Zuschnegg, Josef Steiner, Alexander Lerch, Lara Lammer, and Dimitrios Prodromou. 2018. AMIGO: Towards social robot based motivation for playful multimodal intervention in dementia. In *Proceedings of the 11th Pervasive Technologies Related to Assistive Environments Conference*. ACM, 421–427.
- [81] Palro. 2020. <https://palro.jp/en/case>.
- [82] PePeRo. 2020. <https://www.robotcenter.co.uk/products/papero-robot-nec>.
- [83] Pepper. 2020. <https://www.softbankrobotics.com/emea/en/pepper>.
- [84] Giulia Perugia, Marta Diaz Doladeras, Andreu Català Mallofré, Matthias Rauterberg, and Emilia Barakova. 2017. Modelling engagement in dementia through behaviour. Contribution for socially interactive robotics. In *2017 International Conference on Rehabilitation Robotics (ICORR'17)*. IEEE, 1112–1117.
- [85] Giulia Perugia, Daniel Rodríguez-Martín, Marta Díaz Boladeras, Andreu Català Mallofré, Emilia Barakova, and Matthias Rauterberg. 2017. Electrodermal activity: Explorations in the psychophysiology of engagement with social robots in dementia. In *2017 26th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN'17)*. IEEE, 1248–1254.
- [86] Sandra Petersen, Susan Houston, Huanying Qin, Corey Tague, and Jill Studley. 2017. The utilization of robotic pets in dementia care. *Journal of Alzheimer's Disease* 55, 2 (2017), 569–574.
- [87] Richard Picking and Joanne Pike. 2017. Exploring the effects of interaction with a robot cat for dementia sufferers and their carers. In *2017 Internet Technologies and Applications (ITA'17)*. IEEE, 209–210.
- [88] Maribel Pino, Mélodie Boulay, François Jouen, and Anne Sophie Rigaud. 2015. “Are we ready for robots that care for us?” Attitudes and opinions of older adults toward socially assistive robots. *Frontiers in Aging Neuroscience* 7 (2015), 141.
- [89] Pleo. 2020. <https://www.pleoworld.com>.
- [90] RAMCIP. 2020. <https://ramcip-project.eu>.
- [91] Natacha Rouaix, Laure Retru-Chavastel, Anne-Sophie Rigaud, Clotilde Monnet, Hermine Lenoir, and Maribel Pino. 2017. Affective and engagement issues in the conception and assessment of a robot-assisted psychomotor therapy for persons with dementia. *Frontiers in Psychology* 8 (2017), 950.
- [92] Ryan. 2020. <http://dreamfacetech.com/ryan-2/>.

- [93] Selma Šabanović, Casey C. Bennett, Wan-Ling Chang, and Lesa Huber. 2013. PARO robot affects diverse interaction modalities in group sensory therapy for older adults with dementia. In *2013 IEEE 13th International Conference on Rehabilitation Robotics (ICORR'13)*. IEEE, 1–6.
- [94] Joan Saez-Pons, Dag Sverre Syrdal, and Kerstin Dautenhahn. 2015. What has happened today? Memory visualisation of a robot companion to assist user's memory. *Journal of Assistive Technologies* 9, 4 (2015), 207–218. DOI: <https://doi.org/10.1108/JAT-02-2015-0004>
- [95] Maha Salem, Gabriella Lakatos, Farshid Amirabdollahian, and Kerstin Dautenhahn. 2015. Would you trust a (faulty) robot? Effects of error, task type and personality on human-robot cooperation and trust. In *HRI'15*. Association for Computing Machinery, New York, NY, 141–148. <https://doi.org/10.1145/2696454.2696497>
- [96] Stefan Savenstedt, Per-Olof Sandman, and Karin Zingmark. 2006. The duality in using information and communication technology in elder care. *Journal of Advanced Nursing* 56, 1 (2006), 17–25.
- [97] SCITOS. 2020. <https://www.metalabs.com/en/mobile-robot-scitos-g5/>.
- [98] Arielle A. J. Scoglio, Erin D. Reilly, Jay A. Gorman, and Charles E. Drebing. 2019. Use of social robots in mental health and well-being research: systematic review. *Journal of Medical Internet Research* 21, 7 (2019), e13322.
- [99] Amanda Sharkey. 2014. Robots and human dignity: A consideration of the effects of robot care on the dignity of older people. *Ethics and Information Technology* 16, 1 (2014), 63–75.
- [100] Amanda Sharkey and Noel Sharkey. 2012. Granny and the robots: Ethical issues in robot care for the elderly. *Ethics and Information Technology* 14, 1 (2012), 27–40.
- [101] Takanori Shibata. 2012. Therapeutic seal robot as biofeedback medical device: Qualitative and quantitative evaluations of robot therapy in dementia care. *Proceedings of the IEEE* 100, 8 (2012), 2527–2538.
- [102] Takanori Shibata and Kazuyoshi Wada. 2011. Robot therapy: A new approach for mental healthcare of the elderly—a mini-review. *Gerontology* 57, 4 (2011), 378–386.
- [103] Takanori Shibata, Kazuyoshi Wada, Yousuke Ikeda, and Selma Sabanovic. 2009. Cross-cultural studies on subjective evaluation of a seal robot. *Advanced Robotics* 23, 4 (2009), 443–458.
- [104] Kazue Takayanagi, Takahiro Kiritani, and Takanori Shibata. 2014. Comparison of verbal and emotional responses of elderly people with mild/moderate dementia and those with severe dementia in responses to seal robot, PARO. *Frontiers in Aging Neuroscience* 6 (2014), 257.
- [105] Adriana Tapus. 2009. Improving the quality of life of people with dementia through the use of socially assistive robots. In *2009 Advanced Technologies for Enhanced Quality of Life*. IEEE, 81–86.
- [106] Meritxell Valenti Soler, Luis Agüera-Ortiz, Javier Olazarán Rodríguez, Carolina Mendoza Rebolledo, Almudena Pérez Muñoz, Irene Rodríguez Pérez, Emma Osa Ruiz, Ana Barrios Sánchez, Vanesa Herrero Cano, Laura Carrasco Chillón, et al. 2015. Social robots in advanced dementia. *Frontiers in Aging Neuroscience* 7 (2015), 133.
- [107] Kazuyoshi Wada and Takanori Shibata. 2007. Robot therapy in a care house-Change of relationship among the residents and seal robot during a 2-month long study. In *The 16th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN'07)*. IEEE, 107–112.
- [108] Kazuyoshi Wada, Takanori Shibata, Tomoko Saito, Kayoko Sakamoto, and Kazuo Tanie. 2005. Psychological and social effects of one year robot assisted activity on elderly people at a health service facility for the aged. In *Proceedings of the 2005 IEEE International Conference on Robotics and Automation*. IEEE, 2785–2790.
- [109] Kazuyoshi Wada, Takanori Shibata, Tomoko Saito, and Kazuo Tanie. 2002. Robot assisted activity for elderly people and nurses at a day service center. In *Proceedings 2002 IEEE International Conference on Robotics and Automation (Cat. No. 02CH37292)*, Vol. 2. IEEE, 1416–1421.
- [110] Di Wang, Budhitama Subagdja, Yilin Kang, Ah-Hwee Tan, and Daqing Zhang. 2014. Towards intelligent caring agents for aging-in-place: Issues and challenges. In *2014 IEEE Symposium on Computational Intelligence for Human-like Intelligence (CIHLI'14)*. IEEE, 1–8.
- [111] Rosalie H. Wang, Aishwarya Sudhama, Momotaz Begum, Rajibul Huq, and Alex Mihailidis. 2017. Robots to assist daily activities: Views of older adults with Alzheimer's disease and their caregivers. *International Psychogeriatrics* 29, 1 (2017), 67–79.
- [112] Sally Whelan, Kathy Murphy, Eva Barrett, Cheryl Krusche, Adam Santorelli, and Dympna Casey. 2018. Factors affecting the acceptability of social robots by older adults including people with dementia or cognitive impairment: A literature review. *International Journal of Social Robotics* 10, 5 (2018), 643–668.
- [113] S. Aabanovi AG, C. C. Bennett, W. Chang, and L. Huber. 2013. PARO robot affects diverse interaction modalities in group sensory therapy for older adults with dementia. In *2013 IEEE 13th International Conference on Rehabilitation Robotics (ICORR'13)*. 1–6.

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