


Friends from the Future: A Scoping Review of Research into Robots and Computer Agents to Combat Loneliness in Older People

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Background and Aim: Loneliness is a common problem in older adults and contributes to poor health. This scoping review aimed to synthesize and report evidence on the effectiveness of interventions using social robots or computer agents to reduce loneliness in older adults and to explore intervention strategies.

Methods: The review adhered to the Arksey and O'Malley process for conducting scoping reviews. The SCOPUS, PUBMED, Web of Science, EMBASE, CINAHL, PsycINFO, ACM Digital Library and IEEE Xplore databases were searched in November, 2020. A two-step selection process identified eligible research. Information was extracted from papers and entered into an Excel coding sheet and summarised. Quality assessments were conducted using the Mixed Methods Appraisal Tool.

Results: Twenty-nine studies were included, of which most were of moderate to high quality. Eighteen were observational and 11 were experimental. Twenty-four used robots, four used computer agents and one study used both. The majority of results showed that robots or computer agents positively impacted at least one loneliness outcome measure. Some unintended negative consequences on social outcomes were reported, such as sadness when the robot was removed. Overall, the interventions helped to combat loneliness by acting as a direct companion (69%), a catalyst for social interaction (41%), facilitating remote communication with others (10%) and reminding users of upcoming social engagements (3%).

Conclusion: Evidence to date suggests that robots can help combat loneliness in older adults, but there is insufficient research on computer agents. Common strategies for reducing loneliness include direct companionship and enabling social interactions. Future research could investigate other strategies used in human interventions (eg, addressing maladaptive social cognition and improving social skills), and the effects of design features on efficacy. It is recommended that more robust experimental and mixed methods research be conducted, using a combination of validated self-report, observational, and interview measures of loneliness.

Keywords: robots, embodied conversational agents, computer agents, older adults, loneliness, review

Introduction

Loneliness is a growing public health issue that disproportionately affects older adults.¹⁻³ Its global prevalence has been projected to increase in the coming decades as the population ages,⁴ and this may place a substantial burden on healthcare systems.² Loneliness is a subjective psychological state where a person

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perceives a mismatch between their actual and ideal social relations.⁵ It includes a set of cognitions and emotions that can perpetuate feelings such as perceived problems with social skills and support, reduced self-esteem and optimism, and increased feelings of anxiety, anger, and shyness.⁶

Loneliness is highly prevalent in older adults,^{2,3} which may be due to disability-related barriers to social interaction and more time spent living as widowers.⁴ Older adults experience a shrinking social network size,⁷ and typically have a lower digital literacy to use social media and other forms of communication technology. More recently, lockdowns of long-term care facilities as part of the COVID-19 pandemic response have amplified feelings of loneliness for many older adults as social visits were restricted.⁸

A growing body of research suggests that chronic loneliness can negatively affect the immune system and long-term health. Loneliness has been associated with increased feelings of distress, which may activate the body's "fight or flight" response.⁹ As part of this response, the sympathetic nervous system is activated and when this is maintained over a prolonged period, the body experiences dysregulation of the immune system. Chronic loneliness has been associated with several physical signs of an impaired immune response, including increased circulation of pro-inflammatory cytokines (especially interleukin-6),¹⁰ abnormal ratios of circulating white blood cells (eg, neutrophils, lymphocytes, and monocytes),¹¹ and under-expression of genes that contribute anti-inflammatory glucocorticoid response elements.¹² Chronic loneliness has also been associated with poorer antibody responses to an influenza vaccine¹³ and the Epstein-Barr virus.¹⁴

Chronic loneliness has been shown to increase the risk of long-term health issues, including stress-related physical morbidity (eg, coronary heart disease, high blood pressure, stroke),¹⁵ neurological conditions (eg, cognitive decline, Alzheimer's disease progression),^{16–18} and psychiatric conditions (eg, major depressive disorder, suicidal ideation, generalized anxiety).¹⁹ Loneliness also increases mortality risk.²⁰

A range of psychosocial interventions have been shown to be effective at improving loneliness in older adults.^{4,21,22} These interventions typically target one of the four areas: (1) modifying maladaptive social cognition, (2) improving social support, (3) increasing opportunities for social interaction, and (4) enhancing social skills. Loneliness interventions can be delivered in-person or facilitated remotely

through telephones or computers, and both have shown to be effective for older adults.⁴ The review concludes that the power of technology has yet to be harnessed.⁴

Research is beginning to show that artificial agents, such as social robots and computer agents, may be effective ways to deliver loneliness interventions to older adults. The definition of a social robot is discussed by Hegel et al²³ and is described as a robot with a social interface (a robot is a programmed physical entity that perceives and acts autonomously within a physical environment that has an influence on its behaviour). Social robots often resemble animals or humans, and several have been shown to improve loneliness in older adults.^{24,25} Animal-like social robots may improve loneliness in a similar way to animal-assisted therapy, by providing emotional support and increasing social interaction. Animal robots are more scalable and suitable to hospitals or environments with social restrictions than real animals. Other social robots have supported older adults with daily healthcare and companionship needs using touch-screen interactions,²⁶ and more recently with assessment interviews in care pathways using verbal conversational abilities.²⁷

Computer agents are screen-based, computer-generated entities²⁸ that may include a dialogue system and a digital embodiment (eg, an animation of a human face on a screen).²⁹ Examples include embodied conversational agents, virtual agents, digital humans, and game characters. Virtual agents (sometimes referred to as digital agents) are a form of embodied conversational agent that may include sophisticated social interaction abilities and an elaborate cognitive architecture.³⁰ Many computer agents are capable of engaging in complex conversations which may enable them to deliver a broad range of psychological interventions for loneliness, akin to a human therapist. Computer agents have been shown to help reduce loneliness in older adults by using daily conversations for emotional support, teaching stress management skills, and engaging in casual chit-chat.^{31,32}

The objective of this scoping review was to synthesize and report evidence on the effectiveness of interventions using social robots and computer agents to reduce loneliness in older adults. Prior review papers have focused on the effects of a broad range of psychosocial interventions on older adult loneliness,^{21,22,33} or on the effects of social robots in older adult healthcare more broadly.^{34–38} No reviews to date have collated the evidence on social robots and computer agents specifically for reducing loneliness in

older adults. This may help to guide directions for future research and care.

Materials and Methods

A scoping review was conducted to explore and synthesize the available literature related to the topic.³⁹ Scoping reviews cover the breadth of a research topic by summarising prior knowledge through thematic analyses,⁴⁰ yet are conducted systematically as researchers explicitly describe the literature selection process.^{41,42}

This review was conducted by following the Arksey and O'Malley⁴⁰ five-step process for conducting scoping reviews. This includes (1) identifying the research question, (2) identifying relevant studies, (3) selecting studies, (4) charting the data, and (5) collating, summarizing, and reporting the results. The review is also reported in accordance with the PRISMA-ScR extension for scoping reviews.⁴³ A protocol was registered with OSF Registries (<https://osf.io/dxheu/>) in November, 2020.

Identifying the Research Question

An initial search of the literature identified the promise of social robots and computer agents for reducing loneliness in older adults, but an absence of literature collating evidence of effects. This review therefore sought to explore the following research question: How effective are interventions that use social robots or computer agents for reducing loneliness in older adults, and what techniques do they use?

Identifying Relevant Studies

The following bibliographical databases were searched: SCOPUS, PUBMED, Web of Science, EMBASE, CINAHL, PsycINFO, ACM Digital Library and IEEE Xplore. The reference lists of the included literature were also reviewed, to potentially snowball literature that had been missed in the database searches. The search was conducted in November, 2020.

Key terms were determined using the Medical Subject Headers (MeSH terms). Keywords for the population included: "older adult*", "elder*", "senior*" and "aged". Those pertaining to the intervention included "robot*", "digital agent*", "virtual agent*" and "computer agent" and the keywords for the outcome included "lonel*", "companion*", "social isolation", "social support", "social networking", "social participation" and "social connectivity". All keywords were separated with the Boolean operator "OR" and each line (population, intervention and

Table 1 Examples of the Search Terms Used to Locate Literature Within Two Databases

Database	Keywords and Search Strategy
CINAHL	((older adult* or elder* or senior* or aged) and (robot* or digital agent* or virtual agent* or computer agent) and (lonel* or companion* or social isolation or social support or social networking or social participation or social connectivity))
PsycINFO	((older adult* or elder* or senior* or aged) and (robot* or digital agent* or virtual agent* or computer agent) and (lonel* or companion* or social isolation or social support or social networking or social participation or social connectivity)).mp. [mp=title, abstract, heading word, table of contents, key concepts, original title, tests and measures, mesh]

Note: The asterisk *symbol allowed for keywords to be treated as prefixes.

outcome) was separated with the operator "AND". The asterisk (*) symbol allowed for keywords to be treated as prefixes. For example, "robot*" includes the terms "robot", "robots" and "robotics". Examples of the search terms for two databases are exemplified in Table 1.

Selecting Studies

Search results were uploaded to Covidence⁴⁴ for screening using a two-stage approach. Duplicates were identified and removed by Covidence. Two authors (NG and KL) first independently assessed each article by initially reading the title and abstract, to determine whether articles met the inclusion criteria. The screening process was then repeated a second time, whereby both authors read the full text. Conflicts during each round were identified and discussion resolved any disagreements. A third reviewer (EB) helped to make the final decision, if consensus was not reached. This process was displayed in a PRISMA flowchart.

A study was considered eligible if it was published in English, included a sample of older adults, explored the outcome of loneliness or similar (eg social connection, social networks or reduced isolation) and where the intervention was a social robot or a computer agent (as identified by the study authors). Older adults were defined as 50 years or older, as changes (eg bereavement, loss of social roles, reduced social networks and cognitive decline) during the second half of life may exacerbate loneliness.^{4,7,45} No restrictions were set on the research method, date, setting or methodological quality. Thus, experiments, pilot studies, feasibility studies, qualitative and observational studies were included. Given that research was not

limited by methodological quality, refereed full-length conference papers and theses were included in addition to peer-reviewed journal articles.

Charting the Data

Two authors (NG and ML) extracted the following information into a charting sheet on Excel: author/date, robot or computer agent used, setting, sample age, sample gender, sample size, study duration, study design (eg experiment, observation, interviews), effect size and outcome/results (regarding loneliness).

Quality assessments were conducted using the Mixed Methods Appraisal Tool (MMAT).⁴⁶ The MMAT was deemed appropriate as it provides a consistent tool for evaluating qualitative, quantitative randomised controlled trials, quantitative non-randomized studies, quantitative descriptive and mixed-methods research. Each study was assessed independently by two authors (NG and ML), and a discussion ensued about their quality. Consensus was reached on methodological limitations, and these were synthesised and described.

Collating, Summarizing, and Reporting the Results

Results in the charting sheet were summarised and presented in tables. The focus of the research topic was examined in detail, including the intervention strategies and how effectively the interventions impacted loneliness in older adults. Other information extracted included the context/settings of the research, interventions used and the quality of the research. This information helped to identify gaps in knowledge to inform future research.

Results

In this review, 946 studies were identified and imported into Covidence for screening. After deduplication, the abstracts and titles of 759 studies were independently reviewed for eligibility by two authors (NG and KL). The full-text of 94 studies were then reviewed by both authors, revealing that 65 studies were no longer eligible to be included. Reasons for exclusion were inappropriate outcomes (n=35) (ie, those not related to loneliness), technical papers (n=12), inappropriate population (n=7) (eg, younger adults or children), inappropriate type of publication (n=4) (eg, posters or conference abstracts), full-text not available (n=4), not in English (n=2) and inappropriate intervention (n=1) (ie,

not robots nor computer agents). Twenty-nine studies were included in this review. The PRISMA-ScR flow-chart in [Figure 1](#) shows the identification and screening process.

Characteristics of the Included Studies

Eighteen studies were observational^{26,32,47–62} and 11 were experimental.^{24,25,31,63–69} One was part of a larger RCT.⁷⁰ Ten studies were conducted in the United States of America,^{24,31,32,47,51,59,60,62,66,69} five in New Zealand,^{26,64,65,68,70} three in Australia^{54,55,61} and two in Germany.^{49,50} The remaining studies were conducted in Ireland,⁶³ Taiwan,²⁵ Canada,⁵⁷ Israel,⁶⁷ Norway,⁵² Japan⁵³ and Finland.⁵⁶ Coşar⁵⁸ and D'Onofrio⁴⁸ each conducted their studies across three countries (Greece, UK and Poland, and Italy, UK and Ireland respectively).

Across the studies, sample sizes varied from five to 95 participants, with a mean of 22 and an overall total of 632 participants. On average, participants were aged between 62⁶² and 85.8 years.⁵⁸ Women participated more than men and the percentage of female participants ranged from 50%⁴⁹ to 100%.⁴⁷ Characteristics of the included studies are further summarised in [Table 2](#).

Quality of the Included Studies

The MMAT⁴⁶ considers five specific criteria related to methods (eg, methodological approach, research questions, data collection and analysis) and presentation of findings for each of the five study designs. These include criteria such as whether the qualitative approach is appropriate to answer the research question in the qualitative study design, and whether randomisation was appropriately performed in the quantitative RCT study design.

Cohen's kappa was calculated using IBM SPSS Statistics (version 23) to determine interrater reliability between the two authors (NG and ML) conducting the quality assessments. There was moderate agreement between the two raters, $\kappa = 0.592$ (95% CI, 0.435 to 0.749, $p < 0.0005$), with 86% agreement (124/145). Absolute agreement on the MMAT quality criteria was then reached through discussion.

[Supplementary Table 1](#) presents the quality assessments of each study. Overall, eight studies met all five criteria^{25,47,48,50,51,55,57,61,70} and 12 met four criteria^{26,31,32,50,52–54,60,63–65,67,68} demonstrating moderate to high quality. The qualitative approach or analysis method were not reported for eight mixed methods

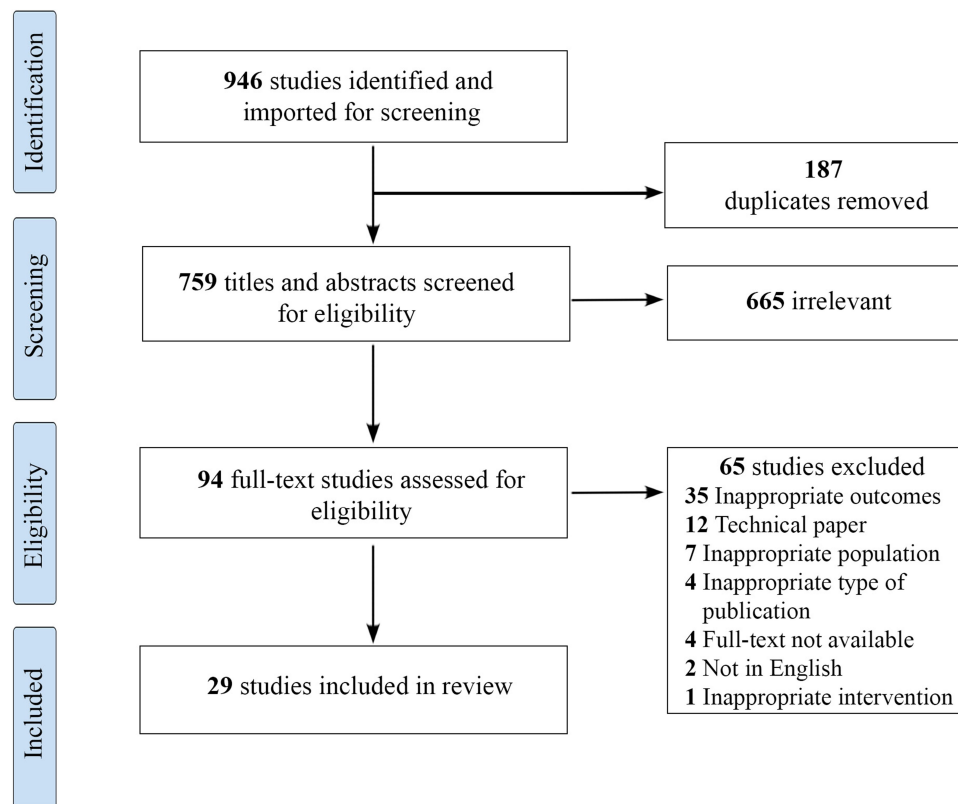


Figure 1 PRISMA-ScR flowchart showing study identification and screening process.

Note: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* 2021;372:n71.

studies^{50,54,56,58,59,62,64,66,69} and the rationale for using mixed methods was also not provided by five.^{56,58,59,62,66,69} In five studies that were either solely randomised controlled trials or RCTs in addition to mixed methods, blinding was either not possible, or not conducted.^{24,64–66,68} Five studies indicated possible incomplete data, or nonresponse bias or retention of less than 80% of participants, resulting in incomplete data.^{26,52,60,65,66} For three quantitative non-randomised studies, confounding factors (eg imbalance of gender or use of robot across groups) may have not been accounted for.^{32,53,63}

Interventions Studied

Types of Interventions

Twenty-four studies investigated the effects of a social robot on loneliness outcomes. The most commonly used robot was the seal companion robot, Paro, which was investigated in six studies.^{25,52,65,68–70} AIBO,^{24,53} MARIO^{48,63} and iRobi^{26,64} were investigated in two studies each, and the remainder of the robots were

investigated in one study (see [Table 2](#)). Five studies^{31,32,47,62,66} used virtual agents. Two used Care Coach,^{32,47} two used Tanya^{31,62} and the final study investigated differences between the AlwaysOn System delivered as both a virtual agent and a robot.⁶⁶

Length of Interventions

As shown in [Table 2](#), the study durations ranged widely from 10-minute sessions, to up to 1 year. The studies also varied widely on whether the participants had time-limited sessions over the study duration, or whether the participants had unlimited 24/7 access to the robot or computer agent over the study period. Therefore, exposure to the interventions was mixed across studies.

Settings and Participants

The majority of studies took place in retirement homes and long-term care facilities (n=20). Six studies were conducted within participants' homes,^{26,31,51,55,62,66} two within laboratory settings^{57,67} and one was conducted in a hospital.³² All 29 studies were conducted with older

Table 2 Characteristics and Summary of the Included Research

First Author, Date	Robot/Agent; Name; Description of Intervention	Setting; Country	Sample Mean Age (Range)	Sample Gender (f: Female; m: Male)	Sample Size	Study Design and Duration	Loneliness Measure	Results	Technique	Effect Size (Cohen's d)
Abdollahi, 2017 ⁵⁹	Robot; Ryan Companionbot Home companion that converses, facilitates memory work (shows photographs of past), plays cognitive games and shows videos.	Homes in retirement villages; USA	n/s	n/s	6	Observational, mixed methods; longitudinal 3–6 weeks	Recorded conversations with the robot; survey on likeability and acceptability; caregiver feedback	<ul style="list-style-type: none"> The robot established a connection with participants. Participants liked interacting with Ryan and accepted it as a companion although it cannot replace human companionship. They spent much time with the robot, liked speaking with it and believed it helped them maintain their schedule, improve their mood, and stimulate them mentally. <ul style="list-style-type: none"> Participants were sad to see the robot go. 	Direct companion	n/a
Banks, 2008 ²⁴	Robot; AIBO Animal-assisted therapy with AIBO for 8 weeks (30 min sessions weekly) may help to decrease loneliness and attachment may occur.	Long term care facility; USA	n/s	n/s	38	Experiment (RCT): control (no animal assisted therapy) and real dog comparator 8 weeks	UCLA; modified MLAPS	<ul style="list-style-type: none"> Those who received animal-assisted therapy (AAT) were significantly less lonely than those who did not. The loneliest individuals improved most with AAT and the most lonely in the control group became more lonely. The UCLA showed the control group was statistically different from the AAT (AIBO/dog) groups, but there was no statistically significant difference between the AIBO and Dog groups. The MLAPS showed significant attachment in both AAT (AIBO or dog) groups. These were not statistically different. 	Direct companion	n/s

Barrett, 2019 ⁶³	Robot; MARIO Facilitated sessions 3 times weekly (60mins) for 4 weeks. Functions: games, music, memories (their photos), news and calendar (eg social activities, birthdays).	Nursing home; Ireland	83	f: 7; m: 3	10	Experiment; single group, pre-post 4 weeks	Bespoke questionnaire; observations	<ul style="list-style-type: none"> Participants' social connectedness increased through more frequent engagement with others (eg staff or other residents) while using MARIO. This included initiating interactions to tell others about MARIO or show the applications. MARIO was a topic of conversation between participants and their family, and had an impact on those not involved in the study (eg other residents danced to MARIO's music). 	Catalyst for social interaction	n/a
Bott, 2019 ³²	Agent; Care Coach Conversational animal avatar used in hospital to re-orient users (to mitigate delirium risk), elicit toilet needs (prevent falls), and engage in social interaction.	Community hospital; USA	76	f: 52; m: 43	95	Observational; case control pre-post test. Control: daily 15-min visit from a nursing student n/s	3-item UCLA	<ul style="list-style-type: none"> Participants with avatars experienced a significant decrease in loneliness, when compared with those in the control group. 	Direct companion	UCLA-d=0.36

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Table 2 (Continued).

First Author, Date	Robot/Agent; Name; Description of Intervention	Setting; Country	Sample Mean Age (Range)	Sample Gender (f: Female; m: Male)	Sample Size	Study Design and Duration	Loneliness Measure	Results	Technique	Effect Size (Cohen's d)
Broadbent, 2014 ⁶⁴	Robot; iRubiQ and Cafero Personal service/homecare robots to improve quality of life, reduce depression, and improve medication adherence.	Retirement village; New Zealand	85.23 (72-94)	f: 15; m: 14	29	Experiment (randomised cross-over trial); control: no robot 12 weeks	Interviews	<ul style="list-style-type: none"> 17 responses were positive and included the robot being a friend. 7 reported positive effects, of which 2 included companionship. Participants also found the Skype function useful. 	Direct companion; Facilitate communication	n/a
Chen, 2020 ²⁵	Robot; PARO 24/7 use of harp seal Paro by individuals (at home) may help to reduce depression and loneliness and improve quality of life.	Long-term care facility; Taiwan	81.1 (65-93)	f: 13; m: 7	20	Experiment; mixed methods; control: no robot 16 weeks	Interviews; version 3 (20-item) UCLA	<ul style="list-style-type: none"> Results from the Paro intervention (from T2 to T4) revealed significant positive changes for loneliness. After the intervention (from T2 to T4), there were significant differences in every time point comparison. Paro provided opportunities for social interaction with others, acted as a companion, brought comfort and helped participants live 'meaningful lives.' Participants thought that Paro could reduce loneliness through direct interaction (eg stroking, petting, conversation) or indirect interactions (eg putting Paro beside them). 	Direct companion; Catalyst for social interaction	UCLA- Paro vs end of 8 weeks- d=2.50

Chi, 2017 ⁴⁷	Agent; Care Coach Conversational animal/pet avatar used at home that provides companionship, entertainment, reminders, and assistance	Homes, retirement complex; USA	78.3 (68–89)	f: 10, m: 0	10	Observational; mixed-methods; longitudinal 3 months	Interviews	<ul style="list-style-type: none"> Most stated that the agent provided companionship. Some reported the relationship as superficial because of the agent's limited conversational ability. Some wanted to bring the agent outside as it could help them to initiate conversations with others. Most enjoyed introducing the agent to friends/families and reported that it enhanced their social interactions with others. 	Direct companion; Catalyst for social interaction	n/a
Coşar, 2020 ⁵⁸	Robot; TIAGO (with embedded home IoT) Homecare robot that delivers cognitive games, healthy tips, facilitates exercise, provides an agenda (calendar), enables calling and presents the weather/news.	Care homes; Greece, UK, Poland	n/s (66–90)	f: 7, m: 4	11	Observational; qualitative; longitudinal 10 weeks	Interviews	<ul style="list-style-type: none"> The robots presence (eg waiting at home) helped to alleviate and cope with loneliness and made the environment more friendly. 	Direct companion; Catalyst for social interaction	n/a

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Table 2 (Continued).

First Author, Date	Robot/Agent Name; Description of Intervention	Setting; Country	Sample Mean Age (Range)	Sample Gender (f: Female; m: Male)	Sample Size	Study Design and Duration	Loneliness Measure	Results	Technique	Effect Size (Cohen's d)
D'Onofrio, 2019 ⁴⁸	Robot; Kompa ¹ 2 (MARIO) Companion and home support robot for people with dementia. Plays music, helps users to reminisce, plays games, shows news and calendar activities and facilitates social engagement.	Residential care, hospital, community; Italy, UK, Ireland	77.08 (55-93)	f: 24; m: 14	38	Observational; quantitative; pretest, posttest n/s	MSPSS; observations	<ul style="list-style-type: none"> There was no statistical difference when comparing the total MSPSS before and after interaction. When looking at only the posttest score, those aged 68-76 years perceived that they had major social support and friends to support them. The people aged 77-85 years perceived they had major family support. During interactions with MARIO, participants spoke about various things, including MARIO, staff, other residents, themselves, the researchers and other. In Ireland, Italy, and the UK the topic of conversations was most often MARIO. 	Direct companion	MSPSS (before vs after)-d=0.61
Fields, 2019 ⁶⁰	Robot; NAO The robot delivers drama therapy (participatory Shakespearean arts activities) one-to-one to help reduce loneliness.	Residential care; USA	85.80 (77-92)	f: 11; m: 4	15	Observational; quantitative; pretest, posttest; longitudinal 3 sessions (each 10mins)	Revised (3-item) UCLA	<ul style="list-style-type: none"> Loneliness significantly decreased across six time periods. The decline was slightly greater in those without dementia, compared to those with dementia. 	Direct companion	UCLA (pre-post test x 3) Session 1-d= 0.45 Session 2-d= 0.12 Session 3-d= 0.25

Gross, 2019 ⁴⁹	Robot: SYMPARTNER Home companion robot that provides functional support. Finds and greets users, wakes them, gives reminders, suggests activities, presents the news/weather forecast, helps video call, shows photos/videos, and responds to emergencies.	Residential complex; Germany	74 (62-94)	f: 16; m: 4	20	Observational; qualitative; longitudinal 1 week	Interviews	<ul style="list-style-type: none"> Majority developed a personal relationship with the robot companion. The robot has potential to be accepted as a meaningful social companion. It provided support in everyday life (eg structure/reminders), provided cognitive stimulation, provided support to keep users on the go and provided emotional stimulation (eg humour). The personal addressing by the robot was helpful. 	Direct companion; Reminder of social interaction	n/a
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Table 2 (Continued).

First Author, Date	Robot/Agent Name; Description of Intervention	Setting; Country	Sample Mean Age (Range)	Sample Gender (f: Female; m: Male)	Sample Size	Study Design and Duration	Loneliness Measure	Results	Technique	Effect Size (Cohen's d)
Gross, 2015 ⁵⁰	Robot: Max Homecare and companion robot that finds users, gives reminders, acts as a fitness coach, helps video call, monitors vital signs, shows photos/videos, presents the weather forecast and responds to emergencies.	Resident complex; Germany	n/s (68–92)	f: 6; m: 3	9	Observational; qualitative; longitudinal 3 days	Interviews	<ul style="list-style-type: none"> Participants talked about a co-presence of the robot. Most treated the robot like a social being, although they were aware that it was a machine. 8/9 named it and were sad to see it go. Participants praised it, felt sorry for failures, ranted to it, cared about it and asked for its opinion. All spoke to it, although it cannot understand them. Participants frequently touched/stroked it. This was part of the emotional bonding. The robotic companion helped to cope with boredom and feelings of loneliness. 	Direct companion	n/a

Hudson, 2020 ⁵¹	Robot; Joy for All companion pets Robot companion pets used at home by self-identified lonely individuals, with the intention of alleviating loneliness.	Homes; USA	76 (65–90)	f: 10; m: 10	20	Observational; qualitative; longitudinal 4 weeks	Interviews	<ul style="list-style-type: none"> Participants with less social connections (and less opportunity) described more engagement with the robot. They were more likely to keep them close and touch them. Some felt comfort/companionship when taking the robot with them during the day. Participants named their robots and showed them to others. This increased opportunities to connect, especially unknown people. The robot helped forge new connections for those who were shy/felt uncomfortable interacting with new acquaintances. A widow explained the pet helped her adjust to her husband's absence, while those who lived alone used the robot as a proxy for a conversational partner. Many thought the robot's presence positively influenced their feelings of loneliness. The robot was as a friend/companion with whom residents formed a strong attachment. 	Direct companion; Catalyst for social interaction	n/a
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Table 2 (Continued).

First Author, Date	Robot/Agent; Name; Description of Intervention	Setting; Country	Sample Mean Age (Range)	Sample Gender (f: Female; m: Male)	Sample Size	Study Design and Duration	Loneliness Measure	Results	Technique	Effect Size (Cohen's d)
Jøranson, 2016 ⁵²	Robot; Paro Group sessions to reduce apathy and increase social interaction for residents with dementia.	Nursing homes; Norway	84.65 (62–92)	f: 16; m: 7	23	Observational; quantitative; longitudinal 12 weeks	Video recordings of sessions	<ul style="list-style-type: none"> Smile/laughter toward other participants increased; conversations with Paro on the lap showed a decrease during the intervention. Conversation with and without Paro on the lap were each registered about 10% of the time, resulting in a total conversation time of 20%. This suggests that participants do not need to have Paro on their lap to contribute to conversations and could indicate that Paro is suitable for increase interactions in groups. Smile/laughter toward Paro and toward other participants/activity leaders was registered more than 2% of the time. 	Catalyst for social interaction	n/a
Kanamori, 2003 ⁵³	Robot- AIBO Interaction with pet-type robot AIBO to help maintain or improve quality of life.	Nursing homes; Japan	68.2	f: 5; m: 1	6	Observational; quantitative; pre-post test; longitudinal 7 weeks	AOK Loneliness Scale	<ul style="list-style-type: none"> The posttest scores of AOK Loneliness Scale with pet-type robot were significantly lower than the pretest scores. The robot acted as a catalyst for social interaction by stimulating sociability. 	Catalyst for social interaction	AOK scores (pre to post difference)- d= 1.32 Baseline- M= 1.00 ± 1.26 Post- M= 3.33 ± 2.16

<p>Khosla, 2019⁵⁵</p>	<p>Robot; Betty Home-based social robot that facilitates communication and helps to support care services in people living with dementia.</p>	<p>Homes; Australia</p>	<p>n/s (75–85)</p>	<p>n/s</p>	<p>5</p>	<p>Observational; mixed methods; longitudinal 3 months</p>	<p>Video recordings of engagement; survey about attitudes</p>	<ul style="list-style-type: none"> ● Positive emotion: participants expressed positive emotion during 6%–10% of the interaction with their robot. ● Two participants strongly agreed that they wanted Betty to come back to them again, whereas others responded neutrally. ● 4/5 agree/strongly agree that Betty is a friend. 	<p>Direct companion</p>	<p>n/a</p>
<p>Khosla, 2013⁵⁴</p>	<p>Robot; Matilda Improves emotional wellbeing (mental and physical health outcomes) and supports healthcare workers in personalizing care.</p>	<p>Residential care facilities; Australia</p>	<p>n/s (71–98)</p>	<p>f: 28; m: 6</p>	<p>34</p>	<p>Observational; mixed methods; longitudinal 2–5 months</p>	<p>Video-recordings of interactions; interviews</p>	<ul style="list-style-type: none"> ● The games and sensory enrichment activities facilitated acceptability of Matilda and encouraged reciprocity/cooperation among older people through their participation in one-to-one interaction activities (eg diet, calendar reminders, and playing quiz). ● The games facilitated interaction with others and brought residents out of social isolation. 	<p>Catalyst for social interaction</p>	<p>n/a</p>

(Continued)

Table 2 (Continued).

First Author, Date	Robot/Agent; Name; Description of Intervention	Setting; Country	Sample Mean Age (Range)	Sample Gender (f: Female; m: Male)	Sample Size	Study Design and Duration	Loneliness Measure	Results	Technique	Effect Size (Cohen's d)
Kidd, 2006 ⁶⁹	Robot; Paro Group sessions in a nursing home to generate social interaction.	Nursing home; USA	n/s	n/s	23	Experiment; Observational; mixed methods; 3 groups (Paro turned on, Paro turned off, No Paro) 4 months	Observations; Social Interaction Questionnaire about Paro	<ul style="list-style-type: none"> • Sessions where Paro was turned on were quieter than those where dialog was prompted. However, these sessions were more lively than other activities in homes, which were often silent. Evidently, Paro (whether on or off) is an improvement over normal settings. • When Paro was turned on many interactions consisted of short exchanges and silence. • Those in the robot on condition felt more encouraged to interact with one another and were more likely to play with the robot. • The novelty effect appeared to wear off in the robot off condition. • In the on condition (with a caregiver present), there is continuing interaction with the caregiver and other residents. • Some residents expressed an attachment to Paro. They named it and conversed with it, using its noises. 	Catalyst for social interaction	n/a

Liang, 2017 ⁶⁵	Robot; Paro Harp seal companion Paro is used at home and in a day care setting to investigate affective, social, behavioural, and physiological effects.	Dementia day cares; New Zealand	n/s (67–98)	64% female	30	Experiment (RCT); mixed methods; control: standard care 12 weeks	Observations	<ul style="list-style-type: none"> Participants in the Paro group showed significantly more positive facial expressions and talked to staff and researchers more, compared to those in the control group. No significant differences in negative facial expressions and other social responses were observed between participants in either condition. Some had conversations with Paro, where they would interpret Paro's noises and respond. Paro encouraged interactions with visitors and other family members. It was a talking point and participants enjoyed showing it off. 	Catalyst for social interaction	n/a
Moyle, 2014 ⁶¹	Robot; Giraff Telepresence robot that enhances engagement between family and a person with dementia living in long-term care.	Long-term dementia care facility; Australia	85 (79–89)	f: 4; m: 1	5	Observational; mixed methods; longitudinal 6–8 weeks	Video recordings; interviews	<ul style="list-style-type: none"> Giraff reduced social isolation and increased connection by enabling residents and their families to virtually visit each other. This was important for those who lived far away or may not have seen each other for some time. Being able to see the family members' face was important in maintaining connection and enhanced communication compared to phone calls. 	Facilitate communication	n/a

(Continued)

Table 2 (Continued).

First Author, Date	Robot/Agent; Name; Description of Intervention	Setting; Country	Sample Mean Age (Range)	Sample Gender (f: Female; m: Male)	Sample Size	Study Design and Duration	Loneliness Measure	Results	Technique	Effect Size (Cohen's d)
Niemela, 2019 ⁵⁶	Robot; Double Telepresence robot that facilitates communication at a residential care home.	Residential care facility; Finland	n/s (83–93)	f: 2; m: 1	3	Observational, pre-post test 6–12 weeks	Interviews; observations	<ul style="list-style-type: none"> Video connection increased feelings of family members' presence by opening connection to family not at the facility. This connection was felt stronger than on the phone. 	Facilitate communication	n/a
Orejaana, 2015 ²⁶	Robot; iRobi Robot helps older adults in rural communities (who are often isolated) with day to day healthcare and provides companionship.	Homes; New Zealand	85.5 (76–94)	f: 4; m: 1	5	Observational; case studies; longitudinal 3–12 months	Interviews	<ul style="list-style-type: none"> There was no influence on external social connections as Skype was not widely used. Residents already communicated with family. It felt like they had a companion at home and they did not feel so alone. They felt that the robot lighting up was its way of interacting with them. All reported that they would miss the robot when it went, with one patient describing the robot as being part of the family. 	Direct companion	n/a

Ring, 2015 ³¹	Agent: Tanya Conversational agent to provide longitudinal social support to isolated older adults.	Homes; USA	65 (56-75)	f: 11; m: 1	12	Experiment; longitudinal; between subjects' design (proactive vs passive agent) 1 week	UCLA; self-reported state loneliness, comfort with agent, and relationship with agent (5-point Likert); diary entries; semi-structured interviews	<ul style="list-style-type: none"> There was a non-significant trend towards greater reductions in UCLA loneliness scores in the proactive group, compared to the passive group. Diary measures showed participants reported feeling less lonely with the proactive system than the passive system. Significant correlations found between time spent interacting with agent and change in UCLA scores, state loneliness, degree of comfort with agent, and degree of relationship formed with agent. Participants reported the agent gave them social support and acted as a friend or pet. 	Direct companion	UCLA Change scores across groups- d=0.92. Diary measure between groups d = 0.51
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Table 2 (Continued).

First Author, Date	Robot/Agent; Name; Description of Intervention	Setting; Country	Sample Mean Age (Range)	Sample Gender (f: Female; m: Male)	Sample Size	Study Design and Duration	Loneliness Measure	Results	Technique	Effect Size (Cohen's d)
Robinson, 2013 ⁶⁸	Robot; Paro Paro mimics animal assisted therapy in a rest home setting and facilitates social interaction.	Residential care facility; New Zealand	n/s (55–100)	f: 27; m: 13	40	Experiment (RCT); control: activities as normal (eg interacting with resident dog) 12 weeks	UCLA; observations	<ul style="list-style-type: none"> There was a significant difference between groups in loneliness change over time, whereby loneliness decreased in the Paro group, but increased in the control group. When comparing social interactions with Paro or the resident dog, residents touched and talked to the robot significantly more. The number of residents who stroked Paro was higher when accounting for the number of people present. Residents talked to each other significantly more about Paro. Staff also started conversation more about Paro, but they did not talk to the robot significantly more than they talked to the dog. More residents talked to each other in the Paro group than in normal activities and when compared to activities with the dog. 	Catalyst for social interaction	$\eta^2 = 0.18$ Change scores (pre-post)- differences between 2x groups- $d = 1.11$

Robinson, 2016 ⁷⁰	Residential care facility, New Zealand	84.4	f: 14; m: 6	20	Part of an experiment (RCT); qualitative analysis of Paro only group 12 weeks	Observations; interviews	<ul style="list-style-type: none"> Companionship: some residents developed an emotional attachment to the robot. They treated it as a pet or friend. Participants who enjoyed Paro were also observed to enjoy sharing it and talking about it. Participants wanted to show the robot to friends/family and other residents. Staff thought that Paro would be good for reducing loneliness, comforting distressed residents or entertaining residents. The reduction in loneliness reported in the RCT was believed to be a result of increased social communication than of companionship from the robot. 	Direct companion; Catalyst for social interaction	n/a
Sidner, 2018 ⁶⁶	Homes; USA	66 (55–91)	n/s	44	Experiment; pretest, posttest; 3 groups: robot, virtual agent, control; nothing 30 days	NSSQ; UCLA; Relationship Closeness Inventory; 5-point likert scale of relationship with agent; interviews; open-ended questions	<ul style="list-style-type: none"> The were no significant differences between the groups for the UCLA and social support. During the interviews, multiple participants said that the agent provided social support and companionship. The agent's personality allowed it to be supportive but not judgmental. Multiple found that the agent "kept [them] company." 	Direct companion	n/s – Insufficient information (no SD)

(Continued)

Table 2 (Continued).

First Author, Date	Robot/Agent Name; Description of Intervention	Setting; Country	Sample Mean Age (Range)	Sample Gender (f: Female; m: Male)	Sample Size	Study Design and Duration	Loneliness Measure	Results	Technique	Effect Size (Cohen's d)
Yardoulakis, 2011 ⁶²	Agent; Tanya This embodied conversational agent was controlled via Wizard-of-Oz and provides social support to isolated older adults.	Homes; USA	62 (56–73)	f: 10; m: 2	12	Observational; Mixed method; pre test 1 week	UCLA at baseline only; agent satisfaction questionnaire; interviews	<ul style="list-style-type: none"> Participants conversed about many topics including weather, family and future plans. All had something positive to say about their experience. Many reported that the agent provided a sense of companionship, while a few felt no connection. One participant felt worse when talking to the agent as she became aware of her lack of friends. 	Direct companion	n/a
Wang, 2017 ⁵⁷	Robot; Ed Robot for people with Alzheimer's disease. Provides stepwise prompting to complete at-home activities.	Simulated home; Canada	77.8 (59–88)	f: 6; m: 4	10	Observational 1 day	Interviews	<ul style="list-style-type: none"> Participants gave examples of how the robot may improve interactions and relationships by avoiding conflict, decreasing worry/anxiety, and moderating frustrating interactions. Perceptions ranged from the robot being a friend to a machine. The robot was seen to provide companionship to someone who lives alone, as they can talk to it, without being judged. 	Direct companion	n/a

Zuckerman, 2020 ⁵⁷	Robot; Prototype robot Robot cognitive word game for healthy older adults, with social interaction as secondary function.	Laboratory; Israel	75	f: 21; m: 18	39	Experiment; Mixed methods; 3 conditions; Companion; Game; and No-Function 1 day	Interviews	<ul style="list-style-type: none"> Participants associated the robot's gestures with feelings related to being-seen. This theme was similar across the conditions. The robot's movements/gestures showed it was paying attention. Some felt they had formed a connection. 14/39 participants described the robot's potential to relieve loneliness, emptiness, and sadness. 	Direct companion	n/a
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Abbreviations: n/s, not stated; n/a, not applicable; UCLA, University of California; Los Angeles Loneliness Scale; MLAPS, modified Lexington Attachment to Pets Scale; MSPSS, Multidimensional Scale of Perceived Social Support; AOK Loneliness Scale; Ando, Osada and Kodama Loneliness Scale; NSSQ, Norbeck Social Support Questionnaire; yellow highlight, positive qualitative evidence for effectiveness; green highlight, positive quantitative evidence for effectiveness; blue highlight, mixed evidence or no evidence for effectiveness.

adults, with five studies specifically focusing on older adults with dementia,^{48,59,61,63,65} and one on older adults with Alzheimer's disease.⁵⁷

Loneliness Measures

Loneliness was measured through both qualitative and quantitative data. At baseline, older adults in many studies did not need to meet specific criteria related to loneliness, to participate.^{25,26,32,47,48,50,52–58,60,61,63–65,67–70} In others, participants were included if they lived alone.^{31,49,59,62,66} Few studies used validated measures to identify lonely individuals to participate.^{24,51}

Seventeen studies used mixed methods,^{25,26,31,47,49,54–56,58,59,61,62,64–67,69} eight were quantitative^{24,32,48,52,53,60,63,68} and four were qualitative.^{50,51,57,70} The majority of studies used semi-structured interviews with the users (n=17) or caregivers/staff (n=3) to obtain qualitative data about loneliness and social support changes. Eleven studies reported observations of the user while interacting with the robot or computer agent, and three recorded the conversations that took place between the user and the robot.^{48,59,62} The quantitative measures included; the 20-item (n=6) and 3-item (n=2) UCLA Loneliness Scale,⁷¹ the modified Lexington Attachment to Pets Scale (MLAPS; n=1),⁷² the Multidimensional Perceived Social Support Scale (MSPSS; n=1),⁷³ the Ando-Osada-Kodama (AOK) Loneliness Scale (n=1),⁷⁴ the Norbeck Social Support Questionnaire (NSSQ; n=1)⁷⁵ and the Relationship Closeness Inventory (n=1).⁷⁶ Lastly, four studies used surveys of acceptability and attitudes of the robots as indicators of possible relationships formed between the user and robot/agent.

Effect of Interventions on Loneliness

Positive Effects

The majority of the studies found positive effects of social robots or computer agents on at least one of the loneliness outcome measures, as shown in Table 2 and summarised below. No substantial differences were found in the effects on loneliness between the studies of people living with dementia/Alzheimer's disease and studies of cognitively intact people. Therefore, these results are discussed together.

Six of the seven studies that measured loneliness with the UCLA Loneliness Scale (either the 20 or three-item version) found that interacting with AIBO,²⁴ Paro,^{25,68} NAO,⁶⁰ Tanya³¹ or the Care Coach Avatar³² significantly decreased loneliness levels. The other study only used the UCLA to

measure loneliness at baseline.⁶² Loneliness, as measured by the AOK Loneliness Scale, was also found to be significantly lower after interaction with AIBO.⁵³ However, Sidner⁶⁶ found no significant difference in loneliness, as rated by the 20-item UCLA Loneliness Scale, between the control groups and the AlwaysOn system as either a robot or virtual agent. Despite this, interviews demonstrated that the intervention provided companionship to some participants. The lack of significant effects in the statistical analysis may be due to lack of power given the small sample size and the authors discuss issues with recruitment.

Other quantitative measures showed similar results. Banks²⁴ found that interacting with AIBO led to an increase in attachment, similar to that of interacting with a dog. Interacting with the MARIO robot led to an increase in perceived social support in particular age groups; however, this was not significant if the sample as a whole was examined.⁴⁸ Ring³¹ found that interacting with a proactive conversational agent decreased self-reported loneliness and increased comfort and relationship with the agent; outcomes which were significantly correlated with the time spent interacting with the agent. Lastly, surveys on acceptability found that users were highly satisfied with the Tanya agent^{31,62} and liked interacting with the robots, saw them as companions or friends, and wanted to continue interacting with them in the future, indicating relationships with the robots were formed.^{55,59}

Cohen's *d* values are reported as estimates of effect sizes for seven studies (see Table 2). If not reported in the articles, Cohen's *d* values were calculated from means and standard deviations reported. The Cohen's *d* values ranged from 0.36 to 2.50 indicating a large range from small to large effects. Sub-analyses of these effect sizes for measures and robot/agent type were unable to be conducted due to the low number of studies with available effect sizes. Effect sizes could not be included from qualitative measures (*n*=19), from studies that did not repeat measures (*n*=1) or those that did not report means and standard deviations (*n*=2).

The qualitative findings indicated that the robots and computer agents were able to decrease loneliness and increase social support and companionship, as indicated by interviews with direct users. Many thought of the robots/agents as social beings that they could communicate with, rather than machines.^{47,50,51,62} Users reported that when the robot or agent was present, they felt there was "someone" there for them and "someone" to talk to, which made them feel less alone.^{26,31,51,58,66,67} This was particularly evident in the animal-like companion robots

(eg Paro and the Joy for All pets) as direct interaction reduced feelings of loneliness and gave them a sense of comfort.^{25,51} Others commented that the robot/agent was more available and less judgmental than humans.⁶⁶ Supplementary interviews with caregivers supported these findings, in which social connections were perceived to have formed between the robots and users.^{57,59}

Within the interviews, it was evident that users were prompted to engage with others when the robot or agents were present, thus leading to an increase in social interactions. Many users noted increased conversations with others, as well as forming new social connections.^{25,51} Social interactions with family were also increased when participants used the video calling functions.^{56,61} However, users in Orejana's²⁶ study noted that the iRobi robot had little influence on external social connections and the Skype application was not widely used. This was because most users already had other virtual means of communication with their families. Therefore, the inclusion of virtual communication technology does not necessarily lead to an increase in social connections and decreased loneliness.

Observations of human-robot interaction indicated that users formed social connections and emotional attachments with the robots, akin to the findings from the interviews. Multiple studies observed an increase in users' positive emotions and facial expressions while interacting with the robots.^{55,65} Many users were observed to express affection towards the robots, including naming them, having conversations with them, and treating them as pets or friends.^{65,69,70} The users' interest in interacting and speaking with the robots also did not appear to decline over time indicating relationship formation, rather than just novelty.⁵⁹

Observations reflected an increase in the number and intensity of conversations and engagements between people (including staff, family and other residents) when the robot was present, compared to when it was not.^{63,65,68–70} The degree of positive emotions towards others, including smiling and laughing with others, was also increased.^{52,65} One study found that this increase in social interaction was observed whether the participant was directly using the Paro robot, or not.⁵² This indicates that the mere presence of a robot may increase social interaction.

Negative Effects

Some studies mentioned unintended negative consequences of robots and computer agents on social outcomes. Four reported that users had negative reactions,

including sadness and regret, to the robots being taken away at the end of the study period.^{25,50,58,59} Chen²⁵ also reported that users were disengaged and reported increased loneliness after the removal of the Paro robot. Three studies mentioned that users had increased anxiety or frustration during use, especially when the robot was not doing what they expected it to.^{55,63,64} In one study, a user reported feeling worse during the time that she interacted with the agent, as it made her realise that she lacked friends.⁶² Similarly, another study mentioned that an in-home robot and/or computer agent was disruptive for users as they felt it was an inconvenience to have to interact with it every day.⁶⁶

Further issues were raised in studies with older adults with dementia and Alzheimer's disease in particular. One issue was that the use of robots may not relieve caregiver burden as hoped. For example, Liang⁶⁵ mentioned that some caregivers of people living with dementia felt like they had to supervise interactions with the Paro robot. Concern was also raised about whether some users were capable of caring for their robots by themselves, especially the Paro robot, and whether this may cause further frustration.⁶⁹ Barrett⁶³ found that negative content, such as news stories and photos of deceased relatives, could increase negative emotions in patients living with dementia. Lastly, Wang⁵⁷ suggested that robots could replace human contact and result in possible family neglect for people with Alzheimer's disease. This was exemplified by a user who enjoyed doing menial tasks (eg household chores) with their husband and believed that the robot might replace this meaningful social contact.

Techniques for Reducing Loneliness

Across the research, four main strategies to combat loneliness were evident. These included the robot or agent acting as a direct companion to the user (69%, 20/29), acting as a catalyst for social interaction (41%, 12/29), facilitating remote communication with others (10%, 3/29) and reminding users of upcoming social engagements (3%, 1/29). Seven studies used two strategies, and 22 used one (see [Table 2](#)).

Direct Companionship

In 20 studies, the robots or agents acted directly as companions to users, to help reduce loneliness.^{24–26,31,32,47–51,55,57–60,62,64,66,67,70} Companionship was established through physical interactions with robots, including petting, cuddling, stroking, grooming, sleeping

with, sitting next to or holding it while watching television.^{25,50,51} The physical presence of robots also helped to establish companionship.^{25,26,51} Participants described that having the robot “waiting” for them at home helped to alleviate loneliness.^{25,56} However, companionship was also formed with computer agents on a screen, without a physical form outside the screen.^{31,47,62} In a direct comparison, there was a trend for users to trust a robot more than an agent, possibly due to the robot's physical interaction abilities.⁶⁶

The responsiveness and proactiveness of the robot or agent are important factors. Many users spoke to the robot or agent,^{25,31,47,50,58,59,62,66} even though in some cases they did not receive a response.^{25,50} However, robots interacted with users in other ways, by lighting up,²⁶ making face tracking motions,⁶⁶ moving and gesturing,⁶⁷ making noises^{25,69} or even verbally addressing users.⁴⁹ Conversation topics reported by Gross⁵⁰ included praising the robot, ranting to it, caring for and enquiring about its condition and asking for its opinion. Conversations with computer agent Tanya included the weather, family and future plans.^{31,62} A participant in Chen²⁵ reflected that speaking to Paro helped them to alleviate boredom as well as loneliness. Proactiveness (the agent initiating a conversation) was a technique that reduced loneliness compared to passivity (the agent only responding).³¹

Consequently, participants in many studies were able to form an emotional attachment and deep connection to the robots and computer agents.^{24,25,49–51,58,59,70} Many even described and treated it as a friend,^{31,55,57,64,70} family member²⁶ or their pet.^{51,70} In a study by Hudson,⁵¹ the robot acted as a proxy for a conversational partner for older adults who lived alone and helped a participant to adjust after the loss of a partner. However, participants in other studies accepted that the robot could not replace human companionship⁵⁹ and were aware that it was a machine.^{50,57} In a study with the Care Coach agent, some participants reported the relationship to be superficial, due to its limited conversational ability.⁴⁷

Catalyst for Social Interaction

One agent⁴⁷ and 11 robot interventions^{25,51–54,58,63,65,68–70} helped to combat loneliness by acting as a catalyst for social interaction. Participants socially connected with staff members, neighbors, other residents and researchers while using the robots, such as by talking about it or showing the robot and its functions to others.^{25,51–53,63,65,68–70} For example, participants using the MARIO robot showed their photographs from the

My Memories function to others.⁶³ The robots and agents were also a topic of conversation with family members^{47,63} and participants reported that family and friends were more willing to visit when the robot was present.⁵⁸

The robots also acted as a catalyst to interact and converse with other people, outside of familiar social networks.^{25,53} Hudson⁵³ highlighted that people who were shy or previously felt uncomfortable interacting with unknown people found the robot to be effective in helping forge new connections. The impact of increased social interaction was reported to be strong, with one study⁷⁰ stating that the reduction of loneliness was attributed to increased social communication, rather than companionship. Additionally, within group sessions with Paro, participants did not need to have the robot on their laps or be using it, to contribute to conversations.⁵² The presence of Paro within the group simply increased social interaction.

Facilitate Remote Communication

Three robot interventions facilitated remote communication and social interaction with family members using Skype and video-calling.^{56,61,64} Two of the robots (Giraff and Double) were labelled as telepresence robots, with the sole purpose of reducing social isolation by enhancing engagement between family and older adults in aged-care facilities.^{56,61} The video function was reported to facilitate a stronger social connection than a phone call,⁵⁶ and enabled older adults to virtually “visit” family members who lived far away and whom they had not seen for some time.⁶¹

Reminders of Upcoming Social Interactions

Providing reminders of social interaction were used in one study as a technique for reducing loneliness.⁴⁹ The robot SYMPARTNER kept users socially active, by reminding them of their schedules, including social engagements.

Discussion

This scoping review systematically searched for and identified research on interventions that attempted to reduce loneliness in older adults, by using robots or computer agents. The review found that robots were the most commonly used intervention, with the Paro robot being the most popular. This finding has been reported in previous literature reviews on socially assistive robots for broader outcomes.^{35,77} Indeed, Paro is so popular that researchers

now commonly use “Paro” as a keyword when searching for studies on companion robots.^{35,38} Nevertheless, 18 other robots and three computer agents were used in interventions in this review.

The review answered our research question: how effective are interventions that use social robots or computer agents for reducing loneliness in older adults and what techniques do they use? We found that the majority of interventions positively impacted at least one loneliness outcome; however, unintended negative consequences on social outcomes were also reported in some studies.^{25,50,58,59} Direct companionship was the most commonly reported strategy (69%), followed by acting as a catalyst for social interaction (41%), facilitating remote communication with others (10%), and sending reminders for social interaction (3%). Overall, the majority of the research was observational in nature, using mixed methods and ranging from moderate to high quality.

Overall Effectiveness of the Interventions

The review supports the effectiveness of using social robots to reduce loneliness in older adults. The majority of the quantitative research demonstrated significant decreases in loneliness for robots, although only two of the five studies on computer agents found significant quantitative effects. However, qualitative data consistently showed that the robots and agents increased companionship and facilitated social interactions for at least some individuals. These findings are consistent with research on loneliness interventions in older adult populations that have human delivery, in which interventions focused on enhancing social support and facilitating social interactions have been shown to be effective (eg, telephone support, shared activities and hobby groups, internet skills training).^{78–80}

Other intervention strategies have been shown to improve loneliness in older adults, but these have yet to be tested with robot or computer agent delivery. Modifying maladaptive social cognition through Cognitive Behavioral Therapy (CBT) is the most effective therapeutic technique for alleviating loneliness.^{4,81} This involves teaching people to identify and change negative automatic thoughts related to loneliness, social interaction and relationships,⁸¹ and behavioral techniques to cope with loneliness-related distress, such as mindfulness.⁸² Additionally, social skills interventions have included techniques such as learning to express appreciation and

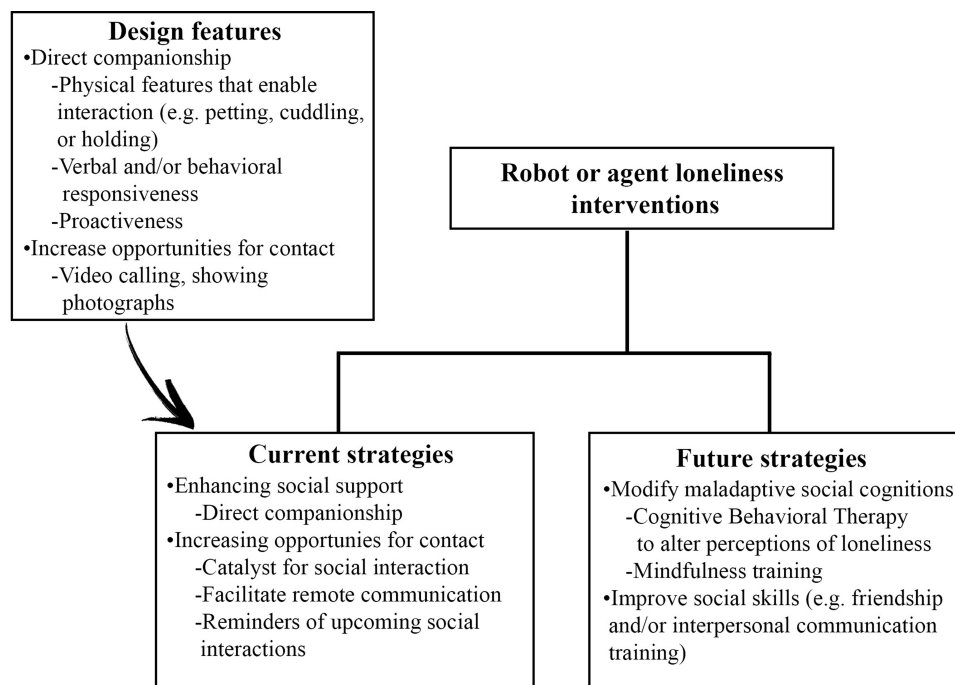


Figure 2 Current strategies used by robots or agents for reducing loneliness in older adults, and possible future strategies. These strategies are enhanced by certain design features, as illustrated.

develop new or existing friendships.^{83,84} These strategies could be integrated into robots or computer agents.

Figure 2 summarizes the current strategies used by robots or agents (predominantly focused on enhancing social support and increasing opportunities for social contact), and strategies that could be added in the future (addressing maladaptive social cognitions and improving social skills). Figure 2 also highlights design features that can contribute to direct companionship with robots or agents: a body that can be cuddled and stroked during sedentary activities,^{25,50,51} proactiveness,³¹ and responsiveness, either verbal⁴⁹ or behavioral (through lights,²⁶ facial tracking,⁶⁶ gestures,⁶⁷ or noises),^{25,69} as well as features that can increase opportunities for social interaction.

The key finding of this review is that robots focused on providing direct companionship and acting as a catalyst for social interaction can reduce loneliness. This has also been shown in children and adults with intellectual disabilities.^{85,86} Paro acted as a catalyst for social interaction between hospitalized children and other patients or staff, and as a direct companion for these children.⁸⁵ In another study, Paro acted as a direct companion to five adults with severe intellectual disabilities who formed an emotional connection with the robot.⁸⁶ Similar results have been found with the Huggable Bear robot, which

has been shown to serve a social catalyst role between hospitalized children and their parents,⁸⁷ and to provide direct companionship.⁸⁸ Robots may also be effective facilitators of social interaction for children; an AV1 tele-presence robot was found to help hospitalized children with cancer connect with classmates during remote learning activities.⁸⁹

Intervention techniques that have been used in other populations could be applicable to older adults and research should explore these areas. Computer agents have been developed to teach social skills to children with autism spectrum disorder,⁹⁰ including in virtual reality.⁹¹ These programs allow children to practice their social skills using an avatar in a safe, virtual environment with real-time feedback. Similar technology could be developed to deliver a social skills intervention to older adults with loneliness.

Within the quantitative findings, a large range of effect sizes was found. This could have been influenced by the different types of robots/agents used, strategies employed, lengths of exposure, and settings, as well as heterogeneous research designs, methods, outcome measures and study sample sizes. Therefore, it remains difficult to fully conclude the degree of effectiveness of robots as an intervention to decrease loneliness in older adults until more standardized RCTs have been conducted. Only five studies

investigated the use of a computer agent as an intervention, and therefore conclusions cannot be made about the effectiveness of computer agents in decreasing loneliness, without further research.

Attachment was sometimes used as an outcome measure, and results indicated that some people did form attachments to robots. While low attachment is not the same as loneliness, it has been correlated with loneliness in research with older adults and pets.^{92,93} Therefore, attachment is a relevant concept to loneliness and warrants further investigation in future studies with older adults and robots.

Ethical Considerations

The reported unintended consequences highlight ethical considerations, particularly for people living with dementia or Alzheimer's disease. Some participants felt sadness, regret and guilt when the robots were removed at the end of the study period.^{25,50,58,59} Similar findings have been reported in other research, whereby participants became distressed when Paro was taken away.⁶¹ Therefore, careful consideration of how robots are removed at the end of a study must be provided when designing robotic interventions. This may include a trial withdrawal period to adapt to life without the robot,⁹⁴ or renting or selling the technologies to users/hospitals after the intervention period has ended. Future work needs to investigate whether these unintended negative effects are transient or have a longer-term impact.

One study used Wizard of Oz methods to control the agent,⁶² highlighting important considerations on how to maintain user privacy when agents are not autonomous. Some participants reported feeling anxious as they did not know who was behind the interaction and may be listening to the conversation. An additional limitation of the Wizard of Oz method was that the agent was not always available.

Recommendations for Future Research

The heterogeneity of studies prevents conclusions about which strategies were the most effective, and further experimental research is needed to determine this. Other strategies, such as CBT and social skills training, could be investigated. Further research could explore the long-term effects of interventions, and include follow-up.

There is a need for more robust experimental designs through RCTs. Future mixed methods research should focus on improving the robustness of the qualitative component, providing an in-depth description of the specific methodological approach, data collection and analysis

methods. A triangulation of loneliness measures could enhance insights into effects, including observations, validated self-report measures, and interviews.

Strengths and Limitations

Strengths include following the Arksey and O'Malley⁴⁰ process for conducting scoping reviews, reporting the review in accordance with the PRISMA-ScR extension for scoping reviews⁴³ and formally assessing methodological quality using the MMAT.⁴⁶ A potential limitation is that research was only included if it was published in English. This may have resulted in the absence of some relevant research published in other languages. No effort was made to extensively look for grey literature or to contact the authors to request more information. Not all sub-types of computer agents were specifically included in the search strategy, meaning that some studies may not have been identified.

Conclusion

Evidence to date suggests that social robots can reduce loneliness in older adults, using features that encourage direct companionship and facilitate social interactions. Little research is available on the effects of computer agents to date.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Disclosure

Elizabeth Broadbent authored/co-authored five studies included in the review. However, Elizabeth did not conduct the quality assessments, so potential conflicts of interest were mitigated. Soul Machines Ltd (a company that makes digital humans) employs Kate Loveys as an intern and contracts Elizabeth Broadbent as a consultant. The authors report no other conflicts of interest in this work.

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