THE GERONTOLOGICAL SOCIETY OF AMERICA®

The Gerontologist
cite as: *Gerontologist*, 2019, Vol. 59, No. 1, e37–e51
doi:10.1093/geront/gny046
Advance Access publication June 12, 2018

OXFORD

Special Issue: Technology and Aging: Review Article

The Effectiveness of Social Robots for Older Adults: A Systematic Review and Meta-Analysis of Randomized Controlled Studies

Lihui Pu, MSN,[1,2] Wendy Moyle, PhD,[1,2,*] Cindy Jones, PhD,[1,2] and Michael Todorovic, PhD[1,2]

[1]School of Nursing and Midwifery, Nathan Campus, Griffith University, Brisbane, Queensland, Australia. [2]Menzies Health Institute Queensland, Griffith University, Brisbane, Australia.

*Address correspondence to: Wendy Moyle, PhD, Menzies Health Institute Queensland, Griffith University, 2.10 Health Sciences (N48), 170 Kessel Road, Nathan, Brisbane, Queensland 4111, Australia. E-mail: w.moyle@griffith.edu.au

Received: November 23, 2017; Editorial Decision Date: April 18, 2018

Decision Editor: Patricia C. Heyn, PhD

Abstract

Background and Objectives: Social robots may promote the health of older adults by increasing their perceived emotional support and social interaction. This review aims to summarize the effectiveness of social robots on outcomes (psychological, physiological, quality of life, or medications) of older adults from randomized controlled trials (RCTs).

Research Design and Methods: A mixed-method systematic review of RCTs meeting the study inclusion criteria was undertaken. Eight databases were electronically searched up to September 2017. Participants' characteristics, intervention features, and outcome data were retrieved. The mean difference and standardized mean difference with 95% confidence intervals (CI) were synthesized to pool the effect size.

Results: A total of 13 articles from 11 RCTs were identified from 2,204 articles, of which 9 studies were included in the meta-analysis. Risk of bias was relatively high in allocation concealment and blinding. Social robots appeared to have positive impacts on agitation, anxiety, and quality of life for older adults but no statistical significance was found in the meta-analysis. However, results from a narrative review indicated that social robot interactions could improve engagement, interaction, and stress indicators, as well as reduce loneliness and the use of medications for older adults.

Discussion and Implications: Social robots appear to have the potential to improve the well-being of older adults, but conclusions are limited due to the lack of high-quality studies. More RCTs are recommended with larger sample sizes and rigorous study designs.

Keywords: Analysis—systematic review, Socially assistive robots, Technology, Well-being

Mental health is a major problem to maintain in older adults, especially in people with dementia. Behavioral and psychological symptoms in people with dementia (BPSD) such as agitation, depression, and anxiety, are highly prevalent among people with dementia, with an estimation of prevalence up to 80% (Pieper et al., 2013). People with these conditions are commonly prescribed antipsychotic medications, which are associated with an increased risk of cardiovascular events (Stoner, 2017) and even death (Gill et al., 2007). Therefore, viable nonpharmacological approaches are recommended as the primary alternative to manage BPSD while avoiding undesirable adverse effects.

Over the last decade, the value of human–animal intervention (HAI) has been widely acknowledged with research showing that interaction with a live animal can improve human health (Beetz, Uvnäs-Moberg, Julius, & Kotrschal, 2012). Although many individuals may enjoy the opportunity to interact with a live animal, this can be difficult to implement within long-term care (LTC). Dogs, for example, usually have one master and they (a) can become stressed when attention is given by numerous residents; (b) may be overfed by zealous residents; and (c) animals can take care staff away from their care of residents (Moyle et al., 2013). Live animals also present issues of hygiene and some residents can experience allergic responses, have a fear of a particular animal type and be bitten by the animals (Moyle et al., 2013). Human–robot intervention (HRI), such as social robots, is an alternative to traditional HAI and can provide the same effect as live animals while avoiding issues such as bites or risk of disease (Kramer, Friedmann, & Bernstein, 2009; Thodberg, Sørensen, Christensen, et al., 2016).

A social robot is defined as an artificial agent embodied with features of a human or an animal (Broekens, Heerink, & Rosendal, 2009; Hegel, Muhl, Wrede, Hielscher-Fastabend, & Sagerer, 2009). It has been identified as an approach to meet the mental health needs of older adults through interaction or information exchange (Broadbent, 2017). The application and effectiveness of social robots have been investigated in mental health care (David, Matu, & David, 2014; Rabbitt, Kazdin, & Scassellati, 2015) and aged care (Khosravi & Ghapanchi, 2016; Sicurella & Fitzsimmons, 2016; Vandemeulebroucke, de Casterlé, & Gastmans, 2018). The advantages of social robots include increased psychological and physiological well-being, as well as improved quality of life (Costescu, Vanderborght, & David, 2014; Mordoch, Osterreicher, Guse, Roger, & Thompson, 2013). However, mixed results have been reported regarding the effectiveness of social robots for older adults. Some studies found that interaction with social robots reduced agitation (Jøranson, Pedersen, Rokstad, & Ihlebæk, 2015; Moyle, Bramble, Jones, & Murfield, 2017), depression and anxiety (Petersen, Houston, Qin, Tague, & Studley, 2017), improved quality of life (Moyle et al., 2013), or sustained quality of life in people with advanced dementia (Jøranson, Pedersen, Rokstad, & Ihlebaek, 2016). However, some other studies indicated that social robots have no significant affect on depression and quality of life (Broadbent et al., 2014; Robinson, MacDonald, Kerse, & Broadbent, 2013). These conflicting results make it difficult to evaluate the effectiveness of social robots.

Previous reviews described the effectiveness of different types of socially assistive robots in aged care (Bemelmans, Gelderblom, Jonker, & de Witte, 2012; Kachouie, Sedighadeli, Khosla, & Chu, 2014). Shibata and Wada (2011) focused on the therapeutic use of the robotic seal PARO to improve the mental health of older adults, especially for those with dementia. Existing reviews based on observational or nonrandomized studies (Mordoch et al., 2013; Rabbitt et al., 2015) have added to knowledge basis and identified potential applications of social robots; however, a meta-analysis of well-designed randomized controlled trials (RCTs) can provide stronger evidence for social robot intervention. In addition, more RCTs have taken place in recent years with more researchers showing interests in robot therapy within aged care. Therefore, a systematic review and meta-analysis, based on currently available evidence of RCTs, is needed to clarify the benefits of social robots for older adults.

Methods

Search Strategy

This review focuses on the existing RCTs using social robots in health care of older adults including those with and without cognitive impairment. This review has been registered with the PROSPERO International Prospective Register of systematic reviews (registration number: CRD42017069542). Online databases searched include Scopus, ProQuest (Nursing & Allied Health Database and Psychology Database), PubMed, Medline and CINAHL (via EBSCO), PsychINFO (via OVID), Science Direct, Web of Science, and Cochrane Library in November 2016 (search strategy was rerun on September 7, 2017). Key words followed the PICOS principals (see Supplementary Material for detailed search strategy), including:

Population: dementia or Alzheimer* or "cognitive impairment" or elder or elderly or "elderly people" or older or "older adults" or "older people" or aged or geriatric or senior

Intervention: robot* or Paro or "seal robot" or "social interactive robot*" or "social assistive robot*" or "social commitment robot*" or "social interactive robot*" or "assistive robot*" or "companion robot*" or "personal assistive robot*" or "personal robot*" or "therapeutic robot*" or "therapeutic seal robot*" or "robot* therapy" or "robot interaction"

Outcomes: pain or "pain management" or "pain relief" or "pain medication" or analgesics or BPSD or "behaviour and psychotic symptom" or "antisocial behavio*" or "disruptive behavio*" or "acting out" or agitat* or aggressi* or problematic or wandering or mood or engagement or "quality of life" or "social interaction" or "stress" or "robot interaction" or "behavio* disturbance" or "aggressive behavio*" or "destructive behavio*" or "resistive behavio*" or depression or sleep or "sleep duration" or "sleep quality."

Eligibility

Titles and abstracts were screened according to the study inclusion criteria: (a) older adults (main participants were 55 years or older); (b) RCTs using social robots without restriction of robot type or intervention frequency; (c) articles were published in English. Excluded articles included: (a) subjects were children or younger adults; (b) reviews, nonrandomized studies, study protocols, case studies, observational studies, cross-sectional studies, qualitative studies, or pre–post studies without a control group; as well as (c) conference abstracts without full-text. In addition, references of the included studies were screened for eligibility, and there were no restrictions on the time of publication. After discarding duplicates, two reviewers (L. Pu and C. Jones) screened titles and abstracts independently according to the inclusion and exclusion criteria. Then, related articles with full-text were retrieved and reviewed by three independent reviewers (L. Pu, C. Jones, and W. Moyle). The inter-rater agreement among reviewers was high ($\kappa = .61, p < .001$) and any disagreements were resolved through discussion.

Quality Assessment

Three reviewers (L. Pu, C. Jones, and W. Moyle) independently assessed the risk of bias using the Cochrane Collaboration tool for assessing risk of bias in randomized trials (Higgins et al., 2011), including (a) random sequence generation (selection bias); (b) allocation concealment (selection bias); (c) blinding of participants and personnel (performance bias); (d) blinding of outcome assessment (detection bias); (e) incomplete outcome data (attrition bias); (f) selective reporting (reporting bias); as well as (g) other bias. Judgments were grouped into three levels as "low risk of bias," "high risk of bias," or "unclear risk of bias." The reviewers assessed the quality of each study independently, and conflicting results were resolved through discussions.

Data Extraction

A data extraction form was designed for included studies, including: (a) study characteristics (publication time, journal, author, country, design, setting); (b) participant (age, gender, sample size, and level of cognitive impairment); (c) intervention and control (type of social robots, duration, intervention frequency, length of follow-up); (d) outcome measurement; as well as (e) results. This form was first piloted, and two reviewers extracted data independently and entered it into an excel spreadsheet.

Data Synthesis

The mean difference (MD) or standardized mean difference (SMD) with 95% confidence interval (CI) was chosen to calculate the effect size of continuous outcomes. If reported, results from an analysis of covariance (ANCOVA) estimate were selected, which considers individual baseline scores as covariates to correct the phenomenon of regression to the mean for baseline imbalance (Twisk & Proper, 2004). Otherwise, change from baseline (change value) with standard deviations (*SD*s) and final scores with *SD*s were selected when results from ANCOVA had not been reported. The number of participants included in the summary statistics was from each outcome measured in both groups. A random-effects model was applied given the clinical or methodological diversity across included studies. Heterogeneity between studies was measured by chi-square test ($p < .10$ and $I^2 > 40\%$). Subgroup analysis on individual and group intervention; the level of cognitive impairment of participants; and self-report and proxy report results were undertaken where applicable. Missing data were obtained from study authors whenever possible; otherwise missing *SD*s of change value was calculated with an estimated correlation from similar studies and missing *SD*s of final scores were imputed using the average *SD*s of similar studies in the meta-analysis. Moreover, carry-over effect and intracluster correlation coefficient (ICC) was considered for data imputation when cross-over or cluster RCTs were included. Studies with multi-arms resulted in the findings from relevant groups (e.g., different types of the social robot) being combined to create a single pair-wise comparison. In addition, a sensitivity analysis was performed to check the robustness of results and publication bias were tested. Data synthesis was performed with RevMan 5.3 software. Results were also presented with a narrative summary if they could not be included in the meta-analysis.

Results

Selected Articles

As shown in Figure 1, a total of 2,202 articles were searched from the databases, and 2 articles were retrieved from reference searching. After removing duplicates, 1,655 articles were screened based on title and abstract, and a total of 1,470 articles were excluded. Therefore, 185 articles remained for full-text screening, and 13 publications from 11 RCTs were identified to meet the study inclusion and exclusion criteria.

Risk of Bias

Most studies reported the method of random sequence generation, including computer generated programs (Broadbent et al., 2014; Moyle et al., 2013), random list generator (Liang et al., 2017; Robinson et al., 2013), random allocation by an external research center (Jøranson et al., 2015; Moyle, Jones, et al., 2017), coin toss (Petersen et al., 2017), a six-sided die (Soler et al., 2015) and block randomization (Thodberg, Sørensen, Christensen, et al., 2016). Low risk of allocation concealment was recorded from five trials (Broadbent et al., 2014; Jøranson et al., 2015; Moyle et al., 2013; Moyle, Jones, et al., 2017; Soler et al., 2015). However, only two trials were judged as low risk of blinding the participants and personnel (Broadbent et al., 2014; Moyle, Jones, et al., 2017) and less than half of the trials mentioned blinding of outcome assessors (Broadbent et al., 2014; Moyle et al., 2013; Moyle, Jones, et al., 2017; Soler et al., 2015). Three studies described the methods to manage missing data, including multiple imputation procedures (Jøranson et al., 2015) and intention-to-treat analysis (Moyle, Jones, et al., 2017). Moyle and colleagues (2013) reported a large amount of missing data due to the advanced cognitive impairment of participants.

Two studies failed to provide enough data for meta-analysis (Banks, Willoughby, & Banks, 2008; Thodberg, Sørensen, Christensen, et al., 2016) and interpretation bias was observed in one study (Jøranson et al., 2015). E-mails were sent to authors asking for more information, but no response was received. Therefore, nine studies were included in the meta-analysis. The risk of bias is presented in Figure 2 and additional file 2.

Study Characteristics

Different study designs were identified among included studies, including cross-over studies (Broadbent et al., 2014; Moyle et al., 2013), two-arm (parallel) trials (Jøranson et al., 2015; Liang et al., 2017; Petersen et al., 2017; Robinson et al., 2013; Tanaka et al., 2012) and multiple-arm trials (Banks et al., 2008; Moyle, Jones, et al., 2017; Soler et al., 2015; Thodberg, Sørensen, Christensen, et al., 2016). These studies were conducted in seven different countries, including Denmark (Thodberg, Sørensen, Christensen, et al., 2016; Thodberg, Sørensen, Videbech, et al., 2016), Norway (Jøranson et al., 2015, 2016), New Zealand (Liang et al., 2017; Robinson et al., 2013), United States (Banks et al., 2008; Petersen et al., 2017), Australia (Moyle et al., 2013; Moyle, Jones, et al., 2017), Japan (Tanaka et al., 2012), and Spain (Soler et al., 2015).

Participants

A total of 1,042 older adults were included in the review, of which 80% were diagnosed with dementia or cognitive

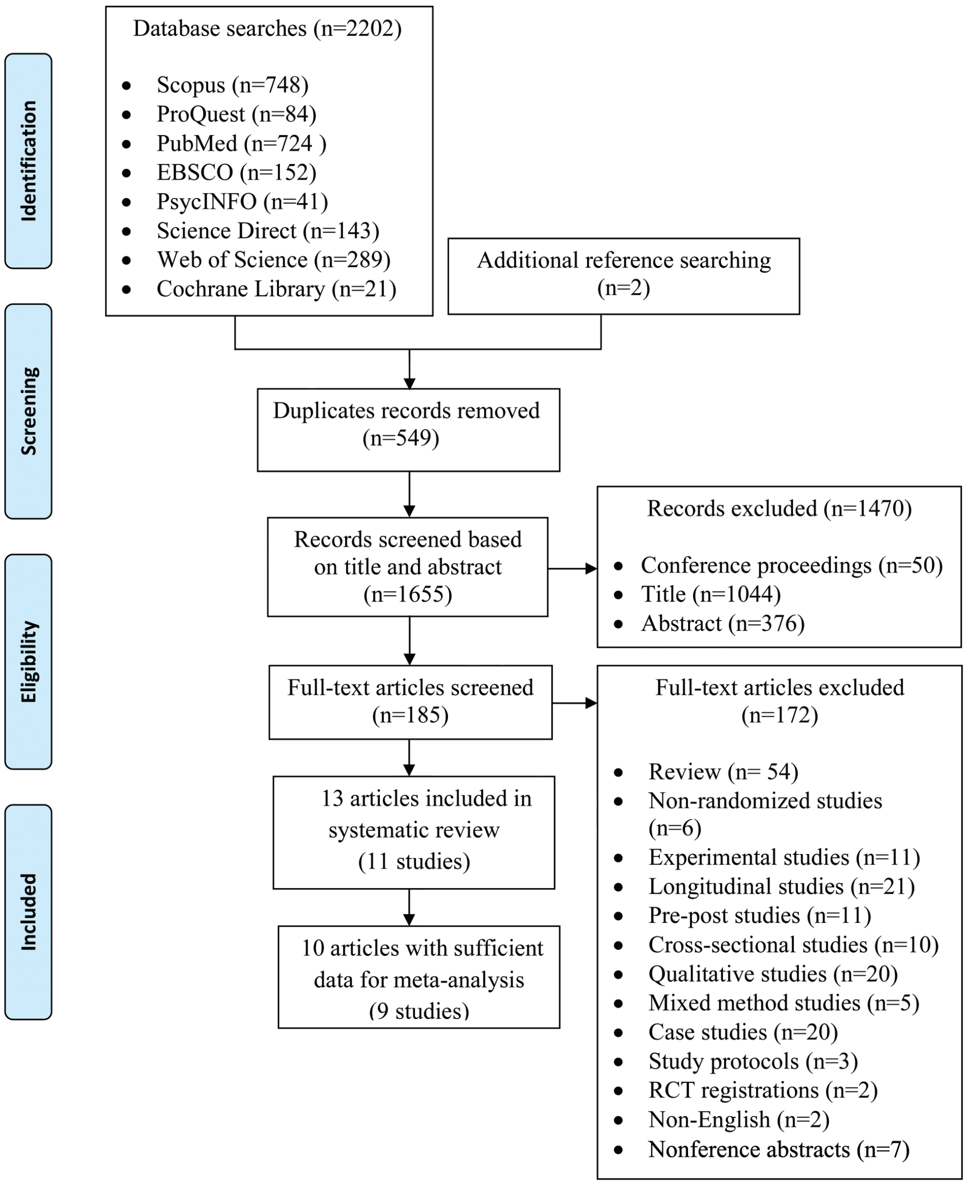

Figure 1. Flow chart of literature review.

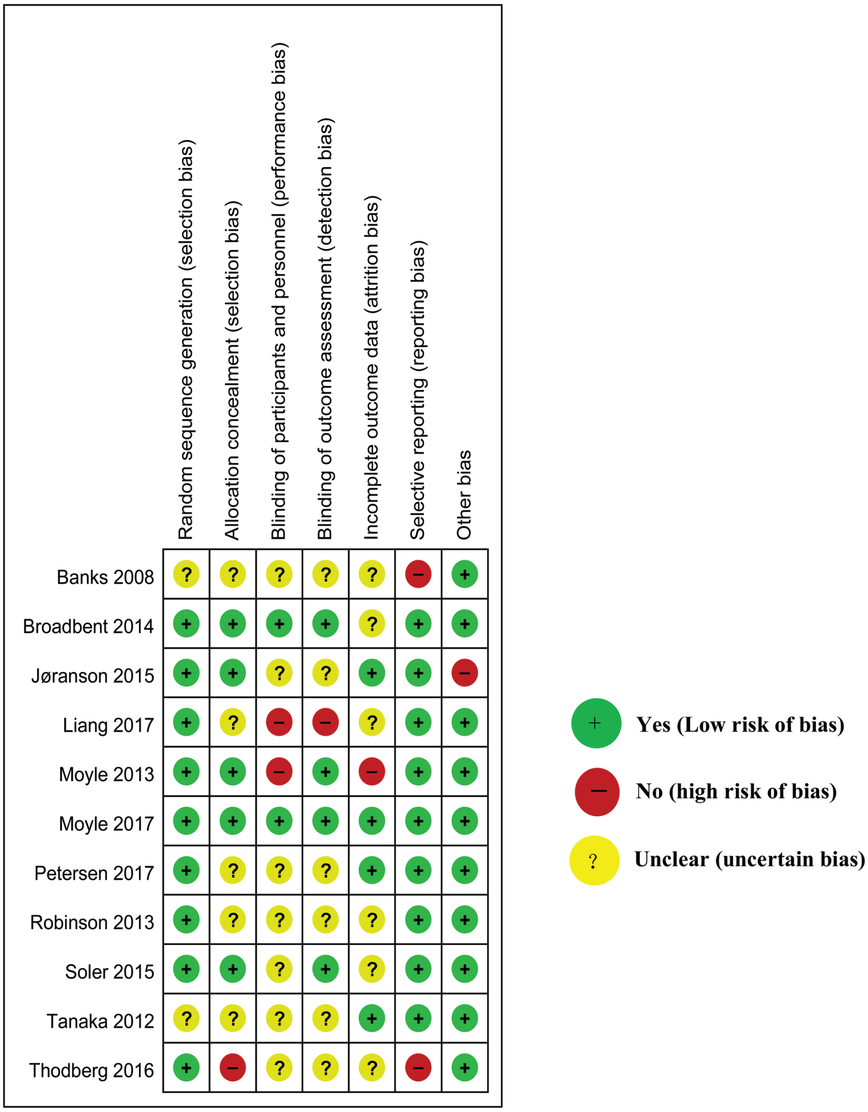

Figure 2. Risk of bias summary.

impairment. The number of participants included in each trial ranged from 18 to 415. The majority of studies were conducted in LTC facilities. However, one study (Tanaka et al., 2012) recruited older females from home settings; Robinson and colleagues (2013) selected participants from both hospital and LTC, and Liang and colleagues (2017) conducted the intervention both at daycare centers and at participants' homes. Detailed information is presented in Table 1.

Social Robots and Control Conditions

Different types of social robot, such as animal-like robots and human-like robots, were used in the included studies. PARO (an abbreviation of the Japanese phrase "Personal Assistance RobOt"), a robotic animal shaped like a baby harp seal, was the most popular and featured in eight studies. In addition, a robotic dog AIBO (Banks et al., 2008), a humanoid communication robot NAO (Soler et al., 2015), a humanoid communication robot with features of 3-year-old boy (Tanaka et al., 2012) and two health care robots IrobiQ and Cafero (Broadbent et al., 2014) were also used in aged care communities. As for control groups, in one study reading activities were provided as a control condition (Moyle et al., 2013). Another study used a similar toy as an active control (Tanaka et al., 2012). In another two studies, participants allocated to the control group received live dog visits (Robinson et al., 2013; Thodberg, Sørensen, Christensen, et al., 2016). In the remaining seven studies, the participants in the control group received usual care or standard treatment without robots or pets. Detailed information is presented in Table 2.

Intervention Form and Duration

Four trials were conducted with group interventions ranging from 20 to 45 min per session. Individual robot

Table 1. Participant Characteristics of Included Studies (n = 11)

Study	Country	Setting	Number of participants	Gender (F/M)	Age (years)	Cognition
Banks et al. (2008)	USA	Long-term care facility	38	—	—	People without cognitive impairment
Broadbent et al. (2014)	New Zealand	Retirement village	29	15/14	85.32 (5.14)[a]	Most participants without cognitive impairment
Jøranson et al. (2015)	Norway	Nursing home	60	40/20	[62, 95][b]	People had a diagnosis of dementia or cognitive impairment
Liang et al. (2017)	New Zealand	Dementia day care centers and home	30	19/11	[67, 98][b]	People with dementia
Moyle et al. (2013)	Australia	Long-term care facility	18	—	85.3 (8.4)[a]	People with moderate to severe dementia
Moyle et al. (2017)	Australia	Long-term care facility	415	314/101	PARO: 84 (8.4)[a] Plush toy: 86 (7.6)[a] Usual care: 85 (7.1)[a]	People with dementia
Petersen et al. (2017)	USA	Dementia units	61	47/14	Intervention:83.5 (5.8)[a] Control: 83.3 (6.0)[a]	People with dementia
Robinson et al. (2013)	New Zealand	Rest home and hospital	40	27/13	[55, 100][b]	48% had cognitive impairment
Soler et al. (2015)	Spain	Nursing home	Phase I 101 Phase II 110	89/12 99/11	84.68[a] 84.7[a]	People with moderate/severe dementia
Tanaka et al. (2012)	Japan	Home	40	40/0	[66, 84][b]	People without dementia
Thodberg et al. (2016)	Denmark	Nursing home	100	69/31	[79, 90][b]	People with cognitive impairment and 30% with dementia

Note. Number of participants refers to the original recruited number. — = no data provided.
[a]Mean (*SD*). [b]Range of age.

interaction activities were employed in five studies varying from 10 to 30 min per session, whereas another study (Soler et al., 2015) adopted group sessions for residents with mild or mild-moderate dementia and individual sessions for patients with moderate-severe and severe dementia. Participants from one study (Liang et al., 2017) received group interventions in daycare centers and individual interventions at home. In terms of the intervention period, the minimum duration was 5 weeks and the maximum 12 weeks. As only three studies (Jøranson et al., 2015; Liang et al., 2017; Moyle, Jones, et al., 2017) had follow-up visits at different times (e.g., 12 weeks, 6 weeks, and 5 weeks after intervention), immediate postintervention results were selected for data analysis.

Statistical Analysis

Baseline between intervention and control groups was similar in included studies, and the majority of included studies reported the final score rather than ANCOVA estimates; therefore, the final score with its *SD*s was synthesized to calculate the effect size. As for missing data imputation, *SD*s of final score (Petersen et al., 2017) were calculated using the average *SD*s from similar studies (Jøranson et al., 2015; Liang et al., 2017; Soler et al., 2015). As two cross-over studies (Broadbent et al., 2014; Moyle et al., 2013) described 3 weeks and 18 days of wash-out to reduce carry-over effects, we, therefore, included results from both periods. However, this method ignored the within-patient correlation and rendered our results to be more conservative. Results from two cluster trials (Jøranson et al., 2015; Moyle, Jones, et al., 2017) were imputed according to the reported ICC (0.84 and 0.068, respectively) to calculate the effective sample size. Subgroup analysis for self-report and proxy report results was performed for anxiety and quality of life measures. However, subgroup analysis was not viable on the types of intervention (i.e., individual or group) or the level of cognitive impairment on key outcome measures (except for cognition) as there were studies that adopted a combination of different types of interventions and included participants with or without cognitive impairment. We evaluated the effect of each

Table 2. Characteristics of Interventions of Included Studies (*n* = 11)

Study	Intervention	Control	Type of intervention	Outcome and measurement
Banks et al. (2008)	AIBO, a living dog	Not receiving animal-assisted therapy	Individual: weekly visits lasting 30 min for 8 weeks	UCLA, MLAPS
Broadbent et al. (2014)	IrobiQ and Cafero	Nonrobot control	Individual: robots in their homes for 6 weeks	GDS-15, SF-12, MARS
Jøranson et al. (2015)	PARO	Treatment as usual	Group: a group session of 30 min twice a week during weekdays over 12 weeks Follow-up after 3 months	BARS, CSDD, QUALID Medication
Liang et al. (2017)	PARO	Standard activities	Group: day care centers 2–3 group sessions each week for 6 weeks Individual: PARO at home for 6weeks Follow-up at week 12	CMAI-SF, NPI-Q, CSDD, Addenbrooke's Cognitive Examination Observational records of responses, salivary cortisol and blood pressure, hair cortisol concentration, medication
Moyle et al. (2013)	PARO	Reading activities	Group intervention: 45 min, three afternoons per week for 5 weeks (group of nine)	AWS, RAID, staff rated RAID, AES, GDS[1], OERS, QoL-AD
Moyle et al. (2017)	PARO, plush toy	Usual care	Individual intervention: Three times a week for15 min over 10 weeks Follow-up at week 15	CMAI-SF Video observation of engagement, mood states, and agitation
Petersen et al. (2017)	PARO	Standard of care	Group intervention: three times a week for 20 min during 12 weeks (group of six)	RAID, CSDD, GDS[2] Pulse rate, pulse oximetry, GSR, and medication
Robinson et al. (2013)	PARO	Dog visits	Group intervention: twice a week for an hour over 12 weeks	UCLA, GDS-15, QoL-AD, staff rated QoL
Soler et al. (2015)	PARO, NAO, a live dog	Conventional therapy	Group and individual intervention: Two days (30–40 min) per week during 3 months	MMSE, NPI, APADEM-NH, QUALID
Tanaka et al. (2012)	Human type communication robot	A control robot	Individual intervention: living with a communication robot at home for 8 weeks	MMSE, blood serum albumin, saliva cortisol, sleep, BMI, GDS-15
Thodberg et al. (2016)	PARO, a soft toy cat	Dog visits	Individual intervention: bi-weekly in dividual visits for 10 min over 6 weeks	BMI, GDS[1], MMSE, sleep duration, weight Behavioral observation and video record

Note. UCLA = University of California Los Angeles Loneliness Scale; MLAPS = Modified Lexington Attachment to Pets Scale; GDS[1] = Geriatric Depression Scale; SF-12 = Health Related Quality of Life Short Form; MARS = Medication Adherence Report Scale; BARS = The Brief Agitation Rating Scale; CSDD = Cornell Scale for Symptoms of Depression in Dementia; QUALID = Quality of Life in Late-Stage Dementia Scale; CMAI-SF = The Cohen-Mansfield Agitation Inventory-Short Form; NPI-Q = Neuropsychiatric Inventory Brief Questionnaire; AWS = Revised Algase Wandering Scales; RAID = Rating Anxiety in Dementia; AES = Apathy Evaluation; OERS = Observed Emotional Rating Scale; QoL-AD = Quality of life for Alzheimer's Disease; GDS[2] = Global Deterioration Scale; GSR = galvanic skin response; MMSE = Mini-Mental State Examination; APADEM-NH = Apathy scale for institutionalized Patients with Dementia Nursing Home version; BMI = body mass index.

study on the pooled results by excluding each single study sequentially, and the results were almost identical, which validated the rationality and reliability of our analysis. A funnel plot of publication bias was not created due to the small number of trials included in the meta-analysis.

Meta-Analysis Results of the Social Robot Intervention

Agitation, Neuropsychiatric Symptoms, and Anxiety

Jøranson and colleagues (2015) reported the Brief Agitation Rating scale (BARS) score while the other two studies reported the Cohen-Mansfield Agitation Inventory-Short Form (CAMI-SF) score (Liang et al., 2017; Moyle, Jones, et al., 2017), so the SMD was used to summarize the results. A small but not statistically significant effect was observed for agitation (three studies, 216 participants, SMD: −0.20, 95% CI: −0.57 to 0.17; Figure 3) and no significant effect was observed for neuropsychiatric symptoms measured by the Neuropsychiatric Inventory (NPI) and Neuropsychiatric Inventory Brief Questionnaire (NPI-Q) (two studies, 95 participants, SMD: 0.09, 95% CI: −0.27 to 0.45; Figure 4). The MD of anxiety measured with the self-reported Rating Anxiety in Dementia (RAID) was 2.8 (95% CI: −1.58 to 7.18) and the staff rated anxiety was −1.14 (95% CI: −6.54 to 4.26), suggesting that social robots have the potential to reduce staff rated anxiety for people with dementia (Figure 5).

Depressive Symptoms and Apathy

Three studies reported the Cornell Scale for Symptoms of Depression in Dementia (CSDD) score while the other three reported the Geriatric Depression Scale (GDS) score. There were no statistically significant effects for depressive symptoms (seven

	Social robots			Control				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Jøranson 2015	20.2	10.1	27	24.7	14	26	33.2%	-0.36 [-0.91, 0.18]
Liang 2017	25.8	9.44	13	22.6	4.57	11	17.5%	0.41 [-0.41, 1.22]
Moyle 2017	27.86	11.43	46	31.38	11.3	50	49.2%	-0.31 [-0.71, 0.10]
Total (95% CI)			**86**			**87**	**100.0%**	**-0.20 [-0.57, 0.17]**

Heterogeneity: Tau² = 0.03; Chi² = 2.72, df = 2 (P = 0.26); I² = 27%
Test for overall effect: Z = 1.07 (P = 0.28)

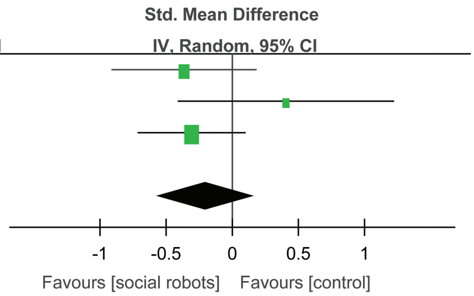

Figure 3. Forest plot: Social robots for agitation ($n = 3$).

	Social robots			Control				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Liang 2017	7.23	5.97	13	6.27	3.1	11	20.0%	0.19 [-0.62, 1.00]
Soler 2015	27.78	19.51	63	26.55	16.05	38	80.0%	0.07 [-0.34, 0.47]
Total (95% CI)			**76**			**49**	**100.0%**	**0.09 [-0.27, 0.45]**

Heterogeneity: Tau² = 0.00; Chi² = 0.07, df = 1 (P = 0.79); I² = 0%
Test for overall effect: Z = 0.50 (P = 0.62)

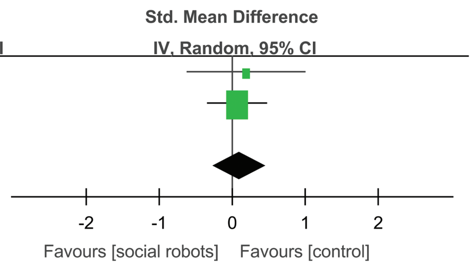

Figure 4. Forest plot: social robots for neuropsychiatric symptoms ($n = 2$).

	Social robots			Control				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
1.3.1 Self-report								
Moyle 2013	9.8	6.5	18	7	6.9	18	100.0%	2.80 [-1.58, 7.18]
Subtotal (95% CI)			**18**			**18**	**100.0%**	**2.80 [-1.58, 7.18]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 1.25 (P = 0.21)								
1.3.2 Staff reported								
Moyle 2013	12.8	11.2	18	17.1	15.1	18	38.6%	-4.30 [-12.99, 4.39]
Petersen 2017	9.5	11.2	35	8.65	15.1	26	61.4%	0.85 [-6.04, 7.74]
Subtotal (95% CI)			**53**			**44**	**100.0%**	**-1.14 [-6.54, 4.26]**
Heterogeneity: Tau² = 0.00; Chi² = 0.83, df = 1 (P = 0.36); I² = 0%								
Test for overall effect: Z = 0.41 (P = 0.68)								

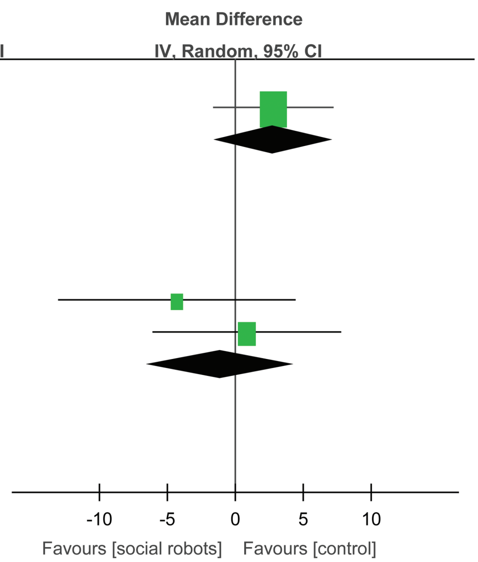

Figure 5. Forest plot: Social robots for anxiety ($n = 2$).

studies, SMD: 0.06, 95% CI: –0.17 to 0.29; Figure 6) and apathy (two studies, SMD: 0.00, 95% CI: –0.34 to 0.35; Figure 7).

Cognitive Level

Four studies provided sufficient raw data to explore the effectiveness of robots on cognition. Three different scales were used including Mini-Mental State Examination (MMSE), Global Deterioration Scale (GDS), and Addenbrooke's Cognitive Examination. No significant result was observed on cognition for people with dementia (SMD: 0.04, 95% CI: –0.33 to 0.26) and those without dementia (SMD: 0.40, 95% CI: –0.28 to 1.09; Figure 8).

	Social robots			Control				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Broadbent 2014	2.08	1.91	29	1.96	2.1	29	19.5%	0.06 [-0.46, 0.57]
Jøranson 2015	7.9	6.7	27	8.1	5.6	26	17.8%	-0.03 [-0.57, 0.51]
Liang 2017	4.77	4.29	13	4.91	2.74	11	8.0%	-0.04 [-0.84, 0.77]
Moyle 2013	4.7	2.9	18	4.3	3.5	18	12.1%	0.12 [-0.53, 0.78]
Petersen 2017	9.69	5.5	35	8.62	4.17	26	19.9%	0.21 [-0.30, 0.72]
Robinson 2013	4.15	2.34	17	4	2.62	17	11.4%	0.06 [-0.61, 0.73]
Tanaka 2012	2.1	2.1	18	2.3	4.1	16	11.4%	-0.06 [-0.73, 0.61]
Total (95% CI)			**157**			**143**	**100.0%**	**0.06 [-0.17, 0.29]**

Heterogeneity: Tau² = 0.00; Chi² = 0.67, df = 6 (P = 1.00); I² = 0%

Test for overall effect: Z = 0.51 (P = 0.61)

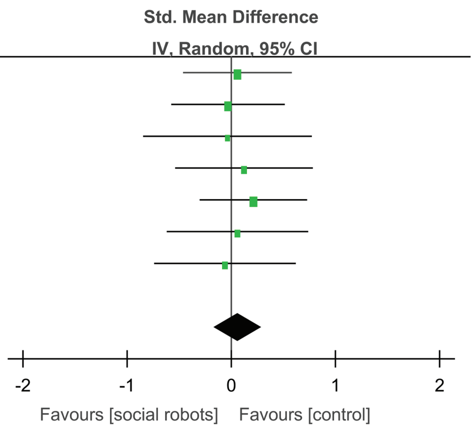

Figure 6. Forest plot: Social robots for depression (*n* = 7).

	Social robots			Control				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Moyle 2013	38.7	13.7	18	36.5	13.7	18	27.5%	0.16 [-0.50, 0.81]
Soler 2015	43.21	22.31	63	44.42	23.59	38	72.5%	-0.05 [-0.46, 0.35]
Total (95% CI)			**81**			**56**	**100.0%**	**0.00 [-0.34, 0.35]**

Heterogeneity: Tau² = 0.00; Chi² = 0.29, df = 1 (P = 0.59); I² = 0%

Test for overall effect: Z = 0.03 (P = 0.98)

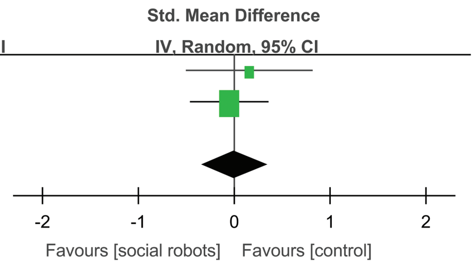

Figure 7. Forest plot: social robots for apathy (*n* = 2).

	Social robots			Control				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
1.6.1 People with dementia								
Liang 2017	38.8	17.6	13	37.1	14.8	11	11.3%	0.10 [-0.70, 0.90]
Petersen 2017	5.53	11.09	35	5.24	9.76	26	28.2%	0.03 [-0.48, 0.53]
Soler 2015	2.59	4.58	63	3.12	4.72	38	44.8%	-0.11 [-0.52, 0.29]
Subtotal (95% CI)			**111**			**75**	**84.3%**	**-0.04 [-0.33, 0.26]**
Heterogeneity: Tau² = 0.00; Chi² = 0.31, df = 2 (P = 0.86); I² = 0%								
Test for overall effect: Z = 0.25 (P = 0.80)								
1.6.2 People without dementia								
Tanaka 2012	29.7	0.7	18	29.2	1.6	16	15.7%	0.40 [-0.28, 1.09]
Subtotal (95% CI)			**18**			**16**	**15.7%**	**0.40 [-0.28, 1.09]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 1.16 (P = 0.25)								
Total (95% CI)			**129**			**91**	**100.0%**	**0.03 [-0.24, 0.30]**

Heterogeneity: Tau² = 0.00; Chi² = 1.67, df = 3 (P = 0.64); I² = 0%

Test for overall effect: Z = 0.23 (P = 0.82)

Test for subgroup differences: Chi² = 1.36, df = 1 (P = 0.24), I² = 26.6%

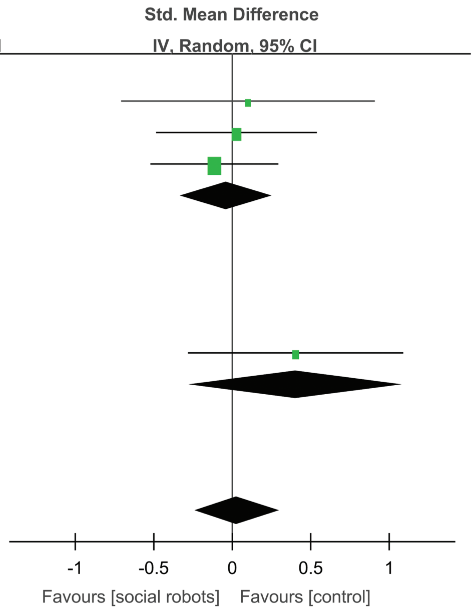

Figure 8. Forest plot: Social robots for cognition (*n* = 4).

Quality of Life

Four studies measured the effect of PARO on quality of life with 297 individuals living with dementia (Jøranson et al., 2016; Moyle et al., 2013; Robinson et al., 2013; Soler et al., 2015). Two studies reported the Quality of Life in Late-Stage Dementia scale (QUALID) final score (Jøranson et al., 2016; Soler et al., 2015) and the other two reported the Quality of life for Alzheimer's Disease (QoL-AD) final score (Moyle et al., 2013; Robinson et al., 2013). The SMD for self-reported QoL of people with dementia was 0.21 (95% CI: −0.47 to 0.88) and 0.24 (95% CI: −0.21 to 0.69) for staff rated QoL favoring the social robot intervention, but not at a statistically significant level (Figure 9). A baseline difference in the Health-Related Quality of Life short form (SF-12) score but without ANCOVA analysis was reported by Broadbent and colleagues (2014). However, we did not include this result in the meta-analysis because imbalance at baseline may bias the comparison of the final score.

Description of Outcomes Not Suitable for Meta-Analysis

Meta-analysis was not applied to the outcomes of behavioral observation of engagement and social interaction, physiological responses, and medication because not enough data were obtained from the included studies. Instead, the effectiveness of social robots on these domains was described and summarized in a narrative review.

Engagement, Social Interaction, and Loneliness

Positive results of engagement and social interaction between participants and social robots were reported in three studies (Liang et al., 2017; Moyle, Jones, et al., 2017; Thodberg, Sørensen, Videbech, et al., 2016) using methods of direct observation or video recordings. Compared to a plush toy or a usual care group, residents with social robots were significantly more engaged in interactions with positive facial expressions and verbal communication with staff, while neutral expressions were reduced (Moyle, Jones, et al., 2017). In addition, evidence from two trials (Banks et al., 2008; Robinson et al., 2013) suggested that robot interactions positively decreased the level of loneliness.

Physiological Indicators

Data from two trials (Tanaka et al., 2012; Thodberg, Sørensen, Christensen, et al., 2016) indicated that there was no effect of social robots on body mass index (BMI), but there was a positive effect on sleep. In addition, Petersen and colleagues (2017) pointed out that PARO could improve oxygenation and cardiac status of people with dementia measured by pulse rate, pulse oximetry, and galvanic skin response (GSR), indicating decreased levels of anxiety and stress. Similar findings were found with reduced level of saliva cortisol (Tanaka et al., 2012). However, Liang and colleagues (2017) found no significant differences in physiological indexes, including salivary and hair cortisol, blood pressure, as well as heart rate between participants in control and intervention groups.

Medication

Jøranson and colleagues (2016) found that a PARO intervention could reduce the use of psychotropic drugs in people with severe dementia. However, there was no difference in medication usage for people with mild or moderate dementia. Petersen and colleagues (2017) also implied that psychoactive medication use decreased after a 3-month period of

	Social robots			Control				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
1.7.1 Self-report QoL								
Robinson 2013	32.73	8.24	17	31.19	6.26	17	100.0%	0.21 [-0.47, 0.88]
Subtotal (95% CI)			**17**			**17**	**100.0%**	**0.21 [-0.47, 0.88]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.60 (P = 0.55)								
1.7.2 Staff rated QoL								
Jøranson 2015	-23.35	7.65	27	-25.31	10.26	26	26.7%	0.21 [-0.33, 0.75]
Moyle 2013	37.2	8.2	18	26.4	16.8	18	21.7%	0.80 [0.12, 1.48]
Robinson 2013	26.71	7.71	17	23.94	5.18	17	21.8%	0.41 [-0.27, 1.09]
Soler 2015	-26.75	8.16	42	-24.72	6.68	32	29.8%	-0.27 [-0.73, 0.20]
Subtotal (95% CI)			**104**			**93**	**100.0%**	**0.24 [-0.21, 0.69]**
Heterogeneity: Tau² = 0.12; Chi² = 7.19, df = 3 (P = 0.07); I² = 58%								
Test for overall effect: Z = 1.05 (P = 0.29)								

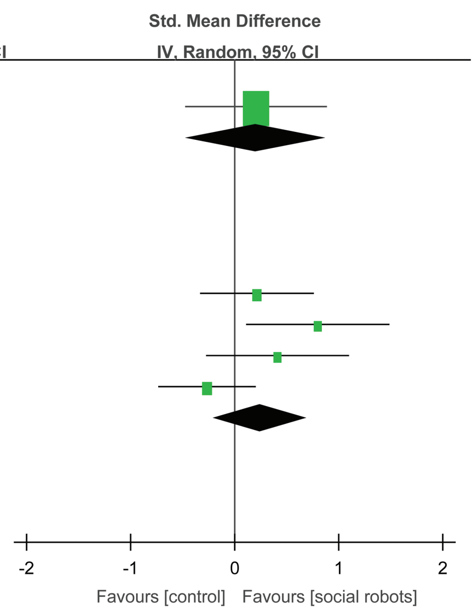

Figure 9. Forest plot: Social robots for the quality of life ($n = 4$).

a PARO intervention. Furthermore, the intervention group used significantly less pain medication when compared with control groups, whereas there was no difference in sleep medication or depression medication. Similar results were reported with no significant differences in the use of dementia-related medication (Liang et al., 2017) and medication adherence (Broadbent et al., 2014).

Discussion

Social robots have developed very quickly in recent years and have been used in several countries. However, the effectiveness of social robots for older adults is not well established. As far as we know, this is the first systematic review and meta-analysis of RCTs to evaluate the effectiveness of social robots for older adults and provides a higher level of evidence for health care providers. Pooled results indicate that social robots have the potential to reduce agitation and anxiety, as well as improve quality of life for older adults. The narrative review indicates that interacting with social robots improves engagement and communication, as well as reduces loneliness, stress responses, and medication use in older adults.

Quality of the Evidence

Although eleven studies were included in this review, most of the included studies were of low to moderate quality and only one trial conducted by Moyle, Jones, and colleagues (2017) met the seven criteria for RCTs. Nine studies reported the method of randomization, but concealment of allocation was unclear in most studies. Although blinding of participants was challenging in social robot interventions, blinding of assessors was practical but only reported in four trials. There was a high drop-out in interventions involving older adults, and missing data management was poorly reported in the included studies. Two trials had an issue of selective reporting resulting in insufficient data being included in the meta-analysis. Therefore, more rigorously designed studies should be conducted to justify the effectiveness of social robots scientifically.

Participants and Intervention Examined

In this review, seven studies involved participants with cognitive impairment or dementia, three studies recruited participants without cognitive impairment, and the remaining study included participants regardless of their level of cognitive function. Both groups of individuals benefited from the social robot interventions, especially for those with dementia. However, inconsistent results were observed in terms of the effects of social robots on participants with different stages of dementia, but we could not conduct a subgroup analysis based on the severity of dementia because most studies reported their results generally. According to Liang and colleagues (2017), people with higher cognitive capabilities engaged more actively than those with lower capabilities, which is similar to findings reported in previous research (Takayanagi, Kirita, & Shibata, 2014). In contrast, Jøranson and colleagues (2016) found that people with advanced dementia benefited from social robots for sustained quality of life and the robot reduced psychotropic medication, whereas no significant differences were found for those groups with mild/moderate dementia. In addition, a quasi-experimental study (Bemelmans, Gelderblom, Jonker, & de Witte, 2015) using PARO in intramural psychogeriatric care found no significant difference in terms of therapeutic outcomes among patients with different stages of dementia. Therefore, more research is needed to identify the relationship between the severity of dementia and responses from using social robots.

Interventions in this review varied largely in the format, frequency, and duration as well as settings of the intervention. Compared to group interventions, individual interactions with PARO were more acceptable and applicable, where users could interact and engage with PARO in a personalized way (Liang et al., 2017; Moyle et al., 2013). In addition, evidence suggested that determining users' preferences or on a per need basis may improve the acceptability and perceived benefits (Kachouie et al., 2014). Furthermore, individual interventions can minimize the interactions of residents with the facilitator and with others in the setting, which indicates that any benefits are more likely to be due to the intervention than any confounding variables.

There is still a lack of RCTs comparing the effectiveness of different dosages of the intervention, such as frequency and duration of the use of the social robot with older adults. Evidence from animal-assisted therapy (AAT) may provide some guidance regarding the dose–response effects of social robot interventions. Results from a meta-analysis of AAT (Nimer & Lundahl, 2007) found that the number of AAT sessions was associated with better behavioral outcomes, such as social interaction or communication, but it was negatively related to well-being, such as anxiety and depression. Similarly, Virués-Ortega, Pastor-Barriuso, Castellote, Población, and de Pedro-Cuesta (2012) suggested that highly intensive AAT interventions may lead to an exhaustion of intervention effects in older adults. These results indicate that the dosage of interventions could be designed according to different outcomes or the preferences of individuals. Further research should focus on the dose–response effects as well as the duration of social robot intervention required to achieve positive outcomes.

Effects of Social Robots on Behavioral and Psychological Indicators

This review indicated that social robots improved agitation and anxiety, but the results were not statistically significant. Although no obvious effects were found on neuropsychiatric symptoms, apathy, and depression, previous interviews with older people mentioned that social robots could help them get through the "gloomy days" (Šabanović, Chang, Bennett, Piatt, & Hakken, 2015). Results from a 17-month observational experiment also supported this result (Kazuyoshi, Takanori, Tomoko, Kayoko, & Kazuo, 2005), indicating that interaction with robots provides stimulation, relaxation, and comfort to participants.

It is not surprising the summarized results did not show any significant differences as only a small number of studies with the majority having small sample sizes were included in this review. This indicates that studies with larger sample sizes are warranted in this research field.

Effects of Social Robots on Cognitive Function

No significant result was found for cognitive function, but this result is limited to subjective outcome measures. However, some experiments reported improved brain function of participants examined by objective devices (e.g., electroencephalogram or functional near-infrared spectroscopy) when people were interacting with social robots. Improved cortical neuron activity was observed for 29 people with dementia after 20 min of robot therapy (Wada, Shibata, Musha, & Kimura, 2005). Similar results were also found for adults (Kawaguchi et al., 2011), which implied that robot therapy has a high potential to improve brain activity and delay the process of cognitive impairment of dementia. However, these studies were conducted with small sample sizes and short-term interventions, further experiments involving more participants are needed to investigate the long-term effects of robots on brain function of older adults.

Effects of Social Robots on Quality of Life

The pooled results indicated that social robots might have the potential to improve both self-report and staff-report quality of life of older adults, but the result was not statistically significant. This finding is consistent with previous studies which found that social robot interventions had a positive effect on quality of life (Bemelmans et al., 2015; Kanamori et al., 2003). Furthermore, compared to the control condition, a higher level of proxy-rated quality of life was observed in people with dementia after interacting with social robots, but this effect was limited to those with advanced dementia (Jøranson et al., 2016; Soler et al., 2015). This may be explained by the fact that older people may experience reduced interaction and social engagement due to limited access to meaningful activities, thus social robots could increase communication and stimulation to fill this gap and provide therapeutic companionship. In addition, people who positively interacted with the robots may experience further improvement in their quality of life (Kanamori et al., 2003; Moyle et al., 2013), and in particular, for those with late stages of dementia. However, the effect of social robots on the quality of life for people with mild/moderate dementia is still unclear.

Effects of Social Robots on Engagement, Social Interaction, and Loneliness

This review indicated that social robots improved engagement and social interaction of older adults and had the potential to reduce loneliness. This is an important finding as loneliness, and social isolation increases with older age, in particular, for people living with dementia (Nicholson, 2012). Although group activities don't allow members to engage for lengthy periods with the social robot, nonetheless actively engaging people with dementia in meaningful group activities with a social robot may help to increase social interaction, which may further stimulate engagement between group members and therefore reduce loneliness (Chu, Khosla, Khaksar, & Nguyen, 2017; Masi, Chen, Hawkley, & Cacioppo, 2011; Moyle, Bramble, et al., 2017). Observation notes or video recordings are common ways to measure engagement; however, a comprehensive coding protocol for engagement should be developed at the project planning stage to avoid observer bias. For example, Jones, Sung, and Moyle (2015) developed a video coding scheme (VC-IOE) to detect six dimensions of engagement including emotional, verbal, visual, behavioral, collective, and signs of agitation. In addition, research is also needed to increase understanding of approaches to enhance or improve engagement duration of users toward social robots to further design personal centered services.

Effects of the Social Robot on Physiological Indicators

Results from three studies indicated that social robot interventions could improve sleep and reduce stress levels. According to a recent study (Robinson, MacDonald, & Broadbent, 2015), both systolic and diastolic blood pressure significantly decreased when older people interacted with PARO, and their heart rate decreased as well. Meanwhile, Petersen and colleagues (2017) also found pulse oximetry and GSR were increased, while pulse rate decreased compared to the control group. A reduced value of 17-KS-S (17-Ketosteroid sulfate) and increased ratio of 17-KS-S/17-OHCS (17-hydroxycorticosteroids) from urinary tests was observed, which confirmed that interaction with social robots might decrease stress levels (Wada & Shibata, 2007; Wada, Shibata, Saito, Sakamoto, & Tanie, 2005). This may be explained by increased levels of oxytocin, which can be released by non-noxious sensory stimulation, such as touch, stroking, light pressure during interaction with social robots (Handlin et al., 2011; Jøranson et al., 2015). Oxytocin offers anti-stress effects and increases the pain threshold (Beetz et al., 2012). In addition, therapy dog visits have been shown to increase levels of oxytocin (Handlin et al., 2011; Miller et al., 2009). Future studies may combine the measurement of oxytocin and biomarkers of stress, such as cortisol, to provide more evidence regarding the underlying mechanism of the physiological effects of social robots on older adults.

Effects of the Social Robot on Medications

Evidence indicated that robot interactions can reduce pain medications and psychotropic medications for people with dementia. According to the progressively lowered stress threshold (PLST) model (Richards & Beck, 2004), unmanaged pain may be regarded as a physical stressor that contributes to stress-related behaviors (Brecher & West, 2016; Sampson et al., 2015) and mood (Husebo, Ballard, Fritze, Sandvik, & Aarsland, 2014; Jaremka et al., 2014). People might be distracted from their pain and anxiety when interacting with robots (Lane et al., 2016; Marti, Bacigalupo, Giusti, Mennecozzi, & Shibata, 2006; Roger, Guse, Mordoch, & Osterreicher, 2012), thus decreasing disruptive behaviors and medication usage. However, Petersen and colleagues (2017) pointed out that although depression improved for participants, health providers were reluctant to change participants' antidepressant medication, which suggested that physicians and pharmacists should be involved in a multidisciplinary team advocating psychosocial interventions to help to manage medications for residents. Furthermore, as little is known about the effectiveness of social robots on pain management in older adults, especially in people with dementia, this area is worthy of study.

Limitations and Future Research

This study is the first systematic review and meta-analysis of RCTs exploring the effectiveness of social robots for older adults. The use of defined inclusion/exclusion criteria, application of a rigorous search strategy from eight databases, strict quality assessment of the studies and systematic combination of findings, are the strengths of this review. However, there are some limitations. First, the small number of trials and participants included in this review reflects the paucity of RCTs in the research field of social robots for older adults. Second, a large variation of intervention types may influence the pooled results due to the substantial clinical heterogeneity. Although results from this review offer guidance regarding social robot interventions for older adults, they should be interpreted with caution because only a few studies were included in the subgroup meta-analysis. In addition, subgroup analysis based on the level of cognitive impairment or intervention types was limited. Inadequate information related to outcomes from included RCTs is also a potential source of bias, suggesting a need for RCTs to follow reporting guidelines. Third, language bias may be considered because only RCTs published in the English language were selected and the age selection was 55 years old, which may exclude younger adults with physical disabilities who may also benefit from social robot intervention. Although RCT is the gold standard of evidence for the highest internal validity, caution is needed in generalizing the findings to a broader population in clinical practice due to the unique subject population in this review. Furthermore, ethical issues should be considered as HRI is not designed to replace human contact but regarded as a possible adjunct to HAI in the care of vulnerable older adults. Human rights and autonomy should be respected during the application of social robots as some individuals may prefer live animal interaction.

Conclusions

This systematic review integrates evidence from RCTs of social robot use with older adults. A total of 13 articles from 11 studies were included in this review. The results implied that current RCTs about social robots were predominately of low to moderate quality, especially in the allocation of concealment and blinding of assessors. Additional rigorously designed studies should be conducted to confirm the effectiveness of social robot use in older adults. Results indicate that robot interactions have potential effects on agitation, anxiety and loneliness, medication consumption as well as the quality of life for older adults. But the potential for social robots to improve cognition, depression, and apathy needs further investigation.

Supplementary Material

Supplementary data are available at *The Gerontologist* online.

Funding

This work was supported by a PhD scholarship from Griffith University and the Chinese Scholarship Council (CSC).

Conflicts of Interest

None reported.

References

Banks, M. R., Willoughby, L. M., & Banks, W. A. (2008). Animal-assisted therapy and loneliness in nursing homes: Use of robotic versus living dogs. *Journal of the American Medical Directors Association*, **9**, 173–177. doi:10.1016/j.jamda.2007.11.007

Beetz, A., Uvnäs-Moberg, K., Julius, H., & Kotrschal, K. (2012). Psychosocial and psychophysiological effects of human–animal interactions: The possible role of oxytocin. *Frontiers in Psychology*, **3**, 234. doi:10.3389/fpsyg.2012.00234

Bemelmans, R., Gelderblom, G. J., Jonker, P., & de Witte, L. (2012). Socially assistive robots in elderly care: A systematic review into effects and effectiveness. *Journal of the American Medical Directors Association*, **13**, 114.e1–120.e1. doi:10.1016/j.jamda.2010.10.002

Bemelmans, R., Gelderblom, G. J., Jonker, P., & de Witte, L. (2015). Effectiveness of robot Paro in intramural psychogeriatric care: A multicenter quasi-experimental study. *Journal of the American Medical Directors Association*, **16**, 946–950. doi:10.1016/j.jamda.2015.05.007

Brecher, D. B., & West, T. L. (2016). Underrecognition and undertreatment of pain and behavioral symptoms in end-stage dementia. *The American Journal of Hospice & Palliative Care*, **33**, 276–280. doi:10.1177/1049909114559069

Broadbent, E. (2017). Interactions with robots: The truths we reveal about ourselves. *Annual Review of Psychology*, **68**, 627–652. doi:10.1146/annurev-psych-010416-043958

Broadbent, E., Peri, K., Kerse, N., Jayawardena, C., Kuo, I., Datta, C., & MacDonald, B. (2014, October). Robots in older people's homes to improve medication adherence and quality of life: A randomised cross-over trial. Paper presented at the Social Robotics: 6th International Conference, ICSR 2014, Sydney, NSW, Australia.

Broekens, J., Heerink, M., & Rosendal, H. (2009). Assistive social robots in elderly care: A review. *Gerontechnology*, **8**, 94–103. doi:10.4017/gt.2009.08.02.002.00

Chu, M. T., Khosla, R., Khaksar, S. M., & Nguyen, K. (2017). Service innovation through social robot engagement to improve dementia care quality. *Assistive Technology*, **29**, 8–18. doi:10.1080/10400435.2016.1171807

Costescu, C. A., Vanderborght, B., & David, D. O. (2014). The effects of robot-enhanced psychotherapy: A meta-analysis. *Review of General Psychology*, **18**, 127–136. doi:10.1037/gpr0000007

David, D., Matu, S.-A., & David, O. A. (2014). Robot-based psychotherapy: Concepts development, state of the art, and new directions. *International Journal of Cognitive Therapy*, **7**, 192–210. doi:10.1521/ijct.2014.7.2.192

Gill, S. S., Bronskill, S. E., Normand, S. L., Anderson, G. M., Sykora, K., Lam, K.,…Rochon, P. A. (2007). Antipsychotic drug use and mortality in older adults with dementia. *Annals of Internal Medicine*, **146**, 775–786. doi:10.7326/0003-4819-146-11-200706050-00006

Handlin, L., Hydbring-Sandberg, E., Nilsson, A., Ejdebäck, M., Jansson, A., & Uvnäs-Moberg, K. (2011). Short-term interaction between dogs and their owners: Effects on oxytocin, cortisol, insulin and heart rate—An exploratory study. *Anthrozoös*, **24**, 301–315. doi:10.2752/175303711X13045914865385

Hegel, F., Muhl, C., Wrede, B., Hielscher-Fastabend, M., & Sagerer, G. (2009, Feburary). Understanding social robots. Paper presented at the 2009 Second International Conferences on Advances in Computer–Human Interactions, Cancun, Mexico.

Higgins, J. P., Altman, D. G., Gøtzsche, P. C., Jüni, P., Moher, D., Oxman, A. D.,…Sterne, J. A.; Cochrane Bias Methods Group; Cochrane Statistical Methods Group. (2011). The cochrane collaboration's tool for assessing risk of bias in randomised trials. *BMJ*, **343**, d5928. doi:10.1136/bmj.d5928

Husebo, B. S., Ballard, C., Fritze, F., Sandvik, R. K., & Aarsland, D. (2014). Efficacy of pain treatment on mood syndrome in patients with dementia: A randomized clinical trial. *International Journal of Geriatric Psychiatry*, **29**, 828–836. doi:10.1002/gps.4063

Jaremka, L. M., Andridge, R. R., Fagundes, C. P., Alfano, C. M., Povoski, S. P., Lipari, A. M.,…Kiecolt-Glaser, J. K. (2014). Pain, depression, and fatigue: Loneliness as a longitudinal risk factor. *Health Psychology*, **33**, 948–957. doi:10.1037/a0034012

Jones, C., Sung, B., & Moyle, W. (2015). Assessing engagement in people with dementia: A new approach to assessment using video analysis. *Archives of Psychiatric Nursing*, **29**, 377–382. doi:10.1016/j.apnu.2015.06.019

Jøranson, N., Pedersen, I., Rokstad, A. M., & Ihlebæk, C. (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**, 867–873. doi:10.1016/j.jamda.2015.05.002

Jøranson, N., Pedersen, I., Rokstad, A. M., & Ihlebaek, C. (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**, 3020–3033. doi:10.1111/jan.13076

Kachouie, R., Sedighadeli, S., Khosla, R., & Chu, M.-T. (2014). Socially assistive robots in elderly care: A mixed-method systematic literature review. *International Journal of Human-Computer Interaction*, **30**, 369–393. doi:10.1080/10447318.2013.873278

Kanamori, M., Suzuki, M., Oshiro, H., Tanaka, M., Inoguchi, T., Takasugi, H.,…Yokoyama, T. (2003, July). Pilot study on improvement of quality of life among elderly using a pet-type robot. Paper presented at the Proceedings 2003 IEEE International Symposium on Computational Intelligence in Robotics and Automation, Kobe, Japan.

Kawaguchi, Y., Wada, K., Okamoto, M., Tsujii, T., Shibata, T., & Sakatani, K. (2011, July–August). Investigation of brain activity during interaction with seal robot by fnirs. Paper presented at the 2011 RO-MAN, Atlanta, GA, USA.

Kazuyoshi, W., Takanori, S., Tomoko, S., Kayoko, S., & Kazuo, T. (2005, June). Robot assisted activity at a health service facility for the aged for 17 months: An interim report of long-term experiment. Paper presented at the IEEE Workshop on Advanced Robotics and its Social Impacts, 2005, Nagoya, Japan.

Khosravi, P., & Ghapanchi, A. H. (2016). Investigating the effectiveness of technologies applied to assist seniors: A systematic literature review. *International Journal of Medical Informatics*, **85**, 17–26. doi:10.1016/j.ijmedinf.2015.05.014

Kramer, S. C., Friedmann, E., & Bernstein, P. L. (2009). Comparison of the effect of human interaction, animal-assisted therapy, and aibo-assisted therapy on long-term care residents with dementia. *Anthrozoös*, **22**, 43–57. doi:10.2752/175303708X390464

Lane, G. W., Noronha, D., Rivera, A., Craig, K., Yee, C., Mills, B., & Villanueva, E. (2016). Effectiveness of a social robot, "Paro," in a VA long-term care setting. *Psychological Services*, **13**, 292–299. doi:10.1037/ser0000080

Liang, A., Piroth, I., Robinson, H., MacDonald, B., Fisher, M., Nater, U. M.,…Broadbent, E. (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**, 871–878. doi:10.1016/j.jamda.2017.05.019

Marti, P., Bacigalupo, M., Giusti, L., Mennecozzi, C., & Shibata, T. (2006, Feburary). Socially assistive robotics in the treatment of behavioural and psychological symptoms of dementia. Paper presented at the The First IEEE/RAS-EMBS International Conference on Biomedical Robotics and Biomechatronics, 2006, Pisa, Italy.

Masi, C. M., Chen, H. Y., Hawkley, L. C., & Cacioppo, J. T. (2011). A meta-analysis of interventions to reduce loneliness. *Personality and Social Psychology Review*, **15**, 219–266. doi:10.1177/1088868310377394

Miller, S. C., Kennedy, C. C., DeVoe, D. C., Hickey, M., Nelson, T., & Kogan, L. (2009). An examination of changes in oxytocin levels in men and women before and after interaction with a bonded dog. *Anthrozoös*, **22**, 31–42. doi:10.2752/175303708X390455

Mordoch, E., Osterreicher, A., Guse, L., Roger, K., & Thompson, G. (2013). Use of social commitment robots in the care of elderly people with dementia: A literature review. *Maturitas*, **74**, 14–20. doi:10.1016/j.maturitas.2012.10.015

Moyle, W., Bramble, M., Jones, C., & Murfield, J. (2017). "She Had a Smile on Her Face as Wide as the Great Australian Bite": A qualitative examination of family perceptions of a therapeutic robot and a plush toy. *The Gerontologist*. doi:10.1093/geront/gnx180

Moyle, W., Cooke, M., Beattie, E., Jones, C., Klein, B., Cook, G., & Gray, C. (2013). Exploring the effect of companion robots on emotional expression in older adults with dementia: A pilot randomized controlled trial. *Journal of Gerontological Nursing*, **39**, 46–53. doi:10.3928/00989134-20130313-03

Moyle, W., Jones, C. J., Murfield, J. E., Thalib, L., Beattie, E. R. A., Shum, D. K. H.,…Draper, B. M. (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**, 766–773. doi:10.1016/j.jamda.2017.03.018

Nicholson, N. R. (2012). A review of social isolation: An important but underassessed condition in older adults. *The Journal of Primary Prevention*, **33**, 137–152. doi:10.1007/s10935-012-0271-2

Nimer, J., & Lundahl, B. (2007). Animal-assisted therapy: A meta-analysis. *Anthrozoös*, **20**, 225–238. doi:10.2752/089279307X224773

Petersen, S., Houston, S., Qin, H., Tague, C., & Studley, J. (2017). The utilization of robotic pets in dementia care. *Journal of Alzheimer's Disease*, **55**, 569–574. doi:10.3233/JAD-160703

Pieper, M. J., van Dalen-Kok, A. H., Francke, A. L., van der Steen, J. T., Scherder, E. J., Husebø, B. S., & Achterberg, W. P. (2013). Interventions targeting pain or behaviour in dementia: A systematic review. *Ageing Research Reviews*, **12**, 1042–1055. doi:10.1016/j.arr.2013.05.002

Rabbitt, S. M., Kazdin, A. E., & Scassellati, B. (2015). Integrating socially assistive robotics into mental healthcare interventions: Applications and recommendations for expanded use. *Clinical Psychology Review*, **35**, 35–46. doi:10.1016/j.cpr.2014.07.001

Richards, K. C., & Beck, C. K. (2004). Progressively lowered stress threshold model: Understanding behavioral symptoms of dementia. *Journal of the American Geriatrics Society*, **52**, 1774–1775. doi:10.1111/j.1532-5415.2004.52477.x

Robinson, H., MacDonald, B., & Broadbent, E. (2015). Physiological effects of a companion robot on blood pressure of older people in residential care facility: A pilot study. *Australasian Journal on Ageing*, **34**, 27–32. doi:10.1111/ajag.12099

Robinson, H., MacDonald, B., Kerse, N., & Broadbent, E. (2013). The psychosocial effects of a companion robot: A randomized controlled trial. *Journal of the American Medical Directors Association*, **14**, 661–667. doi:10.1016/j.jamda.2013.02.007

Roger, K., Guse, L., Mordoch, E., & Osterreicher, A. (2012). Social commitment robots and dementia. *Canadian Journal on Aging*, **31**, 87–94. doi:10.1017/S0714980811000663

Šabanović, S., Chang, W.-L., Bennett, C. C., Piatt, J. A., & Hakken, D. (2015). A robot of my own: Participatory design of socially assistive robots for independently living older adults diagnosed with depression. Paper presented at the Human Aspects of IT for the Aged Population. Design for Aging: First International Conference, ITAP 2015, Held as Part of HCI International 2015, Los Angeles, CA, USA. doi:10.1007/978-3-319-20892-3_11

Sampson, E. L., White, N., Lord, K., Leurent, B., Vickerstaff, V., Scott, S., & Jones, L. (2015). Pain, agitation, and behavioural problems in people with dementia admitted to general hospital wards: A longitudinal cohort study. *Pain*, **156**, 675–683. doi:10.1097/j.pain.0000000000000095

Shibata, T., & Wada, K. (2011). Robot therapy: A new approach for mental healthcare of the elderly—A mini-review. *Gerontology*, **57**, 378–386. doi:10.1159/000319015

Sicurella, T., & Fitzsimmons, V. (2016). Robotic pet therapy in long-term care. *Nursing*, **46**, 55. doi:10.1097/01.NURSE.0000482265.32133.f6

Soler, M. V., Agüera-Ortiz, L., Rodríguez, J. O., Rebolledo, C. M., Muñoz, A. P., Pérez, I. R., … Chillón, L. C. (2015). Social robots in advanced dementia. *Frontiers in Aging Neuroscience*, **7**, 133. doi:10.3389/fnagi.2015.00133

Stoner, S. C. (2017). Management of serious cardiac adverse effects of antipsychotic medications. *Mental Health Clinician*, **7**, 246–254. doi:10.9740/mhc.2017.11.246

Takayanagi, K., Kirita, T., & Shibata, T. (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**, 257. doi:10.3389/fnagi.2014.00257

Tanaka, M., Ishii, A., Yamano, E., Ogikubo, H., Okazaki, M., Kamimura, K.,…Watanabe, Y. (2012). Effect of a human-type communication robot on cognitive function in elderly women living alone. *Medical Science Monitor: International Medical Journal of Experimental and Clinical Research*, **18**, CR550–CR557. doi:10.12659/MSM.883350

Thodberg, K., Sørensen, L. U., Christensen, J. W., Poulsen, P. H., Houbak, B., Damgaard, V.,…Videbech, P. B. (2016). Therapeutic effects of dog visits in nursing homes for the elderly. *Psychogeriatrics*, **16**, 289–297. doi:10.1111/psyg.12159

Thodberg, K., Sørensen, L. U., Videbech, P. B., Poulsen, P. H., Houbak, B., Damgaard, V.,…Christensen, J. W. (2016). Behavioral responses of nursing home residents to visits from a person with a dog, a robot seal or a toy cat. *Anthrozoös*, **29**, 107–121. doi:10.1080/08927936.2015.1089011

Twisk, J., & Proper, K. (2004). Evaluation of the results of a randomized controlled trial: How to define changes between baseline and follow-up. *Journal of Clinical Epidemiology*, **57**, 223–228. doi:10.1016/j.jclinepi.2003.07.009

Vandemeulebroucke, T., de Casterlé, B. D., & Gastmans, C. (2018). How do older adults experience and perceive socially assistive robots in aged care: A systematic review of qualitative evidence. *Aging & Mental Health*, **22**, 149–167. doi:10.1080/13607863.2017.1286455

Virués-Ortega, J., Pastor-Barriuso, R., Castellote, J. M., Población, A., & de Pedro-Cuesta, J. (2012). Effect of animal-assisted therapy on the psychological and functional status of elderly populations and patients with psychiatric disorders: A meta-analysis. *Health Psychology Review*, **6**, 197–221. doi:10.1080/17437199.2010.f

Wada, K., & Shibata, T. (2007, August). Robot therapy in a care house—change of relationship among the residents and seal robot during a 2-month long study. Paper presented at the The 16th IEEE International Symposium on Robot and Human Interactive Communication, Jeju, South Korea.

Wada, K., Shibata, T., Musha, T., & Kimura, S. (2005, August). Effects of robot therapy for demented patients evaluated by EEG. Paper presented at the 2005 IEEE/RSJ International Conference on Intelligent Robots and Systems, Edmonton, Alta, Canada.

Wada, K., Shibata, T., Saito, T., Sakamoto, K., & Tanie, K. (2005, April). Psychological and social effects of one year robot assisted activity on elderly people at a health service facility for the aged. Paper presented at the Proceedings of the 2005 IEEE International Conference on Robotics and Automation, Barcelona, Spain.