Human–Robot Collaboration in Elderly Care: Assessing the Impact of Social Robots on Mental Well-being and Adherence

Author: Emily Cooper **Affiliation:** Department of Computer Science, University of Queensland (Australia)

Email: emily.cooper@uq.edu.au

Abstract

As populations age globally, socially assistive and companion robots are emerging as promising tools to support older adults' mental well-being and adherence to health routines (medication, exercise, appointments). This article synthesizes theoretical frameworks, empirical results, and technological approaches to human–robot collaboration (HRC) in eldercare, with a special focus on mental health outcomes (depression, loneliness, cognitive stimulation) and behavioral adherence (medication, physical activity, therapy attendance). This article provides an extended literature review, propose standardized study designs and evaluation metrics, analyze ethical and deployment challenges, and outline a research and engineering roadmap for clinical translation and large-scale adoption. Evidence shows moderate but promising effects of social robots on loneliness, mood, and adherence when interventions are person-centered, multimodal, and integrated with human care teams; however, methodological heterogeneity, short intervention durations, and limited large-scale trials constrain definitive conclusions. Recommendations include standardized outcome sets, mixed-methods longitudinal trials, privacy-preserving cloud architectures for data sharing, and design principles rooted in ethics of care.

Keywords

Social robots; elderly care; mental well-being; adherence; human–robot collaboration; socially assistive robots; ethics; cloud architectures.

1. Introduction

Population aging is creating pressing needs for scalable, person-centered care models that preserve quality of life and autonomy for older adults while reducing caregiver burden and healthcare costs. Socially assistive robots (SARs) robots designed to provide non-physical assistance through social interaction, reminders, coaching, or companionship represent a rapidly maturing class of technologies aiming to meet these needs. Recent systematic reviews and trials indicate that SARs can reduce loneliness and depressive symptoms and can support adherence to exercise and medication regimens, but findings are heterogeneous and contingent on design, context, and integration with human caregivers.

This article examines HRC in eldercare from interdisciplinary perspectives: theoretical (behavior change and social cognition), technical (robot platforms, AI/ML, cloud architectures), empirical (clinical trials and observational studies), and ethical (privacy, deception, autonomy). We aim to provide an article ready for journal submission (structured, rigorous, and with APA references), synthesizing current knowledge and giving concrete research and engineering recommendations for the targeted venues (IEEE Access; Journal of Cloud Computing; Information Systems Frontiers). The two integrative engineering references provided by the authors (Fatunmbi 2021, 2022) are included and contextualized within the human-centred caregiving domain.

2. Background and Theoretical Frameworks

2.1 Definitions and taxonomy

We adopt the taxonomy used in socially assistive robotics literature: (1) *companion robots* (e.g., PARO, ElliQ) that provide social interaction and comfort; (2) *coach/therapist robots* that promote exercise or cognitive training; and (3) *task/service robots* that support activities of daily living (ADLs) while possessing social interfaces for engagement. Human–robot collaboration (HRC) in this context emphasizes joint action between older adults, robots, and human caregivers where robots augment rather than replace human care.

2.2 Theoretical lenses

We synthesize three complementary theoretical lenses:

1. **Social support and attachment theory:** Robots as social actors can provide perceived social support, buffering loneliness and depressive symptoms, particularly when they trigger meaningful social schemas. Empirical effects correlate with anthropomorphism, perceived agency, and sustained interaction.
2. **Self-Determination and Behavior Change (SDT & BCT):** Effective adherence interventions support autonomy, competence, and relatedness. Robot behaviors designed with motivational interviewing, tailored feedback, and timely prompts can support these psychological needs and thereby improve adherence.
3. **Socio-technical systems and ethics of care:** Robots are embedded in care ecosystems; their value depends on alignment with caregivers' workflows, regulatory environments, and ethical norms (non-deception, privacy, informed consent). Tronto's ethics of care has been adapted to evaluate design choices that support caring values in robotic systems.

3. Extended Literature Review (Selected, annotated)

Note: The following section synthesizes 24 peer-reviewed works and prominent trials to provide a broad and critical evidence base.

3.1 Systematic and scoping reviews

- Bevilacqua et al. (2023) review social robotics for dementia, reporting mood and social interaction improvements in small trials but stressing methodological limits.
- Berridge et al. (2023) examine companion robots and ethical perceptions related to deception and loneliness outcomes.
- Getson et al. (2021) surveyed socially assistive robots for older adults, noting multimodal benefits (cognitive stimulation, social inclusion) but limited long-term follow-up.

3.2 Randomized and controlled trials (examples)

- PARO robotic seal trials show reductions in stress and agitation among people with dementia in some studies, though effect sizes vary by setting and duration.
- A controlled trial of a robot exercise coach demonstrated improved adherence to home exercise programs among older adults compared to self-directed exercise (Getson et al., 2021; see also Dubbeldam 2025).

3.3 Technology and platform studies

- Platform studies describe ElliQ and other commercially available agents delivering conversational support, reminders, and activity prompts in community settings; mixed qualitative evidence shows improved engagement but concerns about technical reliability and privacy.

3.4 Adherence outcomes: medication, exercise, appointments

- Several small studies report improved medication and exercise adherence when robots provide personalized reminders and social reinforcement; however, heterogeneous measurement approaches (self-report vs. objective sensors) limit meta-analytic synthesis. Recent trials integrating robotic reminders with medication dispensing modules show promising feasibility.

3.5 Mental well-being outcomes: loneliness, depression, cognition

- Meta-analyses and narrative reviews suggest moderate reductions in loneliness and depressive symptoms, especially in group-based interventions or long-duration deployments; cognitive benefits are more equivocal and often depend on combined cognitive training tasks.

3.6 Ethics, privacy, and caregiver perspectives

- Multiple reviews highlight ethical issues: deception (especially with cognitively impaired), data privacy, reduction of human contact, and consent complexity. Caregiver and institutional acceptability depends on demonstrable benefits and clear governance.

3.7 Technical enablers: AI/ML and cloud infrastructures

- Integrations of AI, ML, and advanced computing (including the integrative themes in Fatunmbi, 2021, 2022) enable personalization, activity recognition, and predictive adherence support; cloud architectures facilitate model updates, remote monitoring, and caregiver dashboards but raise data governance concerns.

4. Methods: Recommended Study Designs and Evaluation Metrics

To address the heterogeneity in the literature, we propose standardized methods tailored to mixed-methods evaluation of social robots in eldercare.

4.1 Study designs

- **Multi-site randomized controlled trials (RCTs):** Parallel-group RCTs comparing robot + usual care vs. usual care alone; stratify by living arrangement (community vs. residential). Primary outcomes: validated loneliness scale (UCLA Loneliness Scale), Geriatric Depression Scale (GDS), and objective adherence metrics (medication event monitoring systems, step counts). Secondary outcomes: care partner burden, healthcare utilization.
- **Stepped-wedge cluster RCTs:** Useful for ethical rollouts in care homes; allows all sites to receive intervention but enables rigorous causal inference.
- **Longitudinal cohort studies with ecological momentary assessment (EMA):** For nuanced temporal patterns and to study novelty effects.
- **Hybrid effectiveness–implementation trials:** Combine clinical outcome evaluation with implementation science (acceptability, feasibility, cost) to speed translation.

4.2 Sample size and power

- Based on prior meta-analytic effect sizes for loneliness (small–moderate, Cohen's $d \approx 0.30$–0.50), we recommend powering RCTs to detect $d = 0.35$ with 80–90% power, adjusting for cluster design when applicable. Pilot data should predefine minimal clinically important differences (MCIDs) for adherence endpoints.

4.3 Outcome measures (recommended core outcome set)

- Mental well-being: UCLA Loneliness Scale; GDS; WHO-5 Well-Being Index.
- Adherence: objectively measured (electronic pillboxes, wearable step counters) and corroborated with self-report (Morisky Medication Adherence Scale).
- Engagement: interaction logs (frequency, duration), qualitative interviews on perceived usefulness.
- System metrics: uptime, error rates, latency for conversational responses.

- Economic: cost per quality-adjusted life year (QALY) where feasible.

4.4 Data collection and analysis

- **Quantitative:** Intention-to-treat analysis; mixed effects models for clustered and longitudinal data; time-to-event analyses for retention.
- **Qualitative:** Thematic analysis of interviews with older adults, caregivers, and staff; use frameworks like Normalization Process Theory to assess implementation.
- **AI/ML validation:** Predefine training/test splits, cross-validation strategies, and fairness audits for models used in personalization

5. Synthesis of Evidence: What Works, for Whom, and Why?

5.1 Efficacy signals

Evidence suggests SARs can produce small–moderate improvements in loneliness and mood when interventions are sustained beyond novelty periods, socially rich (dialogue, games, group interactions), and personalized to user preferences.

5.2 Adherence effects

Robots that combine reminders with social reinforcement (e.g., praise, progress visualization) and integrate objective monitoring show higher adherence than reminders alone; multimodal interventions (robot + human follow-up) are most effective.

5.3 Moderators and mediators

- **User characteristics:** Cognitive impairment, baseline loneliness, and technological literacy moderate outcomes; those with moderate loneliness and openness to technology often benefit most.
- **Design features:** Empathetic conversational interfaces, continuity (same robot persona over time), and adaptability (learning user routines) mediate sustained engagement.
- **Contextual factors:** Caregiver buy-in, staff training, and infrastructure (Wi-Fi, power) critically influence effectiveness and scale-up success.

6. Technical Architecture and Cloud Integration

6.1 Edge–cloud hybrid architectures

Best practice favors edge processing for latency-sensitive tasks (speech recognition, local privacy filters) and cloud processing for model retraining, aggregated analytics, and caregiver dashboards. This hybrid model enables personalization while minimizing data transmission of sensitive raw data.

6.2 AI/ML pipeline and personalization

- **Sensors and multimodal data:** speech, facial affect, activity sensors, medication dispenser logs.
- **Models:** user state estimation (affect, adherence risk), dialogue managers (policy learned via reinforcement learning or rule-based systems), and recommender systems for activities. Fatunmbi (2021, 2022) underscores integrative ML pipelines and potential for advanced diagnostics and personalization when combined with robust compute (and, prospectively, quantum-accelerated methods in long-term visions).

6.3 Security, privacy, and governance

Implement end-to-end encryption, differential privacy for aggregate analytics, fine-grained access control for caregivers, and transparent consent flows for users and proxy decision-makers. Data minimization principles should guide what sensor streams are retained centrally.

7. Ethical, Legal, and Social Implications (ELSI)

7.1 Deception and informed consent

Deployments with people with dementia raise particular concerns about whether anthropomorphic robots might deceive users into believing they are sentient or human; ethical design should favor transparent embodiment and informed consent procedures adapted for cognitive impairment, including surrogate consent when legally appropriate.

7.2 Equity and access

Ensure that interventions do not exacerbate digital divides consider subsidized models, simplified interfaces, and multilingual support. Equity audits should be part of deployment planning.

7.3 Responsibility and liability

Clear delineation of responsibilities (robot vendor, care provider, family, clinical team) is necessary, particularly when robots provide health-relevant prompts (e.g., medication). Regulatory frameworks are emergent; stakeholders should engage with policymakers.

8. Implementation and Scale: From Pilot to Practice

We synthesize lessons from implementation studies:

- **Stakeholder co-design** increases acceptability (older adults, caregivers, staff).
- **Training and workflows:** Staff training windows and clear integration points in daily routines reduce friction.

- **Maintenance and support:** On-site or remote technical support plans are essential to preserve uptime and trust.
- **Economic case:** Cost–benefit modeling should include caregiver time savings, delayed institutionalization, and mental health QALYs.

9. Limitations in Current Evidence and Research Gaps

Key limitations include small sample sizes, short follow-up, heterogeneous outcome measures, and a relative scarcity of large pragmatic trials. There is also limited transparency in AI model details and data governance practices in many published studies. Future work should prioritize standardization, open data where ethical, and rigorous long-term trials across diverse settings.

10. Roadmap and Recommendations

10.1 For researchers

1. Adopt a core outcome set (well-being, adherence, engagement, cost).
2. Run multi-site, adequately powered RCTs and stepped-wedge designs.
3. Publish software and model details (or redacted reproducible artifacts) to enable replication and fairness audits.

10.2 For engineers and vendors

1. Build edge–cloud hybrid platforms with privacy-by-design.
2. Implement modular interfaces for caregiver dashboards and EHR integration.
3. Support over-the-air updates with verifiable provenance.

10.3 For policymakers and funders

1. Fund long-duration effectiveness and implementation trials.
2. Develop minimum safety and data governance standards for SARs in healthcare contexts.
3. Support equitable access initiatives for underserved older adult populations.

11. Conclusion

Social robots hold substantive promise to improve mental well-being and adherence among older adults when interventions are person-centered, ethically designed, and integrated within socio-technical care systems. Evidence to date is encouraging but limited by methodological heterogeneity and short durations. Addressing these gaps requires interdisciplinary collaborations spanning human-centred design, rigorous clinical evaluation, cloud and edge system engineering, and responsible governance. The two integrative engineering perspectives provided by Fatunmbi (2021, 2022) align with this multidisciplinary approach, highlighting the importance of robust computational backbones and advanced analytics for precision caregiving. Future work that standardizes outcomes, scales trials, and foregrounds ethics will determine whether SARs can meaningfully augment human caregiving at population scale.

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