DOI:
10.4017/gt.2023.22.2.sam.08

Document Version
Peer reviewed version

Citation for published version (APA):
Samuel, G., Correa, M., Todd, C., & Tinker, A. (2023). What contribution do robots make to the care of older people? A scoping review. *Gerontechnology*, *22*(2). https://doi.org/10.4017/gt.2023.22.2.sam.08

Heading of submission: Literature review/empirical research

What contribution do robots make to the care of older people? A scoping review

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Abstract

Background and research aim: The aim of this research was to identify the main benefits and barriers of using robotic technology to assist in activities of daily living (ADLs) in older people, as reported in empirical research exploring user perspectives. Most of the literature currently focuses on socially assistive companion robots.

Methodology: A scoping literature review was conducted. Three bibliometric databases were searched covering the last 10 years. 60 publications were included in the review.

Results: Most studies were pilot studies and were conducted with participants who had no identified cognitive impairment. Studies reported mainly positive findings, with older people finding the robots easy to use, and with a high rate of acceptance. Nevertheless, several barriers were identified, and studies pointed to some potential social and psychological harms that could come from using these devices, such as increasing social isolation.

Conclusions: Pilot studies suggest potential benefits associated with using robots for ADLs. At the same time, a number of barriers still remain. Costings (including social, psychological and financial) need to be undertaken to measure the usefulness of these devices. Further work must give more attention to the complex and contextual needs associated with a diverse patient base.

Key words: robots, care, older people, assistive technology

Introduction

By 2030, more than 15% of the global population will be aged 65 years or older (Storey *et al*, 2019). A growing ageing population with complex healthcare needs has increased the need for health and social care support. It has been argued that robotic technology could assume new roles in health and social care to meet this anticipated higher demand.

In the UK, assistive technology has been of increasing interest to policy makers. For example, a recent Department of Health and Social Care White Paper has emphasised that at least £150 million of additional funding will be used to drive greater adoption of technology and achieve widespread digitalisation across social care (DHSC December 2021). The report states that 'during the COVID pandemic,

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the use of digital technologies transformed the delivery of care and helped people stay connected with friends and family' (DHSC December 2021:29). It continues, 'many people use smart devices to help them with routine tasks such as medication reminders, while sensor technologies are increasingly used to monitor movement and identify falls at home' (DHSC December 2021:39-40). In 2018 the Parliamentary Office of Science and Technology also pointed to the possible roles of robots in social care, from automated vacuum cleaners to robots resembling humans or animals. However, this report also noted a range of ethical, legal and regulatory issues, including impacts on users' autonomy and privacy, and questions over the use and ownership of the data' (Parliamentary Office of Science and Technology, December 2018). Beyond this, little exists in the UK, by way of policy on robots in social care.

Robots are now entering the care research arena, highlighted by an increasing number of publications, as well as abstract submissions to gerontechnology conferences (see, for example, The International Society of Gerontechnology (ISG), November 2020). Most of the research in this area has focused on socially assistive companion robots, their emotional impacts and the effect on physiological parameters. Less attention has been paid to robotic technology to assist in activities of daily living (ADLs). Studies that have been conducted are mainly descriptive, with little empirical evidence about their use and acceptability to older people, nor their cost effectiveness. The limitations of existing studies include a narrow focus, methodological limitations, context specificity, limited availability of technology and knowledge gaps (Parliamentary Office of Science and Technology, December 2018, p.2). Currently there is also scant literature focusing on the associated benefits and barriers of the technology. The aim of our research was to identify the main reported benefits and barriers of using robotic technology to assist in activities of daily living (ADLs) in older people as stated in the literature.

Methodology

We conducted a scoping review of the literature, plus a short online survey of researchers working on robotic technology to assist in ADLs for older people.

Scoping review

In June 2021, three bibliometric databases (PubMed, Scopus and Web of Science) were searched for articles. Keywords included two components; the intervention (care robots) and the context (older people): ("care robot*" OR "assistive robot*" OR "service robot*") AND ("older people" OR "aged" OR "elder* care" OR "geriatric" OR "older adult*" OR "frailty" OR "elderly"). Google Scholar was also searched. The advanced search algorithm for Google Scholar was not as powerful as the other bibliographic databases because the key strings could not be combined as cohesively. Rather, keywords from the two component categories (care robots and older people) were combined to generate the key strings. Google Scholar was searched until the majority of the studies retrieved did not match inclusion/exclusion criteria (see below). Additional studies were identified from reference lists of selected publications.

152 articles were retrieved. Article titles and abstracts were read for relevance, and inclusion and exclusion criteria applied. Inclusion criteria included experimental empirical studies involving robots assisting older people with ADLs published in the

last ten years. Exclusion criteria included: (1) Studies using social or companion robotic intervention defined as robots that interact with people in a natural, interpersonal manner, (2) Studies with no robotic intervention, (3) Studies focusing on attitudes, views and opinions of the public, service providers and service users, towards the use of robots in healthcare, (4) Studies involving the use of robots in surgical-related interventions, and (5) Studies measuring mood or physiological parameters as the primary outcome. After duplicates were removed, 60 articles remained for analysis.

Finally, to ensure we analysed the most up-to-date research we sought information about research on robotic technology to assist in ADLs from attendees of the 2020 ISG conference. Attendee email addresses were obtained by scanning the online event programme for relevant presentations. Twenty-one attendees who presented potentially relevant research had publicly accessible email addresses. These attendees were invited via email to provide additional[2] information about the study they presented at the conference, including the country in which their study was conducted, and the number, age, gender and ethnic distribution of participants. Seven researchers replied and the information they provided was included in our scoping review analysis.

Scoping review analysis

Analysis was conducted using the Participants, Intervention, Comparator and Outcomes approach (PICO)(Sackett, 1997). Data was extracted about (a) study participants (the country in which study was conducted; the number, age range, gender ratio, and ethnicity of participants), (b) the intervention (specific robot used; study setting; study design; study duration), and (c) the outcome (main reported benefits and barriers, and reported limitations.[3]

Findings

Sixty publications were included in the scoping review, involving 1747 participants. Six types of robotic technologies were identified including: medication intake, lifting/carrying items, ambulation, eating/drinking/cooking, shopping, and bathing (*Table 1*).

Most of the studies used participant self-reported data such as surveys and semi-structed interviews to better understand the benefits and barriers to robot implementation from the perspective of the user. The length of the studies varied. Twenty-five studies allowed the participants to interact with the robot more than once with the longest study being six months. The remaining studies either did not state the length of exposure or only exposed the robot to the participants for 2-3 hours.

The majority of studies reported positive findings, with older people finding the robots easy to use and demonstrating a high acceptance rate. Main barriers included lower acceptance amongst those with a mild cognitive impairment and difficulties when trying to operate the robot via their voice. Studies found few dependent variables associated with how participants interacted with the robots. However, participants

[2] Information about the study presented at the conference, its purpose, the robot used and reported benefits and barriers were extracted from the abstracts.

[3] Comparator was not relevant.

with previous computer experience and younger older people (60 -70 years old) had a higher acceptability of robots.

Table 1 Overview of the number of studies in each ADL (n=60)

Type of ADL	**No. Of Studies**
Medication Intake	20
Lifting items	17
Ambulation	7
Eating/Drinking/Cooking	6
Shopping	6
Bathing	4

Medication Intake

Twenty studies involving 679 participants explored the application of robots to assist older people with taking medication. Studies made use of various types of robots. In some studies, the robot served as a means of providing participants with reminders to take medication (Gross *et al*. , Prakash *et al*. , Wu *et al*. 2014, Airola and Rasi 2020). Other studies reported robots that helped prepare and deliver participants' medications promptly (Datta *et al*. 2011, Cousein *et al*. 2014, Beer *et al*. 2017, Foukarakis *et al*. 2017, Airola and Rasi 2020). The overall age range of participants was 55-101 years, with a roughly even gender distribution. Researchers in New Zealand (13%) and France (13%) had conducted the highest proportion of studies. Four percent of studies were each conducted in Austria, Spain, Malaysia, Bangladesh, Belgium and the Netherlands.

Benefits

Robots were reported to reduce error in administration of medicines. Datta *et al*. (2012), for example, tested the incorporation of End User Programming technology into RoboGen, a medication management system robot, demonstrating that the robot was able to assist participants to take their medication successfully in n=42/45 interactions, with zero errors. Other studies reported that robotic interventions could successfully assist older people to administer their medications independently. For example, (Airola and Rasi 2020*)* an ethnographic study that tested the effectiveness of an independent medication dispensing system in the homes of five participants reported that the robot dispensed pre-loaded medication promptly and on time, and that the robot greatly improved the ability of participants to take their medications consistently without aid from carers. Post-exposure semi-structured interviews reported the service easy to use and satisfied needs. Some reported participant reliance on carer home visits reduced during the study.

Barriers

Technical issues limited the degree to which the robot was accepted by participants or deemed usable (Cavallo *et al*. 2018). Robots could often only accommodate a specific type of medication or routine. For example, their design did not permit handling of liquid medicine, irregular medication times, or inhaled/intravenous medications (Cousein *et al*. 2014, Airola and Rasi 2020).

Ambulation

Seven studies involving 168 participants explored the application of robots to assist older people with ambulation - that is, the ability to walk without assistance. Six studies used the robot to walk a pre-set path assigned by the researchers (Shin *et al.* 2015, Hsieh, Huang *et al*. 2016, Mucchiani, Sharma *et al*. 2017, Cavallo, Esposito *et al*. 2018, Jin, Xiong *et al*. 2019, Ferrari, Divan *et al*. 2020). The remaining study used a robot to aid physical activity post-surgery *(Pérez-Rodríguez, Moreno-Sánchez et al. 2020).* The overall age range of participants was 55-96 years, with a roughly even gender distribution. The highest proportion of studies were conducted in Austria (15%), whilst 8% of studies were conducted in a number of other countries including Spain, Japan, Greece and Italy.

Benefits

Three studies reported a quantitative improvement when using robots to assist in ambulation (Hsieh *et al*. 2016, Jin, Xiong *et al*. 2019, Ferrari, Divan *et al*. 2020). In Hseih *et al*'s (2016) study, for example, participants were asked to walk down a corridor and turn left and the robot was able to sense their trajectory and direct them left. In another study, wearing a robotic suit once a week for a six-week period was shown to improve participants' walk ratio (Jin *et al*. 2019).

Qualitative assessments in six studies reported that participants expressed high levels of willingness to use the robot when walking, and perceived robots to be a useful addition when attempting to walk (Shin *et al*. 2015, Hsieh *et al*. 2016, Mucchiani *et al*. 2017, Cavallo *et al*. 2018, Ferrari *et al*. 2020, Pérez-Rodríguez *et al*. 2020). In observational studies and questionnaires, Muchhiani *et al*. (2017) reported that by allowing the participants to walk through the common areas in their assisted living areas, participants were able to greet peers and smile at them, such that the robot increased sociability.

Barriers

The weight and size of the robot was perceived as a barrier (Shin *et al*. 2015, Ferrari *et al*. 2020, Pérez-Rodríguez *et al*. 2020), particularly when used in small areas, such as in post-surgery rooms (Pérez-Rodríguez *et al*. 2020). Shin *et al*. (2015) reported that 81% of participants (n=9/11) believed that a robot could not replace a traditional walker due to its bulky nature raising issues associated with the usefulness of a robot in a social environment. Ferrari *et al*. (2020) reported that the heaviness of the robot meant participants perceived the robot jerky to use.

Eating/drinking/cooking

Six studies involving 76 participants explored the application of robots to assist older people eating, drinking and cooking. Participants were 55-89 years, with a roughly even gender distribution of participants. Four studies (Radder *et al*. 2016, Mucchiani *et al*. 2017, Bedaf, Marti *et al*. 2018, Kostavelis *et al*. 2019) focused on improving oral hydration intake through hydration reminders. Two studies used the robot to deliver water to participants (Bedaf *et al*. 2018, Kostavelis *et al*. 2019). The remaining two studies focused on preparing food and drinks (Ma, Yan *et al*. 2011, Wang, Sudhama *et al*. 2017): Wang *et al*. (2017) assessed the effectiveness of a robot to assist in making a cup of tea and Ma *et al*. (2011) studied the use of a robot in making four dishes. Researchers based in Sweden (22%) and the Netherlands (15%) conducted the highest proportion of studies. Seven percent of studies were conducted in, for example, Spain, Switzerland, the US, and UK.

Benefits

Across all studies, there was high participant satisfaction associated with the usability and accessibility of the robot (Ma *et al*. 2011, Radder *et al*. 2016, Mucchiani, Sharma *et al*. 2017, Wang *et al*. 2017, Bedaf *et al*. 2018, Kostavelis *et al*. 2019)

Four studies (Ma *et al*. 2011, Radder *et al*. 2016, Wang *et al*. 2017, Kostavelis *et al*. 2019) reported that their robot could execute tasks associated with eating and drinking relatively well. Two studies measured this quantitatively (Radder *et al*. 2016, Kostavelis *et al*. 2019), for example, Kostavelis *et al* (2019) measured the percent of correct executions of a predefined task associated with eating or drinking, reporting a 85.7% correct execution rate when the robot was asked to fetch a snack or drink.

Finally, Wang *et al* (2017) reported further hypothetical benefits of using a robot beyond assisting with ADLs (Wang *et al*. 2017). Through semi-structured interviews, participants reported that by using the robots to carry out repetitive activities such as making cups of tea, this put less of a strain on their carer relationships. For example, one participant stated her husband, who she cared for, often apologised for asking her to complete repetitive tasks and thought the robot could be important in helping to ease the burden on caregiving dynamics (Wang *et al*. 2017). The effect of robots on caregiving dynamics was also seen in Broadbent *et al*'s (2014) study where caregivers stated robots doing certain tasks such as distributing meals, aiding with drinking would mean caregivers could have more time to spend with the residents.

Barriers

The barriers identified depended on the specific role of the robot. Mucchiani *et al*'s (2017) study, which assessed robots assisting in water delivery and hydration reminders, was the only study which reported significant technical issues. Although this did not seem to affect participants' overall satisfaction with the robot, there was a low level of trust for the robot from the participants due to the high degree of observer input required. In addition, two studies reported functional issues with their robots (Bedaf *et al*. 2018, Radder *et al*. 2018). Bedaf *et al* (2018) reported that their robot lacked the eye for detail, often involved in caregiving, for example, participants reported the speed of the robot was too slow and had personal preferences regarding where the robot should place their drink (Bedaf *et al*. 2018), raising issues about how robots would interact with individuals in a social or home setting. Though the authors noted that the robot was remote controlled by the participant and so these issues could be attributed to the participant.

Shopping

Six studies including 242 participants involved robots assisting older adults with shopping. The specific role of the robot in each study ranged from using a robot to create a shopping list (Granata *et al*. 2013, Wu *et al*. 2014, Di Nuovo *et al*. 2016) to a robotic shopping delivery service (Bevilacqua *et al*. 2015, Cavallo *et al.* 2018, Di Nuovo *et al*. 2018) in which participants created a shopping list, sent the robot to a supermarket, and then received the delivery in their homes or the experimental facility. Two studies (Granata *et al* 2013, Wu *et al* 2014) included participants who were diagnosed with mild cognitive impairment (MCI).[4]

Benefits

Participants were willing to use robots to carry out their shopping, despite the relative complexity of operating the robotic interface. All studies reported participants to be enthusiastic about using the robot for shopping and deemed them 'somewhat' useful. Di Nuovo *et al* (2018) noted that users with less technological experience reported higher levels of usefulness when trialling the robot for shopping, compared to participants who had previous experience with computers or phones. The authors hypothesised that older adults are "selective learners" and will only learn what is necessary. Therefore, older adults with computer experience felt they could do their shopping online through a supermarket delivery service, whilst those with less technological experience were more likely to find the robots useful as this was perceived at the most effective approach to completing their shopping.
Some studies (Di Nuovo *et al* 2018, 2016, Granata *et al* 2012) reported that multi-modal user interfaces which encompassed voice, touch and visual aids worked well for participants when trying to complete a shopping task. Cavallo, *et al* (2018) and Wu *et al* (2014) reported that participants often desired voice communication which was deemed by participants as less tiring and a faster and easier alternative.

Barriers

Selecting individual items onto a shopping list meant participants had to use a graphical interface. Icons used to represent certain food items were often too small and the limited screen space meant labels were difficult to add, therefore participants often struggled to recognise items (Bevilacqua *et al* 2018). Authors suggested that this could present a larger problem for certain users such as older adults who are visually impaired and would require robots to have certain adaptations such as the utilisation of voice commands. Two studies explored the use of robots for older adults with a MCI. Both studies reported that participants made significantly more errors, took longer to complete the shopping task, and required additional aids compared to those without a MCI (Granata *et al*, 2013, Wu *et al* 2014). Finally, Cavallo reported that participants did not necessarily want a robot for their shopping. Although they did see a potential use for these robots, for example during a temporary mobility impairment or bad weather, participants perceived shopping to be a social task; for some participants, shopping was the only reason they left their house. This need for socialising was seen in Di Nuovo *et al* (2018) and Bevilacqua *et al* (2018) as participants stressed the importance of the robot becoming a companion rather than just a tool to carry out certain tasks. Participants from both studies wanted the robot to speak to them like a friend.

Bathing

Four studies including 88 participants examined the use of robots in assisting older adults with showering or bathing. Showering an older person can often be difficult, involving multiple subtasks which include: getting into the shower, applying soap, rinsing off with water and drying oneself (Naik *et al*. 2004). All included studies used the robot in each stage of showering: washing, rinsing and scrubbing (Beedholm *et*

[4] This is a broad term, which in future research needs to be defined, since participants with different types of MCI will have different needs.

al. 2015, Bäccman *et al*. 2020, Werner *et al*. 2020, Zlatintsi *et al*. 2020). Three studies used a robot with a seat and mechanical arm (Bäccman *et al*. 2020, Werner *et al*. 2020, Zlatintsi *et al*. 2020), one study used a robotic bathtub, whereby the participant laid down in a way that allowed the robot to assist with moving the participant into a washing cylinder (Beedholm *et al*. 2015).

Benefits

In three studies, older people perceived a greater sense of independence when using a robot during showering (Bäccman *et al*. 2020, Werner *et al*. 2020, Zlatintsi *et al*. 2020). This was despite the fact that other robotic tasks led to concerns about the removal of certain social interactions between carers and older people–potentially because of the intimateness of this care task (Bäccman *et al*. 2020). Two studies assessed the effectiveness of using gestural performance i.e. using certain movements to control the shower and voice commands (Werner *et al*. 2020, Zlatintsi *et al*. 2020)–and reported gesture and voice commands were recognised by the robots. Zlatintsi *et al*. (2020), whose study included participants who had suffered from a physical disability and often struggled to shower, reported that spoken and gestural robotic commands were easily remembered by participants, suggesting this robot could be effective in a population that requires it the most.

Barriers

While one of the main justifications for implementing robot use in the care of older people is to reduce the workload on healthcare staff and carers, two studies reported that healthcare professionals were still needed to either monitor the older adult whilst in the shower (Beedholm *et al*. 2015) or help them to operate the hand shower (Bäccman *et al*. 2020). Furthermore, authors noted that solely relying on gestural commands may mean certain older adults, such as those suffering from strokes, which impact motor actions, or those who are cognitively impaired would struggle to use a robot effectively. Healthcare staff interviewed in Beedholm *et al*'s 2015 study stated the financial cost would prevent them from purchasing a robotic shower for the care home, although exact figures were not quoted in any studies. Despite the high cost, standard showers would also need to be installed at the same time to ensure enough people could be showered. There was limited evidence in these studies as to whether the installations of robotic showers or baths would be cost-effective, and would increase rather than replace consumption, presenting a potential barrier in implementing these robots on a larger scale.

Lifting/Carrying Items

Seventeen studies including 579 participants assessed the effectiveness of using robots in assisting older people in lifting and carrying objects. Fifteen studies used a mobile platform robot with an attached mechanical arm; two studies used a robotic glove that participants could wear when lifting items (Radder *et al*. 2018, Radder *et al*. 2019).

Benefits

Most studies reported that robots were perceived to function well when lifting and carrying items and demonstrated a high level of usability (Eftring and Frennert 2016, Bedaf *et al*. 2018, Cavallo *et al*. 2018, Chivarov *et al*. 2018, Radder *et al*. 2018, Kostavelis *et al*. 2019, Radder *et al*. 2019, Nishiura *et al*. 2021). Nishiura *et al* (2021) reported that when the robot was asked to clean a table, the robot achieved a success rate of 91.6% as defined by the participant. Similar results were seen with Koceska *et al*'s (2019) study which reported a success rate of 88%. Participants reported relative ease with requesting the robot to lift and carry items, with the robot identified as saving time and energy (Beer *et al*. 2017, Bedaf *et al*. 2018, Cavallo *et al*. 2018, Chivarov *et al*. 2018, Radder *et al*. 2018, Radder *et al*. 2019). In fact, across the studies, participants perceived the lifting/carrying function of robots was particularly useful, and aligned with their primary desired function for a robot (Körtner *et al*. 2014, Eftring and Frennert 2016, Fischinger *et al*. 2016, Beer *et al*. 2017, Bajones *et al*. 2018, Bedaf *et al*. 2018). Authors noted that previous studies have reported older adults to have difficulties lifting and grasping objects due to the neural and muscular decline seen in the ageing process (Mcleod 2016). Furthermore, cognitive decline can weaken the areas of the brain that coordinate movement leading to difficulties when attempting to lift objects (McGrath 2019).

Barriers

The weight the robot could withstand was a key identified barrier. Robots could only lift smaller items such as medication packets or bottles. Exceptions included the robot used by Radder *et al* (2019) whose robotic arm could lift heavier objects because it was worn by the user (rather than being a mobile platform). Heavier objects stored at an elevated height (such as bed sheets or towels) were unable to be accessed by the robots, meaning, human assistance would still be required to conduct certain ADLs such as household chores (Bajones *et al*. 2018). Furthermore, only a handful of studies placed robots in participants homes, where they were usually large and often struggled to move down narrow hallways. Eftring and Frennert (2016) reported that their robot struggled to move between rooms without the use of ramps, and could not move across carpets. Across studies, it was unclear whether robots could be adapted to participant home settings, and the potential additional financial costs this would incur. Beer *et al*.'s (2017) study, which was conducted in a controlled setting, reported participant perceived fears that a robot would damage their walls and personal belongings.

Limitations of the studies analysed

Most studies were pilot studies and therefore had a number of limitations. For example, they were quasi-experimental, cross-sectional studies and were unable to establish causality between intervention and outcome. Further limitations included, first, small sample sizes (sometimes as low as n=2), and second, participants who were often recruited voluntarily making the sample vulnerable to volunteer and selection bias. For example, Boadbent *et al* (2014) conducted a study that recruited participants who were already capable of administering their own medications independent of support workers. Furthermore, the self-selection bias means that the selection of participants is likely to correlate with individuals who have some level of interest in the use of robots in daily activities, and so their experiences will be framed in this way. Third, studies were often in artificial environments, limiting the generalisability of the findings to participants' actual living situations. For example, in Shin *et al*.'s (2015) study on ambulation, participants expressed concerns about the ability to use the robot outside, especially when considering uneven roads or attempting to mount curbs. Fourth, studies were short – sometimes only for few hours in a controlled setting. Results may therefore be unindicative of how effective these robots can be for older adults, making it difficult to establish whether robots could have a meaningful impact on participants' daily lives. In fact, participants with no previous experience with robots were only given a limited time to interact with the robot, therefore producing results which may not be truly indicative of how effective these robots can be for older adults. This was especially true for participants with MCI, who often require more time than someone who is cognitively intact to complete a task. In fact, the limited inclusion of participants with MCI is problematic because participants with different types of MCI will have different needs. Future studies need to assess the cognitive status of all participants and ensure inclusion of a wide range of participants. Finally, using self-reported data made the results vulnerable to biases - such as social desirability bias - and limits the external validity of the results. Furthermore, in older people, not only do issues with memory and cognition affect results but Körtner *et al*. (2014) reported older people to be much more likely to give positive feedback and blame any faults or flaws on themselves rather than the intervention.

Conclusion

The empirical studies included in our review indicated that there are a range of benefits and barriers associated with research that involves robots being used to assist older people with ADLs. Studies pointed to a range of factors beyond financial and technical value that need to be considered in robotic research, including social, personal, emotional, and psychological value. For example, in some instances robots could potentially do more harm than good if they promoted reduced social interactions of older people within the community. A more holistic approach that appreciates both physical care needs, psychological requirements, economic implications, and more broadly the sustainable value of robots to society is required. Furthermore, further work must give more attention to the complex and contextual needs associated with a diverse patient base, including those with various MCIs.

Practical implications

The scoping review curates the benefits and barriers associated with the use of robots for ADL for older people, as reported by researchers. This is useful for practitioners designing robots, as well as policymakers driving the promise of these technologies.

Social implications

While policy discourse promotes the benefits of older people using robots in ADLs, costings (including social, psychological and financial) need to be undertaken to measure the effectiveness of these devices. More attention needs to be paid to the contextual needs of a diverse patient base, as well as the potential for social and psychological harms that could come from using these devices.

Limitations of this study

Our first attempts at developing keywords for the analysis led to a large number of results that mostly did not meet the inclusion criteria. As such, we narrowed our keywords. While we maintained them sufficiently broad, we may have missed some literature. Furthermore, only the last 10 years were covered in the literature. Finally, much work on robotic technologies is being conducted by commercial developers and will not be reported in the academic literature.

Research funding: The King's College London Undergraduate Research Fund paid for two undergraduates (Michele Correa and Chelsea Todd) to undertake research during the summer of 2021.

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