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Review Article

Co-Designing Technology for Aging in Place: A Systematic Review

Jennifer Sumner, MSc, PhD,[1,2,*] Lin Siew Chong, BSc, MSc,[1,2] Anjali Bundele, BDS, MPH,[2] and Yee Wei Lim, MBBS, PhD[1,2]

[1]Yong Loo Lin School of Medicine, Department of Medicine, National University of Singapore, Singapore. [2]Medical Affairs—Research Innovation & Enterprise, Alexandra Hospital, National University Health System, Singapore.

*Address correspondence to: Jennifer Sumner, MSc, PhD, Medical Affairs-Research, Alexandra Hospital, 378 Alexandra Road, Singapore 159964. E-mail: Jenny.sumner@york.ac.uk

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Abstract

Background and Objectives: There is a growing interest to involve older adults in the co-design of technology to maintain their well-being and independence. What remains unknown is whether the beneficial effects of co-designed solutions are greater than those reported for non co-designed solutions. The aim of this study was to evaluate the effects and experiences of co-designed technology that support older adults to age in place.
Research Design and Methods: We conducted a systematic review to (a) investigate the health and well-being outcomes of co-designed technology for older adults (≥60 years), (b) identify co-design approaches and contexts where they are applied, and (c) identify barriers and facilitators of the co-design process with older adults. Searches were conducted in MEDLINE, EMBASE, CINAHL, Science Citation Index (Web of Science), Scopus, OpenGrey, and Business Source Premiere.
Results: We identified 14,649 articles and included 34 projects. Four projects reported health and well-being outcomes; the effects were inconsistent. Co-design processes varied greatly and in their intensity of older adult involvement. Common facilitators of and barriers to co-design included the building of relationships between stakeholders, stakeholder knowledge of problems and solutions, and expertise in the co-design methodology.
Discussion and Implications: The effect of co-designed technology on health and well-being was rarely studied and it was difficult to ascertain its impact. Future co-design efforts need to address barriers unique to older adults. Evaluation of the impact of co-designed technologies is needed and standardization of the definition of co-design would be helpful to researchers and designers.

Keywords: Co-design, User-centered design, Participatory design

The desire to remain independent and live at home or within an individual's community is increasingly recognized as the preferred living arrangement among older adults (Binette & Vasold, 2018; Grimmer, Kay, Foot, & Pastakia, 2015; Wiles, Leibing, Guberman, Reeve, & Allen, 2012). Governments and international agencies conceptualize this preference to age in the community as "aging in place." The United States Center for Disease Control and Prevention defines "aging in place" as "the ability to live in one's own home and community safely, independently, and comfortably, regardless of age, income or ability level" (Centers for the Disease Control and Prevention, 2009). Policies and initiatives supporting successful and independent aging have increased in many countries (HM Department for Work and Pensions, 2015; Ministry of Health, 2016; National Prevention Council, 2016; United Nations Department of

Economic and Social Affairs Population Division, 2015; World Health Organisation, 2016). These policies preserve older adult independence through infrastructure development, urban planning, developing community-based resources, and the deployment of technologies (Divo, Martinez, & Mannino, 2014; Patterson, 2014; Pefoyo et al., 2015; The Lancet, 2017). However, older adults living in the community are more prone to suboptimal management of chronic diseases, encounter accidents, experience social isolation, and depression (World Health Organisation, 2018). Technological solutions have emerged to facilitate safe and active aging at home, through the detection of accidents in the home, remote health monitoring, and social engagement (Sixsmith & Gutman, 2013).

The range of older adult-targeted technology is diverse. They include telecommunication systems (Van den Berg, Schumann, Kraft, & Hoffmann, 2012), health monitoring devices (Dupuis & Tsotsos, 2018), social and assistive robots (Pearce et al., 2012; Pu, Moyle, Jones, & Todorovic, 2019), and "smart home" systems (Liu, Stroulia, Nikolaidis, Miguel-Cruz, & Rios Rincon, 2016; Moraitou, Pateli, & Fotiou, 2017; Vegesna, Tran, Angelaccio, & Arcona, 2017). However, the implementation of these technological solutions has been met with resistance and underuse (Cook et al., 2016). One explanation for poor uptake could be the lack of consideration of end-user perspectives and needs, from limited, late, or no end-user involvement during development. The perceived usability, usefulness and adaptability of technology, cost, security, and a threat to an individual's identity and independence can influence technology adoption (Berridge & Wetle, 2019; Cook et al., 2016; Greenhalgh, Wherton, Hinder, Proctor, & Stones, 2013; Peek et al., 2014). As a reaction, design methodologies evolved to incorporate consumer perspectives into product development (Donetto, Pierri, Tsianakas, & Robert, 2015; Horne, Khan, & Corrigan, 2013; National Development Team for Inclusion, 2013).

The user-centered design was the first design approach to involve end-users. It largely refers to a passive form of end-user involvement. For example, end-users may be asked their opinion of concepts generated by experts (Sanders & Stappers, 2008). Since the establishment of user-centered design, newer design methodologies expand the influence of the end-user in design. These newer design approaches are termed "participatory design" and aim to engage the end-user as a partner in design, including ideation of new concepts (Sanders & Stappers, 2008). "Co-design" is the latest evolution in participatory design, but no single definition exists. Osborne, Radnor, and Strokosch (2016) define co-design as "the voluntary or involuntary involvement of public service users in any of the design, management, delivery and/or evaluation of public services." The Western Australia Council of Social Service sums up co-design as "collaboratively designing services with service-users, service-deliverers and service-procurers" (Giolitto, 2016). Another definition from the Point of Care Foundation states that "experience-based co-design (EBCD) is an approach that enables staff and patients (or other service users) to co-design services and/or care pathways, together in partnership" (Point of Care Foundation, 2013). The variation in these definitions introduces ambiguity. For instance, the level of end-user relationship can be inferred differently between the terms "involvement," "collaboratively," and "partnership," the latter describing more equal or joint engagement. The definition by Osbourne and colleagues is also the only one that details specific stages at which co-design could occur. The evolving nature of co-design is in part due to its newness as an idea. The potential promise of co-design led to rapid adoption of the approach by practitioners, which might explain why convergence toward a common definition and operationalization of co-design has not been reached.

Despite the lack of a uniform definition of the co-design process, recent studies seem to suggest that co-designed solutions have a positive impact on health outcomes. Case studies, systematic, and narrative reviews of co-design in healthcare show improvements in the care experience, including improved patient knowledge, ability to cope with the disease, and better access to healthcare, reductions in falls and medical errors, improved patient satisfaction, better disease control, increased disease knowledge, and reductions in cost (Bombard et al., 2018; Clarke, Jones, Harris, & Robert, 2017; Robert et al., 2015; Sharma, Knox, Mleczko, & Olayiwola, 2017; Spencer, Dineen, & Phillips, 2013). What remains unknown is whether the beneficial effects of co-designed solutions are greater than those reported for non-co-designed solutions (Liu et al., 2016; Moraitou et al., 2017; Pearce et al., 2012; Pu et al., 2019; Van den Berg et al., 2012; Vegesna et al., 2017). The objectives of this study were to (a) investigate the health and well-being outcomes of co-designed technology supporting older adults aging in place and where possible compare the effects of co-designed versus non co-designed solutions (≥60 years), (b) to identify co-design approaches and the contexts they are applied in, and (c) to identify barriers to and facilitators of the co-design process with older adults.

Methods

The study is reported and conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group, 2009). The systematic review protocol was prospectively registered on the PROSPERO database of systematic reviews (registration number CRD42019133419). A copy of the PRISMA checklist is included in Supplementary Table 1.

Literature Search

MEDLINE, EMBASE, CINAHL, Science Citation Index (Web of Science), Scopus, OpenGrey, and Business Source Premier were searched in July 2018. An updated search was then conducted in September 2019 (search dates 2009–2019). A combination of MeSH terms and keywords on the themes: older adults, community setting, and co-design were used. As health-related technology is an extremely broad theme, we decided not to include it in our search strategy to avoid the exclusion of novel approaches. The initial search strategy was developed in MEDLINE with an information specialist and converted for use in the other databases. Key journals (*CoDesign: International Journal of Cocreation in Design and The Arts*, *Design Studies: The Interdisciplinary Journal of Design Research*, and the *Interaction Design and Architecture*) were also hand searched for further relevant articles. A copy of the search strategy conducted in MEDLINE is included in Supplementary Table 2.

Study Selection

Titles and abstracts were initially screened for inclusion by a single reviewer. Shortlisted articles were full-text screened by two independent reviewers for eligibility (Table 1). Disagreements were discussed and resolved with a third reviewer if required. When eligibility of a study was unclear from a publication, an attempt was made to contact the author(s) for clarification.

Data Extraction and Management

Data extraction was undertaken by one researcher and checked for consistency by a second independent researcher. Extracted data items included study and population characteristics, intervention details, information on the co-design process, facilitators of and barriers to the co-design process, and health and well-being outcome measures (e.g., clinical outcomes, health-related quality of life [QOL]). The extraction sheet was piloted on a sample of papers and refinements made prior to full data extraction.

Quality Assessment

The Cochrane risk of bias tool was used to assess the quality of studies reporting health and well-being outcomes (Higgins & Green, 2011). Two researchers independently assessed the risk of bias and any disagreements were discussed.

Data Synthesis

Studies that included health and well-being outcomes were synthesized narratively. Facilitators of and barriers to the co-design process were extracted and organized according to the co-design framework outlined by Pirinen (2016). The framework contains five domains: collaboration, origination, processes, implementation, and methods (Pirinen, 2016).

Results

We identified 11,681 unique articles of which 28 projects met the eligibility criteria and were included. The updated

Table 1. PICOS Eligibility Criteria

Criteria	Definition
Participants	Older adults at least 60 years of age living in the community or "aging in place." Community dwelling was defined as adults living within their own home or within a senior living community who may be receiving some level of assisted care but are otherwise living independently. Participants residing in care homes, hospice, or those receiving inpatient hospital care were ineligible.
Intervention	Health-related technology co-designed with the target population (i.e., community-based older adults), including information communication technologies, mobile and electronic health solutions, or new treatments, which involve technology as well as new ways of organizing healthcare. The co-design approach should include the following attributes: (1) Evidence of collaboration between consumer and provider beyond only information gathering from consumers. (2) Evidence that consumer involvement is for the development of a product or service for the benefit of the consumer. Excluding studies that use an older adult proxy (e.g., a persona). (3) Evidence that the consumer is involved in the development process at more than one point in time (i.e., to represent a meaningful contribution). (4) The "consumer" may also be primary caregivers looking after older adults (including informal caregivers), not including health professionals.
Control	For interventional studies, the control group is defined as those not using a co-designed technology. Studies without a control group were also eligible for inclusion if the other criteria were met.
Outcomes	Any articles with clinical or patient-reported health and well-being outcome measures, which included a control group, were eligible. This may include any clinical variable (e.g., blood pressure and functional status) or well-being outcome (e.g., health-related quality of life, depression, and loneliness). Papers with data on the experience of the co-design process, including facilitators of and barriers to co-design, were also eligible.
Study types	All study types were considered; experimental or observational designs.
Other	Studies were restricted to the English language only articles and the search was limited to the last 10 years. The date restriction was chosen to identify relevant technologies for the modern-day context.

literature search (conducted in September 2019) identified a further 2,968 articles of which a further six projects were included (Figure 1).

Study Characteristics

The characteristics of the included projects are presented in Table 2. Projects were largely from Europe (*n* = 28) and the remainder from Australia (*n* = 4), United States (*n* = 1), and Canada (*n* = 1). Twenty projects targeted older adult's general needs or concerns (≥60 years old) and an additional 14 targeted specific medical conditions or problems such as cognitive or physical impairments. Technological solutions included robots, online applications and software, smart televisions, computer games for exercise, global positioning solutions, smart home systems, and design of care pathways. Solutions mostly targeted older adults as individuals (*n* = 30) rather than group applications (*n* = 4) and functions included support of activities of daily living (ADLs), facilitation of social interaction, remote exercise or rehabilitation, education and disease self-management, safety monitoring, item location, and reminder systems. Some solutions addressed multiple functions, for example, robots that were designed to support ADLs were also designed to be a source of social interaction.

Health and Well-Being Outcomes

Of the 34 projects included, four had evaluated health and well-being outcomes in five randomized controlled trials (RCTs) (Bjerk, Brovold, Skelton, & Bergland, 2017; Bjerk, Brovold, Skelton, Liu-Ambrose, & Bergland, 2019; Mira et al., 2014; Oesch et al., 2017; Weering, Jansen-Kosterink, Frazer, & Vollenbroek-Hutten, 2017). Outcome measures fell into four categories: balance and falls, level of physical activity (including compliance) and

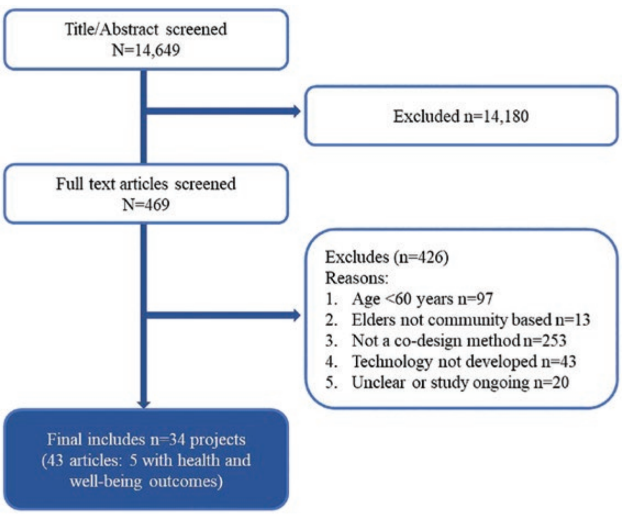

Figure 1. PRISMA flow diagram.

physical function, QOL and mental health, and clinical measures. Reported outcome measures were too diverse across studies to synthesize in meta-analyses. Results were usually not statistically significant (Table 3). Statistically significant effects in favor of the interventions were reported for measurements of balance, physical function, short form survey-36, physical component summary [SF-36 (pcs)], short form survey-12 (SF-12), medication adherence, errors, and missed doses. Statistically significant effects in favor of the control were reported for measurements of adherence to exercise, Short form survey-36, mental component summary [SF-36 (mcs)], and cholesterol. Three additional projects included health and well-being outcomes but could not be extracted. One, a cross-sectional study, had no comparison group (Lehto, 2013), the second, a pre–post cohort, reported predictors of falls and disability (Vermeulen et al., 2015), and the third, another pre–post study (Hepburn, 2018), has yet to publish its health and well-being findings.

Risk of Bias Summary

Using the Cochrane risk of bias tool, we evaluated the quality of five RCTs with health and well-being outcomes (Figure 2). High performance and detection bias were identified in two trials (Oesch et al., 2017; Weering et al., 2017), high reporting bias in one trial (Oesch et al., 2017) and high allocation concealment bias in another trial (Weering et al., 2017). As no observational studies could be extracted no other quality assessment tools were used.

Co-Design Approaches

Across projects and between the design phases of individual projects, the intensity and method of older adult involvement varied greatly. Design approaches relating to needs and ideation, prototyping, and pilot testing are discussed here.

Needs and Ideation

Projects varied in the number of design steps, number of rounds within each design step, and the types of methods used. Workshops, focus groups, interviews, and direct observations (within the home environment and during workshops) were commonly used for needs assessment and generation of ideas. Less frequently reported techniques included participant diaries (Cozza, Tonolli, & D'Andrea, 2016; Lopes et al., 2016), sketching (Hwang, Truong, & Mihailidis, 2012b; Uzor, Baillie, & Skelton, 2011), and use of photographs/videos (Giorgi, Ceriani, Bottoni, Talamo, & Ruggiero, 2013; Pettersson et al., 2019). There were multiple examples of participant priming in the design process (i.e., preparing someone for involvement in the co-design process or in product use). For example, a project may include a practical assessment

Table 2. Study Characteristics

Author, country	Aim of the project	Target population	Product designed
Blusi, Nilsson, & Lindgren, 2018, Sweden	To develop and design a model for enabling online participation in individualized meaningful social activities	Older adults/group-based	Computer-based communication platform for remote social interaction
Botella, Borras, & Mira, 2013, Spain[a]	To design, implement, and evaluate a mobile application to assist older adults and carers to self-manage their medication	Older adults/ individual-based	A mobile application (Virtual Pillbox) to help patients reduce medication errors and improve compliance
Brox et al., 2015, Norway[a]	To develop an exergame using 3D Kinect for home exercising	Older adults/ individual-based	An online exergame, comprising of seven games, which tracks user movements to improve balance, leg strength, and flexibility
Cahill et al., 2017; Cahill, McLoughlin, & Wetherall, 2018, United Kingdom	To develop online, sensor-based infrastructures to support wellness, independence, and social participation in older adults	Older adults/ individual-based	Ambient-assisted living technology incorporating Internet of Things and a sensor-based infrastructure to support wellness, independence, and social participation
Cavallo et al., 2013; Cavallo et al., 2014; Esposito et al., 2015, Italy	Design, develop, and test the ASTROMOBILE system for favorable independent living, improved quality of life, and efficiency of care and to demonstrate the general feasibility	Older adults/ individual-based	The ASTROMOBILE system to support independent living. Composed of the ASTRO robot and an ambient intelligent infrastructure to localize users inside the domestic environment
Chevalier et al., 2018, France	To create motivational and enjoyable solutions to help seniors practice appropriate physical activity at home	Older adults/ individual-based	An online user interface “Motiv@Dom” that supports physical activity in the home
Cozza et al., 2016, Denmark	Developing innovative services for the welfare of citizens, with a focus on older people	Older adults/ individual-based	Fall detection technologies: smartphone worn in belt/pouch or smartwatch connected to smartphone
Davies et al., 2016, United Kingdom	To develop a toolkit of heuristics to aid practitioners in making end-of-life care decisions for people with dementia	Dementia/ individual-based	Four heuristics developed for use by practitioners in different settings to aid decisions in (a) eating/swallowing difficulties, (b) agitation/restlessness, (c) ending life-sustaining treatment, (d) routine care at the end of life
Fitrianie et al., 2013, The Netherlands	To develop a smart television platform—“Care@Home,” which integrates assistive living services for older adults in their homes	Older adults/ individual-based	A low-cost smart television platform (Care@Home) integrating assistive living services for older adults in their homes. The service provides a hub that connects older adults to care networks, family, friends, communities, as well as services for household help, healthcare, exercise programs, and entertainment
Frennert et al., 2013, multisite (Europe)	To develop a social and assistive robotic system that enables older people to live in their homes for as long as possible	Physically impaired (vision, hearing, mobility)/ individual-based	An autonomous social assistive robot able to self-localize, navigate safely, interact with humans through voice, text to speech, gesture recognition, and a touch screen. Also able to detect and handle objects
Gallagher et al., 2009, United States	To develop, implement, and evaluate the impact of an advanced practice nurse-run case-management program in a senior citizen community center	Older adults/ individual-based	An advanced nurse run case-management program, “The Nurse Is In”

Table 2. Continued

Author, country	Aim of the project	Target population	Product designed
Giorgi et al., 2013, Italy	To foster the active participation of older people as producers of resources related to their experience and know-how and to the activities carried out in the centers, to be shared in a community context	Older adults/group-based	An interactive table (a horizontal multitouch screen) based in a recreational center, designed as a platform for resource sharing within the community
Goeman, King, & Koch, 2016, Australia	To establish and refine a culturally sensitive model of dementia support and care pathway to overcome barriers to health and social care services	Dementia/ individual-based	A culturally and linguistically diverse specialist dementia nurse care model with quick reference cards to navigate services
Gronvall & Kyng, 2011; Gronvall & Kyng, 2013; Aarhus, Gronvall, & Kyng, 2010, Denmark	To design technology to support vestibular rehabilitation at home	Vestibular dysfunction (dizziness)/ individual-based	Portable technology-based solutions to support home-exercises including a foldable RGB-LED light system, an interactive flower, and a dart game
Hepburn, 2018, United Kingdom	To co-create digital applications for older adults	Older adults/ individual-based	A tablet-based digital app to help users with shopping
Hwang et al., 2012a, 2012b; Hwang et al., 2015, Canada	To develop the COACH system; a smart home interface that supports people with dementia in activities of daily living (ADLs)	Dementia/ individual-based	An intelligent home system (COACH) that leverages machine learning and computer vision to guide and support older adults with dementia through ADLs
Iacono & Marti, 2014, multisite (Europe)	To facilitate independent living of seniors at home using an assistive robot in a smart home environment	Older adults/ individual-based	An autonomous social assistive robot (Care-o-Bot) able to self-localize, navigate safely, interact with humans (via voice, text to speech, gesture recognition, and a touch screen), and ability to detect and handle objects
Kort, Steunenberg, & Van Hoof, 2019, The Netherlands	To create a website providing aging-in-place information for people living with dementia	Dementia/ individual-based	An online website offering information about home modifications for older adults with dementia and their family caregivers
Lehto, 2013, Finland	The Safe Home project aims to investigate, develop, produce, and evaluate interactive programs and eServices—"Caring TV," to support the health and well-being of older adults in their own homes	Older adults/ individual-based	An interactive platform "Caring TV" hosting e-services that support health, well-being, and social interaction
Leong & Johnston, 2016, Australia	To produce a companion robot in the form of a networked robotic dog	Older adults/ individual-based	A robot dog (Hardy Hound) designed as a social companion with some assistive functions for the home
Lopes et al., 2016, France	To conceive and assess an innovative item locator device that effectively addresses needs, capacities, and goals in older adults with a cognitive disorder	Cognitive impairment/individual-based	An item locator for the cognitively impaired consisting of a wand, RFID tags, and headphones for sound-directed location
Mincolelli et al., 2019, Italy	To enrich the home with a collection of re-engineered objects equipped with sensors and actuators that assist older adults	Older adults/ individual-based	An integrated system comprising of an interface, an armchair, a wearable device, and a localization system. Designed to support ADLs, reduce risk of fall or getting lost, and increasing independence
Ogrin et al., 2018, Australia	To design and evaluate the feasibility and acceptability of a foot health education app to prevent serious foot complications in diabetics	Diabetes/ individual-based	A diabetes foot health education app (Healthy feet). The app supplements health care provider intervention, encourages self-care, and earlier help-seeking to prevent serious foot complications

Table 2. Continued

Author, country	Aim of the project	Target population	Product designed
Pettersson et al., 2019, Sweden	To develop and evaluate an electronic fall prevention program	Older adults/ individual-based	A self-management digital exercise program (SafeStepv1) that improves balance and strength
Pino et al., 2012, France	To develop a socially assistive robot for older adults with cognitive impairment	Mild cognitive impairment/ individual-based	A semi-autonomous, remotely controlled robot with speech control and a touch screen. Provides cognitive and social support to the user through a suite of applications (task reminder, cognitive training, navigation support, and communication)
Pratesi et al., 2013, United Kingdom	To develop an "intelligent" activity monitoring system that will support older and/or disabled people's independence, safety, and quality of life	Older adults/ individual-based	An "intelligent" activity monitoring system (Smart Distress Monitor) that charts activity/inactivity patterns in the home living environment. The system learns patterns of behavior, including deviations, using thermal imaging
Robinson et al., 2009, United Kingdom	To create acceptable and effective technologies to facilitate independence for people with dementia	Dementia/ individual-based	An armband-held device and an electronic notepad with location tracking and the ability for two-way communication
Sabater-Hernandez et al., 2018, Australia	To develop and implement a novel community pharmacy service for screening and enhancement of self-management for atrial fibrillation	Hypertension, atrial fibrillation/ individual-based	A community pharmacist-led service incorporating patient education, self-monitoring, and pharmacist consultation
Uzor et al., 2011; Uzor, Baillie, & Skelton, 2012, United Kingdom[a]	To design and develop multimodal rehabilitation exercise games	Those at risk of falls/individual-based	A home-based multimodal rehabilitative computer game incorporating body sensors for movement tracking
van Velsen et al., 2015, multisite (Europe)[a]	To develop a health service for detecting and preventing frailty among older adults by offering eHealth services	Older adults/ individual-based	A technology-supported service for screening for frailty/pre-frailty in older adults and a platform of e-health interventions including those designed to improve physical and cognitive functioning and knowledge of nutrition
Vermeulen et al., 2013, The Netherlands	The development monitoring system with a mobile interface that provides feedback to older adults regarding changes in physical functioning and to test the system in a pilot study	Older adults/ individual-based	A monitoring system including a bathroom scale for weight and balance, a grip-ball for grip strength, and a mobile phone with a built-in accelerometer for monitoring physical activity and functioning
Williamson et al., 2013, United Kingdom	To create a digital reminder system for the home	Older adults/ individual-based	A digital reminder system linking a paper-based calendar with a smartpen device
Wikberg-Nilsson et al., 2018, Sweden	To further knowledge of user experiences of interface design and to develop a digital service to promote healthy and active aging	Older adults with sensory decline/ individual-based	A digital platform called HealthCloud that enables healthy and active aging
Magnusson & Hanson, 2012, multisite (Europe)	To develop "ACTION" (Assisting Carers using Telematics Interventions to meet Older people's Needs), to increase the autonomy, independence, and quality of life of frail older people and their carers	Frail older adults/ individual-based	An information and communication technology-based support service (ACTION) including online information, educational material, and a call center to support informed decision making

[a]Projects with health and well-being outcome data, extracted in Table 3.

Table 3. Health and Well-Being Outcomes of the Five Included Randomized Controlled Trials

Measurement category	Measurement	Outcome
Balance and falls		
Brox *n* = 54 (Oesch et al., 2017)	Accelerometer	ns
Uzor *n* = 22 (Uzor, 2014)	Timed up & go test, falls efficacy scale	ns
Uzor *n* = 155 (Bjerk et al., 2019)	Berg balance scale	+ve
Uzor *n* = 155 (Bjerk et al., 2019)	Falls efficacy scale, balance confidence (CONFBAL)	ns
Physical activity and function		
Brox *n* =54 (Oesch et al., 2017)	Adherence to exercise time (min/day)	−ve
Van velsen *n* = 37 (Weering et al., 2017)	Adherence to exercise (times/week and minutes/session)	ns
Uzor *n* = 22 (Uzor, 2014)	Adherence to exercise (sessions/week), walking speed (cm/s), stride length (cm), stride time (s)	ns
Uzor *n* = 155 (Bjerk et al., 2019)	30 s Sit to stand test, 4-min walk test	+ve
QOL and mental health		
Uzor *n* = 155 (Bjerk et al., 2019)	SF-36 (mcs)	−ve
Uzor *n* = 155 (Bjerk et al., 2019)	SF-36 (pcs)	+ve
Van velsen *n* = 37 (Weering et al., 2017)	EQ-5D, SF-12 (pcs)	ns
Van velsen *n* = 37 (Weering et al., 2017)	SF-12 (mcs)	+ve
Botella *n* = 99 (Mira et al., 2014)	Self-perceived health status	ns
Other clinical measures		
Botella *n* = 99 (Mira et al., 2014)	Medication adherence (MMAS-4), medication errors, missed doses	+ve
Botella *n* = 99 (Mira et al., 2014)	Glycated hemoglobin (mmol/mol), blood pressure (mmHg)	ns
Botella *n* = 99 (Mira et al., 2014)	Cholesterol (mg/dL)	−ve

Note: Outcome rating: statistical significance favoring control: −ve; statistical significance favoring intervention: +ve; nonsignificant changes: ns. EQ-5D = European quality of life index- 5 dimensions; MMAS-4 =Morisky medication taking adherence scale-4; QOL = quality of life; SF-12 (mcs) = Short form survey-12, mental component summary; SF-12 (pcs) = Short form survey-12, physical component summary; SF-36 (mcs) = Short form survey-36, mental component summary; SF-36 (pcs) = Short form survey-36, physical component summary.

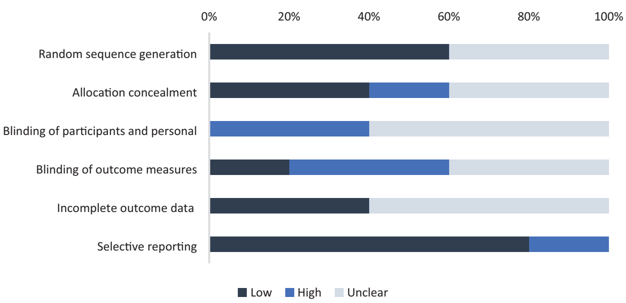

Figure 2. Cochrane risk of bias assessment of the five included randomized controlled trials.

of existing products or introductory material on the research project and technological possibilities (Lopes et al., 2016). Priming also occurred immediately before product evaluation in some cases. In one study, a nonfunctional polystyrene robot was placed in the homes of older adults prior to deployment of the functional robot. In this way, participants became accustomed to having a robot in their home before the evaluation of the functional robot took place (Frennert, Eftring, & Ostlund, 2013).

Prototyping

Prototype use was common to almost all projects, although the purpose differed. Prototypes facilitated discussion, built knowledge, and raised awareness of technological possibilities. Prototypes were also used to test the usability of a technological solution. Prototypes could be fully functional, partially functional, or nonfunctional. An example of a nonfunctional prototype was a simple pen and paper drawing used to represent a tablet interface (Giorgi et al., 2013) or a full-scale robot shaped in polystyrene (Frennert et al., 2013). Prototypes of a single aspect of a larger product were also created, particularly in robot designs. For example, a prototype of the robot user interface may be created separately from the full mechanical robot (Iacono & Marti, 2014; Pino, Granata, Legouverneur, & Rigaud, 2012).

Pilot Testing

Twenty-three projects evaluated products in a real-world setting, of which four projects (five RCTs) evaluated the health and well-being outcomes of the final product. Evaluation in the real-world setting often occurred as part of prototype development, to test and refine the functionality of the product before final evaluation. Five of the included projects discussed the use of a "living lab" environment (Cavallo et al., 2013; Frennert et al., 2013; Iacono & Marti, 2014; Lehto, 2013; Lopes et al., 2016). Of these projects, most used the term "living lab" incorrectly to refer to an experiment in a controlled laboratory setting and not in the field. For example, a mockup of a living room may be set up within a laboratory to test the suitability of a prototype within that environment but not within an actual home. The conventional definition of "living lab" is much broader: "a user-centered, open innovation ecosystems based on systematic user co-creation approach, integrating research and innovation processes in real life communities and settings" (European Network of Living Labs, 2019).

Barriers to and Facilitators of the Co-Design Process

Eighteen projects reported on the barriers and facilitators of the co-design process. Barriers and facilitators fell into four of the five domains outlined by Pirinen (2016). No findings on barriers to the implementation of the co-designed solution were identified (Figure 3). The most frequently reported barriers and facilitators related to "relationships and trust building," "stakeholder knowledge building," and "methods and skill in co-design."

Relationship and Trust Building

Factors that enabled relationship building included an early focus on relationship and trust building between stakeholders (Frennert et al., 2013; Pratesi, Sixsmith, & Woolrych, 2013); stakeholders finding common ground (Frennert et al., 2013); making time for socializing among participants during design; using a suitable environment for socializing (Frennert et al., 2013; Magnusson & Hanson, 2012); and keeping the co-design group small (Magnusson & Hanson, 2012). Conversely, relationship building was hindered by existing hierarchies between stakeholders. For example, the traditional paternalistic relationship between healthcare professionals and patients hindered the design process, where there is a perception that professionals "know best." In cases where a hierarchy between stakeholders is a concern, researchers acted as advocates of older adults. This was reported in projects where professionals were reluctant to collaborate. In these instances, professionals did not value older adult involvement or they viewed older adults as "weak" stakeholders (Gronvall & Kyng, 2011; Pratesi et al., 2013). Advocating for older adults during co-design can therefore be important to overcome hierarchies and negative perspectives, but it needs to be performed carefully. Some authors noted that overreliance on researchers could lead to older adults becoming dependent on the researcher to advocate their views, leading to misrepresentation. Older adults could also attempt "to please" researchers in their responses to design-related questions (Brox, Evertsen, Asheim-Olsen, Hors-Fraile, & Browne, 2015; Gronvall & Kyng, 2011).

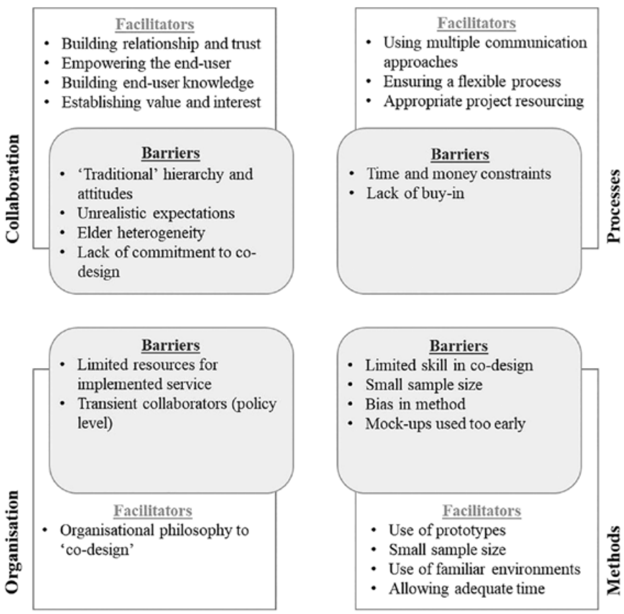

Figure 3. Examples of barriers and facilitators to co-design in the included projects.

Stakeholder Knowledge Building

An important aspect of co-design is knowledge building among stakeholders. Knowledge building aims to improve understanding of different stakeholders' perspectives and experiences, knowledge of a disease or condition to be addressed, and what could be achieved through technological solutions (Cozza et al., 2016; Frennert et al., 2013; Gronvall & Kyng, 2011; Pino et al., 2012; Pratesi et al., 2013). A lack of knowledge could cause unrealistic expectations and hinder the design process (Gronvall & Kyng, 2011; Pratesi et al., 2013). For example, participants may become demotivated if they incorrectly blame themselves for product faults (Brox et al., 2015). Knowledge building to overcome the "digital divide" between older participants and designers would help realize the full design potential of the co-design process (Giorgi et al., 2013; Gronvall & Kyng, 2011).

Methods and Skill in Co-Design

Skill and knowledge in co-design techniques are needed to avoid design ineffectiveness. Skill in co-design techniques is applicable to researchers, professionals, and the end-users themselves. In one project, participants did not know where to begin with a particular design activity as they had "never done it before" (Uzor et al., 2011). In another project, technology experts were reluctant to engage with older adults as the participatory approach was "alien" to them (Pratesi et al., 2013). A lack of understanding of the co-design process also led to stakeholders not understanding why it is time-consuming (Gronvall & Kyng, 2011), which can hinder support from the participants.

When working with older adults, collecting observational data (Brox et al., 2015; Cozza et al., 2016), limiting the number of interview questions (Brox et al., 2015; Uzor et al., 2011), and using multiple design techniques (Frennert et al., 2013; Iacono & Marti, 2014) were reported as useful tactics in the co-design process. These tactics maximized the ability of participants to participate in the co-design process. Using mockups or scenarios was also found to facilitate the process of co-design (Cozza et al., 2016; Frennert et al., 2013; Giorgi et al., 2013; Gronvall & Kyng, 2011; Hwang et al., 2012b; Iacono & Marti, 2014; Uzor et al., 2011), but the timing of mockup use was important. Too early and the design process may be compromised, as participants may dismiss concepts based on the aesthetics of the mockup alone (Cozza et al., 2016; Gronvall & Kyng, 2011).

Discussion and Implications

Preserving the independence of older adults is an important goal for healthcare systems. Health technology can support safe and active aging in the home and in the community, but its acceptance and use can be suboptimal without consideration of the end-users' needs and preferences (Cook et al., 2016). Participatory approaches, which involve end-users in the solution development process, are now commonplace in healthcare (Donetto et al., 2015; Horne et al., 2013; National Development Team for Inclusion, 2013). Co-design is one such approach and involves stakeholders collaborating in an iterative manner. Our review found that the impact of co-designed technology for aging in place remains unclear. This fits with a recent review of gerontechnology, which found few studies evaluated outcomes or the process of participatory design itself (Merkel & Kucharski, 2019). However, researchers frequently commented on the value of involving older adults in terms of solution generation and concept refinement.

The projects we included were exclusively from developed western countries, in particular Europe. This may be partially explained by the inclusion of only English language articles. Technological solutions that were co-designed were diverse and often multifunctional. For example, robots that encouraged social interaction were also designed to assist in ADLs. Older adults with dementia were commonly targeted end-users, probably due to their higher need for assistance at home. Other chronic diseases were less frequently addressed. For example, no technological solutions were designed for older adults with arthritis or depression. One project targeted heart disease (Sabater-Hernandez et al., 2018) and the other project targeted diabetes (Ogrin et al., 2018). This may be explained by our eligibility criteria (≥60 years). Chronic diseases often occur at an earlier age, thus studies that involved younger groups were not included in our review. Future projects should focus on co-designing solutions for chronic diseases with an older adult focus.

How older adults engaged in the co-design process varied greatly. We found a mixture of approaches including workshops, interviews, focus group discussions, sketching (Hwang et al., 2012b; Uzor et al., 2011), video tours (Giorgi et al., 2013), participant diaries (Cozza et al., 2016; Lopes et al., 2016), and the use of low- and high-functioning prototypes during the co-design process. Using a variety of methods fits with guideline recommendations. A mixture of methods improves opportunities for participant contribution, because participants may have different ability levels and physical capabilities (Giolitto, 2016; The Health Foundation, 2013). For example, an older adult who is hard of hearing may struggle to contribute in a focus group setting, but he or she could interact more effectively in a one-to-one interview. The range of ways older adults were engaged in the design process could also reflect the broad definition of the concept of co-design and the heterogeneity of technologies developed. The development of an app may dictate a specific approach of collecting data from participants who may be less useful in the design of a smart home. The diversity of methods used in co-design processes makes it harder to compare across studies and identify which approaches are effective and which are less appropriate.

The intensity of older adult involvement in the co-design process varied as well. Not all projects included all four phases (needs, ideation, prototype, and pilot testing in the field) and the number of rounds within a phase were different between projects. In some cases, the absence of the later co-design phases was an indication of the stage of development, that is, papers reported studies that were ongoing and have not reached the latter stages of co-design process (such as field testing). In other projects, different groups of older adults were involved in different phases of the co-design process, as the project progressed. This could lead to a lack of participant continuity and potentially cause a mismatch between needs and outcomes. It must be acknowledged that the co-design process requires the commitment of a significant amount of time and resources. Some projects may have to rationalize limited resources and determine when and how older adults are involved in the design process. This can affect the number and type of sessions conducted (some co-designed phases might be skipped or minimized). It remains unknown how variability in implementing the co-design phases affects the design output. It is unclear what level of involvement is ideal and how resource limitations could hinder proper execution of the co-design process. Many articles were excluded due to a clear lack of older adult involvement, despite claiming to be "co-design" projects. Prior reviews of participatory design studies also report limited end-user involvement, despite claiming to follow a participatory methodology (Corrado, Benjamin-Thomas, McGrath, Hand, & Rudman, 2019; Merkel & Kucharski, 2019). For co-design, researchers should refer to existing co-design guidelines and toolkits (Giolitto, 2016; The Health Foundation, 2013) to understand the degree and breadth of stakeholder involvement required in the co-design process.

Older adult needs and physical capabilities can affect their involvement in co-design. Age-related physiological changes and the presence of disease require researchers to be thoughtful in adapting co-design methods. For instance, one study reported that during focus group discussion, researchers purposefully moved close to each older adult when asking questions to make sure they could hear researchers' questions clearly (Brox et al., 2015). Lack of consideration of age-related issues can lead to older adults being reluctant to participate. Authors suggested increasing allocated time, providing a supportive environment, using short questionnaires, taking time to direct questions to each participant in group discussions, and ensuring questions are understood (Brox et al., 2015; Magnusson & Hanson, 2012) to avoid design difficulties with older adults. It is also well documented that some older adults find using technology a challenge, leading to lower adoption rates, resulting in what is often described as a "digital divide" (Hargittai, Piper, & Morris, 2019; Mitzner et al., 2018). By involving older adults in the co-design process, designers can appreciate their challenges and customize technology that would facilitate adoption and improve ease of routine use. The studies we reviewed indicated that this process of engagement takes time and requires designers to consider existing assumptions they may have about older users (Giorgi et al., 2013; Gronvall & Kyng, 2011). If researchers can adhere to inclusive design principles, such as the Universal Design principles (equity, flexibility, simplicity, perceptibility, tolerance for error, low effort, and accessibility; Gassman & Reepmeyer, 2008), challenges of designing technology with older adults can be managed.

Only four projects (five RCTs) evaluated health and well-being related outcomes (Bjerk et al., 2017, 2019; Mira et al., 2014; Oesch et al., 2017; Weering et al., 2017). Projects tended to limit their evaluations to measuring product usability and end-user satisfaction. In the five RCTs that examined health and well-being outcomes, there were insufficient data to draw definitive conclusions. A recent systematic review of co-creation and co-production in healthcare reported a lack of outcomes measurement as well (Voorberga, Bekkersa, & Tummersb, 2014). Even though the usability and utility of technology are important, if it does not positively affect the health and well-being of the consumer, it is difficult to ascertain the value of the new technology in the long run. It would benefit healthcare professionals and end-users to commit a bigger part of the resource for technology development to a systematic evaluation of new co-designed technologies. Researchers should consider evaluating health-related impact including disease control measures, quality of life, physical functional status, access to service, and service experience (Clarke et al., 2017; Elwyn, Nelson, Hager, & Price, 2019; Robert et al., 2015; Sharma et al., 2017). Without proper evaluation, it will be difficult to support greater adoption of the co-design process because it is resource intensive and involves multiple stakeholders.

Limitations

There is no single definition of co-design in the literature, which has led to a high degree of terminology variability. It is possible our literature searches did not include all relevant co-design terminology and articles were missed. We attempted to minimize this risk by expanding our list of search terms. In many cases, the methodology reported in the papers was limited and made it difficult to ascertain whether a study was truly co-design. Where possible we searched for linked articles and contacted authors for clarification. In addition, one of our eligibility criteria required that older adults must be involved in at least two phases of the co-design process. We acknowledge there is no consensus on this requirement and thus we may have excluded relevant articles that had lesser older adult involvement in their design process. However, given the range of interpretations of what co-design is in the field, we deemed it important to include this criterion to increase our confidence that included projects involved older adults in a meaningful way. We also decided not to include terms related to dementia and Alzheimer's in our search strategy. Prior reviews have explored this extensively and the focus of this review was not to identify solutions in specific disease groups, but rather technology that supports aging in place more generally. Many articles on dementia and Alzheimer's were identified, but many were excluded for not meeting our eligibility criteria (i.e., age ≥60 years) or methods not co-designed.

Conclusions

Co-design is an evolving methodology that is increasingly adopted by healthcare organizations to improve the care and well-being of end-users. The scope of user involvement was variable, and the interpretation of "co-design" was often misunderstood in studies. Researchers should strive to follow existing co-design guidelines, while balancing against the additional resource costs of end-user involvement. Evaluation of health and well-being outcomes was limited. Future efforts should continue to involve older adults and a greater commitment to evaluating the impact of co-designed technologies that support aging in place is required.

Supplementary Material

Supplementary data are available at *The Gerontologist* online.

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Conflict of Interest

None reported.

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