The Role of Socially Assistive Robots in Elderly Wellbeing: A Systematic Review

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Abstract. The population of the world is aging and one of the main concerns of the aged care industry is to provide appropriate care for elderly people as their health and independent functioning declines. This paper reports a systematic review of the roll of Socially Assistive Robots (SAR) in elderly wellbeing, based on Cochrane principles. Relevant publications from diverse databases, including healthcare, engineering, and robotics were sourced and screened. Ninety-five studies in forty-two study groups have been synthesized. The reported outcomes have been categorized based on five PERMA constructs (Positive emotion, Engagement, Relationships, Meaning, and Achievement) in addition to a sixth category (other effects). The findings indicate that SAR has the potential to enhance elderly wellbeing and decrease the workload of caregivers. Based on concerns that emerged during the quality appraisal process, several significant recommendations are made to improve future research and its applicability. Furthermore, acknowledging individuals' needs, expectations, and preferences alongside multi-modal interaction and data collection translates into improvement of personalization of care. The development of new approaches such as web-based interfaces and cloud computing are highly recommended as the means of overcoming the constraints of the limited computing and storage capabilities of SAR. Moreover, human-like engagement characteristics of socially assistive robots should be seamlessly integrated with other assistive technologies such as tele-health, e-health, and smart homes.

Keywords: Socially assistive robots · Elderly wellbeing · Assistive technologies · Aged care · Systematic review

1 Introduction

A decline in birth rates and extended longevity have resulted in an increase in the elderly population worldwide. Consequently, the ratio of the number of people aged between 15 and 64 to one elderly person (aged 65 years or above) dropped dramatically from 12 to 9 between 1950 and 2000 and is forecasted to decrease to 4 in 2050 [1]. One of the main concerns of the aged care industry is the provision of appropriate care for the elderly as their ability to function independently declines.

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Researchers are working on the development of different technologies such as biomedical devices, nano-medicine, tele-health, smart homes, and robots to support the process of care giving and keeping the elderly at home longer. However, research in the interdisciplinary area of Socially Assistive Robots (SAR) is increasingly interested in overcoming the missing human element and the issue of human-robot engagement.

Systematic reviews of past studies help us to better understand what is already known [2] and unites current research and existing knowledge in the literature [3–5]. This research aims to synthesize existing knowledge in the field of SAR and its effects on elderly wellbeing. In line with existing literature [e.g., 89], this systematic review mostly follows the principles explained in the Cochrane Handbook for Systematic Reviews of Interventions [6], and integrates evidence from qualitative and quantitative studies. Critical appraisal frameworks for the analysis and interpretation of evidence from qualitative and quantitative research have been adopted [i.e. 7, 8]. We have not excluded any of the studies that did not meet a minimum quality threshold, since the exclusion of such studies would lead to the loss of valuable information.

This systematic review summarizes the reported effects of socially assistive robots on elderly wellbeing, and reveals the potential opportunities and drawbacks of the design of field trials in this domain. It attempts to address the following question: "What does existing research tell us about socially assistive robots?" In total, 1231 potentially relevant publications were found and screened, which resulted in 95 publications meeting the inclusion criteria. In synthesizing these studies, we had the opportunity to consider similarities, differences, and limitations. The review also sheds light on how SAR has the potential to improve the wellbeing of elderly people, and reveals the areas that have been neglected. All in all, this systematic review intends to offer a better foundation for the design of future research.

The applications of SAR need to be reviewed for the purpose of future development in the field, and several researchers have begun to do so. In a very valuable review which was carried out in September 2009, Bemelmans et al. [9] outlined the effectiveness of SAR and its effects on the elderly and observed that, while there are reported positive effects, the scientific value of the evidence is inadequate. This review was carried out in 2009 and includes 41 publications, reporting on 17 studies, and involving four robot systems and one undefined robot. Another valuable review was conducted by Broekens et al. [10] who summarized the effects of assistive social robots on the health and psychological wellbeing of elderly people. This review was undertaken in 2007 and includes 43 studies and the application of eight different robots in elderly care. A more recent review has addressed the role of social commitment robots in the care of elderly people with dementia [11]. This review was conducted in 2012 and includes a total of 21 studies. Several other recently-published reviews can be found in the literature [e.g. 12–14] although these are neither systematic nor focused on socially assistive robots.

One major contribution of this research is that it is holistic and includes almost all the studies reported in previous reviews. Because it is a comprehensive review, it may prove to be a valuable reference for future researchers. Some of the previous reviews focused only on specific databases or did not cover all the related research areas (e.g. healthcare, engineering, and robotics). Moreover, they rarely cite studies from 2009 onwards; however, according to our finding if we select the latest publication as the

representative of each group, the number of studies has doubled since 2009. Apart from the increase in the number of related studies, several recent studies have conducted field trials with significantly larger samples [e.g. 15 which had 80 participants]. Moreover, some recent studies carried out trials in other geographical regions such as Khosla et al. [16] in Australia, and Jayawardena et al. [17] in New Zealand. Furthermore, some robots such as Brian, Ifbot, and Matilda have been used in elderly care since 2009. Additionally, the number of home trials has increased dramatically in recent years and the results have been more conclusive since human-robot interaction has taken place without the presence and intervention of researchers.

Another contribution of this review is that, by comparing previous reviews, it links the findings to wellbeing theory and PERMA, which enables future studies be designed with a stronger focus on wellbeing. The existing reviews have drawn general conclusions regarding the positive effects on the elderly or reported positive effects of SAR in terms of (socio) psychological and physiological parameters. However, this review explicitly mentions the reported effects of SAR and summarizes the effects according to PERMA.

2 Background

Researchers broadly categorize assistive robots for the elderly into two major groups, rehabilitation and assistive social robots [10]. Rehabilitation robots are intended for physical assistive purposes and are typically not communicative; these types of robots include artificial limbs and exoskeletons [18], robotic walker [19, 20], and smart wheelchairs [21]. There are two sub-categories of assistive social robots: service robots for supporting basic tasks of independent living, and companion robots for enhancing the health and psychological wellbeing of the elderly. In another study, healthcare robots are classified into health and safety monitoring, physical assistant, and companion robots [22].

Researchers in the field of SAR are trying to assist elderly people to experience objectively healthy living standards and to feel subjectively satisfied. It could be presumed that the eventual goal of SAR is to enhance the wellbeing and quality of life of elderly. Many researchers agree that wellbeing is a multifaceted concept [e.g. 23–26] and a large range of wellbeing definitions exist [27], although there is disagreement about which components to take into account [28]. Thus, there is a need for methods to collect and merge subjective and objective information. According to a group of researchers, wellbeing is "the dynamic process that gives people a sense of how their lives are going through the interaction between their circumstances, activities, and psychological resources" [24].

Diener and Seligman [29] state, "Current measurement of well-being is haphazard, with different studies assessing different concepts in different ways" (p. 2). In some studies [e.g. 30–32] the effects of robots were classified according to three inter-related groups: psychological, physiological, and social effects. Also, in another study, Khosla et al. [33] chose five constructs including positive engagement, acceptability through reciprocity, personalization of care, encouragement for healthy living, and usefulness through mental activity engagement, to determine the impacts of robots on elderly

wellbeing. A new approach to wellbeing suggests that there are five constructs of which one or more should be nurtured in order for people to experience wellbeing [34]. These constructs are recognized by the acronym PERMA (Positive emotion, Engagement, Relationships, Meaning, and Accomplishment).

Forgeard et al. [35] state "these five elements are the best approximation of what humans pursue for their own sake[1], which is why they have a place in wellbeing theory". In a highly cited article, Forgeard et al. [35] summarized various domains of wellbeing measures and highlighted wellbeing theory defined by PERMA. Moreover, PERMA has been validated in various settings and contexts such as universities [36], adventure tourism [37], and institutional leadership and culture change [38].

3 Review Design

In this systematic review, the authors followed the principles in the Cochrane Handbook for Systematic Reviews of Interventions [6]. Elderly care and human-computer interaction are multifaceted and convoluted, so most prior studies in these fields adopted a mixed-methods approach. Hence, the authors incorporated evidence from qualitative, quantitative, and mixed-methods studies.

A list of potentially related studies was compiled in January 2013, based on a search of various databases, and was updated in December 2013. In the first phase, related conference proceedings and journal articles were systematically searched in a broad range of databases including ACM digital library, IEEE digital library (Xplore), ProQuest, SCIRUS, JSTOR, the Cochrane library, the MEDLINE and PubMed, BioMed, and CINAHL. Moreover, a free search was carried out in Google Scholar and La Trobe university library. Only English publications were included, without any limitation regarding date of publication.

The search term included the subject ("robot*", "assis* device*", "assis* technolo*", "self-help device", "AIBO", "Care-o-bot", "CERO", "Feelix", "Hug", "iCat", "Ifbot", "Matilda", "Meka", "NAO", "NeCoRo", "PaPeRo", "Paro", "Pearl", "Robocare", "PR2", and "Sparky") in any conjunction with the context ("aged", "elder*", "senior*", "old person*", "old people", and "dementia") and their associated Medical Subject Headings (MeSH) terms, their database-specific thesaurus equivalent and subheadings. The asterisk (*) character was used to replace any other possible character(s) in the search term; as a result, "elder*" stands for the terms "elder", "elders", "elderly" and "elderliness". Usually, existing reviews assist to detect potentially related references [39]; hence, references to existing reviews were scanned and related studies were added to the list.

Edwards et al. [40] state that during the review process, the possibility of excluding relevant studies will be minimized by engaging at least two reviewers. Two authors independently scored each study on a three-point scale (zero = not relevant, one = relevant, two = very relevant) based on the relevance of the title to the subject of socially assistive robots in elderly care. After adding the scores from two reviewers, publications

[1] Emphasis was in original text.

that scored zero were excluded. Decisions were made regarding the eligibility of publications with a score of one. Subsequently, abstracts of the remaining publications were extracted and then subjected to the same screening process. After this stage, full texts of the remaining publications were obtained and independently assessed by two reviewers. When there were discrepancies between the reviewers' opinions, these were addressed in face-to-face discussions.

The frameworks developed by Thomas et al. [8] and Spencer et al. [7] were used to appraise the quality of quantitative and qualitative studies respectively. Authors did not exclude any studies because of poor methodological quality.

4 Search Results

After discarding identical publications, a total of 1231 potentially relevant publications were found. In total, two hundred and ninety-six and then 127 publications remained after screenings based on title and abstract respectively. Inter-related agreement between two reviewers were calculated using Cohen's kappa coefficient [41] and resulted in 0.67 and 0.81 which shows good and very good agreement strength between two raters [42]. After a comprehensive review, 94 publications remained which met the inclusion criteria.

The inclusion criteria were: the publications had to be in English, the participants had to be elderly, and the study reported a field trial or human-robot interaction. Technical descriptions of robot characteristics were excluded. None of the publications was excluded based on the location of the interaction; therefore, the interaction could occur in places such as the participant's home, a nursing home, medical center, or retirement village. No robot was excluded based on low level of autonomy or intelligence.

After data extraction, publications were clustered into study groups because many of the screened publications are just republished versions of previous research with some changes. These changes included publishing only some parts of the study, merging and mixing new and old data, or just changing the title. If any study was published more than once with some changes, a study cluster synthesis and a report was conducted based on the one which is most complete or of the longest duration. For example, if two studies are similar, but one included more tests and measures and/or the study lasted longer, we based the report on this study.

5 Quality Appraisal

During the quality appraisal process, several issues emerged, which threaten the generalization of outcomes. One major limitation is the inadequacy of the research methodology. Most of the studies used uncontrolled trials, and there was infrequent use of control groups. Moreover, most of the studies were not long enough to eliminate the novelty effect (e.g. interest or stress in facing new technology) and Hawthorne effect (e.g. in case of supervised interactions), thereby compromising external validity [e.g. 43, 44]. Other limitations include small sample sizes, cultural bias (most of the studies have been carried out in Japan), and gender imbalance.

Research in the field of socially assistive robots is in the early stages and therefore has limitations. Several recommendations have been made to overcome these limitations and improve future research applicability. Innovative research strategies are required in order to address the shortcomings. The quality of observational studies would be improved with the application of methodological approaches such as Randomized Controlled Trial (RCT) to reduce allocation bias [45], triangulation-use of multiple data sources- for rigorous qualitative research [46], and Propensity Score Matching (PSM) to correct for sample selection bias [47]. To improve the quality of studies, trials should be long enough to eliminate the novelty effect, and the sample size should be adequate enough so that the findings can answer the research questions effectively.

Several of the studies overcame some of these limitations. For example, Banks et al. [48] used a control group; Wada et al. [49] implemented very good measures; Wada, Shibata [50] applied a more solid research methodology; Libin, Cohen-Mansfield [51] applied a good methodology and their findings are, arguably, very reasonable. Moreover, Khosla et al. [52] linked each robot service to one aspect of the emotional wellbeing of elderly people.

6 Findings

Although virtually all of the included studies report the positive effects of SAR on the wellbeing of elderly people, there are few studies which tested and reported the effects of SAR on nursing staff, although there is evidence of positive effects such as a decrease in nursing staff's mental poverty [53] and stress [54]. In order to acquire comprehensive and more organized information about the reported effects, we based our discussion on PERMA constructs and tried to link the reported effects with one of the PERMA constructs. However, these constructs are highly interrelated and mapping the effects mentioned in some of the studies to these constructs is difficult. In addition, there is no explicit construct for mapping the physical and physiological wellbeing of elderly people. Keeping these perspectives in view, the following section reviews the reported effects. Some of the reported effects were too general or could be linked with more than one construct, so we created a new category for them - 'Other effects'.

6.1 Positive Emotion

To experience wellbeing, individuals need positive emotion in life such as peace, satisfaction, hope, and love. Positive emotions influence how individuals perceive their overall happiness. In most of the included studies, it is reported that SAR has the potential to produce positive emotions in the elderly (e.g. [51, 54–60]). Some studies pointed out that the feelings and moods of the elderly improved [54, 55, 59, 61, 62], while others stated that SAR increased the sense of security and joy in life of elderly people [62, 63]. Furthermore, it has been observed that elderly people became calmer [64], revealed richer expressions [65], increased laughter [54, 65], and their stress level decreased [55–57] during trials. Moreover, several other studies confirmed that the trials improved the emotional state of elderly people [59, 66].

6.2 Engagement

Engagement is a self-reported psychological state of individuals who are immersed in and are concentrating on an activity [35]. When an individual has clear objectives, is interested in the ongoing activity and receives feedback, s/he is experiencing a high level of engagement [35].

It is reported that elderly people who participated in trials had an evocative experience and could externalize their internal emotions more easily [64]. Some research shows that the daily activities of elderly people increased [67, 68] and they performed movements actively, especially in outdoor activities [69]. In some studies, researchers used a robot to motivate physical exercise and to encourage the elderly to engage in activities [70].

6.3 Relationships

'Relationship' refers to the condition of connection among individuals who are related to, or deal with, each other. Individuals who establish a positive relationship can relate to others and perceive other people in their lives who care about them. It was found that by taking part in field trials and using SAR, elderly people increased their social interactions and activities, networks, and ties [68, 71, 72]. Moreover, it decreased the loneliness experienced by the participants [48, 67]. Researchers have found that using SAR facilitates the establishment of a friendly relationship and encourages communication among elderly people [64, 65, 69]. Moreover, in some cases, participants developed a friendship with the robot [73].

6.4 Meaning

Meaning can be defined in several ways from "the ontological significance of life from the point of view of the experiencing individual" [74] to "feeling of belonging and serving something larger than the self" [34]. Researchers mentioned that robots decreased depression in the elderly who participated in trials [54]. According to Hamada et al. [75], when elderly people engage with SAR, their perception of the external world is more positive.

6.5 Accomplishment

'Accomplishment' means the highest degree of success, attainment, or mastery in a specific area [76]. At an individual level, accomplishment means achieving a desired status and progression toward goals [77]. Accomplishment is strongly related to competence. During a field trial, by winning in one-on-one or group games supervised by the robot, the elderly experienced a sense of achievement [16, 33]. Achieving, achieving perceived autonomy [78] and improvement in response time [79, 80] can be considered as two accomplishments resulting from SAR.

6.6 Other Effects

In this review, the 'other effects' group was added as a category for those outcomes that were too general or could be associated with more than one construct. Some studies reported that the wellbeing of the elderly increased after engaging with robots (e.g. [33, 81]). One study found that using a robot led to improvement in the personalization of care [16, 33]. Moreover, some researchers reported that engaging with robots reduced physically disruptive behavior and overall agitation in elderly people [51, 82]. Several studies (e.g. [61, 83]) reported the positive psychological effects of SAR on the elderly. Tapus [79, 80] refers to improvement in SMMSE (Standardized Mini–Mental State Examination) score, and in another research, Tanaka et al. [84] discuss possible improvement of cognitive function of the elderly by engaging with SAR. However, some studies revealed that SAR could have some negative effects on the elderly; for instance, it could increase the level of anxiety due to fear of breaking or doing something wrong with the robot [85] as well as negligible improvement in users' health [86].

7 Conclusion

Finding and addressing the impacts of SAR on the wellbeing and quality of life of the elderly is important for a variety of stakeholders, from the elderly themselves to health sector policymakers, and from elderly family members to nursing home managers and nurses. Policy makers and practitioners can use this work for health economics evaluation, long-term impact on health care costs and quality of life of the elderly. In total, ninety-five studies in forty-two study groups have been examined and synthesized in this systematic review. Our review revealed that a variety of robots have been developed with different designs, attributes, and applications; however, there is not a single ideal design of SAR.

The results of this systematic review indicate that SAR potentially can enhance the wellbeing of the elderly and decrease the workload of nurses. Because wellbeing is multifaceted, and in order to acquire more organized knowledge, we categorized the reported outcomes according to PERMA (Positive emotion, Engagement, Relationships, Meaning, Accomplishment) [34]. In addition, we included a sixth category for more general or physiological effects. This review revealed that SAR could improve all six sub-categories of elderly wellbeing, especially their positive emotions and relationships. The different aspects of wellbeing are strongly interrelated, and an improvement in wellbeing overall does not necessarily occur as a result of improvement in one aspect only; hence there is a need for a balanced improvement. Therefore, robots which are capable of improving all or most aspects of elderly wellbeing are potentially more beneficial and effective compared to ones with fewer applications; hence, future studies should consider wellbeing from different perspectives. This review also revealed that most of the studies that were examined have focused on the first three aspects of PERMA (positive emotions, engagement, and relationship) and the other two aspects (meaning and accomplishment) have been under-studied. There is still a need for further studies regarding the potential application of SAR.

Furthermore, if consideration is given to individuals' needs, expectations, and preferences, this may lead to improved personalization of care. For example, Wu et al. [87] found that older people and young adults perceived robot expressions differently. They argue that robots should be designed to match the target population. In addition, concentration on person-centered care, multi-modal interaction and data collection translate into a better SAR design. In line with Mayer and Panek [88], we also propose that human-like engagement characteristics of socially assistive robots could be exploited by integrating them seamlessly with other assistive technologies such as tele-health, e-health, and smart homes. Moreover, the development of new approaches such as web-based interfaces and cloud computing is highly recommended in order to overcome the impact of the limited computing and storage capabilities of SAR.

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