Assistive social robots in elderly care: a review.

Joost Broekens, Marcel Heerink, and Henk Rosendal

Delft University of Technology, Delft, The Netherlands (D.J.Broekens@tudelft.nl)
University of Applied Sciences, Amsterdam, The Netherlands (m.heerink@hva.nl)
University of Applied Sciences, Leiden, The Netherlands (rosendal.h@hsleiden.nl)

Abstract

Context: Assistive social robots, a particular type of assistive robotics designed for social interaction with humans could play an important role with respect to health and psychological wellbeing of elderly.
Objectives: Assistive social robots are believed to be useful in eldercare for two reasons, a functional one and an affective one. Such robots are developed to function as an interface for elderly to digital technology, and to help increase the quality of life of elderly by providing companionship respectively. There is a growing attention for these devices in the literature. However, no comprehensive review is yet performed to investigate the effectiveness of such robots in the care for elderly. Therefore, we systematically reviewed and analyzed existing literature on the effects of assistive social robots in healthcare for elderly. We focused on the companion function.
Data Sources: A systematic search of MEDLINE, CINAHL, PSYCHINFO, The Cochrane Library databases, IEEE, ACM libraries and finally Google Scholar was performed for records through December 2007 to identify articles of all studies with actual subjects aimed to assess the effects of assistive social robots on elderly. This search was completed with information derived from personal expertise, contacts and reports.
Study Selection and Data Extraction: Since no randomized controlled trials (RCT)'s have been found within this field of research, all studies reporting effects of assistive robotics in elderly populations were included. Information on study design, interventions, controls, and findings were extracted for each article. In medical journals only a few articles were found, whereas about 50 publications were found in literature on ICT and robotics.
Data Synthesis: The identified studies were all published after 2000 indicating the novelty of this area of research. Most of these publications contain the results of studies that report positive effects of assistive social robots on health and psychological well-being of elders. Solid evidence indicating that these effects can indeed be attributed to the actual assistive social robot, its behavior and its functionality is scarce.
Conclusions: There is some qualitative evidence as well as limited quantitative evidence of the positive effects of assistive social robots with respect to elderly. The research designs however are not robust enough to establish this. Confounding variables can often not be excluded. This is partly due to the chosen research designs, but also because it is unclear what research methodology is adequate to investigate such effects. Therefore, more work on methods is needed as well as robust, large-scale studies to establish the effects of these devices.

Keywords: Assistive Robotics, Companion robots, Elderly, Aibo, Paro, Huggable, iCat, Effects, Review

INTRODUCTION

Because of the graying of our western population, there is a growing necessity for new technologies that can assist elderly in their daily living. There are two main arguments for this. First, it is expected that western countries will face a tremendous shortage on staff and qualified healthcare personnel in the near future [1]. Second, people prefer more and more to live in their own homes as long as possible instead of being institutionalized in sheltered homes, or nursery homes when problems related to ageing appear. To address these issues, we not only need sufficient healthcare personnel, but also the presence and appliance of high-tech devices [2]. ICT-technology and robotics are developing quickly nowadays, resulting in products that have the potential to play an important role in assisting elderly [3]. In order to use new technology in an effective and efficient way, robust information with respect to their effects is needed, especially when used in health-care.
In this review we focus on health- and psychological well-being-related effects of assistive social robots on elderly. Robot research in eldercare concerns assistive robots that can be both rehabilitation robotics and social robots (Figure 1). The first type of research features

physical assistive technology that is not primarily communicative and is not meant to be perceived as a social entity. Examples are smart wheelchairs [4], artificial limbs and exoskeletons [5]. The field of social robotics concerns systems that can be perceived as social entities that communicate with the user. Of course there are also projects with social robots aimed at rehabilitation [6] and vice versa.

(Figure 1 about here)

Studies on social robots in eldercare feature different robot types. First, there are robots that are used as assistive devices which we will refer to as *service type robots*. Functionalities are related to the support of independent living by supporting basic activities (eating, bathing, toileting and getting dressed) and mobility (including navigation), providing household maintenance, monitoring of those who need continuous attention and maintaining safety. Examples of these robots are 'nursebot' Pearl [7], the Dutch iCat (although not especially developed for eldercare) and the German Care-o-bot [8]. Also categorized as such could be the Italian Robocare project, in which a robot is developed as part of an intelligent assistive environment for elderly people [9]. The social functions of such service type robots exist primarily to facilitate interfacing with the robot. Studies typically investigate what different social functions can bring to the acceptance of the device in the living environment of the elder, as well as how social functions can facilitate actual usage of the device.
Second, there are studies that focus on the pet-like companionship a robot might provide. The main function of these robots is to enhance health and psychological well-being of elderly users by providing companionship. We will refer to these robots as *companion type robots*. Examples are the Japanese seal shaped robot Paro [10], the Huggable [11] (both especially developed for experiments in eldercare) and Aibo (a robot dog by Sony, see below). Social functions implemented in companion robots are primarily aimed at increasing health and psychological well-being. For example, studies investigate whether companion robots can increase positive mood in elderly living in nursery homes.
However, not all robots can be categorized strictly in either one of these two groups. For example, Aibo is usually applied as a companion type robot, but can also be programmed to perform assistive activities [12] and both Pearl and iCat can provide companionship.

This review aims to provide a first overall overview of studies that investigate the effects of assistive social robots on the health and wellbeing of elderly. Since the majority of the assistive social robot studies with actual elderly people as subjects involve the robots Aibo, Paro, iCat and 'nursebot' Pearl, these robots are briefly highlighted next.

Aibo
Aibo is an entertainment robot developed and produced by Sony [13]. It is currently out of production. It has programmable behavior, a hard plastic exterior and has a wide set of sensors and actuators. Sensors include a camera, touch sensors, infra red and stereo sound. Actuators include 4 legs, a moveable tail, and a moveable head. Aibo is mobile and autonomous. It can find its power supply by itself and it is programmed to play and interact with humans. It has been used extensively in studies with elderly in order to try to assess the effects on the quality of life and symptoms of stress. In this article we will review these studies.

Paro
Paro is a soft seal robot [10, 14]. It has been developed by the Intelligent Systems Research Institute (ISRI) of the National Institute of Advanced Industrial Science and Technology (AIST) in Japan, and is produced by Intelligent System Co., Ltd.. It is developed to study the effects of Animal Assistive Therapy with companion robots, and is targeted at elderly. It has programmable behavior as well as a set of sensors. Sensors include a touch sensor over the complete body, an infra red sensor, stereoscopic vision and hearing. Actuators include eyelids, upper body motors, front paw and hind limb motors. Paro is not mobile. It has been used extensively in studies with elderly to assess the effects of robot therapy.

iCat
The iCat has been developed and is produced by Philips [15]. Its design aim is to be a research platform for human-robot interaction. It is made of hard plastic and has a cat-like appearance. Furthermore, it has a face that is able to express emotions. Studies typically investigate how users perceive the iCat as interface to new technology. The iCat is not particularly aimed at being a companion (i.e., affective assistance) but more at functional assistance (classified as service type). However, it is included in this study as some studies

involving elderly typically measure acceptance under the influence of different social iCat behaviors. Therefore the iCat strongly relates to social interaction between elderly and robots as well.

Pearl
Of the four most-cited and studied robots, Pearl is targeted most heavily on functional assistance. Pearl is the second generation of nursebots developed by Carnegie Mellon University [7, 16]. It is a mobile robot that can help elderly to navigate through the nursing facility. It does have a user-friendly interface with a face, and can also provide advice and cognitive support for elderly.

(Figure 2 about here)

Other eldercare robots that have only briefly been included in this review are the Care-o-bot [8] and Robocare [9]. Their effects have been measured, but not directly related to health or psychological well-being. Finally, for the Huggable [11], a good example of a companion robot, we did not find any publications on user studies at the time of collecting the data for the review. As can be seen in Table 1 in the results section, many of the health- and psychological well-being-related effects on elderly have been found in studies with the 4 devices described above.

METHOD

The data collection process consisted of three steps (Figure 3). First, a systematic search of MEDLINE, CINAHL, PSYCHINFO, The Cochrane Library databases, IEEE, ACM libraries and finally Google Scholar was performed for records through December 2007 to identify articles of all studies with actual subjects aimed to assess the effects of assistive social robots on elderly. These databases were searched using the following search terms: *Companion robot*, *Aibo, Paro, iCat, Pearl*, *nursebot, Care-o-bot, Homie, Huggable* and *Robocare* combined in all possible ways with *elderly, assistive robotics, healthcare* or *health* and *care*. This particular use of search terms ensured that no study involving companion robots and elderly was missed. Further, our use of particular robot names in combination with their use in the area of health care ensured that we also included all studies with robots that are often used as companion robot but might not have the exact term included in the article. The search was restricted to publications in English, with no limitations on dates of publication or venue. All three researchers independently screened the initial set of results. Studies were selected for inclusion if they actually reported studies that related assistive social robotics to elderly people. This first step in the data collection process resulted in an initial list of 229 studies (first box in Figure 3).
Second, this list of potentially relevant full-text articles was reviewed by all three of the reviewers separately according to the main criterion for this review: *the publication delivers empirical data on the effects of assistive robotics in health care for elderly*. Key criterion for inclusion was that the study involved real elderly subjects. Since this is a relatively new field, we preferred a complete overview of the field and therefore included all study-designs in this review. This selection process resulted in a list of 68 studies (box two in Figure 3).
Third, disagreements about the inclusion of articles were resolved in a face to face discussion and a study was included in the final list of to be reviewed publications (box three in Figure 3) if two out of three researchers agreed to include it.
Subsequently, the final set of 43 studies were reviewed with respect to the robustness of evidence, the chosen study design, the number of patients involved, the outcome measures, the period of follow-up, and the results.

RESULTS

The initial review identified 229 citations. Of these, 68 were selected after reviewing the abstracts. After discussion between the authors, this resulted in a total of 43 citations that were included in our review (see Method section).

(Figure 3 about here)

These citations are summarized per type of device in Table 1. The table presents all 43 studies that have been included in the final review. For each study we report the research design, the type of assistive social robot, the main outcome measures used in the study to measure the effects of the intervention, the number of participants in the study, whether or not the results were positive, negative or mixed and the time period the study spanned. We also include our main observations for each study.

In the studies included in this review, a variety of effects, or one could say functions, of assistive social robots have been studied. These functions include: increased health by decreased level of stress, more positive mood, decreased loneliness, increased communication activity with others, and thinking and remembering the past. Most studies report positive effects, and the effects are diverse (see Table 1 for details). With regards to mood, companion robots are reported to increase positive mood, typically measured using evaluation of facial expressions of elderly people as well as questionnaires. Further, elderly people are reported to become less lonely with the intervention of companion robots as measured with loneliness measurement scales. With regards to health status, companion robots are reported to alleviate stress (e.g., measured by stress hormones in urine) and increase immune system response. Some studies report a decrease on existing dementia measurement scales. One study explicitly reports that a companion robot (the My Real Baby in this case) elicited memories about the past. Many studies report positive findings with regards to social ties between elderly in homes (measured by the frequency of contact between elderly) as well as between elderly and family. Typically, the companion is the topic of conversation.
With regards to the perception of the companion robot, narrative records present in a large portion of these studies show that most elderly actually report liking the robots (or their controls, such as a pet toy, for that matter).

In the studies examined, four patterns emerge that limit the strength of the evidence for the positive effects reported. The first pattern is that the majority of studies are with the Aibo and Paro companion robots. This means that little has been published on experimentation with different forms of assistive social robots. This is interesting, as it has been concluded that form and material does matter a lot to acceptance and effects of assistive social robots (see e.g. [42, 23]).
Second, the majority of the studies are done in Japan. As it has been shown that robot perception is culturally dependent [17] results should therefore not be generalized too easily to other cultures.
Third, practically all of the studies are done with elderly people in nursery homes, not with elderly people still living in their own house, even though there is growing number of elderly people that get support in their own home. We do not know if the effects of social assistive robots are the same in these two cases.
Fourth, and most importantly, the research methods used to derive effects are from a methodological point of view not very robust. Control conditions are often lacking and when present, the results are difficult to interpret in the sense that the control condition (e.g., a fake Paro) has a comparable effect as the experimental condition or the number of participants is too small to conclude much [10, 18-22]. Some studies are even contradictory in terms of their outcome [18, 23]. Also, many studies are not long-term enough to exclude novelty effects. Further, the exact way of interacting with the elderly is often not described in enough detail to repeat the study. Therefore, we should be careful to conclude that the cause of any effect is really due to the robot, since a Hawthorne effect (a temporary change to behavior in response to a change in the environment) can not be excluded in several studies. Notable exceptions to this are recent studies by Kidd et al. [42] and Wada and Shibata [14] where participants could play with the robot without intervention by the researchers. Other exceptions to this are studies that investigate robot acceptance and design criteria that include a larger number of participants and generally allow subjects to play with the robot by themselves without intervention of the researchers [24-29]. However, it should be noted that this latter type of research is aimed at extracting requirements for robot design and understanding robot acceptance and as such does not focus on physical and mental health as treatment effects of robots.

CONCLUSION

Many different studies report positive reactions of elderly to assistive social robots. As a wide variety of research designs has been used, and many of these studies indicate a positive effect of companion robots on elderly, we conclude that there is some evidence that companion type robots have positive effects in healthcare for elderly with respect to at least mood, loneliness and social connections with others. However, the strength of this evidence is limited, since (a) most studies have been done in Japan, with (b) a limited set of companion robots, i.e., Aibo and Paro, and (c) research designs are not robust enough, usually not described in enough detail to repeat, and confounding causal variables cannot be excluded. However, as several studies mention subjective reports from elderly people indicating that they like the companion robots, we conclude that it is worth-while to invest in research methods that are able to attribute the causality of the beneficial effects to the robot as well as invest in robust, large-scale cross-cultural studies to better establish the effects of these devices.

IMPLICATIONS FOR FUTURE RESEARCH

Given the large number of studies that show positive effects of either the robot or it's placebo version, such as a non-functional robot or a pet toy, we believe this type of devices have definitely merits in eldercare. Further, and of importance, elderly seem to be open to this kind of technology (see, e.g., Heerink et al. [25-28]).

We consider it necessary to address the methodological problems, or at the very least vagueness regarding methodology often encountered in these studies. It is a little unfair to judge so harsh these studies, as they attempt to do something quite difficult and novel: experiment with a novel form of treatment in a real life situation without having the benefit of being able to set up randomized blind trials, as the placebo version of the robot is also perceptually different. This is obviously not the case with drug-research for example. However, we surely think that several of the other experimental design issues need to be addressed.

First, it is absolutely necessary to have a control group that is not in contact with the experimental group. Second, researchers need to start replicating results of others, and for this to be possible they need to have access to the methods used, the same control conditions and preferably the same robots. This implies that all studies should describe their research design and methods clearly and in such a way that the research can be completely repeated somewhere else. Third, studies must be long-term. The novelty value of something that enters the life of an elderly person may take some time to wear off. Fourth, many studies attempt to derive statistical significant results from a far too small number of subjects. This is problematic, because of sample group selection bias and lack of statistical power.

In summary, we need large-scale experiments that are rigorously set up, and an adequate methodology by which these studies are done and compared to each other. Further, we need more variation in the form and function of these robots to figure out what parts actually contribute to the beneficial effects. Setting up a large scale, international (e.g. EU-based) program to establish the merits of these, and related, devices could be of great importance for elderly as well as for healthcare in general.

REFERENCES

1. WHO, *Investing in the health workforce enables stronger health systems*, in *Fact sheet*. 2007: Belgrade, Copenhagen.
2. Miskelly, F.G., *Assistive technology in elderly care.* Age and Ageing, 2001. 30(6): p. 455-458.
3. Pollack, M., *Intelligent Technology for an Aging Population: The Use of AI to Assist Elders with Cognitive Impairment.* AI Magazine, 2005. Summer: p. 9-24.
4. Gomi, T. and A. Griffith, *Developing intelligent wheelchairs for the handicapped.* Assistive technology and AI. LNAI-1458, Berlin: Springer-Verlag, 1998: p. 150-78.
5. Kazerooni, H., *Exoskeletons for human power augmentation.* Intelligent Robots and Systems, 2005.(IROS 2005). 2005 IEEE/RSJ International Conference on, 2005: p. 3459-3464.
6. Tapus, A., M.J. Mataric, and B. Scassellati, *The grand challenges in socially assistive robotics.* 2007. IEEE Robotics And Automation Magazine Special Issue On Grand Challenges In Robotics.
7. Pollack, M.E., S. Engberg, J.T. Matthews, S. Thrun, L. Brown, D. Colbry, C. Orosz, B. Peintner, S. Ramakrishnan, and J. Dunbar-Jacob, *Pearl: A mobile robotic assistant for the elderly.* AAAI Workshop on Automation as Eldercare, 2002. 2002.
8. Graf, B., M. Hans, and R.D. Schraft, *Care-O-bot II—Development of a Next Generation Robotic Home Assistant.* Autonomous Robots, 2004. 16(2): p. 193-205.
9. Bahadori, S., A. Cesta, G. Grisetti, L. Iocchi, R. Leone, D. Nardi, A. Oddi, F. Pecora, and R. Rasconi, *RoboCare: an Integrated Robotic System for the Domestic Care of the Elderly.* Proceedings of workshop on Ambient Intelligence AI* IA-03, Pisa, Italy, 2003.
10. Wada, K., T. Shibata, T. Saito, and K. Tanie, *Effects of robot assisted activity to elderly people who stay at a health service facility for the aged.* Intelligent Robots and Systems, 2003.(IROS 2003). Proceedings. 2003 IEEE/RSJ International Conference on, 2003a. 3.
11. Stiehl, W.D., J. Lieberman, C. Breazeal, L. Basel, R. Cooper, H. Knight, L. Lalla, A. Maymin, and S. Purchase, *The huggable: a therapeutic robotic companion for*

relational, affective touch. Consumer Communications and Networking Conference, 2006. CCNC 2006. 2006 3rd IEEE, 2006. 2.
12. Bartlett, B., V. Estivill-Castro, S. Seymon, and A. Tourky, *Robots for pre-orientation and interaction of toddlers and preschoolers who are blind.* Proceedings of the 2003 Australasian Conference on Robotics and Automation, CD-Rom Proceedings, 2003: p. 0-9587.
13. Fujita, M., *AIBO: Toward the Era of Digital Creatures.* The International Journal of Robotics Research, 2001. 20(10): p. 781.
14. Wada, K. and T. Shibata, *Living With Seal Robots—Its Sociopsychological and Physiological Influences on the Elderly at a Care House.* Robotics, IEEE Transactions on [see also Robotics and Automation, IEEE Transactions on], 2007. 23(5): p. 972-980.
15. van Breemen, A., X. Yan, and B. Meerbeek, *iCat: an animated user-interface robot with personality.* Proceedings of the fourth international joint conference on Autonomous agents and multiagent systems, 2005: p. 143-144.
16. Pineau, J., M. Montemerlo, M. Pollack, N. Roy, and S. Thrun, *Towards robotic assistants in nursing homes: Challenges and results.* Robotics and Autonomous Systems, 2003. 42(3-4): p. 271-281.
17. Bartneck, C., T. Suzuki, T. Kanda, and T. Nomura, *The influence of people's culture and prior experiences with Aibo on their attitude towards robots.* AI & Society, 2007. 21(1-2): p. 217-230.
18. Saito, T., T. Shibata, K. Wada, and K. Tanie, *Relationship between interaction with the mental commit robot and change of stress reaction of the elderly.* Computational Intelligence in Robotics and Automation, 2003. Proceedings. 2003 IEEE International Symposium on, 2003. 1.
19. Tamura, T., S. Yonemitsu, A. Itoh, D. Oikawa, A. Kawakami, Y. Higashi, T. Fujimooto, and K. Nakajima, *Is an Entertainment Robot Useful in the Care of Elderly People With Severe Dementia?* Journals of Gerontology Series A: Biological and Medical Sciences, 2004. 59(1): p. 83-85.
20. Wada, K., T. Shibata, T. Saito, and K. Tanie, *Psychological and social effects of robot assisted activity to elderly people who stay at a health service facility for the aged.* Robotics and Automation, 2003. Proceedings. ICRA'03. IEEE International Conference on, 2003b. 3.
21. Wada, K., T. Shibata, T. Saito, and K. Tanie, *Psychological, physiological and social effects to elderly people by robot assisted activity at a health service facility for the aged.* Advanced Intelligent Mechatronics, 2003. AIM 2003. Proceedings. 2003 IEEE/ASME International Conference on, 2003c. 1.
22. Wada, K., T. Shibata, T. Saito, and K. Tanie, *Relationship between familiarity with mental commit robot and psychological effects to elderly people by robot assisted activity.* Computational Intelligence in Robotics and Automation, 2003. Proceedings. 2003 IEEE International Symposium on, 2003d. 1.
23. Taggart, W., S. Turkle, and C.D. Kidd, *An interactive robot in a nursing home: Preliminary remarks.* CogSci 2005 Android Science Workshop, 2005.
24. Giuliani, M.V., M. Scopelliti, and F. Fornara, *Elderly people at home: technological help in everyday activities.* Robot and Human Interactive Communication, 2005. ROMAN 2005. IEEE International Workshop on, 2005: p. 365-370.
25. Heerink, M., B. Kröse, V. Evers, and B. Wielinga, *Studying the acceptance of a robotic agent by elderly users.* International Journal of Assistive Robotics and Mechatronics, 2006b. 7(3): p. 33-43.
26. Heerink, M., B. Kröse, B. Wielinga, and V. Evers. *Human-Robot User Studies in Eldercare: Lessons Learned*. in *Smart Homes And Beyond: ICOST2006: 4th International Conference on Smart Homes and Health Telematics*. 2006c.
27. Heerink, M., B.J.A. Kröse, B.J. Wielinga, and V. Evers. *The Influence of a Robot's Social Abilities on Acceptance by Elderly Users*. in *Proceedings RO-MAN*. 2006a. Hertfordshire.
28. Heerink, M., B.J.A. Kröse, B.J. Wielinga, and V. Evers. *Observing conversational expressiveness of elderly users interacting with a robot and screen agent*. in *Proceedings International Conference on Rehabilitation Robotics (ICORR)*. 2007. Noordwijk.
29. Yanagi, H. and S. Tomura, *A Pilot Study for Animal-Assisted Therapy using Companion Animal Type Robot (AIBO) in Primary Care Setting.* Japanese Journal of Primary Care, 2002. 25(2): p. 108-114.
30. Fujita, M., *On Activating Human Communications With Pet-Type Robot AIBO.* Proceedings of the IEEE, 2004. 92(11): p. 1804-1813.

31. Kanamori, M., M. Suzuki, and M. Tanaka, *Maintenance and improvement of quality of life among elderly patients using a pet-type robot.* Nippon Ronen Igakkai Zasshi, 2002. 39(2): p. 214-8.
32. Kanamori, M., M. Suzuki, H. Oshiro, M. Tanaka, T. Inoguchi, H. Takasugi, Y. Saito, and T. Yokoyama. *Pilot study on improvement of quality of life among elderly using a pettype robot*. in *IEEE International Symposium on Computational Intelligence in Robotics and Automation*. 2003.
33. Mival, O., S. Cringean, and D. Benyon, *Personification Technologies: Developing Artificial Companions for Older People.* CHI Fringe, 2004.
34. Suga, K., M. Sato, H. Yonezawa, S. Naga, J.U.N. Shimizu, and C. Morita, *Change in the concentration of salivary IgA by contact of elderly subjects with a pet robot.* Journal of Analytical Bio-Science, 2002. 25(3): p. 251-254.
35. Sakairi, K., *Research of robot-assisted activity for the elderly with senile dementia in a group home.* SICE 2004 Annual Conference, 2004. 3.
36. Suga, K., M. Sato, H. Yonezawa, S. Naga, and J. Shimizu, *Effects of robot-assisted activity on senior citizens-Indicators of HVA, MHPG, and CS concentrations in saliva.* Journal of Analytical Bio-Science, 2003. 26(5): p. 435-440.
37. Turkle, S., W. Taggart, C.D. Kidd, and O. Dasté, *Relational artifacts with children and elders: the complexities of cybercompanionship.* Connection Science, 2006. 18(4): p. 347-361.
38. Looije, R., F. Cnossen, and M.A. Neerincx, *Incorporating guidelines for health assistance into a socially intelligent robot.* Robot and Human Interactive Communication, 2006. ROMAN 2006. The 15th IEEE International Symposium on, 2006: p. 515-520.
39. Kriglstein, S. and G. Wallner, *HOMIE: an artificial companion for elderly people.* Conference on Human Factors in Computing Systems, 2005: p. 2094-2098.
40. Giusti, L. and P. Marti, *Interpretative Dynamics in Human Robot Interaction.* Robot and Human Interactive Communication, 2006. ROMAN 2006. The 15th IEEE International Symposium on, 2006: p. 111-116.
41. Kazuyoshi, W., T. Shibata, T. Saito, and K. Tanie, *Robot assisted activity to elderly at a health service facility for the aged*. Neural Engineering, 2003. Conference Proceedings. First International IEEE EMBS Conference on, 2003: p. 470-473.
42. Kidd, C.D., W. Taggart, and S. Turkle, *A Sociable Robot to Encourage Social Interaction among the Elderly.* Robotics and Automation, 2006. ICRA 2006. Proceedings 2006 IEEE International Conference on, 2006: p. 3972-3976.
43. Marti, P., M. Bacigalupo, L. Giusti, C. Mennecozzi, and T. Shibata, *Socially Assistive Robotics in the Treatment of Behavioural and Psychological Symptoms of Dementia.* Biomedical Robotics and Biomechatronics, 2006. BioRob 2006. The First IEEE/RAS-EMBS International Conference on, 2006: p. 483-488.
44. Saito, T., T. Shibata, K. Wada, and K. Tanie, *Examination of Change of Stress Reaction by Urinary Tests of Elderly before and after Introduction of Mental Commit Robot to an Elderly Institution.* Proc. of the 7 thInt. Symp. on Artificial Life and Robotics, 2002. 1: p. 316-319.
45. Wada, K., T. Shibata, T. Saito, and K. Tanie, *Analysis of factors that bring mental effects to elderly people in robot assisted activity.* Intelligent Robots and System, 2002. IEEE/RSJ International Conference on, 2002a. 2.
46. Wada, K., T. Shibata, T. Saito, and K. Tanie, *Effects of robot assisted activity for elderly people at day service center and analysis of its factors.* Intelligent Control and Automation, 2002. Proceedings of the 4th World Congress on, 2002b. 2.
47. Wada, K., T. Shibata, T. Saito, and K. Tanie. *Psychological and social effects in long-term experiment of robot assisted activity to elderly people at a health service facility for the aged*. in *Intelligent Robots and Systems, 2004.(IROS 2004). Proceedings. 2004 IEEE/RSJ International Conference on*. 2004a.
48. Wada, K., T. Shibata, T. Saito, and K. Tanie, *Effects of Robot-Assisted Activity for Elderly People and Nurses at a Day Service Center.* Proceedings of the IEEE, 2004b. 92(11): p. 1780-1788.
49. Wada, K., T. Shibata, T. Saito, and K. Tanie, *Effects of three months robot assisted activity to depression of elderly people who stay at a health service facility for the aged.* SICE 2004 Annual Conference, 2004c. 3.
50. Wada, K., T. Shibata, T. Saito, K. Sakamoto, and K. Tanie, *Psychological and Social Effects of One Year Robot Assisted Activity on Elderly People at a Health Service Facility for the Aged.* Robotics and Automation, 2005. Proceedings of the 2005 IEEE International Conference on, 2005a: p. 2785-2790.

51. Wada, K., T. Shibata, K. Sakamoto, and K. Tanie, *Quantitative analysis of utterance of elderly people in long-term robot assisted activity.* Robot and Human Interactive Communication, 2005. ROMAN 2005. IEEE International Workshop on, 2005b: p. 267-272.
52. Wada, K., T. Shibata, T. Musha, and S. Kimura, *Effects of robot therapy for demented patients evaluated by EEG.* Intelligent Robots and Systems, 2005.(IROS 2005). 2005 IEEE/RSJ International Conference on, 2005d: p. 1552-1557.
53. Wada, K., T. Shibata, T. Saito, K. Sakamoto, and K. Tanie, *Robot assisted activity at a health service facility for the aged for 17 months-an interim report of long-term experiment.* Advanced Robotics and its Social Impacts, 2005. IEEE Workshop on, 2005c: p. 127-132.
54. Wada, K., T. Shibata, T. Saito, and K. Tanie, *Robot assisted activity at a health service facility for the aged for ten weeks: an interim report of a long-term experiment.* Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering, 2006. 220(8): p. 709-715.
55. Wada, K. and T. Shibata, *Robot Therapy in a Care House-Its Sociopsychological and Physiological Effects on the Residents.* Robotics and Automation, 2006. ICRA 2006. Proceedings 2006 IEEE International Conference on, 2006: p. 3966-3971.
56. Montemerlo, M., J. Pineau, N. Roy, S. Thrun, and V. Verma, *Experiences with a mobile robotic guide for the elderly.* Proceedings of the AAAI National Conference on Artificial Intelligence, 2002: p. 587–592.

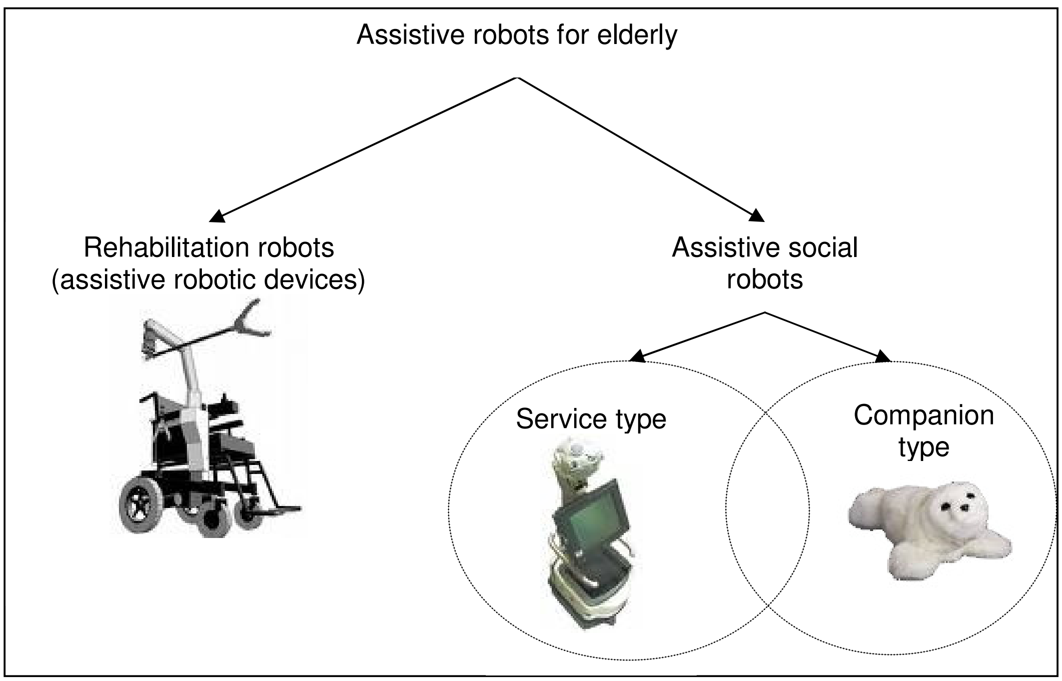

Figure 1. Categorization of assistive robots for elderly

Figure 2. Assistive social robots, from left to right. the top row: Aibo, Pearl and Robocare (with and without screen); second row: Care-o-bot I, II, III and Homie; third row: iCat, Paro and Huggable.

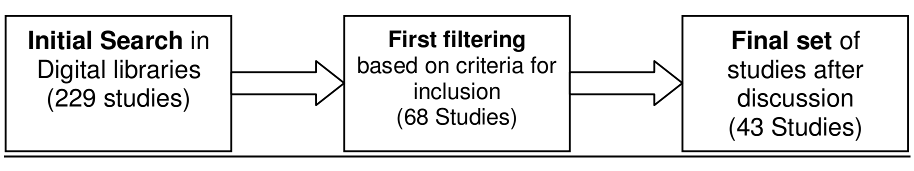

Figure 3, Flow diagram outlining the review process.

Table 1

Author	Ref.	Companion	Design	Outcome measures	*n*	Results	Term
Fujita 2004	[30]	Aibo					
Kanamori et al. 2002	[31]	Aibo	3	1,5	3	+	?
Kanamori et al. 2003	[32]	Aibo	3	1,3,4,5	5	+	7 weeks
Mival et al. 2004	[33]	Aibo	6	5	10, 12		
Suga et al. 2002	[34]	Aibo	3	1	23	+	2 months
Sakairi 2004	[35]	Aibo	3	3,5	8	+	30 minutes
Suga et al. 2003	[36]	Aibo	3?	1	15	+	?
Tamura et al. 2004	[19]	Aibo	3	3	?	+/-	5 minutes intervention
Turkle et al. 2006	[37]	Aibo, My Real Baby	3	5, 6	2	+	several months
Yanagi and Tomura 2002	[29]	Aibo	3	5	46	+	Several hours
Graf et al. 2004	[8]	Care-o-bot	3	5	6	+	?
Heerink et al. 2006a	[27]	iCat	2	5	40	+/-	minutes
Heerink et al. 2006b	[25]	iCat	2	5	40	+/-	minutes
Heerink et al. 2006c	[26]	iCat	2	5	40	+/-	minutes
Heerink et al. 2007	[28]	iCat	2	5	40	+/-	minutes
Looije et al. 2006	[38]	iCat	6	5	6	+/-	< 1 hour
Kriglstein and Wallner 2005	[39]	Homie	3	3, 5	2	+	?
Giusti and Marti 2006	[40]	Paro	3	3	5		1 month twice a week
Kazuyoshi et al. 2003	[41]	Paro	3	2	12, 11	+/-	3 weeks
Kidd et al. 2006	[42]	Paro	2	3,2	23	+	4 months
Marti et al. 2006	[43]	Paro	3	3	1	+	1 time
Saito et al. 2002	[44]	Paro	3	1	20	+	6 weeks
Saito et al. 2003	[18]	Paro	3	5	12, 11	-	3 weeks, 4 days a week, 1 hour
Taggart et al. 2005	[23]	Paro	2	3	18	+	20 minutes
Wada et al. 2002a	[45]	Paro	3	2	11	+/-	3 weeks, 1-3 times per week, 20 minutes
Wada et al. 2002b	[46]	Paro	3	2	11	+/-	3 weeks, 1-3 times per week, 20 minutes
Wada et al. 2003a	[10]	Paro	3	1,2	4,3,9	+	3 weeks, 4 days a week, 1 hour
Wada et al. 2003b	[20]	Paro	3	2	7,11,12,9	+	3 weeks, 4 days a week, 1 hour
Wada et al. 2003c	[21]	Paro	3	1,2	4, 7, 11	+	3 weeks
Wada et al. 2003d	[22]	Paro	3	2	4, 7, 11	+	3 weeks
Wada et al. 2004a	[47]	Paro	3	1	10	+	14 weeks
Wada et al. 2004b	[48]	Paro	3	2	12, 11	+	5 weeks, 1-3 times per week, 20 minutes
Wada et al. 2004c	[49]	Paro	3	2	12,11	+	5 weeks, etc.
Wada et al. 2005a	[50]	Paro	3	2	23	+	1 year
Wada et al. 2005b	[51]	Paro	3	3	?		1 year
Wada et al. 2005d	[52]	Paro	3	5	14	+	20 minutes
Wada et al. 2005c	[53]	Paro	3	2	8	+	17 months
Wada et al. 2006	[54]	Paro	3	2	14	+	10 weeks
Wada and Shibata 2006	[55]	Paro	3	1,3	11		1 month, 9h per day
Wada and Shibata 2007	[14]	Paro	3	1,3	12	+	1 month, 9h per day
Montemerlo et al. 2002	[56]	Pearl	3	5	6	+	5 days
Pineau et al. 2003	[16]	Pearl	3	5	6	+	5 days
Giuliani et al. 2005	[24]	Robocare	-	5	123		?

Legend

For the column "Design"		For the column "Outcome"	
1. RCT	4. Narrative/opinion	1. Health status	4. Loneliness
2. Comparative cohort	5. Other	2. Mood	5. Other / Design criteria
3. Case series	6. Focus group.	3. Communication	6. Remembering / thinking about the past

Table 2

Author		Specifics
Fujita 2004	[30]	Overview article
Kanamori et al. 2002	[31]	All three cases are reported to have decreased stress and decreased loneliness, but the research method is not clear about other influences of the actual visit during the 20 AIBO sessions.
Kanamori et al. 2003	[32]	20 sessions, but it is unclear if the positive effects are due to sessions themselves or due to the robot.
Mival et al. 2004	[33]	A study to find design criteria for companion robots
Suga et al. 2002	[34]	Positive immune system response. Unclear how AIBO is used exactly, difficult to attribute causality.
Sakairi 2004	[35]	No control group and no statistics reported, difficult to attribute causality.
Suga et al. 2003	[36]	No control group, and the study's design is unclear so its difficult to attribute causality to the AIBO
Tamura et al. 2004	[19]	Although both toy dog (=control) and AIBO increased activity of demented patients, there was no difference (or even less patient activity) in the AIBO case then in the toy dog case, probably due to the fact that the AIBO was not perceived as a puppy dog.
Turkle et al. 2006	[37]	The form and behavior of a robot pet might matter for its acceptance. Two cases are described with positive results in terms of social interaction with the My Real Baby robot
Yanagi and Tomura 2002	[29]	Study in a waiting room in clinic, the exact result measure is unclear from abstract
Graf et al. 2004	[8]	Describes results with walking aid robot and grabber. Elderly are able to work with the robot.
Heerink et al. 2006a	[27]	Study to investigate robot acceptance and design guidelines
Heerink et al. 2006b	[25]	Study to investigate robot acceptance and design guidelines
Heerink et al. 2006c	[26]	Study to investigate robot acceptance and design guidelines
Heerink et al. 2007	[28]	Study to investigate conversational behavior
Looije et al. 2006	[38]	Study to investigate guidelines for iCat interface design.
Kriglstein and Wallner 2005	[39]	Ideas about design
Giusti and Marti 2006	[40]	Demented elderly started talking a lot about PARO and to PARO, but there was no control group, nor a clear effect measure. Also difficult to establish causality.
Kazuyoshi et al. 2003	[41]	Same experiment as Saito et al (2003). Different measure. Some hints at positive effect, but no statistical analysis. Control condition (fake PARO) and experimental condition (real PARO) had the same effect.
Kidd et al. 2006	[42]	More lively communication in the PARO-on case compared to the PARO-off case. Experimenters took care to not influence the sessions. No statistics mentioned. Extra result with My Real Baby: is used to calm down residents, but the baby is often too much of a care burden.
Marti et al. 2006	[43]	PARO was introduced with therapist. Demented patient accepted PARO and talked about it.
Saito et al. 2002	[44]	Urinary tests show a lower stress level
Saito et al. 2003	[18]	Negative (stress hormone) result for the less active PARO in the less demented group (n=12), but there seems to have been a problem with the urine samples. The more demented group with the active PARO had no results. Again difficult to interpret.
Taggart et al. 2005	[23]	Form is important for expectations (PARO in bathtub). Acceptation is still an important issue. Less active PARO had fewer reactions of subjects. Weird considering the result in the opposite direction in study of Saito et al (2003)
Wada et al. 2002a	[45]	Slightly positive results, one item of the mood scale (vigor) was significantly better in Aibo intervention case. No control group.
Wada et al. 2002b	[46]	Same as Wada et al (2002)
Wada et al. 2003a	[10]	Non-significant increase in immune system function as measured by urinary hormones (n=4). PARO (n=3) and fake PARO group (n=9) both had positive effect on depression
Wada et al. 2003b	[20]	Subjects were happier with the real PARO (n=7) than with fake PARO (n=11) but they kept liking the fake PARO (n=12) better throughout the study compared to the real PARO (n=9).
Wada et al. 2003c	[21]	Same as data and results in study Wada (2003b) and (2003c)
Wada et al. 2003d	[22]	Correlation between emotion change and familiarity with PARO (n=4). Fake PARO (n=11) has same interest effect as real PARO (n=7), i.e. subjects keep liking both robots.
Wada et al. 2004a	[47]	No statistically sound evidence of effect (n=10) of PARO on dementia scale. One case seems promising (woman). Application of PARO to elderly seems different than in other 2003 studies. It is unclear what the amount of involvement of the researcher is. No control condition with fake PARO.
Wada et al. 2004b	[48]	Increase in mood and emotion faces test, but unclear where the effect came from. The intervention with PARO is mediated, and the measurement is before and after intervention.
Wada et al. 2004c	[49]	Same as Wada et al (2004c)
Wada et al. 2005a	[50]	Longer term study with a small number of subjects (n=8). Unclear what the statistical power of the main reported effect (emotion faces) is. Suffers from same problem as many other studies: no control condition and unclear about the researchers' interactions with the subjects during the study.
Wada et al. 2005b	[51]	Same as Wada et al (2005), but including data on number of utterances. Silent PARO provokes significantly less utterances in subjects than the normal PARO.
Wada et al. 2005d	[52]	Strong intervention and dubious interpretation of cortical neuron activation. Also only a short term effect.
Wada et al. 2005c	[53]	Long term study but no new insights compared to the other work of the same group.
Wada et al. 2006	[54]	
Wada and Shibata 2006	[55]	Participants could play themselves with the robot without caregivers intervening. This is a clean study but does not have a good control group/situation. Social network increased in size and stress hormone indicated better immune system.
Wada and Shibata 2007	[14]	Participants could play themselves without caregivers intervening. This is a clean study because it tries to eliminate researcher intervention, however the control group/situation is not clear.
Montemerlo et al. 2002	[56]	An experiment with robot guidance, not so much about companions.
Pineau et al. 2003	[16]	Experiment with elderly guidance using a robot. Same as Montmerlo et al (2002)
Giuliani et al. 2005	[24]	Evaluation of robot perception amongst elderly