Attitudes Towards Socially Assistive Robots in Intelligent Homes: Results From Laboratory Studies and Field Trials.

Elena Torta
Eindhoven University of Technology, Faculty of Industrial Engineering and Innovation Sciences, Human-Technology Interaction Group, Den Dolech 2, 5600MB Eindhoven, The Netherlands
Johannes Oberzaucher, Franz Werner
CEIT Raltec, Institute of Rehabilitation and Assistive Living Technologies, Concorde Business Park 2/F A 2320 Schwechat, Austria
and
Raymond H. Cuijpers, James F. Juola
Eindhoven University of Technology, Faculty of Industrial Engineering and Innovation Sciences, Human-Technology Interaction Group, Den Dolech 2, 5600MB Eindhoven, The Netherlands

---

The near future will see an increasing demand of elder care and a shortage of professional and informal caregivers. In this context, ageing societies would benefit from the design of intelligent homes that provide assistance. The choice of interfaces between the assistive environment and the user is of great importance and determines the degree of user acceptance of this technology. Socially assistive robots are one of the most promising interfaces. Their embodiment and multimodal communication channels could potentially provide a large number of services that otherwise would have to be carried out by a variety of dedicated systems. Furthermore, evidence suggests that people perceive robots more as companions and social actors than tools and this is likely to steer user acceptance positively. This paper presents the authors' work related to the EU-FP7 project KSERA, a project that aims at introducing a socially assistive robot that acts as a proactive communication interface in smart home environments. In particular, it gives an overview of (1) human–robot interaction studies conducted in Eindhoven (The Netherlands) whose general aim was to preliminary assess the added value of socially assistive robots in intelligent homes and (2) the KSERA project field trials in Schwechat (Vienna) and Tel Aviv (Israel) that tested an integrated smart-home/robot system with real end users (*N=16*) in three real-world scenarios. Overall, results show that socially assistive robots positively affect user experience and motivation compared to standard smart environment interfaces such as touch screens. However, people still tend to prefer conventional interfaces for receiving information.

Keywords: Human–robot interaction, smart homes, sensors, proxemics, attention, field trials, ambient assisted living AAL

Journal of Human-Robot Interaction, Vol. 1, No. 2, 2012, Pages 76-99. DOI 10.5898/JHRI.1.2.Torta

1. Introduction

In Europe life expectancy is higher than in the past. The number of seniors aged 65 and above continues to increase, whereas the economically productive proportion of the population decreases (Carone & Costello, 2006; Hewitt, 2002). The potential support ratio, reflecting the number of people of working ages per person of 65 and older, is decreasing in all developed countries. Worldwide, in 2010, there were fewer than nine persons of working age per elderly person of 65 or older. By 2050, this ratio is expected to decrease to fewer than four working-age persons per elderly person (Bremner et al., 2010). It is expected that, in the near future, the increasing proportion of elderly persons will lead to both an increasing demand for care and a shortage of caregivers (Tapus, Matarić, & Scassellati, 2007). In addition, children today tend to live farther away from their parents, and can no longer provide the care and support their parents need.

Elderly people need support due to their declining capabilities and also to age-related illnesses. Ageing societies would benefit from the design of "intelligent" homes that provide assistance (Steg, Strese, Loroff, Hull, & Schmidt, 2006). Such systems can assist elderly persons effectively in everyday tasks such as communication with the external world and provision of medicine and health check reminders in a proactive fashion (Cesta et al., 2007). Furthermore, recent studies suggest that, contrary to expectations, elderly people tend to show positive attitudes toward existing technology in the home (Mitzner et al., 2010). Elderly people often experience reduced mobility within the home and high levels of stress and anxiety; therefore the correct choice of interfaces between the assisting environment and the user is of high importance.

In the present context, the EU-FP7 project KSERA (Knowledgeable Service Robots for Ageing) aims at designing, developing and demonstrating a modular approach to seamlessly integrating an intelligent home environment, able to ubiquitously monitor the elderly person with the small humanoid robot Nao by Aldebaran Robotics (Figure 1) (see Louloudi, Mosallam, Marturi, Janse, & Hernandez, 2010). In our project, the robot serves the function of proactive interface between the

Figure 1. The robot Nao is the main interface between the intelligent home of the KSERA project and the user.

intelligent environment and the user. The robot also has the psychological function of motivating the user to adopt a healthier lifestyle and, in general, to increase the user acceptance. Indeed, previous research suggests that people's attitude toward robots seems to be positive when people are shown that robots might take over household chores such as cleaning the kitchen or the bathroom (Beer et al., 2012). The fact that people show a positive attitude toward the robot is of importance because, in most scenarios, the robot is the most visible component of the system and from a user's perspective it is likely to determine the level of acceptance of this assistive technology.

This paper describes work done within the KSERA project to assess peoples' attitudes toward a socially assistive robot in relevant scenarios for the project domain. In particular, we report results of user studies carried out in a controlled laboratory set-up following a Wizard of Oz methodology. We have linked them to the results of field trials in which a fully automated system has been deployed in a real-life environment. This paper is organized as follows: Section 2 summarizes relevant work related to the use of socially-assistive robots. Section 3 describes the user needs the project addresses and the research questions and hypotheses that steered the design of the undertaken studies. Section 4 presents four user studies that have been carried out before the realization of the field trials to get a preliminary understanding of the validity of the research hypotheses. The studies presented in this section have been carried out with a Wizard of Oz methodology. Section 5 reports the results of the first iteration of the project field trials. Unlike the user studies, participants in the field trials experienced interaction with a fully automated system. Section 6 provides an interpretation of the results presented in Section 5 comparing them with the results reported in Section 4. Finally, Section 7 describes perspectives and future research directions based on the experience the authors gained from the field trials.

2. Related Work

More and more robotic applications have been developed that can provide assistance to people in general and to the older people in particular. This assistance can be roughly divided into social and functional support. Functional support can come in the form of a proactive interface which reminds or instructs people about a specific task such as the nursing robot Pearl (Pineau, Montemerlo, Pollack, Roy, & Thrun, 2003) or the Korean robotic language teacher EngKey (S. Lee et al., 2011). Robots can also provide forms of mobility aids such as intelligent walkers (Yu et al., 2010), wheel chairs (Vanhooydonck et al., 2010), or exoskeletons (Ruiz, Rocon, Raya, & Pons, 2008). Social support typically aims at reducing social isolation and enhancing well-being. Most successful are the artificial pets, like the PARO robot which helps patients relax (Wada & Shibata, 2007) and Ugobe's Pleo robot, a small robotic dinosaur that one needs to pet and train (Kim, Leyzberg, Tsui, & Scassellati, 2009).

Although the media "equation" suggests that people tend to look at technological artefacts as social actors (Reeves & Nass, 1996; Min Lee, Jung, Kim, & Kim, 2006; Friedman, Kahn, & Hagman, 2003), the social skills of more serious service robots are still far from being completely effective.

Human-traits, such as personality (K. M. Lee, Peng, Jin, & Yan, 2006) or moral accountability (Kahn et al., 2012), can be attributed to robots and this raises expectations for the robot's social competence. A special class of social robots is the so-called socially assistive robots, which provide functional help in the form of social interaction with users (Feil-Seifer & Matarič, 2005). In other words, the robot's physical embodiment and multimodal communication channels allow it to communicate with users (verbally and non-verbally) in a social manner so that users benefit from communication or, more generally, from interaction and not just from the robot's physical abilities, e.g., carrying things. As a consequence, socially-assistive robots might be perceived as companions by users. As such they can reduce the feeling of social exclusion and are helpful for decreasing the level of stress, both common problems of ageing (for reviews see Bemelmans, Gelderblom, Jonker, & Witte, 2012; Broekens, Heerink, & Rosendal, 2009). As an example, Banks, Willoughby, and Banks (2008) report the results of a study in which the authors compared the ability of a living dog (dog) and a robotic dog (AIBO) to treat loneliness in elderly patients living in a nursing facility. They show that loneliness significantly decreased in both conditions with respect to the level of loneliness of a control group. Another study was conducted by Wada and Shibata (2007) with the baby seal robot PARO. The robot was left in a senior center for 1 month and was activated for 9 hours a day when residents could interact with it. Behavioural analysis of video footages, questionnaires, and interviews revealed that the introduction of PARO increased the level of social interactions of the seniors and decreased their level of stress. Other interesting results come from research on the interaction between autistic children and robots. Typically, in this domain, the functional added value of socially-assistive robots is related to the high degree of duplicability and controllability of motion patterns, whereas the added social value is related to the improvement of social behaviours of autistic children after the therapeutic sessions (Scassellati, 2005; Scassellati, Admoni, & Matarič, 2012). Autonomous socially-assistive robots need to possess a wide range of social and cognitive skills that should be seamlessly integrated in order to enable them to interact effectively (Dautenhahn, 2007). The nature of these skills, social and cognitive, varies according to the domain in which the robot is deployed. Several EU-projects have addressed issues related to modelling, defining and implementing social and cognitive skills in socially-assistive robots. Most of them focus on the domain of ageing. As an example, the EU-FP6 project Cogniron (The COGNItive RObot companion), presented several results related to the study of social distances between robots and people (e.g., Huettenrauch, Eklundh, Green, & Topp, 2006; Syrdal, Kheng, Walters, & Dautenhahn, 2007) and on human–robot communication (e.g. Lohse, Rohlfing, Wrede, & Sagerer, 2008). Along the same line, the EU-FP7 project Companionable focuses on integrating a companionable robot in a smart home environment for general purposes (for an overview of the project findings, see Huijnen, Badii, Heuvel, Caleb-Solly, & Thiemert, 2011) .

3. User Needs and Hypothesis

The KSERA project has followed a socio-technical perspective to define technical features while taking into account the social aspects posed by the field of application (Reddy, Pratt, Dourish, & Shabot, 2003). This has been realized through iterative user involvement in the design process and through the identification of their needs, objectives, and living contexts. During the initial KSERA research phase, qualitative methods (free discussions, semi-structured interviews, and focus groups) were used to identify central user needs for primary (older people) and secondary users (family members, informal and formal caregivers, medical professionals, and patient organizations). The results were discussed with medical experts from the Austrian Lung Union (ÖLU), heads of the lung disease unit in Vienna hospitals and experts at Maccabi Healthcare facilities (Israel). During this process, the following user needs were identified as being central for the primary users:

UN1 Users with walking difficulties need a system that has a mobile interface that can approach them.

UN2 Users need a solution when they feel isolated, are lonely, and miss social contacts. Users need to be in contact with their families, (remotely) see and speak to them, and to talk with medical caregivers.

UN3 Users need to be reminded to take the right medication at the right time.

UN4 Users need motivation to do physical exercises and need positive feedback about the accomplishment of personal goals.

UN5 Users need to know whether the outside environmental conditions are safe to go for a walk.

UN6 Users need help (an emergency call) when their vital signs are outside the normal range.

The user needs (UN1–UN6), which a combined smart home/robot system can address, are very diverse in nature. In principle, all of them could be addressed by dedicated solutions. As an example, the possibility of ubiquitously communicating with the user (UN1 and UN5) can be fulfilled by a loudspeaker system distributed in a smart environment or by a smart phone (Koskela & Väänänen-Vainio-Mattila, 2004). Showing healthful exercises (UN4) can be achieved by virtual agents such as avatars (Jan et al., 2011). However, many solutions are infeasible: the loud-speaker system may be difficult to hear, the smart phone can be considered impersonal, and avatars on a screen may be out of reach because the user is in a different room. A mobile socially assistive robot could potentially provide a large number of services that otherwise would have to be carried out by a variety of dedicated systems. The flexibility of robots comes at the price of efficiency and simplicity. Indeed, dedicated solutions are, by definition, optimized for solving a specific task and, therefore, under a functional perspective, they are likely to show better performance. In any case, people will likely attribute more social skills to robots than to other devices. In turn, this is expected to lead to higher levels of acceptance and increased levels of likeability. Some research suggests that people tend to attribute human-like characteristics to socially-assistive robots (Min Lee et al., 2006; Friedman et al., 2003) and regard them more as companions than as tools (Wada & Shibata, 2007; Banks et al., 2008). So we expect that (H1) socially assistive robots, as interfaces with the smart environment, should generate more positive feelings in the user than other technological means. From a user perspective, the robot is the most visible component of the intelligent assistive system. Therefore it is likely that attitudes towards the robot will result in high correlations with the attitudes towards the system. Thus (H2) if the robot is perceived as friendly and likeable, the entire assistive system is perceived as friendly and likeable, and users will be more likely to accept it. When people talk to each other, they often make gestures such as hand movements that accompany speech (see Andric and Small (2012) for a review of how gestures correlate with speech and speech content). Humanoid robots have a shape comparable to ours; therefore people tend to expect them to produce co-speech gestures or, in general to move their faces, arms, and bodies consistently with the task they are accomplishing. Therefore, it seems reasonable that (H3) attitudes toward the robot should improve when the robot uses appropriate gestures in communication.

4. Human–Robot Interaction: Laboratory Experiments

Four user studies have been carried out to provide a preliminary assessment of the validity of research hypotheses H1 and H3, and to define robotic social skills that were then implemented in the project's first prototype. Research hypothesis H2 was tested during the field trials (Section 5). All the user studies presented here followed a Wizard of Oz methodology. Participants were, in general, elderly people and the majority of them was different between experiments.[1]

4.1 The role of embodiment

To address the added value of an embodied robotic artifact as a communication channel (H1), we measured how quickly people could categorize messages delivered by the robot Nao (see Figure 1) in comparison to a ubiquitous smart home system. Reaction times give insight into the mental workload associated with processing the information provided by an agent (Bakhtin & Correll, 2012). Thus, differences in reaction times to the same stimulus, provided by different agents, give an indication of the workload that an agent poses on the mental processing of the information. The robot Nao and the loudspeaker system are both able to ubiquitously address the user, thus addressing UN1 and UN5. We also measured user experience using the Godspeed questionnaire (Bartneck, Kulić, Croft, & Zoghbi, 2009).

4.1.1 Method Ten participants (61–74 years old, mean age 66.8) were each seated on a couch in a mimicked living room. Their task was to listen to messages belonging to one of four categories: (1) health, (2) leisure time, (3) household activities and (4) energy savings. The messages were conveyed either by hidden loud speakers or by the robot Nao. There were three different messages

[1] In the user study presented in Section 4.4 participants were younger because the study was not meant to assess the validity of the research hypotheses but to derive a robotic social skill that is presumably age independent.

per category, leading to a total of 4× 2×3=24 messages. The message delivery method (Nao or smart home) was presented in blocks. The order of the two blocks was counterbalanced across participants. Within each block, the messages were presented in random order. Participants were instructed to categorize each message by pressing the corresponding button on a keyboard positioned in front of them as soon as possible. The start of the message was signalled by a sound. We recorded the reaction time between the start of the message and the button press. After every block, participants evaluated the agent (Nao or smart home) by answering the Godspeed questionnaire (Bartneck et al., 2009).

4.1.2 Results Overall, the mean reaction time for responses to messages presented by the robot was longer than those presented by the smart home, but this difference was significant only for the Health category ($F(1,9) = 17.48$, $p = 0.001$). This is shown in Figure 2 where the reaction time is expressed for each category and for each message delivery method. A repeated-measures

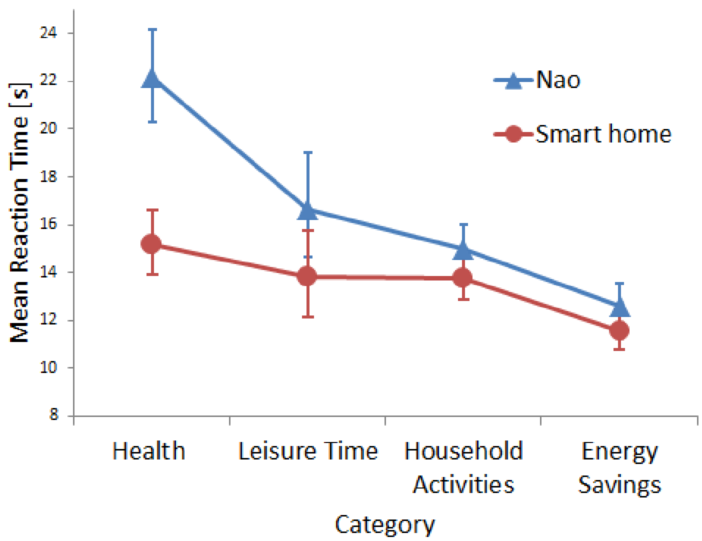


Figure 2. Mean reaction time expressed in seconds for the Smart home and the Nao robot for every message category.

analysis of variance (ANOVA) revealed that there was a significant main effect of message delivery method ($F(1,9) = 5.91$, $p = 0.038$ for the agent) and message category ($F(2.5,23) = 27.64$, $p < 0.001$). The interaction between manipulations was also significant ($F(2.09,18.85) = 4.26$, $p = 0.028$). Here the degrees of freedom were corrected using the Greenhouse–Geisser method to compensate for the assumption of sphericity. Analysis of the questionnaire results showed that there was a significant difference between the evaluation of the Nao robot and that of the smart home after the second block of the experiment. A significant effect was found for the dimensions Likeability ($F(1,8) = 7.79$, $p = 0.024$) and Animacy ($F(1,8) = 9.04$, $p = 0.017$). As shown in Figure 3, the Nao robot was evaluated higher in both aspects. Differences for the other dimensions were not significant.

4.1.3 Conclusion We tested the assumption that users appreciate embodied communication through a robotic artefact more than through a ubiquitous smart home environment. We found that our participants do indeed like the robot more and that they consider it more alive. Surprisingly

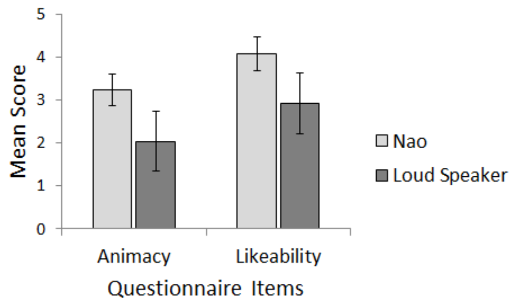


Figure 3. Mean five−point Likert scale score for the dimensions Animacy and Likeability of the Godspeed questionnaire

the reaction times in the categorization task were slower for the robot than for the smart home. One possible explanation is that the robot used gestures, which caused the participants to wait for them to complete before starting with the categorization task. Either way, our results support the added value of an embodied robotic system for conveying a message, because it shows that people tend to have a more positive attitude toward the robot than toward the loud speaker system.

4.2 Comparison Between Communication Channels for Attracting Attention

This study investigated the expected effects of different communication channels with which a robot can attract attention from the user by assessing the user's reaction time and attitude toward the action. This is related to H3 as the robot uses waving gestures for attracting attention. This study is of importance for the fulfillment of all the user needs as the robot, before starting communication with the human, may eventually need to attract his attention. Results of the study were used during the field trials to select ways in which the robot could attract the attention of its human partner (for details see Torta, Heumen, Cuijpers, & Juola, 2012).

4.2.1 Method Twelve participants between 62 and 70 years of age (mean 66.83 years) were each seated on a couch in front of a television screen in a simulated living room. Their task was to watch news items taken from a local Dutch news website and answer a few questions about them afterwards. Half of the news items were arbitrarily labelled as important by showing a red box that appeared on the top of the screen. Participants were instructed to remember the content of the important news items. At random moments during the broadcast of the news, Nao performed one of four actions designed to attract the user's attention: (1) making eye-contact: the robot turned its face toward the participant's face, (2) blinking the LED eyes: the LED eyes are turned on and off with a 50% duty cycle, (3) waving: the robot waves its arms and (4) speech: the robot utters the word "hello". In conditions 2, 3 and 4 the robot did not turn its face toward the participant's face. Participants were instructed to press a button as soon as they noticed the robot's attempt to attract attention. The reaction time, defined as the difference between the moment the robot's action started and the moment participants pressed the button, was recorded. The experiment had a within-subjects design with 4 (actions) $\times$ 2 (type of news) conditions that were repeated 3 times. Therefore participants experienced a total of 24 trials. After the last trial, participants were instructed to evaluate the four types of actions by answering a questionnaire, which consisted of a five-point Likert scale response chart for the items: clarity, presence, friendliness, pleasantness and calmness.

4.2.2 Results The mean reaction times for each of the four actions are reported in Figure 4. It clearly shows a much longer reaction time for attracting attention by making eye contact, whereas speaking resulted in the shortest response times.

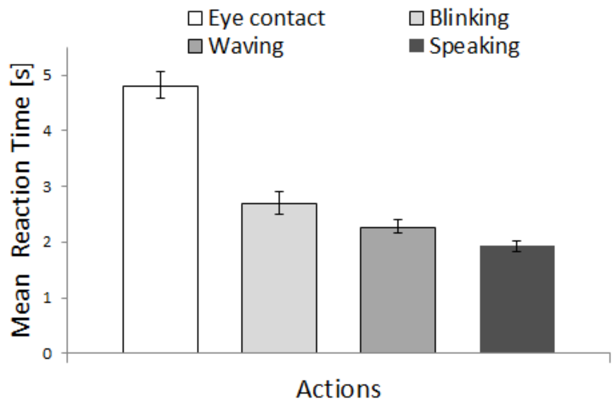


Figure 4. Mean reaction times (adjusted values) for the four robot's actions to attract attention. Error bars denote 95% confidence intervals for the adjusted values.

To test the significance of these effects, a factorial repeated-measures ANOVA was used with reaction time as the dependent variable and both manipulations (news item importance and robot action) as the independent variables. There was a significant main effect of the type of action on reaction time ($F(2.22, 24.44) = 140.00, p < 0.001$) but not of news item importance. To correct for the assumption of sphericity (Mauchly's test on action type, $\chi^2(2) = 5.048$, $p = 0.412$), the degrees of freedom were adjusted using Greenhouse-Geisser estimates of sphericity ($\epsilon = 0.741$). Contrast analysis revealed that there was a significant difference, in terms of reaction time, between all the types of actions. In particular, reaction time for eye contact was longer than for blinking the LED eyes, ($F(1, 11) = 140.84, p < 0.001$), longer for blinking the LED eyes than waving, ($F(1, 11) = 8.67, p = 0.013$), and longer for waving than speaking, ($F(1, 11) = 26.65, p < 0.001$).

In Figure 5, the mean scores on the five-point Likert scale are shown for each dimension of the questionnaire and for each of the four robot's actions to attract attention. It can be seen that the mean ratings for waving and speaking are larger for the dimensions: clarity, presence and friendliness whereas blinking the LED eyes and making eye contact are considered less clear, present and friendly. It is also evident that the robot's action mostly affects the clarity dimension and, to a lesser degree, presence and friendliness.

One-way repeated measures ANOVA showed that the rating was significantly affected by the type of actions for the items Clear ($F(1.35, 14.80) = 17.05, p < 0.001$), Friendly ($F(3, 33) = 4.79$, $p = 0.007$) and Present ($F(3, 33) = 17.54$, $p = 0.001$). The actions had no significant effect on the items calm and pleasant. In accordance with the pattern of reaction times, contrast analyses revealed that participants judged the actions waving and speaking more clearly than the actions blinking ($p = 0.011$ for waving and $p = 0.018$ for speaking) and eye contact ($p = 0.003$ for waving and $p = 0.005$ for speaking). Interestingly, the results showed that only waving was judged more present than the others ($p = 0.004$ for eye contact, $p = 0.027$ for blinking). The differences between judgements for waving and speaking were not statistically significant.

4.2.3 Conclusion We compared the effectiveness of four types of robotic actions designed to attract attention. We found that people were able to change their focus of attention between 2 and 5 s. The fastest response was obtained for waving and speaking, and making eye contact resulted

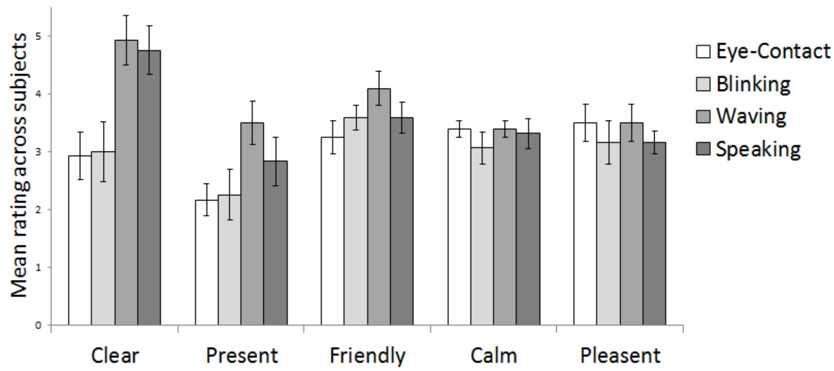


Figure 5. Results of the questionnaires.

in the slowest response times. This shows that sound (from speech or from the robot's motors) is more salient than pure visual cues. Making eye contact was hardest to detect and people sometimes did not notice it at all. As for people's attitudes toward the robot's actions, we again find a benefit of waving and speaking in comparison to using the LED eyes and making eye contact. For the item clarity, this is perfectly in line with the reaction time results, but the effect on friendliness is somewhat surprising. Eye contact is considered a natural social cue, but here we find that it is not particularly liked. One way to interpret this is that the robot is staring rather than making eye contact, which, of course, would explain the negative affect. Another way of interpreting this result is simply that speech, and sound in general, is the best way to attract attention when visual attention is occupied.

4.3 Health Exercises With an Embodied Agent

One of the needs of older people in general is to exercise regularly, because it is known that keeping the body in good shape prevents exacerbations of age-related conditions. The question is whether doing health exercises with an embodied agent is considered beneficial. Here we tested how people's attitudes toward the robot change after performing physical health exercises involving arm movements, and results are related to H3 as performing physical exercises requires the robot to make gestures. This study is for the realization of UN4 as we want to investigate how performing health exercise with a robot can improve the user's attitude towards the robot and, eventually, towards physical activity in general.

4.3.1 Method Sixteen participants (aged 35–70 years, age 54.4 years) had to perform a series of health exercises, which were demonstrated by the Nao robot. We manipulated speed of movement execution (low-high), the number of repetitions (4–8) and the presence or absence of music. Thus, the experiment had a 2(speed) $\times$ 2(number of repetitions) $\times$ 2(music) within-subjects design. Exercises were presented to the participants in randomized order. Before and after the experiment, participants rated their impression of the robot by answering the Godspeed questionnaire (Bartneck et al., 2009).

4.3.2 Results The internal consistency of the questionnaire was verified using Cronbach's alpha test. After removing one item from the appropriateness dimension, Cronbach's alpha was between 0.778 and 0.923. A repeated-measures ANOVA on the mean score differences of the dimensions of the Godspeed questionnaire revealed a significant increase of the dimension Likeability ($F(1, 15) =$

$7.014, p = 0.018$) between pre- and post-questionnaire. No other results were significant. The mean values are reported in Figure 6. Results suggest that performing physical training with the robot Nao

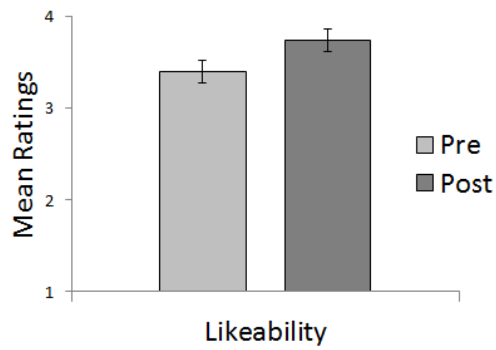


Figure 6. Mean score on the dimension Likeability of the Godspeed questionnaire before (pre) and after (post) doing a health exercise with the robot. Error bars denote 95% confidence interval (adjusted values).

improves the attitude of people towards it in terms of likeability, and there were no negative effects on the other dimensions of the Godspeed questionnaire.

4.4 Proxemic Behaviour

This study aimed at gathering quantitative data to assess how users evaluate the robot's proxemic behaviour. In particular we wanted to measure the optimal distance and angle of approach in terms of the user's experience. Like the user study presented in Section 4.2, this user study is of importance for addressing all user needs because in order to communicate the robot needs to approach its human partner. These results were used to model the user's personal space and applied in a navigation algorithm (for more details see Torta, Cuijpers, Juola, & Pol, 2011, 2012).

4.4.1 Method Ten participants (aged 16–51 years, mean age = 24.4) were seated on a chair in a simulated living room. The Nao robot approached them from five different directions $\{(4m, -70°), (4m, -35°), (4m, 0°), (4m, 35°), (4m, 70°)\}$. A schematic diagram of the set-up is shown in Figure 7.

Participants were instructed to stop the robot at a comfortable distance for verbal communication by pressing a button. There were three different conditions: participants should stop the robot at the optimal distance, the closest comfortable distance, or the furthest comfortable distance. The task had to be performed three times for each condition and for every direction of approach, thus resulting in 45 trials per participant. After every trial, the distance between the robot and the person was recorded via a ceiling-mounted camera and participants evaluated the approach of the robot on a five-point Likert scale that ranged from very bad to very good. The results of the questionnaire were normalized to obtain values between 0 and 1 that were used to define the model of the personal space.

4.4.2 Results In Figure 8, the stopping distances are shown for each angle of approach and for each condition. The optimal distance is always in between the furthest and the closest stopping distance as one would normally expect. The far stopping distance is practically constant, but the near and optimal stopping distances are larger in the middle than on the sides. We approximated the data with second-order polynomial functions to characterize the curvature. In a similar way, the subjective evaluation of the stopping distances is plotted in Figure 9 for each angle of approach

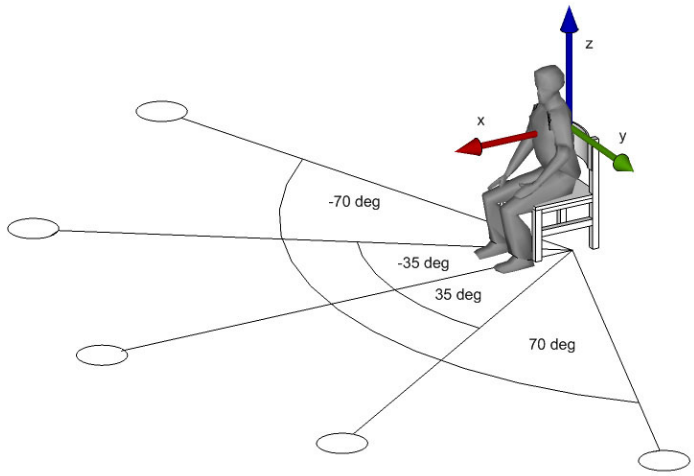


Figure 7. A schematic diagram of the experimental set-up where the participant is seated on a chair and where the robot approaches the participant from five different locations indicated by the circles.

and for each condition. The pattern is the same for the close stopping distance (left panel), optimal stopping distance (centre panel), and the far stopping distance (right panel). In all cases the rating is highest for the central three approach directions (0 deg and $\pm 35°$) and lowest for the approaches from the side ($\pm 70°$).

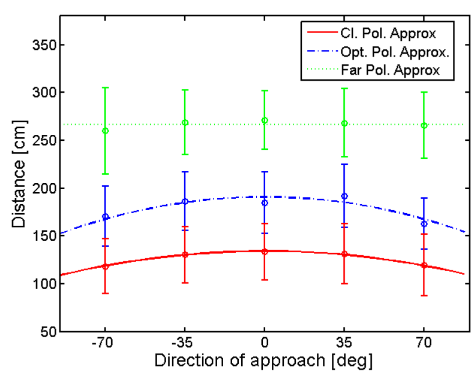


Figure 8. Far (diamonds), optimal (squares), and close (circles) stopping distance as a function of angle of approach. The lines indicate second–order polynomial fits. Error bars denote standard deviations.

4.4.3 Conclusion The results of the user study reported in Figure 8 show that the distance range of the personal space in the case of the robot Nao (indicatively 137 –265 cm centred at 194.4 cm) is larger than the distance range of the personal space in human–human interaction context (indicatively 45–120 cm, see Lambert, 2004). There are two potential reasons for this. First, the robot is small and coming too close would lead to an uncomfortable position as the participant would have to look down. Secondly, robots are technological artefacts for which reliability is unknown. So people

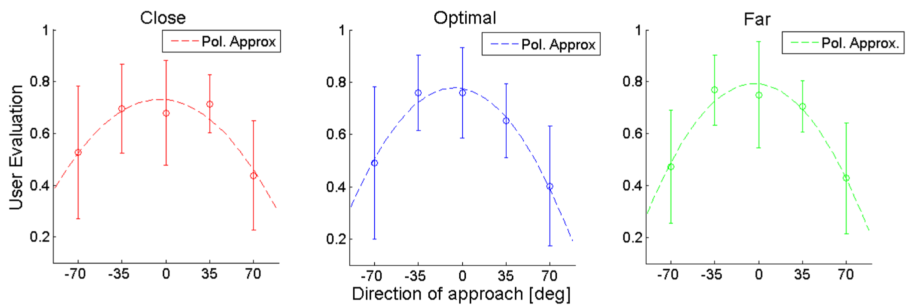


Figure 9. User rating for stopping the robot at the close (left panel), optimal (centre panel), and far (right) stopping distances as a function of angle of approach. The dashed lines indicate second–order polynomial fits. Error bars denote standard deviations.

may be inclined to keep a safe distance. Thus the application of human–human interpersonal distances in human–robot interaction should be verified beforehand because the distance range differs significantly from human–human interaction, contrary to what is reported in Walters et al. (2009). We also argue that user evaluation of robotic proxemic behaviour depends on the direction at which the robot approaches the user (see Figure 9). Therefore models of personal space should be included in the navigation algorithms.

5. Field Trials in Austria and Israel

The aim of field trials was to evaluate the complete KSERA system in a real–world environment with real end users. The field trials were carried out at two test sites, one being a senior citizen home in the "Living Lab Schwechat" (Austria) and the other being a senior citizen home in Tel Aviv (Israel). A full-featured KSERA system installation was undertaken in both facilities which we will describe first.

5.1 Description of the KSERA System

The KSERA system consists of a smart home environment with devices for measuring air quality and for monitoring the user's health, a Nao robot that acts as an interface to the system and various sensors to support the functioning of the robot. Navigation was based on the personal space model derived from the results of the user study presented in Section 4.4, the details of which are reported in Torta et al. (2011); Torta, Cuijpers, et al. (2012). Robot and person localization were achieved by means of a ceiling mounted camera (for details, see Yan, Weber, & Wermter, 2011). Details on the integration of intelligent algorithms for realizing navigation in a cluttered environment and the description of the computer vision algorithms used during interaction between the person and the robot can be found in Yan et al. (2012). A ceiling–mounted microphone was used for basic speech recognition. Two sensors were present in the environment: a pulse oximeter (a sensor for measuring blood oxygen level) and a temperature sensor. The camera, the robot, and the sensors were connected to the KSERA server via blue-tooth or WiFi wireless connections. Communication between processes within the KSERA server was achieved through the Robotic Operating System (ROS) (Quigley et al., 2009). The KSERA server was connected to the external world to derive information about the outside weather conditions. A schematic version of the interconnection of components within the KSERA installation is shown in Figure 10.

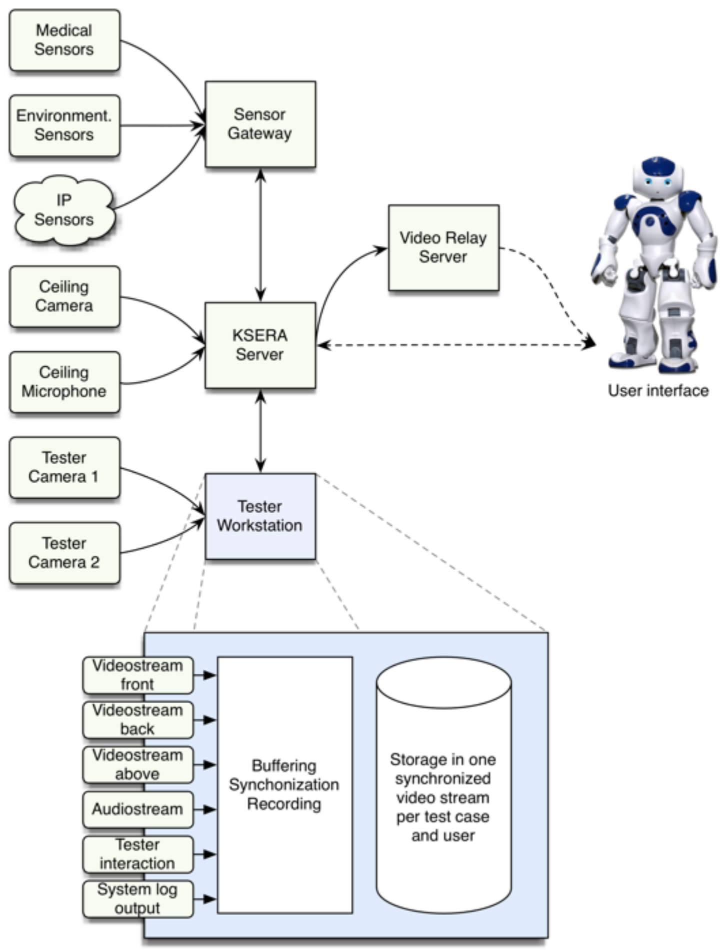
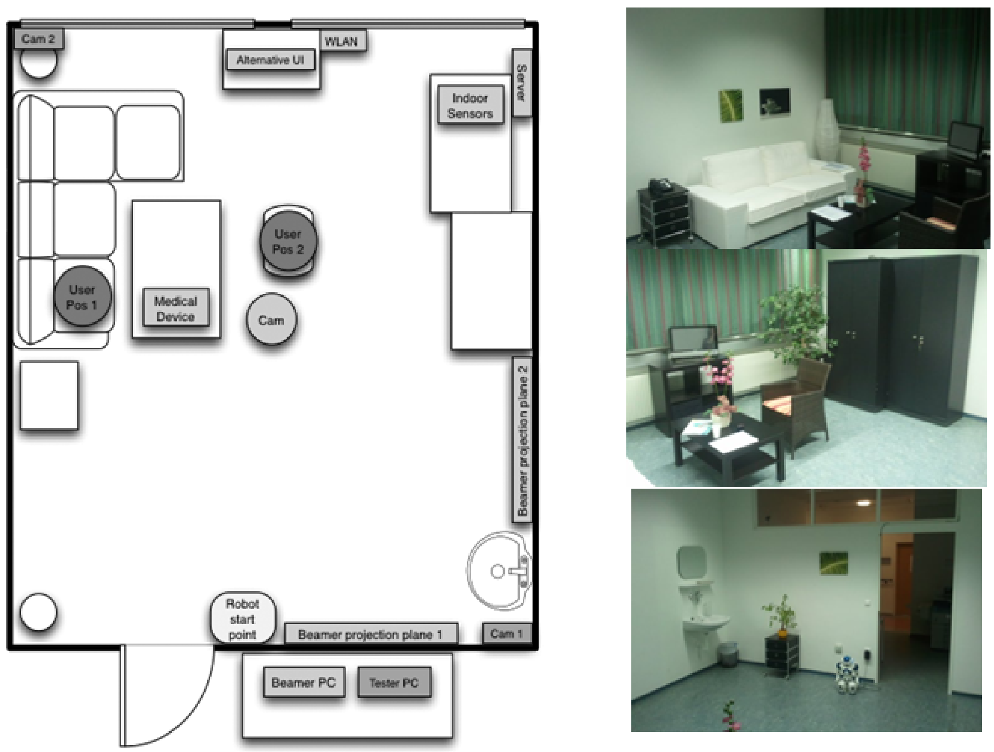


Figure 10. Schema of the KSERA installation and the connection of the components.

5.1.1 Experimental Set-Up Participants experienced the KSERA system in an environment mimicking a real user environment. In addition to the KSERA system, the home environment was equipped with additional cameras and microphones for recording the user's behaviour during interaction sessions. A dedicated tester workstation (Figure 10) was used for monitoring and recording the trials. The system logs were recorded as well as the video from three different cameras: two positioned on the walls and one on the ceiling. The audio stream was also recorded. The data allowed a retrospective interpretation of the test results in addition to live observation. Figure 11 shows the map and the test environment and the location of the system components in the Living Lab Schwechat in Austria.

5.2 Participants

The field trials involved a group of 16 elderly people (ages 71–90, mean age 77 years; 2 male, 14 female). Exclusion criteria were cognitive impairments and physical impairments that prohibited



(a) (b)

Figure 11. (a) Test room floor plan of the Living Lab Schwechat —dark grey: researcher components and user positions; light grey: KSERA system components; white: robot starting position. (b) Camera images from the Living Lab Schwechat

conducting the physical training scenarios.

5.3 Design

During the trials, users experienced three different test cases (TC1–TC3), which addressed some of the user needs described in Section 3.

5.3.1 Test Case 1 (TC1). The first test case, TC, (see Figure 12), addresses the user needs UN1 and UN3. The robot navigated to the participant and stopped when it reached the target point (UN1). The robot then checked whether the person was paying attention to it using head pose estimation, see (for details, see Pol, Cuijpers, & Juola, 2011) . For attracting attention, the robot first used speech, saying “Please look at me”; if this was not enough (indicated by the person not looking at the robot), it waved its hands and blinked its eyes. The sequence was chosen based on the results of the user study reported in Section 4.2. When the user paid attention to the robot, the latter asked the user to measure the blood-oxygen level (UN3) using the pulse oximeter, a wireless measurement device. The robot then connected to the KSERA database, read the measurement and, according to its value, uttered a speech message as feedback on the measurement.

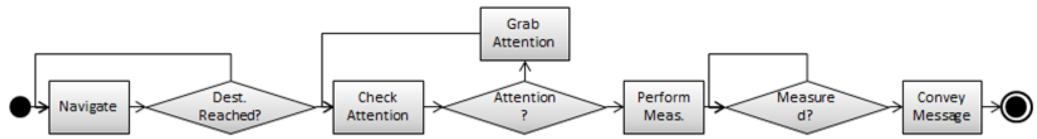


Figure 12. Flow chart of Test Case 1.

5.3.2 Test Case 2 (TC2). The second test case, TC2, addressed UN1 and UN4, and its flow chart is reported in Figure 13. The robot navigated toward the exercise position (UN1) and, when it reached the destination, started demonstrating the health exercise (UN4). Exercises were based on a physical training video usually used at Maccabi Healthcare Center (Israel) and consisted of typical physical training exercises for older people. When the exercise terminated the robot provided feedback to the user and the test case ended.

Figure 13. Flow chart of Test Case 2.

5.3.3 Test Case 3 (TC3). The third test case addressed UN5. The robot informed the user about the weather conditions, gathered through the KSERA system from a web service provider. The flow diagram is shown in Figure 14.

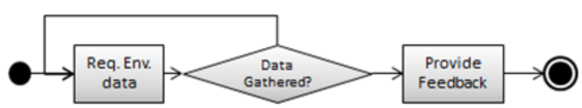


Figure 14. Flow chart of Test Case 3.

5.4 Procedure

Participants entered the test facilities and were welcomed by the experimenters. Participants received a general explanation of the technology present in the test setting (robot, camera, pulse oximeter, and temperature sensor) and signed the informed consent form. This phase was conducted without the robot being visible. Participants then entered the test room. Two experimenters were seated outside the test room and one experimenter was standing at the door of the test room. Participants then experienced the three test cases. The order of the test cases was fixed: TC3, TC2, and TC1. At the end of the third test case, participants evaluated their experiences by answering some questionnaires. These consisted of (Q1) the Godspeed questionnaire (Bartneck et al., 2009) and (Q2) the KSERA Quality of Life questionnaire (Oberzaucher, Werner, Lemberger, & Werner, 2013). Furthermore, specific questions (Q3) were asked concerning the use of the robot as a personal assistant during physical training. Answers were given on a Likert scale from "very much" to "not at all much". The questions were as follows:

3.1 How much is Nao motivating me to do the task?

3.2 Is Nao motivating me more than a human trainer?

3.3 Is Nao motivating me more than a standard training-plan?

Each participant took part in the experiment twice. The time between two iterations was 2 weeks. During the second iteration, participants at the Schwechat test site performed each test case first with the robot and then with a stationary touchscreen to allow for a comparative evaluation. The touchscreen is a smart home user interface (GUI) developed for the ICT-ISP project Long Lasting Memories[2]. The test cases with the touchscreen had the same flow of events as the test cases with the robot Nao, except from the initial phase in which the robot walked to the user. Instead, the touchscreen was already placed close by the user. At the end of the last test case (TC1), participants at the Austrian test site (n=8) filled an additional questionnaire (Q4) in order to compare their impression of the robot Nao with the impression of the touchscreen. For each item of the questionnaire, participants had to choose between the robot, the GUI or both. Questions were of the form "which system do you think is better for... ? " :

4.1 motivating you to do a task.

4.2 informing you.

4.3 raising your attention.

4.4 explaining exercises.

4.5 motivating you for doing exercises.

4.6 using in your own home.

4.7 receiving important information.

4.8 easily informing you.

5.5 Results

The analysis of the answers given to Q1 and Q2 (16 participants at both test sites), shows that the KSERA system and the robot were both rated as likeable. Indeed, the mean scores were all significantly greater than 3, the middle point of the Likert scale from 1 to 5 ($p < 0.01$ for both the system and the robot). The score for the likeability of the robot Nao was higher than the score for the likeability of the system and reached a mean value of 4.28 (mean = 4.28, SE = 0.16). The KSERA score for likeability (Cronbach alpha = 0.86) reached a mean value of 3.68 (mean = 3.68, SD = 0.23). The perceived enjoyment (PE) of the KSERA system was also rated positively (mean = 4.32, SD = 0.19). The results are graphically reported in Figure 15.

The attitude toward the robot presents a high correlation with the attitude towards the system which is not surprising considering that the robot is the most visible component of the KSERA system. Indeed, Nao likeability was significantly correlated with KSERA likeability ($r = 0.64$, $p < 0.01$) and with KSERA perceived enjoyment (PE) ($r = 0.66$, $p < 0.01$). In both cases the correlation is positive. The distribution of the data points in both cases is visible in Figure 5.5.

[2]http://www.longlastingmemories.eu/

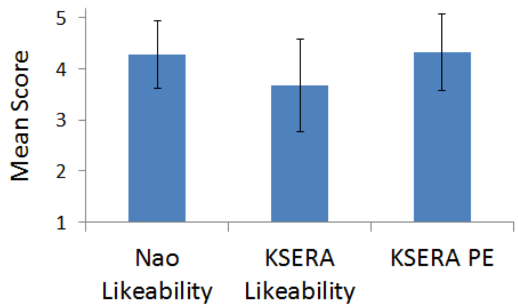


Figure 15. Users mean ratings of Nao likeability, KSERA likeability, and KSERA perceived enjoyment (PE). Error bars represent standard deviations.

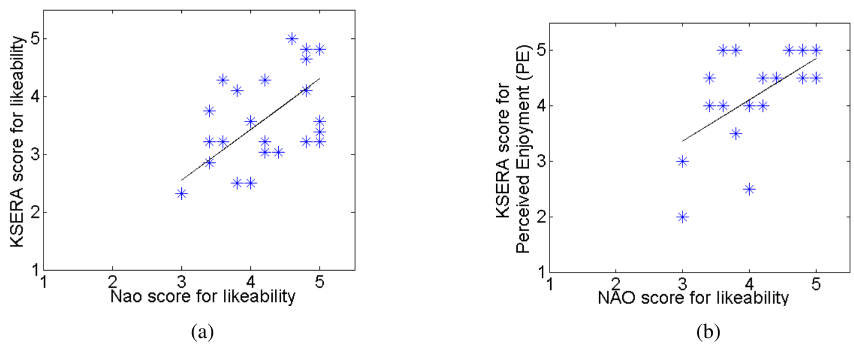


Figure 16. Comparison of the likeability of the robotic component vs. the likeability of the system (a) and vs. the PE of the whole system (b).

The analysis of the answers given to Q3 (16 participants at both test sites), which is shown in Figure 17, shows that 71% of the trial participants reported that Nao was motivating them "very much" or "a lot". As an expected result about 60% of the participants reported that a human trainer would motivate them more than Nao. However 82% of the participants rated Nao to be a better motivator than standard training plans they use in daily life. The analysis of the answers given to Q4 (8 participants only at the Schwechat test site), which is graphically reported in Figure 18, allows a comparative evaluation of the Nao and of a stationary touch screen (GUI) as an interface. The results show that the robot is preferred for motivating the user to do a task (71%), for raising attention (62%), for motivating to do exercise (50%) and for explaining the task (62%). Participants also reported that the robot would be the preferred system for use in their own homes (50%). However, the traditional touch screen interface was preferred for retrieving information (86%), for very important information (88%) and for easily providing information (62%).

6. General Discussion

In this paper, we presented several laboratory studies that tested the validity and added value of socially-assistive robots in a domestic environment. These results were used in the KSERA system, which integrates a smart home with a robotic artefact. In the field trials, we evaluated the

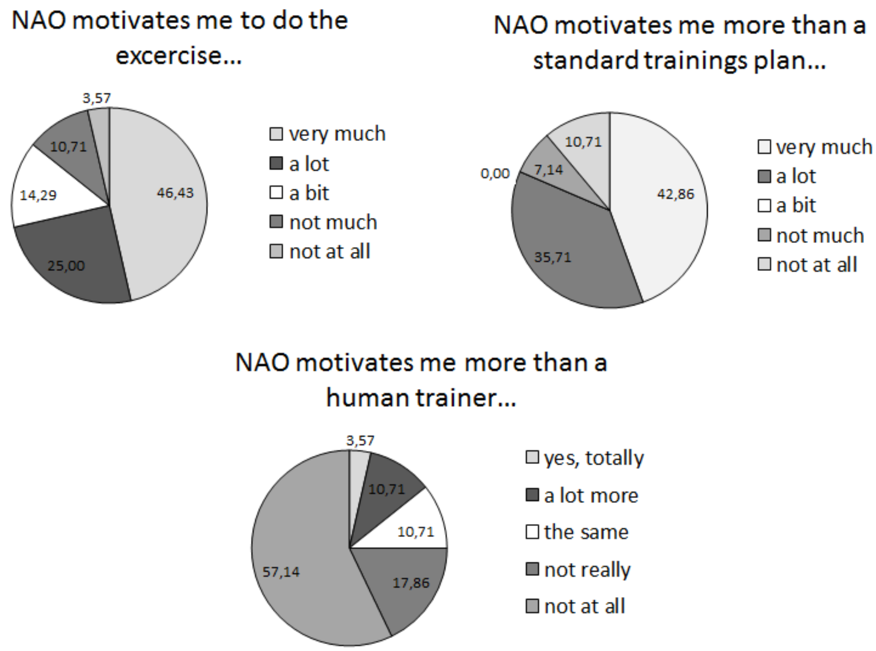


Figure 17. Results of the questionnaire Q3. Percentages are reported in the graphs.

system with real end users in three real–world scenarios. The first hypothesized added value that we addressed was that (H1) "socially assistive robots, as communication interfaces, generate more positive feelings in the user than other state–of–the–art smart home interfaces". The results of the KSERA field trials show that participants tended to prefer conventional interfaces (touch screen) for receiving information. This result is in accordance with the results of the study on the role of robot embodiment, reported in Section 4.1, which shows that participants' reaction time in responding to the robot is, overall, longer than when responding to a ubiquitous smart home system. This might be due to the novelty effect of the robot or to a higher cognitive load due to the robot embodiment. So our results suggest that, in terms of efficiency of information transfer, conventional systems seem to be better. This is not so surprising, however, because conventional systems are designed to do this and only this. Another factor that may have played a role is that robotics systems are still frailer than conventional user interfaces. This might have induced users to prefer more robust technological artefacts for receiving information because they required lower levels of mental efforts. Indeed previous research on attitudes of elderly people toward conventional home technology reports that people tend to have negative attitude toward technology that demands increasing efforts or higher levels of mental efforts (Mitzner et al., 2010). Nevertheless, during the field trials participants reported that Nao would motivate them more than a standard touch-screen for accomplishing a task. This is also in accordance with the results of the user study reported in Section 4.1 which shows that participants rated Nao as more likeable and animated than a ubiquitous smart home system, even though they reacted faster in the latter case. Therefore, according to our results from field trials and user studies, the Nao robot appears to be more likeable than state–of–the–art smart home interfaces and, thus, they generate more positive feelings. The second assumption (H2) that we formulated is: "If the socially assistive robot is perceived as friendly and likeable, the entire assistive system is perceived

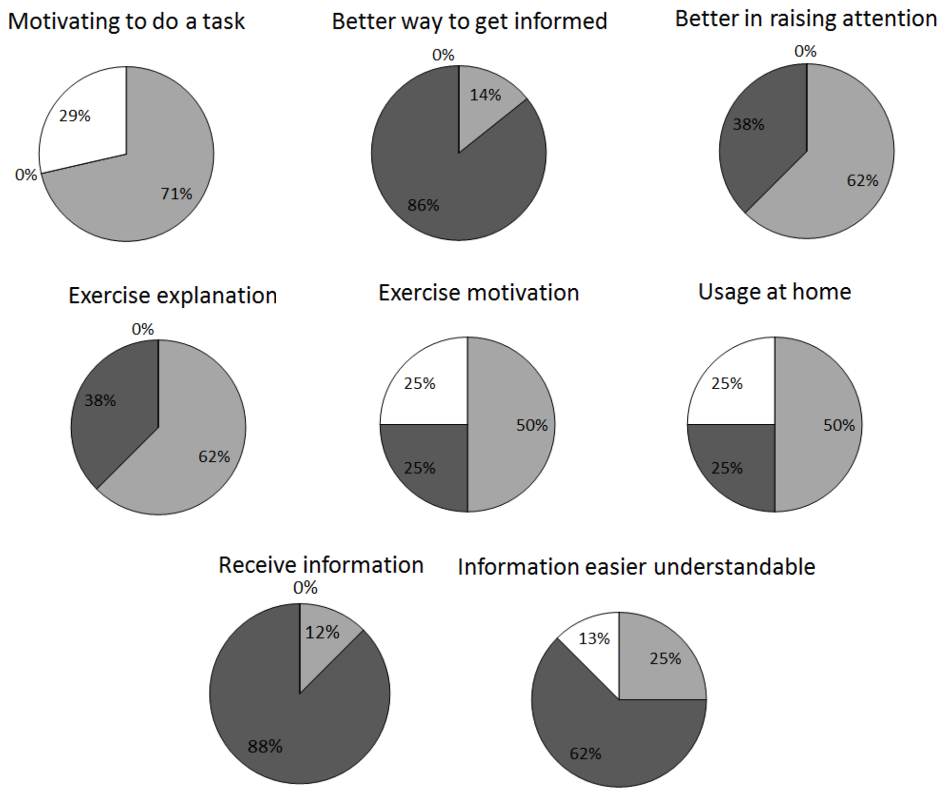


Figure 18. The pie charts indicate the relative percentages of participants who preferred the Nao robot (light grey), the GUI (dark grey), or who were indifferent (white).

as friendly and likeable and users will tend to accept it". We did not test this assumption during the user studies, but results of the field trials show that there is a significant positive correlation between the scores related to the likeability of the robot Nao and the scores related to the likeability of the overall KSERA system. Although the correlation analysis does not show which variable causes the observed correlation, we believe that the likeability of the KSERA system is caused by the Nao as the robot embodies the KSERA system and it is its most visible component and the main user interface. The third assumption (H3) that we have formulated states that "the attitude towards the robot improves when the robot shows hand gestures". The results of the user study reported in Section 4.2 showed that people tended to judge a waving gesture as a more friendly way of attracting attention when looking at TV news and the results of the user study reported in Section 4.3 show that people tended to perceive the robot better after they performed physical training with it that involved arm movements. This effect might be due to the expectations that users may have about how the Nao robot moves. If the robot gesticulates like humans, user's expectations are more likely to be met. This in turn is expected to improve likeability. Also, results of the field trials suggest that the robot is perceived as better when it moves its limbs consistently with the tasks to be accomplished. This hypothesis was not evaluated directly during the field trials, but results showed that participants, in general, preferred the robot for physical training as opposed to standard training platforms.

7. Conclusion and Future Perspectives

This paper presents the authors' work related to the EU-FP7 project KSERA, a project that aims at introducing a socially assistive robot in a smart home environments. In particular, the paper gives an overview of the results of the laboratory user studies conducted in Eindhoven (The Netherlands) and the field trials carried out in senior citizen centres in Schwechat (Austria) and Tel Aviv (Israel). Beyond the functional results, related to the realization of an intelligent environment, with a distributed sensory network (robot and sensors), the results of the field trials as well as the results of the user studies suggest that socially assistive robots, as embodied agents, positively affect user experience compared to standard smart environment interfaces such as touch-screens. Even though already existing communication interfaces might still provide a more efficient way of communication, robots appear to be perceived as better motivators. But it still remains a challenge to assess whether this effect holds for interactions that span a longer period of time. Perceiving robots as better motivators suggests that socially assistive robots can act as persuasive agents (Fogg, 2003) in smart home environments more than standard interfaces. The persuasive power of robots might be used to trigger healthier behaviours. Socially assistive robots are still far from being robust technological artefacts, and users are still more efficient and experienced with standard technology as a tool for communication and information exchange. However, our results confirm the great potential of embodied systems to interact with people in a wide variety of tasks. People tend to have positive feelings towards the socially assistive robot, and because the robot is the most visible component of the system, such attribution is likely to steer the acceptance of the entire assistive environment in a positive way. The robustness and safety of assistive technology, that uses socially assistive robots as communication interfaces, still need to be improved, but perhaps more importantly the social skills of robotic agents need to be developed so that they can tap into this great potential of embodied systems.

User studies and field trials spanned one (for the user studies) or two (for the field trials) interaction sessions, so it is unclear whether we would get the same results in longer interactions. At least they show the potential of socially assistive robots in intelligent homes but dedicated long–term studies will have to confirm this. Previous research by Wada and Shibata (2007) suggests that users tend to maintain positive attitudes towards socially assistive robots, at least for robots with very limited functionalities such as PARO. In the next iteration of the KSERA field trials, participants will interact with the socially assistive robot in an intelligent home for a longer period of time and for more sessions. This will likely allow us to get a better understanding of how users' attitudes towards the robot change over time. We will also extend the test cases of the KSERA system to address UN2 and UN6 which was not possible to address in the current iteration.

In the KSERA project as well as in any cross-cultural human–robot interaction project the cultural background of the developers, the experimenters, and the trial participants have an influence on the research results (Beu, Honold, & Yuan, 2000; Day & Evers, 1997, 1999). In order to minimize this influence during the field trials, several measures were undertaken. Scenarios shown were preselected based on the comparability between Austria and Israel in a way that circumvented known issues such as differences in the acceptance of passing personal data, differences in living situations at home (e.g., having an air conditioning system or not), and differences in the understanding of robot behaviour. Regarding robot behaviour, relevant parts of the interaction between the robot and the human (e.g., speech generation, content) were customized to the local setting. Gestures performed by the robot were adapted to ensure the correct comprehension of gestures by all trial participants. During the trials, the researchers and trial participants always had the same cultural background in order to avoid misunderstanding, which is also stressed as one of the major problems in cross–cultural human–computer interaction testing (Vatrapu & Pérez-Quiñones, 2006). It is possible that differences in cultural socialization of the trial participants have influenced the results of the field trials, but this is hard to ascertain and avoid. In our project, cross-cultural teams analyzed the quantitative and qualitative data to identify trial site and culture–dependent results in e.g., questionnaire data. Regarding the results presented in this paper, no cross-cultural influence was found.

8. Acknowledgements

The research leading to these results is part of the KSERA project (http://www.ksera-project.eu) funded by the European Commission under the 7th Framework Programme (FP7) for Research and Technological Development under grant agreement $nos.2010 - 248085$.

We would like to thank all trial participants for taking part in the study and the senior citizen homes and caretakers in Austria and Israel that supported us during the trials.

We would also like to thank all the students who helped us with the realization of this paper: Rolijn van Vught, Jim van Heumen, Federica Izzi, and Simona Carosielli.

References

Andric, M., & Small, S. L. (2012). Gesture's neural language. *Frontiers in Psychology*.

Bakhtin, Y., & Correll, J. (2012). A neural computation model for decision-making times. *Journal of Mathematical Psychology*.

Banks, M., Willoughby, L. M., & Banks, W. (2008). Animal–assisted therapy and loneliness in nursing homes: Use of robotic versus living dogs. *Journal of the American Medical Directors Association*, *9*(3), 173-177, http://dx.doi.org/10.1016/j.jamda.2007.11.007.

Bartneck, C., Kulić, D., Croft, E., & Zoghbi, S. (2009). Measurement Instruments for the Anthropomorphism, Animacy, Likeability, Perceived Intelligence, and Perceived Safety of Robots. *International Journal of Social Robotics*, *1*, 71-81, http://dx.doi.org/10.1007/s12369-008-0001-3.

Beer, J. M., Smarr, C.-A., Chen, T. L., Prakash, A., Mitzner, T. L., Kemp, C. C., et al. (2012). The domesticated robot: design guidelines for assisting older adults to age in place. In *Proceedings of the ACM/IEEE Seventh Annual International Conference on Human-Robot Interaction* (pp. 335-342, http://doi.acm.org/10.1145/2157689.2157806). New York, NY, USA: ACM.

Bemelmans, R., Gelderblom, G. J., Jonker, P., & Witte, L. de. (2012). Socially Assistive Robots in Elderly Care: A Systematic Review into Effects and Effectiveness. *Journal of the American Medical Directors Association*, *13*(2), 114-120, http://dx.doi.org/10.1016/j.jamda.2010.10.002.

Beu, A., Honold, P., & Yuan, X. (2000). How to build up an infrastructure for intercultural usability engineering. *The International Journal of Human–Computer Interaction*, *12*, 347-358 DOI:10.1080/10447318.2000.9669063.

Bremner, J., Frost, A., Haub, C., Mather, M., Ringheim, K., & Zuehlke, E. (2010). World population highlights: Key findings from PRB's 2010 world population data sheet. *Population Bulletin*, *65*(2).

Broekens, J., Heerink, M., & Rosendal, H. (2009). Assistive social robots in elderly care: A review. *Journal of Gerontechnology*, *8*(2), 94-103 http://dx.doi.org/10.4017/gt.2009.08.02.002.00.

Carone, G., & Costello, D. (2006). Can Europe Afford to Grow Old? *International Monetary Fund Finance and Development Magazine*.

Cesta, A., Cortellessa, G., Giuliani, V., Pecora, F., Rasconi, R., Scopelliti, M., et al. (2007). Proactive Assistive Technology: An Empirical Study. In C. Baranauskas, P. Palanque, J. Abascal, & S. Barbosa (Eds.), *Human–Computer Interaction. INTERACT 2007* (Vol. 4662, p. 255-268 http://dx.doi.org/10.1007/978-3-540-74796-3_25). Berlin / Heidelberg: Springer.

Dautenhahn, K. (2007). Socially intelligent robots: dimensions of human–robot interaction. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *362*(1480), 679-704, http://dx.doi.org/10.1098/rstb.2006.2004.

Day, D., & Evers, V. (1997). The role of culture in interface acceptance. *Human Computer Interaction, INTERACT'97*.

Day, D., & Evers, V. (1999). Questionnaire development for multicultural data collection.

Feil-Seifer, D., & Matarìc, M. (2005). Defining socially assistive robotics. In *9th International Conference on Rehabilitation Robotics. ICORR 2005.* (pp. 465-468, http://dx.doi.org/10.1109/ICORR.2005.1501143).

Fogg, B. J. (2003). *Persuasive technology: Using computers to change what we think and do* (Vol. 18) (No. 1). Morgan Kaufmann Publishers.

Friedman, B., Kahn, P. H., Jr., & Hagman, J. (2003). Hardware companions?: what online aibo discussion forums reveal about the human-robotic relationship. In *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 273-280, http://dx.doi.org/10.1145/642611.642660). New York, NY, USA: ACM.

Hewitt, P. (2002). Depopulation and Ageing in Europe and Japan: The Hazardous Transition to a Labor Shortage Economy. *Internationale Politik und Gesellschaft*, *Part 1*, 111 –120.

Huettenrauch, H., Eklundh, K., Green, A., & Topp, E. (2006). Investigating Spatial Relationships in Human–Robot Interaction. In *IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS 2006* (pp. 5052-5059, http://dx.doi.org/10.1109/IROS.2006.282535).

Huijnen, C., Badii, A., Heuvel, H. van den, Caleb-Solly, P., & Thiemert, D. (2011). "Maybe It Becomes a Buddy, But Do Not Call It a Robot" – Seamless Cooperation between Companion Robotics and Smart Homes. In D. Keyson et al. (Eds.), *Ambient Intelligence* (Vol. 7040, pp. 324-329, http://dx.doi.org/10.1007/978-3-642-25167-2_44). Berlin / Heidelberg: Springer.

Jan, D., Chance, E., Rajpurohit, D., DeVault, D., Leuski, A., Morie, J., et al. (2011). Checkpoint Exercise: Training with Virtual Actors in Virtual Worlds. In H. Vilhjálmsson, S. Kopp, S. Marsella, & K. Thórisson (Eds.), *Intelligent Virtual Agents* (Vol. 6895, pp. 453-454, http://dx.doi.org/10.1007/978-3-642-23974-8_59). Berlin / Heidelberg: Springer.

Kahn, J. P. H., Kanda, T., Ishiguro, H., Gill, B. T., Ruckert, J. H., Shen, S., et al. (2012). Do people hold a humanoid robot morally accountable for the harm it causes? In *Proceedings of the Seventh Annual ACM/IEEE International Conference on Human–Robot Interaction* (pp. 33-40, http://dx.doi.org/10.1145/2157689.2157696). New York, NY, USA: ACM.

Kim, E. S., Leyzberg, D., Tsui, K. M., & Scassellati, B. (2009). How people talk when teaching a robot. In *Proceedings of the 4th ACM/IEEE international conference on human robot interaction* (pp. 23-30, http://dx.doi.org/10.1145/1514095.1514102). New York, NY, USA: ACM.

Koskela, T., & Väänänen-Vainio-Mattila, K. (2004). Evolution towards smart home environments: empirical evaluation of three user interfaces. *Personal and Ubiquitous Computing*, *8*, 234-240, http://dx.doi.org/10.1007/s00779-004-0283-x.

Lambert, D. (2004). *Body Language*. London: Harper Collins.

Lee, K. M., Peng, W., Jin, S.-A., & Yan, C. (2006). Can robots manifest personality?: An empirical test of personality recognition, social responses, and social presence in human–robot interaction. *Journal of Communication*, *56*(4), 754-772, http://dx.doi.org/10.1111/j.1460-2466.2006.00318.x.

Lee, S., Hyungjong, N., Jonghon, L., Kyungsong, L., Geunbae, G., Seongdae, S., et al. (2011). On the effectiveness of robot–assisted language learning. *ReCALL*, *23*(01), 25-58, http://dx.doi.org/10.1017/S0958344010000273.

Lohse, M., Rohlfing, K., Wrede, B., & Sagerer, G. (2008, may). When users change their discursive behavior in human–robot interaction. In *IEEE International Conference on Robotics and Automation. ICRA 2008.* (pp. 3481-3486, http://dx.doi.org/10.1109/ROBOT.2008.4543743).

Louloudi, A., Mosallam, A., Marturi, N., Janse, P., & Hernandez, V. (2010). Integration of the humanoid robot Nao inside a smart home: A case study. In *Proceedings of the Swedish AI Society Workshop* (Vol. 48, pp. 35-44, http://www.ep.liu.se/ecp/048/008/index.en.asp). Linköping University Electronic Press.

Min Lee, K., Jung, Y., Kim, J., & Kim, S. R. (2006). Are physically embodied social agents better than disembodied social agents?: The effects of physical embodiment, tactile interaction, and people's loneliness in human–robot interaction. *International Journal of Human-Computer Studies*, *64*(10), 962-973, http://dx.doi.org/10.1016/j.ijhcs.2006.05.002.

Mitzner, T. L., Boron, J. B., Fausset, C. B., Adams, A. E., Charness, N., Czaja, S. J., et al. (2010). Older adults talk technology: Technology usage and attitudes. *Computers in Human Behavior*, *26*(6), 1710 - http://dx.doi.org/10.1016/j.chb.2010.06.020.

Oberzaucher, J., Werner, F., Lemberger, J., & Werner, K. (2013). *KSERA deliverable 5.3: Formative evaluation.*

to be published in 2013. (Tech. Rep.).

Pineau, J., Montemerlo, M., Pollack, M., Roy, N., & Thrun, S. (2003). Towards robotic assistants in nursing homes: Challenges and results. *Robotics and Autonomous Systems*, *42*(3-4), 271-281, http://linkinghub.elsevier.com/retrieve/pii/S0921889002003810.

Pol, D. van der, Cuijpers, R. H., & Juola, J. F. (2011). Head pose estimation for a domestic robot. In *Proceedings of the 6th International Conference on Human–Robot Interaction* (pp. 277-278, http://doi.acm.org/10.1145/1957656.1957769). New York, NY, USA: ACM.

Quigley, M., Conley, K., Gerkey, B. P., Faust, J., Foote, T., Leibs, J., et al. (2009). *ROS: an open-source robot operating system.*

Reddy, M., Pratt, W., Dourish, P., & Shabot, M. (2003). Sociotechnical Requirements Analysis for Clinical Systems. Methods of Information in Medicine. *Methods of Information in Medicine*, *42*, 437-44, http://ukpmc.ac.uk/abstract/MED/14534647.

Reeves, B., & Nass, C. (1996). The media equation: how people treat computers, television and new media like real people and places. *New York: Cambridge University Press.*

Ruiz, A., Rocon, E., Raya, R., & Pons, J. (2008, may). Coupled control of human-exoskeleton systems: An adaptative process. In *Conference on Human System Interactions, 2008* (pp. 242-246, http://dx.doi.org/10.1109/HSI.2008.4581441).

Scassellati, B. (2005, aug.). Quantitative metrics of social response for autism diagnosis. In *IEEE International Workshop on Robot and Human Interactive Communication. ROMAN 2005.* (pp. 585-590, http://dx.doi.org/10.1109/ROMAN.2005.1513843).

Scassellati, B., Admoni, H., & Matarìc, M. (2012). Robots for use in autism research. *Annual Review of Biomedical Engineering*, *14*(1), http://dx.doi.org/10.1146/annurev-bioeng-071811-150036.

Steg, H., Strese, H., Loroff, C., Hull, J., & Schmidt, S. (2006). Europe is facing a demographic challenge Ambient Assisted Living offers solutions. http://www.aal-europe.eu/Published/reports-etc/Final%20Version.pdf.

Syrdal, D., Kheng, L. K., Walters, M., & Dautenhahn, K. (2007, aug.). A personalized robot companion? - The role of individual differences on spatial preferences in HRI scenarios. In *The 16th IEEE International Symposium on Robot and Human Interactive Communication. RO–MAN 2007.* (pp. 1143-1148, http://dx.doi.org/10.1109/ROMAN.2007.4415252).

Tapus, A., Matarić, M. J., & Scassellati, B. (2007). The Grand Challenges in Socially Assistive Robotics. *Robotics and Automation Magazine*, *14*(1), 1-7, http://dx.doi.org/10.1109/MRA.2007.339605.

Torta, E., Cuijpers, R., Juola, J., & Pol, D. van der. (2011). Design of robust robotic proxemic behaviour. In B. Mutlu, C. Bartneck, J. Ham, V. Evers, & T. Kanda (Eds.), *Proceedings of the International Conference on Social Robotics ICSR 2011* (Vol. 7072, pp. 21-30, http://dx.doi.org/10.1007/978-3-642-25504-5_3). Berlin / Heidelberg: Springer.

Torta, E., Cuijpers, R., Juola, J., & Pol, D. van der. (2012). Modelling and testing proxemic behaviour for humanoid robots. *International Journal of Humanoid Robotics*, http://dx.doi.org/10.1142/S0219843612500284.

Torta, E., Heumen, J. van, Cuijpers, R., & Juola, J. (2012). How can a robot attract the attention of its human partner? a comparative study over different modalities for attracting attention (in press). In *Proceedings of the international conference on social robotics ICSR2012* (Vol. 7621, p. 288-297 DOI:http://dx.doi.org/10.1007/978-3-642-34103-8_29). Berlin / Heidelberg: Springer.

Vanhooydonck, D., Demeester, E., Hantemann, A., Philips, J., Vanacker, G., Van Brussel, H., et al. (2010). Adaptable navigational assistance for intelligent wheelchairs by means of an implicit personalized user model. *Robotics and Autonomous Systems*, *58*(8), 963-977, http://dx.doi.org/10.1016/j.robot.2010.04.002.

Vatrapu, R., & Pérez-Quiñones, M. A. (2006). Questionnaire development for multicultural data collection. *Journal of Usability Studies*, *1*, 156-170.

Wada, K., & Shibata, T. (2007). Living with seal robots; Its sociopsychological and physiological influences on the elderly at a care house. *IEEE Transactions on Robotics*, *23*(5), 972-980 http://dx.doi.org/10.1109/TRO.2007.906261.

Walters, M., Dautenhahn, K., Boekhorst, R., Koay, K., Syrdal, D., & Nehaniv, C. (2009). An empirical framework for human-robot proxemics. In *Proceedings of the symposium on new frontiers in human-robot interaction AISB2009. Edinburgh, Scottland.* (p. 8-9). Citeseer.

Yan, W., Torta, E., Pol, D. v. d., Meins, N., Weber, C., Cuijpers, R., et al. (2012). Learning robot vision in ambient homes (in press). In *In josé garcía-rodríguez and miguel cazorla (eds.), robotic vision: Technologies for machine learning and vision applications* (pp. 257-281, http://dx.doi.org/10.4018/978-1-4666-2672-0.ch015). IGI Global.

Yan, W., Weber, C., & Wermter, S. (2011, August). A hybrid probabilistic neural model for person tracking based on a ceiling-mounted camera. *Journal of Ambient Intelligence and Smart Environments*, *3*(3), 237-252, http://dl.acm.org/citation.cfm?id=2010465.2010469.

Yu, K.-T., Lam, C.-P., Chang, M.-F., Mou, W.-H., Tseng, S.-H., & Fu, L.-C. (2010, oct.). An interactive robotic walker for assisting elderly mobility in senior care unit. In *IEEE Workshop on Advanced Robotics and its Social Impacts (ARSO), 2010* (pp. 24-29, http://dx.doi.org/10.1109/ARSO.2010.5679631).

Contact information: Elena Torta, Eindhoven University of Technology, Faculty of Industrial Engineering and Innovation Sciences, Eindhoven, The Netherlands. Email: `e.torta@tue.nl`.