How Socially Assistive Robots Supporting on Cognitive Tasks Perform

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Abstract. Understanding the effects of Socially Assistive Robots (SAR) on human's task performance is crucial for designing powerful assistive systems. A variety of interaction design questions have to be taken into account in order to implement SAR. We present the results of a case-control study (no robot present vs. robot giving generic motivational feedback vs. robot giving task performance related feedback) for a scenario in which a SAR assists users on a cognitive task. Results show that SARs can have positive effects on user's task performance on cognitive tasks and that the task is perceived as pleasurable if the robot's feedback is appropriate to the user's task processing.

1 INTRODUCTION

Socially Assistive Robots (SAR) are a unique form of assistive robots. While, assistive robots can be divided into robots that can guide through physical interaction (e.g. in rehabilitation therapy, wheelchair robots [8, 15]) or as service robots [1], socially assistive robots are meant to assist people through their mere presence and social interaction [3]. This implies that interaction relies on purely human like capabilities and ranges from verbal and nonverbal behavior, emotional expressions to suitable assistive interaction strategies. Whereas those strategies have to take the users needs and progression into account to be helpful. In order to create effective social support that might help users, a variety of questions need to be addressed. Can SARs induce behavioral change? What are suitable interaction strategies to assist humans? How do people perform on tasks under load (cognitive load, time pressure) while being assisted from an embodied social entity? Answers to those questions can help to build meaningful assistive companions and guidelines for building social interactive robots which can support users on different tasks.

In a previous work we have investigated the effects of different assistive interaction strategies during cognItive tasks on people [13]. A robotic system assisted users on a cognitive task. We compared two different interaction strategies, one where the robot just gave structuring and randomized motivational feedback and one where the robot gave implicit feedback regarding the user's task performance. In this work we want to investigate and present how our previous results compare to an experimental setup where participants do not have assistance by a robot at all. The question left to explore is whether the robots presence has positive or negative effects on humans' task performance. Hence, this work does not give new methodology insights for research in SARs, but it shows the facilitation effects robots can have on humans during cognitive tasks.

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We hypothesize that the presence of a robot has a positive effect on the task performance and that the perception of being evaluated and observed during task execution is higher compared to a condition where the robot's feedback is not related to user's task processing and to a *no-robot* condition. We also hypothesize that the experiment is perceived as more pleasurable when the participants are accompanied by a robot. Furthermore, we want to investigate if robot assistance and interaction strategies can have an impact on the general attitudes towards robots.

The next section shows work done in the field of socially assistive robots. In Section 2 we describe our study methodology. Section 3 shows our obtained results which are discussed in Section 4. The last section gives a conclusion about the presented work.

1.1 Related Work

Previous work investigated the effects of robotic assistance on several different tasks (diet coaching, classroom tutor, energy management) using different methodologies (e.g. quantitative measurements like task performance, or duration of interaction, or qualitative meauserements like self-reported questionnaires). The impact of positive and negative social feedback on users energy consumption behavior has been studied in [9]. Results showed that people were sensitive to social feedback. Kidd et al studied the effects of long-term human robot interaction on behavior change while dieting [6]. They compared a sociable robot to a standalone computer and a paper log. They used the body weight and interaction time as quantitive measures for the effect of the robot. The results show that there is no significant difference between the three groups regarding the body weight. Nevertheless, the user had a stronger alliance and used the robot longer than in the other two conditions.

Explicit motivation and induced enhancement of task performance using SARs on a cognitive task have been studied in [2]. Three different interaction conditions were evaluated: A baseline condition in which the robot served as a game instructor and evaluator, a praise condition in which explicit verbal feedback according to task performance was given, and a challenge condition where the system changed the difficulty of the test to challenge participants and increase enjoyment. Task enjoyment was highest in the challenging condition and the task was perceived less frustrating compared to the other conditions. Furthermore, participants felt motivated by the robot and reported the highest enjoyment in the condition where they performed best.

Closely related is a study by Leyzberg and Scassellati, where they investigated the effects of physical presence of a robot tutor during a cognitive task [7]. Their results show that participants in the physically-present robot group outperformed every other group.

Moreover, participants in the robot condition improved their same-puzzle solving skill significantly in terms of time measurement for a problem set.

Chan et al. studied how robotic system can engage individuals in a memory pair game [5]. In their social HRI experiment they evaluated whether an action of the robot changes the user's state from a stressed to a non-stressed state (n=10). They show that their assistive robot is able to learn its optimal assistive bahviours in personalized interactions. Nevertheless, they did not show whether the robot's feedback has a positive impact on the user's task performance nor did they compare their implemented behavior to a non adaptive behavior, or a condition without a robot present.

The use of SAR for designing intelligent cognitive therapies for people with dementia has been studied in [14]. They hypothesized that an adaptive behavior of a SAR can improve patient's task performance on a cognitive game. The adaption adjusts the difficulty of the game to the abilities of the player. They observed an improvement in game performance and got more engaged to the robot and game task over time. However, they did not show any significant results that can explain that the robot's feedback had significant impact on user's task performance. Also they did not show whether the task engagement was induced by the robotic system or the task itself.

These works show insights for designing socially assistive robots. The influence of different feedback types on user's behavior change give strong indications for designing feedback mechanisms. The differences in user's task performance between physical present robots and no physical presence show that the embodiment has influence on the user's learning gains and that robots can elicit social pressure effects. This is also supported by a social facilitation study using an anthropomorphic robot head [12]. Furthermore, people tend to have a stronger alliance to robots and task enjoyment is also higher when accompanied by a robots than with a non physical present robot. Thus, there is a strong indication that the physical presence of a robot has an impact on the user's task performance, which led to an exclusion of evaluating our system to an avatar.

Compared to previous studies, our study investigates how different interaction strategies (e.g. a robot providing generic motivational feedback or task related feedback while assisting during a cognitive task) influences the perception of the robot and task compared to a *no-robot* condition where no feedback is given at all. As described in the introduction, we hypothesize that users perform better on a cognitive task due to social facilitation effects and that a task-related feedback has a stronger impact on the user's task performance.

2 METHODOLOGY

2.1 Participants

In total we had 60 participants (30 female), which we assigned to the different groups as follows. There were 21 participants with mean age 27 (*SD*=5.84) in the *no robot* group, 20 participants with mean age 23.1 (*SD*=0.93) in the performance group and 19 with mean age 24 (*SD*=2.21) in the structuring group. Most participants were German undergraduate and graduate students from Bielefeld University and received chocolate bars for their efforts. The experiments were conducted in one of our laboratories on campus.

2.2 Apparatus

The participants were asked to solve several mental rotation problem sets, each consisting of 12 mental rotation tasks [11]. They had three minutes for one set and a one minute break between two sets. In conditions where a robot tutor was present, the tutor gave either performance related feedback (*performance condition*) or simple motivational phrases (*structuring condition*) between two problem sets . We compare the amount of succesfull answered problems between the groups, as well as the survey answers the participants gave after the experiment.

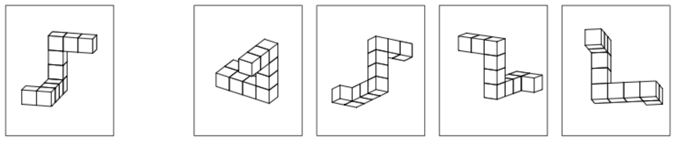

Figure 1: Sample item of the cognitive test. Stimulus on the left is the target, on the right four possible solutions are presented, with stimuli 1 and 3 being correct rotations of the target.

Task The cognitive test we used in our experiment examines the ability to mentally rotate three-dimensional objects. We used three different versions, each consisting of 24 different items evenly distributed over two test halves. Version B comprises reshuffled items taken from Version A, while Version C requires both vertical and horizontal mental rotation. Each item consists of one target and four possible answers (comp. Figure 1). Two of them are rotations of the target, two are distractors. To answer one problem correctly, the participant has to mark the two correct rotations of the target figure. The mental rotations test thus provides a quantitative measure in terms of test scores allowing an evaluation of the effects of the robot's assistive behavior. Originally, subjects have three minutes per test half and a four minute break in between. In order to induce more stress, we changed the test procedure to a one minute break between to test halves.

In every condition, the task was running on a touch screen computer where the participants could navigate through the task introduction and example test and mark their chosen answers using the touch interface. In the *performance* condition, the users also had the option to navigate through the task introduction and example test via voice command the robot. However, they still had to mark their answers during the test using the touch interface.

Task Measure To asses the user's task performance, we used a task measure based on the cognitive test. In each problem set, the user has 12 problem sets, where each set consists of two correct solution of the mental rotation and two wrong. A problem set is answered correctly if both correct rotations were marked. Thus, the user can have a maximum score of 12 and a minimum score of 0 for one problem set and a maximum of 24 points for each version respectively. Furthermore, the systems evaluates how often the user changes his decision on one problem set, how much time they needed to answer a problem and how much time they needed in total to answer the whole problem set. Based on these features, the system in the *performance* condition can generate appropriate feedback according to the task measurements which is described in the following paragraph.

Robot We used the humanoid robot NAO [4] as platform, which was equipped with face detection and speech recognition capabilities. In both *robot-present* groups the participants were introduced to the test procedure and conducted a trial exercise instructed by the robot (see Fig. 2). In order to compare the *robot-present* groups and the *no-robot-present*, the same text the robot spoke during the introduction was also displayed on the touch screen computer. Besides the feedback the robot gave during the breaks, it also warned the user when there was only one minute left for answering the current problem set. The robot in the *structuring* condition provided the user with simple motivational phrases (i.e. “You are doing really well, keep up!”, “You are halfway through the test, only three problem sets left.” or “Try to relax a bit during the break.”). The phrases are accompanied by gestures and postures (i.e. folding hand behind robot’s neck to indicate relaxation). During the *performance* condition, the robot gave feedback to the user regarding their task processing (i.e. ”Try to stick to an answer.“ when they changed their mind to often on a problem set and their task score is low, ”Don’t rush through the problems. You have plenty of time.“ when they answered the set very quickly and their task score is low, or ”You were doing really good“ when their task score was high).

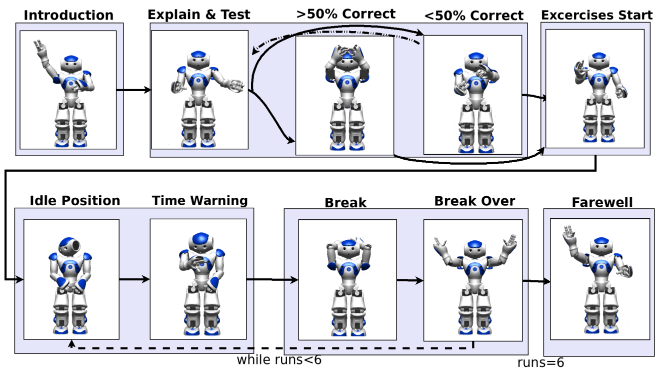

Figure 2: Robot’s structuring baseline behavior.

Since, we wanted to evaluate the effects of the physical presence of the robot, users in the *no-robot-present* condition had no performance or motivational feedback at all. Using this evaluation setup, we want to examine whether the physical presence of the robot has positive effects at all and is not a distraction for the user (e.g. the user in the *no-robot-present* condition could also have significantly higher test results compared to the *robot-present* conditions because the robot is a distraction or puts them under too much social pressure).

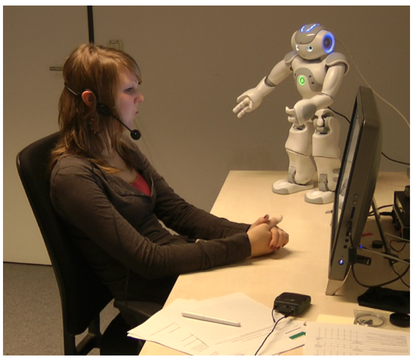

Figure 3: Experimental setup: Participant, Nao, and touch screen computer.

Procedure The participants were introduced to the touch computer, told to follow the instructions on the display/of the robot and to answer the survey after they have completed the test. During the experiments, participants were alone with the computer and the robot (in conditions including a robot). They were recorded with cameras behind and in front of them. The survey included the Negative Attitudes towards Robots Scale (NARS), task complexity (e.g. ”How {difficult|exhausting|stresful|complicated|annoying|interesting| fun|challenging|unusual} was the task?“), a personality scale and how the perceived the experiment (”Did you have fun?“,”Did you know the exercise?“,”Did you feel evaluated?“,”Did you feel observed?“). The survey answers were mapped on 7-point Likert-scales(1:strongly disagree, 7:strongly agree).

3 RESULTS

This study questioned whether presence and different interaction strategies of a socially assistive robot have positive effects on human’s task performance during cognitive tasks. Hence, we implemented a control condition in order to approve the results of our previous study. If the robot has measurable positive effects on the human, the performance in the control study should be lower than the one in the structuring feedback group and in the one where the robot gave personalized performance feedback. Moreover, due to novelty effects, the task where the robot was present should be evaluated as more pleasant and more fun.

First of all, the groups do not differ in their experience with robots and mental rotation tests .

Task Performance Figure 4 shows the results for each test set. While there is a significant difference between the *perfomance based* condition and the *structuring* condition(($t(34) = 1.70, p < .05$) for the first test version (MRT A) and $t(34) = 1.81, p < .05$ for the last test set (MRT C 1), there is no significant difference between the *no-robot* and *structuring* condition (see Table 1). Nevertheless, there is a significant difference between the *performance based* condition and the *no-robot* condition for MRT A ($t(36) = 1.7385, p < .05$)

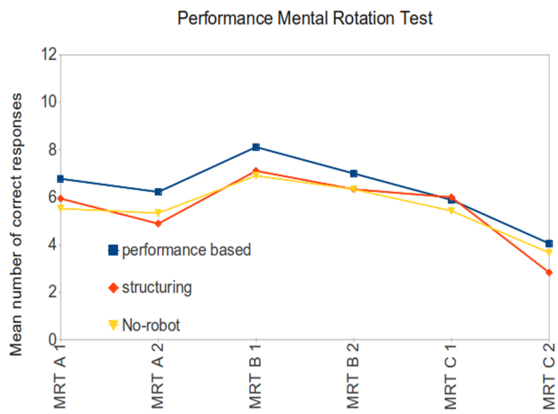

Figure 4: Average test score for the mental rotation test. Overall, the test scores are increasing at first due to adaptive effects. Afterwards the results are decreasing again due to cognitive load.

Negative Attitudes Towards Robot Scale We investigated anxieties towards robots using the *Negative Attitudes Towards Robots Scale* (NARS)[10]. The results show that there is tendency for lower anxiety from the *performance based* condition compared to the *no-robot* condition (see Figure 5). A comparison between the groups

Table 1: Task perception and performance - Mean (*M*) and standard deviation (*SD*) for the *structuring*, *performance based* and *no-robot* condition.

	structuring		*performance based*		*no-robot*	
	M	*SD*	*M*	*SD*	*M*	*SD*
MRT A	5.41	1.85	6.5	1.96	5.4386	2.71
MRT C, 2nd set	2.83	1.61	4.05	2.36	3.7	2.13
feeling evaluated	5.41	1.85	6.5	1.96	4.05	1.98
observed	2.83	1.61	4.05	2.36	3.71	1.97
fun	4.58	1.68	4.9	1.56	3.8	2.33
exercise known	2.61	2.09	2.63	2.01	2.80	2.06

showed that in the condition where no robot was present, the negative attitudes towards robots were significantly lower compared to the group where the robot gave simple structuring feedback (no-robot vs. structuring: $t(38)$=-2.3823, $p<0.05$, no-robot vs. performance: $t(38)=t(36)$=-3.2585, $p=0.5290$).

Subjective Task Ratings Furthermore, we investigated if the user's perception regarding the task has changed and whether the user felt more observed or evaluated while being assisted during task execution (see Table 1 for mean values and standard deviation). Figure 5 shows the mean values.

First of all, the task was unkown for the greater part of the participants. Participants in the *no-robot* group and the *performance* group have felt significantly more evaluated, than in the *structuring* group ($F(2,56)$=5.4036, $p<0.05$, *performance* vs. *structuring*: $t(36)$=-3.2585, $p<0.05$, *no-robot* vs. *structuring*: $t(38)$=-2.992, $p<0.05$).

The perception of being observed was highest in the *no-robot* condition and lowest in the *performance* condition, but not significantly different (*no-robot* vs. *performance*: $t(38)$=-1.7646, $p=0.0857$).

Furthermore, the participants in the *performance* condition rated the experiment as more pleasant/fun as in the *no-robot* condition (*no-robot* vs. *performance*: $t(37)$=1.7145, $p<0.05$, *no-robot* vs. *structuring*: $t(37)$=1.1925, $p=0.2407$)

The task rating (challenging, exhausting, annoying, complex) was the lowest in the no-robot condition. This means that participants in the *no-robot* condition perceived the task easier, less annoying and less complex than in the other conditions. However, the differences are not significant (*no-robot* vs. *structuring*: $t(38)$=-1.5343, $p=0.0917$, *no-robot* vs. *performance*: $t(38)$=-1.0896, $p=0.2828$).

4 Discussion

Results from our previous work showed that different interaction strategies have an impact on the perceived assisting capabilities of a system [13]. Participants in the *performance* condition felt significantly more evaluated by the presence of the robot than in the *structuring* condition. They also rated the system as more competent and motivating. This is also supported by the finding that people who rated the task as exhausting felt more motivated and the presence as appropriate than in the condition where the robot just gave motivational phrases.

Our current results confirm that a present robot has positive effects on user's performance. Nevertheless, the results suggest that assistive robots can not only have positive effects on task performance, they can also be a disturbance for the user. This can be concluded from the result that users in the *structuring* condition have no significantly better task results than the participants in the *no-robot* condition. One explanation could be that the robot gives them just general advices and feedback which is not related to the real user's performance and thus distracts them. The disturbance might also arise from the unique task and the study conditions. We changed the original task procedure to induce time pressure and thus creating a strenuousness situation. Thus, task irrelevant feedback from the robot could even worsen the user's ability to concentrate on the task. However, the curve characteristic is the same in all conditions. The score is dropping from the first to the second set and rising again due to learning effects. Afterwards, the score is dropping due to high cognitive load.

Surprisingly, participants in the *no-robot* condition felt significantly more observed than in any other condition. Hence, one can assume that the presence of the robot could have a relieving effect on user's comfort feeling, because they can ascribe to the robot that it is observing them. Whereas, in the *no-robot* condition the users did not know at all what the experiment is used for and who is going to evaluate their results.

Moreover, our reported result that feeling of beeing evaluated is significantly higher in the *no-robot* and *performance* condition than in the *structuring* shows that not only the presence of the robot has an effect on the user's experimental perception, but that an assistive robot also needs to have a meaningful feedback towards the user in order to evoke behavioral and sensation change.

The hypothesis that robots elicit more enjoyable experimental condition is supported by the results that users rated the experiment as more pleasurable than in any other condition when the robot was present and gave actual task related feedback to the user.

Previously, we hypothesized that a *no-robot* condition would lead to a decrease in motivation (in terms of task difficulty). Our results do not show that the presence of a robot has an effect on the task perception rating. The participants in the *no-robot* condition rated the task as easiest compared to the other conditions. This might be an indication for social facilitation effects, where the presence of a robot during execution of difficult and unknown tasks leads to weaker performance and causes discomfort [12].

Interestingly, in conditions where the users rated the highest feeling of being evaluated, they also felt the task as more difficult and reported the highest negative attitudes towards robots. This result indicates that the task difficulty is closely coupled to the presence of the robot and the interaction strategy of the robot. When they have problems with the task, they feel even more evaluated by the assistive system and therefore also tend to have in general more anxieties towards robots. Hence, the presence of robot's feedback has a biasing effect on how people perceive robots in general. The participants reported higher feelings of negative attitudes towards robots, if the present robot did not give adequate assistance according to the task. This can also be supported from the result that user's rated the robot more competent in the *performance* feedback condition than in the *structuring* condition ($t(34)$=1.79, $p<.05$).

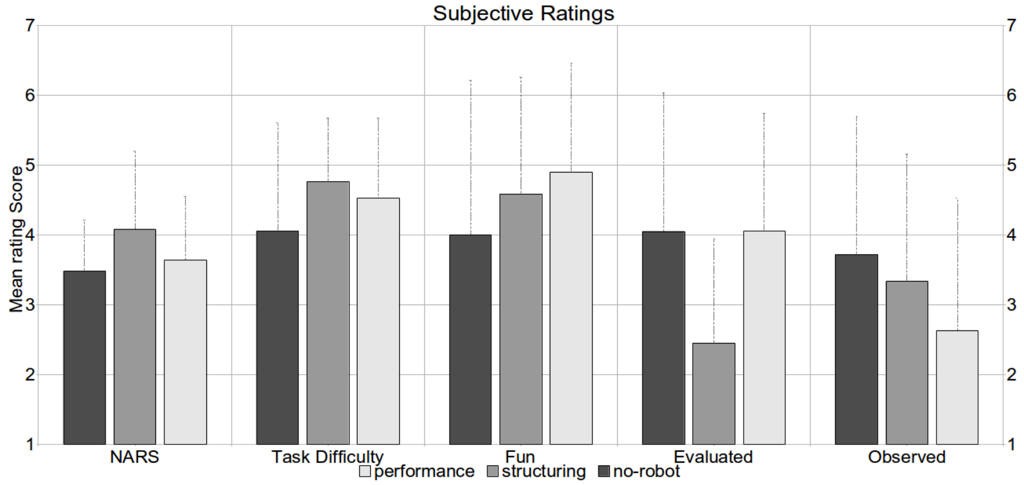

Figure 5: Results of the survey completed after the cognitive task.

5 Conclusion

Concluding, our work presents effects socially assistive robots have on a user's task perception and performance while being assisted during a cognitive demanding task. Three studies were conducted, two with a robot assisting the user and one without a robot. Our results indicate that a robot giving performance related feedback has significant effects on task performance compared to conditions where the robot gave structuring feedback or no robot was present at all. Our hypothesis, that the user feel more observed during task execution when accompanied by a robot can neither be confirmed nor rejected, because we have no significant different results.

Moreover, we showed that a robot giving user specific advices leads to a higher exercise enjoyment compared to structuring feedback and no feedback at all. We also have results indicating that the presence of a robot and the regarded helpfulness can bias the general negative attitudes towards robots.

Future work includes an objective validation of the task perception (in terms of strenuousness). This might include physiological measurements to objectively investigate the cognitive demands and to be able to qualify the assistance during our presented task and other stressfully or cognitive demanding tasks. Furthermore, also a study setup with a fairly easy task needs to be implemented in order to evaluate social facilitation effects. A robot assisting users during easy tasks might be a distraction for the user.

The effects need to be tested in the long term. One can assume that a robot giving always the same feedback which is not adapting to the user's experience will be boring for the user. Hence, a study can reveal what requirements arise when designing such a system for repeating long-term interactions. Moreover, in the long-term not only the response of the robot should adapt to the user's experience, but also the task difficulty itself. As previous related work shows, an adaptive task difficulty enhances the user's engagement and enjoyment to the training.

At last, the results of this work compared with lessons learned from previous studies, show that a combination of a physical present robot giving performance related feedback which adapts on the long-term to the user's experience will have the biggest impact on the user's task performance, enjoyment, engagement and motivation to interact with the system over extended periods of time. Our results show that the robot's type of feedback is important to have an eye on when designing SAR scenarios and that there is a connection between the perception of the robot's helpfulness and the difficulty of the task. Thus, our findings should help upcoming research to consider how they want to design a robot's feedback and that not only motivational or praising phrases have an effect on the user's task processing and task perception, but also that the feedback needs to be suited to the user's demands.

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REFERENCES

[1] J. Engelberger, *Robotics in Service*, MIT Press, 1989.

[2] J. Fasola and M. J. Matarić, 'Robot motivator: Increasing user enjoyment and performance on a physical/cognitive task', in *International Conference on Development and Learning*, Ann Arbor, MI, (Aug 2010).

[3] Terrence W Fong, Illah Nourbakhsh, and Kerstin Dautenhahn, 'A survey of socially interactive robots', *Robotics and Autonomous Systems*, (2003).

[4] David Gouaillier, Vincent Hugel, Pierre Blazevic, Chris Kilner, Jérôme Monceaux, Pascal Lafourcade, Brice Marnier, Julien Serre, and Bruno Maisonnier, 'Mechatronic design of nao humanoid', in *Proceedings of the 2009 IEEE International Conference on Robotics and Automation*, ICRA'09, pp. 2124–2129, Piscataway, NJ, USA, (2009). IEEE Press.

[5] Goldie Nejat. Jeanie Chan, 'Social intelligence for a robot engaging people in cognitive training activities.', *Int J Adv Robot Syst*, (2012).

[6] Cory D. Kidd and Cynthia Breazeal, 'Robots at home: Understanding long-term human-robot interaction', in *IROS*, pp. 3230–3235, (2008).

[7] D. Leyzberg, S. Spaulding, M. Toneva, and B. Scassellati, 'The physical presence of a robot tutor increases cognitive learning gains', in *Proceedings Proceedings of the 34th Annual Conference of the Cognitive Science Society*, (2012).

[8] Richard M. Mahoney, H. F. Machiel Van der Loos, Peter S. Lum, and Chuck Burgar, 'Robotic stroke therapy assistant.', *Robotica*, **21**(1), 33–44, (2003).

[9] C. Midden and J. Ham, 'Using negative and positive social feedback from a robotic agent to save energy', in *Proceedings of the 4th International Conference on Persuasive Technology*, Persuasive '09, pp. 12:1–12:6, New York, NY, USA, (2009). ACM.

[10] T. Nomura, T. Kanda, T. Suzuki, and K. Kato, 'Prediction of human behavior in human–robot interaction using psychological scales for anxiety and negative attitudes toward robots', *IEEE Transactions on Robotics*, **24**(2), 442–451, (2008).
[11] M. et al. Peters, 'Brain and cognition', volume 28, pp. 39–58, (1995).
[12] N. Riether, F. Hegel, B. Wrede, and G. Horstmann, 'Social facilitation with social robots?', in *International Conference on Human Robot Interaction, HRI 2012*, (2012).
[13] Sebastian Schneider, Ingmar Berger, Nina Riether, Sebastian Wrede, and Britta Wrede, 'Effects of different robot interaction strategies during cognitive tasks.', in *ICSR*, eds., Shuzhi Sam Ge, Oussama Khatib, John-John Cabibihan, Reid G. Simmons, and Mary-Anne Williams, volume 7621 of *Lecture Notes in Computer Science*, pp. 496–505. Springer, (2012).
[14] A. Tapus, C. Tapus, and M.J. Mataric, 'The use of socially assistive robots in the design of intelligent cognitive therapies for people with dementia', in *Rehabilitation Robotics, 2009. ICORR 2009. IEEE International Conference on*, pp. 924–929, (June 2009).
[15] Holly A. Yanco, 'A robotic wheelchair system: Indoor navigation and user interface', in *Lecture notes in Artificial Intelligence: Assistive Technology and Artificial Intelligence*, pp. 256–268. Springer-Verlag, (1998).