Robot Motivator: Increasing User Enjoyment and Performance on a Physical/Cognitive Task

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Abstract— **We describe the design and implementation of a socially assistive robot that is able to monitor the performance of a user during a combined cognitive and physical task, with the purpose of providing motivation to the user to complete the task and to improve task performance. The work presented aims to study the effects of verbal praise, encouragement, and motivation on a user's enjoyment of the task, and to analyze the effectiveness of online adaptation of the task in response to user performance, with the goal of reducing user frustration and increasing user intrinsic motivation. A three-condition study was constructed for evaluation of the robot; the results of the robot's interaction with human users are presented.**

I. Introduction

SOCIALLY Assistive Robotics (SAR) [1] is an area of Human-Robot Interaction (HRI) that focuses on aiding users through social rather than physical interaction, and has the potential to enhance the quality of life for large user populations, including the elderly, people with physical impairments, and those involved in rehabilitation therapy (e.g., post-stroke patients). The world's population is growing older, thereby introducing a wide array of societal challenges. It is estimated that in 2050 there will be three times more people over the age 85 than there are today. Many are expected to need physical and cognitive assistance. As the elderly population continues to grow, a great deal of attention and research will be dedicated to assistive systems that allow the elderly to live independently in their own homes. In those contexts, the main purpose of socially assistive robotics technology is not to replace human care-givers, but rather to provide assistance where human assistance is not available or affordable.

The American Alzheimer's Association reported that more than one million residents in assisted living residences and nursing homes have some form of dementia or cognitive impairment [2]. As with numerous other diseases, there is no cure for dementia but medication and special therapy can improve disease symptoms. Non-pharmacological treatments focus on physical, emotional, and mental activity.

The robotics literature concerned with long-term studies in the area of therapeutic robots for individuals suffering from dementia and cognitive impairment is very limited. Some of the representative work is described below. In their research work [11], Libin and Cohen-Mansfield describe a preliminary study that compares the benefits of a robotic cat and a plush toy cat as interventions for elderly persons with dementia. Furthermore, Kidd, Taggart, and Turkle [12] use Paro, a seal robot, to explore the role of the robot in the improvement of conversation and interaction in a group. Past work from our group, by Tapus, Tapus and Matarić [5], describes SAR-supervised cognitive task learning for individuals with mild Alzheimer's Disease.

The majority of existing work in post-stroke rehabilitation robotics focuses on hands-on robotic systems for passive exercise. Burgar, Shor et al. [13] developed a robot-assisted arm therapy workstation, in which patients can exercise their upper limbs and evaluate their performance. A similar device that also depends on hands-on robotic technology was developed by [14].

Our focus is on building and studying the effectiveness of socially assistive robotics technology towards providing affordable customized care for individuals in need of assistance [4, 5], with particular emphasis on how the user's intrinsic motivation can be influenced by a socially assistive robot in order to maximize the probability of success of the therapeutic intervention.

II. Intrinsic Motivation Theory

Motivation is a fundamental tool in establishing adherence to a therapy regimen or task scenario and in promoting behavior change. There are two forms of motivation: intrinsic motivation, which comes from within a person, and extrinsic motivation, which comes from sources external to a person. Extrinsic motivation, though effective for short-term task compliance, has been shown to be less effective than intrinsic motivation for long-term task compliance and behavior change [6].

Intrinsic motivation, however, can be and often is affected by external factors. In a task scenario, the instructor (a socially assistive robot, in our case) can impact the user's intrinsic motivation through verbal feedback. Praise, for example, is considered a form of positive feedback and has the potential to increase the user's intrinsic motivation for performing the task, whereas criticism, a form of negative feedback, tends to negatively impact the user's intrinsic motivation [9, 10]. The effect of positive feedback, however, is closely tied to the user's own perceived competence at the task. That is to say, once the user believes he is competent at the task, then additional praise no longer affects his intrinsic motivation.

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Indirect competition, wherein the user is challenged to compete against an ideal outcome, has also been shown to increase user enjoyment on an otherwise non-competitive task [7]. For example, when the user is shown her high score on the task, her intrinsic motivation for the task tends to increase as she strives to compete with her previous accomplishments. Thus, in a task scenario, it is important that the task instructor continually reports to the user his/her task performance scores during the performance of the task, for motivational purposes.

Verbal feedback provided to the user by the instructor certainly plays an important role in task-based motivation, but the task itself and how it is presented to the user perhaps plays an even more significant role. Csikszentmihalyi's research suggests that "when one engages in an optimally challenging activity with respect to one's capacities there is a maximal probability for task-involved enjoyment or flow" [8]. He also states that intrinsically motivated activities are those characterized by enjoyment. Simply put, people are "intrinsically motivated under conditions of optimal challenge" [3]. If a task is below the optimal challenge level, it will be too easy for the user and result in boredom. Alternatively, if the task is above the optimal challenge level, it will be too hard and the user will get anxious or frustrated. Therefore, an instructor that oversees user performance in a task scenario should also be aware of the user's current affective state or try to infer that state from task performance. The task must be continually adjusted to meet the appropriate needs of the user in order to increase or maintain intrinsic motivation to perform the task.

III. Goals and Approach

The work presented in this paper is an experimental implementation of a socially assistive robot whose purpose is to motivate users to complete and improve their performance on a combined cognitive and physical activity. The overall goal of the pilot study is to evaluate and validate the effectiveness of the SAR technology to gain insight for a future study geared towards the intended user populations in need of such customized assistance, such as the elderly and/or stroke patients.

The specific aims of the study were to analyze the following factors:

1) The effects of verbal praise and encouragement on the participant's enjoyment level of the task;
2) The participant's motivation to increase performance when prompted by the robot to try and improve upon their previous scores;
3) The effects of online adaptation of the task itself, in response to the performance level of the participant, for the purpose of increasing the intrinsic motivation of the user to complete the task.

IV. Robot Test-Bed

To address the role of the robot's physical embodiment, we used a biomimetic anthropomorphic robotic platform that consists of a humanoid torso, mounted on a MobileRobots Pioneer 2DX mobile base (equipped with a speaker, and a SICK LMS200 eye-safe laser range finder). The custom-developed torso contains 21 controllable degrees of freedom: 7 DOF arms (x2), 1 DOF gripping hands (x2), 2 DOF pan/tilt neck, 1 DOF expressive eyebrows, and a 2 DOF expressive mouth. A picture of the robot is shown in Fig. 1. All actuators are servos allowing for gradual control of the physical and facial expressions. The laser range finder mounted on the robot was used to actively track the user during the experiment conditions, expressed with the robot's head panned directly towards the user at all times, for the purposes of increasing user engagement with the robot.

Fig. 1: Robot platform used in the experiments.

V. Experiment Design

A. Experiment Scenario

The experiment scenario consisted of a socially assistive robot whose purpose was to instruct, evaluate, and motivate a human user to perform a combined cognitive and physical task. The task was a memory game similar to Simon, wherein the robot gives the user a sequence of buttons to press, to be remembered and performed correctly. The sequences could range in difficulty, from three buttons up to nine buttons, and the time taken by the user to complete the sequences was measured by the robot in order to motivate improvement. Each sequence was reported to the user through the robot's speech interface, after which the user was given thirty seconds to repeat the sequence. Upon correct completion or failure, the robot reported the score to the user in the form of announcement of failure or success with the elapsed time. Three buttons (A, B, and C) were used to construct the sequences; they were located on stands that were placed at positions around the room such that no two were within arm's reach of one another. The placement of the buttons, along with the reporting of the elapsed time on the task, contributed a physical component to the game to complement the traditional cognitive (memory) component.

The buttons were placed between the robot and the user in order to encourage the user to look at the robot during the game to facilitate the interaction and social connection between the two, needed for the robot to effectively motivate the user. A schematic of the experiment layout is shown in Fig. 2.

This combined physical/cognitive task was chosen because of its potential to challenge the participants of the pilot study according to their capabilities, who comprised exclusively of university students. While the task is most likely not suitable for elderly and stroke patient populations in an assistive context, the insights and general principles gained from this study, primarily concerning the robot's effect on user motivation and enjoyment, can be applied to a future study in which the task is appropriately modified for the populations in need of assistance.

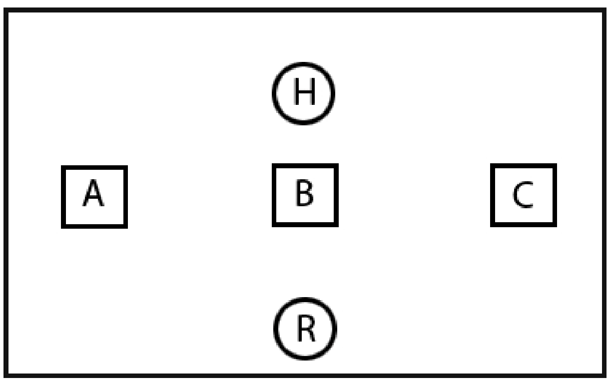


Fig. 2: Experimental setup with locations of buttons (A,B,C), human participant (H), and robot (R) shown.

B. Experiment Conditions

Three experiment conditions were tested in the study in order to evaluate the effectiveness of different components of the system and the users' reaction to them. The conditions developed were grounded in theories obtained from research in psychology, in the area of intrinsic motivation. The three conditions were as follows:

1) Report Condition: The baseline condition for the experiment was the Report condition, in which the robot only served as the game instructor and evaluator. The robot did not try to explicitly motivate the user to improve performance on the task, and hence all desire for improvement came from the user's own intrinsic motivation upon receiving the scores reported by the robot. In this condition, the robot increased the difficulty level of the sequences at a constant rate without taking into account the performance of the user. At each level (determined by the button sequence length), the robot first reported two sequences for the user to try to repeat, and instead of a novel third sequence, the robot then prompted the user to repeat one of the two previous sequences. This allowed the user to try and improve on recent performance, without the robot explicitly challenging the user to do so. Therefore all, if any, motivation to improve came solely from the user.

2) Praise Condition: The game sequencing in the Praise condition was the same as in the Report condition, as the difficulty increased again at a constant rate. However, in this condition, the robot not only reported the score to the user, but also praised the user for correct sequences, and reassured the user in the case of failure. For example, upon successful completion of a sequence, the robot might have said to the user "Great job!" or "Wow, that was awesome" in addition to reporting the elapsed time. If the user instead failed to correctly repeat the sequence, the robot might have said "Unlucky, it was BCB, not BCA." The robot chose randomly at run time from a large set of phrases for praise and reassurance, to keep the interaction fluid and unpredictable. To test the ability of the robot to motivate the user, when a sequence was presented for the second time, the robot explicitly challenged the user to improve performance time.

3) Challenge Condition: The Challenge condition was exactly the same as the Praise condition, except in the way the robot changed the difficulty level of the sequences given to the user. The goal of this condition was to continually modify the difficulty of the game in order to reach the user's optimal challenge level for maximal enjoyment, based on Csikszentmihalyi's theory on intrinsic motivation. The robot tried to accomplish this by quickly advancing in the game based on the user's performance. For example, the game started at the base level with three buttons in a sequence; if the user repeated the sequence correctly, the robot increased the difficulty immediately to four buttons in the next sequence. The robot continued to increase the difficulty level based on the user's success, and only stopped when the user failed on a sequence. The robot kept track of all sequences given along with user performance, so as to continually assess the appropriate level of difficulty to give the user. If the user failed at a certain level, the robot decreased the difficulty, however if the user did well enough on the resulting level, the robot jumped to the next level again in order to maintain the state of optimal challenge. The pseudo-code for this adaptation procedure is provided in Fig. 3. An example condition given for level promotion is one in which the user got two sequences correct in a row at the current level; alternatively an example given for level demotion is on one in which the user got a sequence incorrect at the current level and the correctness record at the current level was below 50%. This was a departure from the game sequencing in the previous two conditions, which increased difficulty at a constant rate and never decreased the difficulty level during the game. When the user's performance called for a level promotion, the robot may have instead challenged the user to repeat and improve upon the previous button sequence before level promotion occurred; this sequence repetition was used to test the robot's motivational capabilities.

C. Hypotheses

The hypotheses motivating the study were as follows:

1) The participants will find the Praise condition more enjoyable than the Report condition;
2) The participants will find the Challenge condition more enjoyable than the Praise and Report conditions respectively;
3) The participants will find the Challenge condition less frustrating than the Praise and Report conditions, respectively;
4) The robot will be able to motivate the participants to try to improve task performance.

The first hypothesis was motivated by the results from Vallerand and Reid [9, 10], namely that verbal praise and encouragement can increase intrinsic motivation and hence the enjoyment level on a given task. For the same reason, the Challenge condition was hypothesized to be more enjoyable than the Report condition. The Challenge condition was hypothesized to create greater enjoyment over the Praise condition due to its attempt to adapt to the user's "optimal challenge" level based on their performance. This, in turn, had the potential to further increase the user's intrinsic motivation to perform the task beyond the level reached from verbal praise alone. Similarly, the third hypothesis reasoned that the adaptation procedure of the Challenge condition had the greatest potential of the three conditions to reduce user frustration by adjusting the difficulty level of the task itself. The fourth hypothesis was based on the notion of "indirect competition," where the user was challenged to compete against an ideal outcome. In the cases of the Praise and Challenge conditions, the ideal outcome was the previous score the user obtained on the given button sequence to be repeated, a goal which needn't have been considered unbeatable by the user, and hence may have provided an additional incentive to improve on the task.

```
ADAPTGAMELEVEL(level_cur, correct_row, incorrect_row)
state ← empty
if correct_row ≥ 2  OR
   ( ABOVE50(level_cur)  AND  correct_row ≥ 1
     AND ( num_given[level_cur + 1] = 0  OR
           num_correct[level_cur + 1] ≥ 1 ) )
  state ← PROMOTE
else if incorrect_row ≥ 1  AND
        NOT ABOVE50(level_cur)
  state ← DEMOTE
else
  state ← STAY
return state


ABOVE50(level)
return num_correct[level] / num_given[level]  ≥  0.5
```

Fig. 3: The game adaptation procedure of the Challenge condition, which takes as arguments the current level, the current number of sequences the user has completed correctly in a row, and the current number of sequences the user got incorrect in a row (these two are mutually exclusive).

VI. RESULTS

A. Data Collection

Ten participants were recruited to take part in all three conditions of the study; all were university students with technical knowledge of engineering. The order of the conditions presented to the participants was counter-balanced. As such, out of the six possible orderings of the three conditions, five were presented twice with only one ordering given to a single user. The button sequences given by the robot in the Report and Praise conditions were the same for all participants. The sequences given by the robot in the Challenge condition changed due to the adaptation of the robot based on the participant's performance and were randomly generated at run-time. During each condition, the performance of the user, namely time on task and correctness for each sequence given, was recorded for analysis. After the three conditions were finished, each participant was asked to complete a short questionnaire regarding the experience with the robot.

The following questions were asked in the questionnaire:

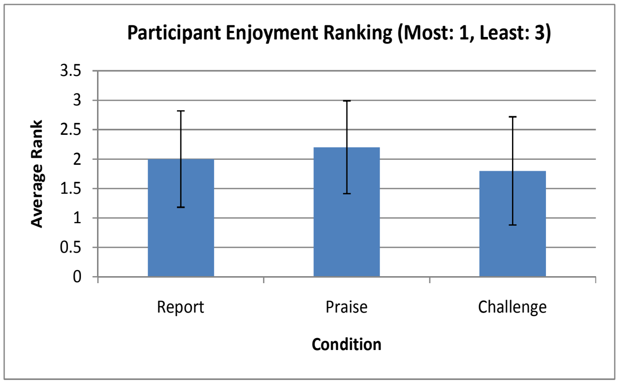
1) Rank the conditions in order of most enjoyable to least enjoyable.
2) Rank the conditions in order of most frustrating to least frustrating.
3) Rank the conditions in order of most challenging to least challenging.
4) Did you feel like you were interacting with the robot, or did you tend to ignore it?
5) Did you feel motivated by the robot to improve your performance when the robot challenged you to do so?

B. Hypothesis 1: Praise > Report Enjoyment

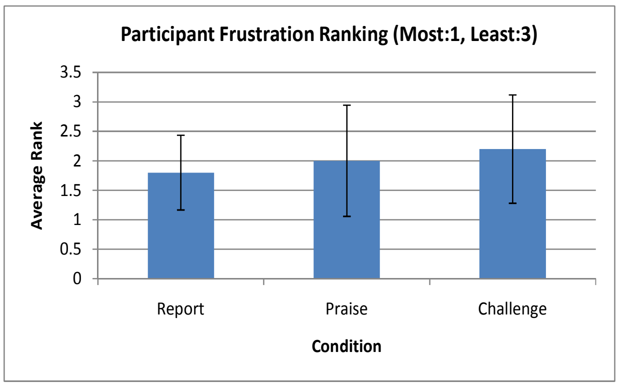
The average ranking of the three conditions among all participants in answer to the first question is shown in Fig. 4(a). The results demonstrate that our first hypothesis is not supported by the data, as the Praise condition received an average ranking of 2.2, in a ranking scale where 1 indicates the most enjoyable condition and 3 indicates the least enjoyable condition, while the Report condition received an average ranking of 2.0, which suggests that the Praise condition was slightly less enjoyable than the Report condition. Furthermore, only 4 of 10 participants surveyed reported the Praise condition as being more enjoyable than the Report condition, and the Praise condition received 4 votes for the least enjoyable condition, the maximum in that category.

C. Hypothesis 2: Challenge > Praise, Report Enjoyment

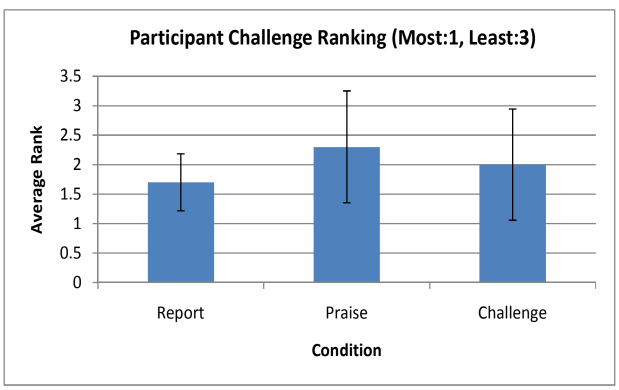
The results show that our second hypothesis is supported by the data collected, as the Challenge condition received an average ranking of 1.8, while the Report and Praise



(a)



(b)



(c)

Fig. 4: Graphs of average rank of conditions for three survey questions, with standard deviation shown. (a) Enjoyment ranking. (b) Frustration ranking. (c) Challenge ranking.

conditions received average rankings of 2.0 and 2.2, respectively, in answer to the first survey question. These results suggest the Challenge condition was found to be slightly more enjoyable than both the Report and Praise conditions. In addition, 6 of 10 participants reported the Challenge condition as being more enjoyable than the Report and Praise conditions respectively, and the Challenge condition received 5 votes for the most enjoyable condition, the maximum total in that category.

D. *Hypothesis 3: Challenge < Praise, Report Frustration*

The average ranking of the three conditions in answer to the second survey question among all participants is shown in Fig. 4(b). The results show that our third hypothesis is consistent with the experience of most of the study participants, as the Challenge condition received an average ranking of 2.2, while the Report and Praise conditions received average rankings of 1.8 and 2.0 respectively, on a scale where 1 indicates the most frustrating condition and 3 indicates the least. Hence, the survey responses suggest that the Challenge condition was found to be slightly less frustrating than both the Report and Praise conditions. Furthermore, 6 of 10 participants reported the Challenge condition as being less frustrating than the Report and Praise conditions. The Challenge condition also received 5 votes for the least frustrating condition, the maximum in that category.

E. *Hypothesis 4: Robot Motivation*

The survey results show that 6 of 10 participants confirmed that the robot was able to motivate them to try and improve their performance, which supports our fourth hypothesis. There were 3 participants who stated that the robot did not have any motivational effect on them, and 1 participant was undecided.

F. *Discussion and Further Results*

The survey question asking participants to rank the three conditions based on the challenge level was given in order to more appropriately assess the relationship between perceived challenge and user frustration and enjoyment. The average rankings of the conditions in answer to this question are presented in Fig. 4(c). The survey responses indicate that the participants largely agreed that the Report condition was both the most frustrating and the most challenging condition of the three. In contrast, the Challenge condition was found to be the least frustrating while still being capable of challenging the user. This result suggests that the Challenge condition's praise and adaptation technique was a key element in achieving a good balance between raising the difficulty level of the task and minimizing the frustration level of the user on the task; a balance which may have also helped to increase user task enjoyment as evidenced by the participant responses to the first survey question.

Among the four hypotheses analyzed in the study, three were seen to be consistent with the data collected from the participants. Unfortunately, none of the results were statistically significant, due to the size of the pilot study. An important note to consider is that the order of the conditions presented had an effect on participation level, as some participants reported getting mentally tired towards the end of the experiment, specifically during their third condition. Other participants, however, reported "getting the hang of it" and played better as they participated in subsequent conditions, and stated that neither cognitive nor physical fatigue played a role in their performance. In analyzing the performance of the users on each condition with respect to the condition ordering they were given, no link was found that was deemed statistically significant, which suggests that any effects that the condition ordering may have had on user performance were due primarily to the user's own inclinations and not the conditions themselves.

One of the most interesting results obtained from correlating the participant responses with their recorded performance on all three trials was the fact that 7 of 9 participants with performance records (one participant's performance data failed to be recorded) reported the most enjoyable condition to be the one in which they performed the best, where performance is based on percentage of sequences identified correctly. This result suggests user enjoyment on a task is highly correlated with their performance, and therefore, focus should be put on maximizing the potential for user success when designing the task scenario. In some sense, the Challenge condition embraces this concept, as it was designed to maximize user success by avoiding giving the users sequences that were deemed "too hard" for them. However, facilitating user success does not guarantee user success, and hence there were some cases where participants fared better in either the Report or Praise condition over the Challenge condition.

In response to the survey question on the amount of perceived interaction with the robot, 9 of 10 participants reported feeling little interaction with the robot and that they tended to not look at the robot as it reported the button sequences. Although the responses to this question are not encouraging, almost all of the participants stated that their minimal interaction with the robot was due to the fact that they needed complete concentration when listening to the button sequences, and so their attention was focused on memorization for the task rather than on the robot. This feedback suggests that in order to maintain an acceptable level of human-robot interaction, the amount of cognitive load placed on the user must not be so great as to turn focus away from the robot in order to perform the task. As a result, task scenarios that focus more on the physical rather than cognitive aspect, such as a robot exercise instructor scenario, may be the most suitable for target populations in the assistive context as they promote social interaction while also providing a necessary therapeutic intervention.

VII. Conclusions

In this paper we have presented the design and implementation of a socially assistive robot capable of interacting with people and motivating them to complete a task and, in some cases, improve their performance on that task. The experimental results show the potential of the robot in motivating users and provide insights that inform experimental design for future studies and for the development of SAR systems for use with participants from target populations in need of assistance, such as the elderly and/or stoke rehabilitation patients.

Evidenced by the results is the potential for increasing user task enjoyment by modifying the task online in response to the user. The adaptation procedure implemented in the Challenge condition seems to be the most appropriate method of task design for increasing user enjoyment; however it still may not be the best option for some users who might like to be challenged further or in different ways. To address this issue, increased user feedback during the task may be appropriate. For example, instead of modifying the difficulty of the task according to a set rule book, the robot may ask the user to try something harder or easier. Hence, more direct user control over the task may help with the overall goal of increasing the user's intrinsic motivation and enjoyment on the task, and is worth investigating.

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