Look Like Me: Matching Robot Personality via Gaze to Increase Motivation

Sean Andrist,[1] **Bilge Mutlu,**[1] **Adriana Tapus**[2]
(1) University of Wisconsin–Madison, Madison, WI, USA; (2) ENSTA-ParisTech, Palaiseau, France
sandrist@cs.wisc.edu; bilge@cs.wisc.edu; adriana.tapus@ensta-paristech.fr

ABSTRACT

Socially assistive robots are envisioned to provide social and cognitive assistance where they will seek to motivate and engage people in therapeutic activities. Due to their physicality, robots serve as a powerful technology for motivating people. Prior work has shown that effective motivation requires adaptation to user needs and characteristics, but how robots might successfully achieve such adaptation is still unknown. In this paper, we present work on matching a robot's personality—expressed via its gaze behavior—to that of its users. We confirmed in an online study with 22 participants that the robot's gaze behavior can successfully express either an extroverted or introverted personality. In a laboratory study with 40 participants, we demonstrate the positive effect of personality matching on a user's motivation to engage in a repetitive task. These results have important implications for the design of adaptive robot behaviors in assistive human-robot interaction.

Author Keywords

Human-robot interaction (HRI); gaze; personality; motivation; compliance; similarity-attraction

ACM Classification Keywords

H.1.2 **Models and Principles**: User/Machine Systems—*human factors, software psychology*; H.5.2 **Information Interfaces and Presentation**: User Interfaces—*evaluation/methodology, user-centered design*

INTRODUCTION

Technologies with robotic features and social competence have long been envisioned as integrating into the working and living environments of people. In recent years, this vision has started to become reality, with the development and commercialization of social robotic products such as Jibo[1] and Pepper[2] that serve as family companions in homes, Baxter[3] and Hospi[4] that work alongside people in organizations such as factories and hospitals, and Autom[5] that takes on the role of a personal weight loss coach. Moving forward, social robots are expected take on even larger roles in areas such as education, collaboration, and rehabilitation.

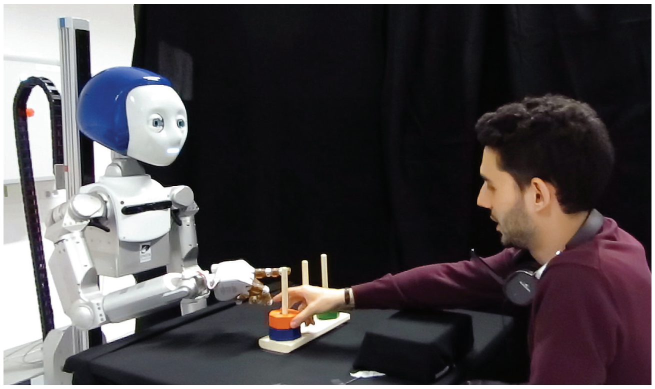

Figure 1. A socially assistive robot guiding a user in a puzzle-solving task.

In the area of rehabilitation, social robots hold great promise for improving the quality of life of the elderly, individuals with physical impairment, and those with cognitive disorders. Social robots envisioned for use in these contexts are referred to as *socially assistive robots* [11]. The purpose of these robots is to assist users by providing information, motivation, and feedback in order to increase compliance with an exercise regimen, take medication on a schedule, perform repetitive tasks for physical or cognitive therapy, and so on. Socially assistive robots are currently being developed to work as caregivers alongside doctors, nurses, and physical therapists [20]; therapy aids for children with autism [12, 39]; and as companions in nursing homes [10, 26].

Patient compliance with treatment for chronic diseases in the U.S. is often below 50%; over half of patients do not take their medication correctly [33]. Following a stroke, one of the most effective rehabilitation methods is for patients to repeatedly exercise the affected limb(s), an activity patients find quite difficult to keep up without a therapist present [9]. A powerful way of improving motivation and compliance in such settings is through nonverbal behaviors and adapting behaviors to the patient's characteristics. Socially assistive robots are particularly engaging in such scenarios due to their physical embodiment and ability to employ nonverbal cues.

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[1] http://www.myjibo.com

[2] http://www.aldebaran.com/en/a-robots/who-is-pepper

[3] http://www.rethinkrobotics.com

[4] http://news.panasonic.net/archives/2013/1105_24824.html

[5] http://myautom.com

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Gaze is a particularly important nonverbal cue in social interactions that robots have at their disposal [8]. Research in human-robot interaction (HRI) has investigated the positive outcomes achievable through a robot's gaze behavior, including increasing the robot's competence in conversations with people [1, 30, 29], enabling joint attention and referential communication [17, 41], and improving upon the robot's ability to hand objects to people [27]. To be truly effective, the robot must be able to *adapt* its behaviors in two ways. First, it must adapt to the unique characteristics of its user, and second, it must adapt to changes in user needs and behaviors throughout an interaction and across multiple interactions.

In this paper, we investigate how robots may achieve the first form of adaptation and present the design and evaluation of gaze behaviors for socially assistive robots that enable the robot to match the personality of the user, thereby more effectively motivating users to repeatedly engage in a therapeutic task. We focus on the extroversion dimension of the Big Five personality model [19] as it is the most accurately observable dimension of personality expressed by nonverbal behaviors over short timescales [25]. We also demonstrate the importance of taking the user's intrinsic motivation into account when attempting to motivate and increase compliance.

BACKGROUND

Three threads of research inform this work, including previous work on socially assistive robots, previous work on adapting technologies to the characteristics—especially personality—of users, and social-science research on the relationship between nonverbal behaviors, personality, and motivation.

Socially Assistive Robots

Prior work has established that the mere presence of a robot can positively affect user compliance in an array of contexts. In previous work where participants were recruited for a weight-loss program, Kidd found that adherence to the program was shortest when participants tracked their progress with pen-and-paper, longer with a computer interface, and significantly longer when reporting their progress to a robot [21]. Even a very simple robot—a Roomba vacuum cleaner robot augmented with a facial display—has been shown to be capable of helping people with medication compliance [42]. Social facilitation theory [28] provides some explanation for the effectiveness of robots in these contexts; the presence of an embodied humanlike robot increases motivation in the same way that the presence of other people increases an individual's drive and enhances their performance in tasks in which the individual is skilled. The robot's physical embodiment and shared physical context create an opportunity for strong engagement between the robot and the user.

To improve effectiveness, the robot must relate to the user with praise and feedback on their actions. Previous research has examined the positive effects of relational discourse—including praise and feedback—in an exercise coach robot leading elderly participants in physical and cognitive exercises [10]. Relational agents have also been found to be effective for delivering health communication and health behavior change interventions to older adults, especially those with low functional health, reading, or computer literacy [2].

Previous research has investigated the ability of social robots to provide cognitive therapy to users, such as older adults with mild cognitive impairments that need help planning and executing everyday activities [3]. Robot therapists for the elderly have also been employed to play memory enhancing music games with their users [45]. For individuals suffering from dementia and/or other cognitive impairments, socially assistive robots have been shown to improve, through social interaction, the cognitive abilities of their users, and thus their quality of life [46]. Robots are also educationally useful interventions to improve social interactions for individuals with Autism Spectrum Disorders (ASD) [32].

Socially assistive robots are capable of providing physical therapy for users without needing to make physical contact. Individuals who have recently suffered a stroke may benefit from the use of robots in this domain. Previous work has investigated the influence of robot coaching styles designed to enhance motivation and encouragement on post-stroke individuals during motor task practice [49]. In other prior work, a robot asked healthy users to engage in physical exercises similar to those used during standard stroke rehabilitation, such as repeatedly lifting and moving books or pencils. Participants were asked to perform the tasks for as long as they wished. Researchers manipulated the interaction style of the robot and found that extroverted participants preferred and complied more with a robot that challenged them rather than one which focused on nurturing praise [44]. In subsequent work, the robot adapted its behavior to match each participant's preferences in terms of therapy style, interaction distance, and movement speed [43]. In that work, as well as in research presented in the next section, it is shown that adaptation is key to creating positive interactions, especially in assistive contexts. The present work aims to further this research by presenting personality-expressing gaze behaviors and demonstrating that they must be targeted to the personality of users.

Adapting to Users

Previous research in HRI has demonstrated the benefit of a robot adapting to its users. In prior work in which a robot provided cooking help to participants in a kitchen, researchers found that adaptive dialogue—in which the robot adapted the content of its speech depending on the expertise of the user—improved information exchange and social relations, especially when users were under time pressure [47]. Previous research with children investigated the use of adaptive empathic behaviors (e.g., encouraging comments and offering help) for a chess-playing robot [24]. Children responded positively to the robot when the empathic behaviors were employed adaptively, rather than randomly. Previous work has also investigated the positive effect in eliciting user compliance of matching a "playful" or a "serious" robot (conveyed through the robot's speech) to a playful or serious task [14].

Adapting to user personality has been more widely studied in HCI. For example, previous research shows that computer interfaces can be manipulated to exhibit an extroverted or introverted personality through the use of language, pictures, and sounds, and that introverted users will perform tasks faster when using introverted software [36]. This result follows from the theory of *similarity-attraction* which predicts that a person will be attracted more to others who match their personalities than to those who mismatch [22]. In the same way, matching the personality of a synthesized voice, expressed through pitch, prosody, and so on, to user personality positively affects users' feelings of social presence, especially in extroverts [22]. Emotion matching is also important in computer interfaces. In a study of emotional speech generation for car interfaces, it was found that when the emotion expressed by the car voice (energetic or subdued) matches the emotional state of the driver (happy or upset), drivers have fewer accidents, attend more to the road, and speak more to the car [31]. Our research in socially assistive robots parallels these efforts by following similarity-attraction theory to match the gaze behaviors of the robot to the personality of the user.

Nonverbal Behaviors, Personality, and Motivation

Nonverbal behaviors, especially gaze, have long been recognized in social-sciences literature as useful tools in persuading others to comply with requests or demands. A number of theories have been proposed to explain this phenomenon, including speech accommodation theory, demand theory, and arousal intimacy theory [40]. According to *speech accommodation theory*, people may change their communication behaviors when interacting with others and convergence toward the style of the partner should produce a positive attitude in the partner and thus lead to compliance. According to *demand theory*, nonverbal behaviors can function as demands (e.g., staring as a demand for a response), producing a level of arousal that targets can alleviate by complying with any implicit or explicit demands. In *arousal intimacy theory*, nonverbal behaviors are predicted to produce compliance because they produce greater perceptions of intimacy between the source and target, leading to compliance when the target experiences positive arousal. Each of these three theories predicts a strong relationship between nonverbal behaviors and compliance.

A large amount of previous research has empirically demonstrated the positive effect of gaze on compliance. When a collector of money for charity engaged in mutual gaze with possible donors, rather than looking at the collecting tin, they were more successful in receiving donations [4]. Nonverbal behavioral cues, such as gaze, gesture, and proxemics, are sometimes referred to as *immediacy* cues [6]. Students are more likely to comply when they perceive their teachers as moderately to highly immediate, and are more likely to choose to reject requests made by nonimmediate teachers [5]. Similarly, attraction and dominance increase compliance and cues of such are often expressed through nonverbal cues like gaze [34]. Gaze is also closely tied to personality, with extroverts commonly engaging in significantly more mutual gaze with their conversational partners than do introverts [37].

In addition to nonverbal behaviors and personality, attempts to increase compliance in others must take into account a person's motivation, which can vary not only in magnitude but also in orientation [38]. The most basic distinction in motivation orientation is between intrinsic, which refers to doing something because it is inherently interesting or enjoyable, and extrinsic, which refers to doing something because it is accompanied by external pressure or control. In the current work, we use socially assistive robots to create extrinsic motivation in users, but also take into consideration the intrinsic motivation that those users have to complete the task.

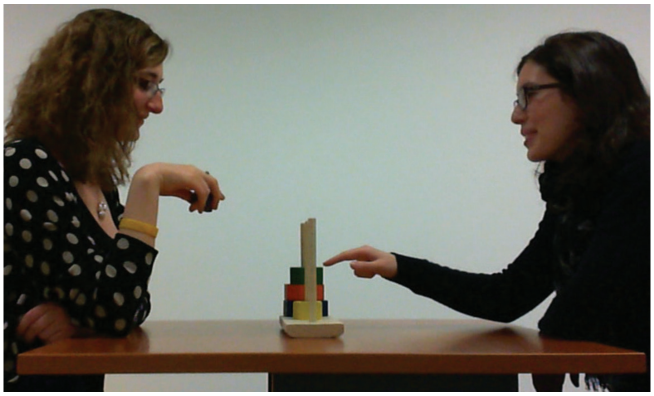

Figure 2. Setup of the human-human data collection study. The participant on the right (instructor) is providing extrinsic motivation to the participant on the left (worker) to complete the puzzle.

DESIGNING PERSONALITY-EXPRESSING GAZE

In order to develop adaptive gaze behaviors for a socially assistive robot to employ, we first sought to understand the relationship between gaze and personality, focusing particularly on extroversion, in a motivational context. In this section, we present a human-human data collection study we conducted in order to inform the design of personality-expressive gaze behaviors. We also present an online validation study we conducted to confirm that the designed robot gaze behaviors express the intended personality.

Data Collection and Modeling

To understand the relationship between gaze and personality in a motivational task, we sought to answer the following questions. How do people use their gaze when attempting to motivate others and increase compliance? What is the relationship between their use of gaze and their respective personalities? To answer these questions, we conducted a human-human data collection study with four participant dyads, obtaining more precise measurements of gaze behavior than what is traditionally presented in the social-sciences literature. We chose the Tower of Hanoi puzzle for participants to complete collaboratively. The goal of this puzzle is to move a number of colored blocks from one location to another while following some simple rules. This task was chosen for its mix of cognitive (solving the puzzle) and physical (actually moving the pieces around) elements, mapping well to tasks commonly used in physical and cognitive rehabilitation. The task can also be broken down into two repeating phases common to rehabilitation activities: (1) the actual execution of the task, which we will refer to here as the *in-task phase*, and (2) the time between tasks when the therapist must provide encouragement to persist with the task, which we will refer to here as the *between-task phase*.

Participants filled out the Big Five inventory prior to participation to determine their position on the extroversion-introversion spectrum [19]. The Big Five questionnaire con-

Worker Compliance & Mutual Gaze

Outcome	Compliance			Instructor Gaze toward Partner (%)		Worker Gaze toward Partner (%)	
Measure	Time (s)	Puzzles Done	Blocks Moved	In-Task Phase	Between-Task Phase	In-Task Phase	Between-Task Phase
Dyad (Instructor–Worker)							
Extroverted–Extroverted	1369	18	541	7.66	14.74	5.20	11.91
Introverted–Introverted	703	14	352	3.79	8.57	2.74	8.68
Extroverted–Introverted	320	9	227	5.31	10.53	1.77	8.97
Introverted–Extroverted	295	7	121	1.91	4.39	4.94	14.74

Table 1. Results from the human-human data collection on worker compliance in each dyad, as well as the amount of partner-directed gaze for all participants.

tains 44 items on a five-point rating scale that ask the participant to rate their agreement or disagreement with statements about their own personality and activities. Eight of these items contribute to the extroversion dimension of the participant's overall personality score. These items have good internal reliability (Cronbach's α = .88). Participants scoring lower than 2.5 on the extroversion dimension were labeled as introverted, and those above 2.5 were labeled as extroverted.

In each dyad, one participant was assigned to be the *instructor* and the other the *worker*. Each of the four dyads covered one of the four possible combinations of participant personality and role. The experimenter first explained the puzzle to the instructor without the worker present. Next, the instructor practiced solving the puzzle with the experimenter. The instructor was required to successfully solve the puzzle a number of times in front of the experimenter to prove that they were comfortable with the task. Then, the instructor was asked to carry out the following procedure: (1) explain the task to the worker, (2) monitor the worker as they complete the task, (3) provide encouraging feedback during the puzzle solving, (4) motivate the worker to keep working between puzzle tasks, and (5) correct workers when they make a mistake. The worker was told by the experimenter that everything would be explained by the instructor, but that they were welcome to work on the task for as long as they wished and that it was up to them to decide when they would like to stop.

The two participants sat at a table facing each other, with the puzzle between them (Figure 2). Over-the-shoulder view cameras recorded the gaze of each participant, and a side camera with wide-angle view was used for recording the entire task. The compliance of the worker to the instructor was measured in three ways: (1) total time spent solving puzzles, (2) total number of puzzles completed, and (3) total number of puzzle pieces moved. Worker compliance in each dyad, as well as the percentage of each participant's attempt to engage in mutual gaze with their partner, is presented in Table .

Gaze Lengths (Mean (Standard Deviation))

Personality	Extroverted		Introverted	
Phase	In-Task	Between-Task	In-Task	Between-Task
Partner	2.66 (0.80)	3.91 (1.22)	0.57 (0.19)	1.59 (0.39)
Puzzle	4.04 (2.12)	1.01 (1.26)	11.65 (11.17)	6.21 (8.14)

Table 2. Means and standard deviations of gaze fixations (in seconds) to the partner and to the puzzle for extroverted and introverted participants, divided into in-task and between-task phases of the interaction.

All videos were coded for participant gaze behavior. Participant gazes were recorded and labeled for two targets: the other participant and the shared workspace. The mean and standard deviation of these gaze lengths are presented in Table .

We observe three trends from the data. First, extroverts seem to be attempting to engage in more mutual gaze with their partner than do introverts. This relationship between extroversion and gaze behavior has been similarly demonstrated in previous research, including a study of dyadic interviews in which it was found that extroverts gaze at their interviewer more than introverts do [18]. Second, there is more mutual gaze between puzzle phases when the instructor is attempting to motivate the worker to solve more puzzles and much less mutual gaze during the actual puzzle completion. Third, there is some preliminary indication that personality matching is an effective strategy for increasing compliance, as personality-matching dyads exhibited longer time-on-task than the mismatching personality dyads. This point is explored further in the experimental evaluation presented later in this paper.

The results presented in Table are used to generate two models of gaze behavior for robots, one to express an extroverted personality and the other to express an introverted personality. The presented means and standard deviations are used to create normal distributions of gaze lengths that the robot draws from when planning and executing gazes toward the user and toward the task space. In an expression of the extroverted model, the robot gazes into the face of the user more, while the introverted model generates more gaze toward the task space. In both models, more gaze is generated toward the user in the motivational between-task phase than in the in-task phase, which involves monitoring the user's actions. For example, an extroverted robot drawing from the distributions in Table might generate a four-second gaze toward the user in a between-task phase, followed by a one-second gaze toward the task space. This sequence of long user fixations and short task fixations—randomly generated according to the distributions—would repeat until the start of the next in-task phase. At this point, the extroverted robot might generate a four-second gaze toward the task space followed by a two-and-a-half-second gaze to the user. This cycle of gaze shifts would repeat throughout the in-task phase.

Implementation

Following the data collection and analysis from human dyads, we next designed and implemented a system to allow a robot to take on the instructor role in the same puzzle completion scenario. We implemented the system on the Meka robot platform (Figure 1). We use the Robot Operating System (ROS) to handle the execution and communication amongst each of the system components described below (Figure 3).

Tracking the participant and task state—A depth camera mounted in Meka's chest was used for face tracking. A small amount of noise is added to the tracking output so that the robot's gaze does not remain motionless when gazing toward

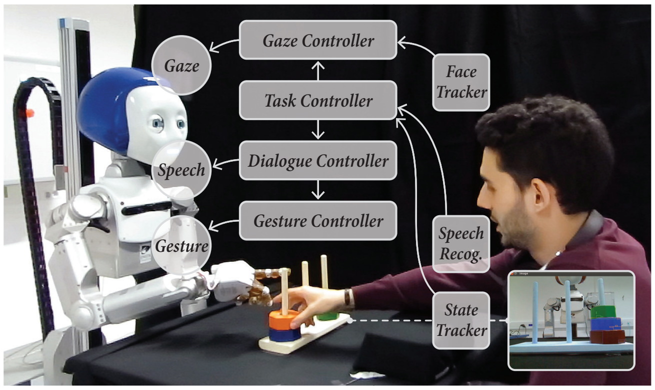

Figure 3. The implementation of the socially assistive robot. Participant face location, speech, and task state are tracked and passed to the dialogue controller, task controller, and gaze controller. These controllers determine the gaze, speech, and gestures of the robot. Rounded squares, circles, and rounded rectangles denote sensing, output, and control modules, respectively.

the user's face. For puzzle tracking, a separate webcam is placed on the table and focused on the puzzle. Color blob tracking is employed to determine the current locations of each of the different colored puzzle pieces. Google speech recognition is utilized for capturing the user's requests for help and requests to terminate the task.

Task controller—This component manages the flow of the overall scenario. It keeps track of the current task phase (in-task or between-task) and continuously solves the puzzle from the current state so the robot can provide hints and help when requested. The robot can provide general strategies or suggest moves to make in completing the puzzle. If the user makes five bad moves in a row or does not make a move for ten seconds, the robot automatically provides help. The robot also randomly provides positive feedback when it detects that the user has made a good move. Providing these hints and feedback has been shown in previous work to positively affect people's motivation to engage in a task [48].

Generating robot behavior—Depending on the current phase of the scenario (introduction, in-task, between-task, closing), the dialogue controller generates the robot's speech appropriately. If a request for help is detected, the dialogue controller generates the response speech and the gesture controller generates a pointing gesture to the appropriate puzzle piece. The gaze controller generates gaze shifts according to the personality being expressed and the current phase of the interaction. The values in Table are used to create distributions that the robot draws from when planning and generating gaze shifts toward the puzzle or toward the user. When gazing toward the puzzle, the robot looks toward blocks that are in motion, creating a stronger sense of responsiveness and lifelikeness.

Model Validation

After implementing the system, we conducted an online study to determine if the extroverted and introverted gaze behaviors generated by the gaze controller would actually be perceived as such. We filmed four one-minute videos of the robot interacting with a human user in the Tower of Hanoi scenario. In two of the videos, the robot utilized the extrovert model of gaze behaviors, with the other two videos depicting the robot utilizing the introvert model. This study used a within-participant design; all four of the videos were shown to each participant in a random order. Following each video, participants rated the perceived extroversion of the robot on six five-point rating scales which have also been used in previous research to rate the perceived personality of robots [23].

Participants in this study were recruited using Amazon's Mechanical Turk. We recruited 30 participants (15 Female, 15 Male) with a mean age of 34.9 (SD = 8.5). Standard IP-filtering techniques were employed to limit participation to the United States and prevent multiple participation. In order to eliminate participants that were not focusing on the videos, we asked participants to indicate the color of the robot's head (blue) at the end of the study, discarding data from participants who failed to provide a correct answer. We also tracked the amount of time that the browser window containing the video stimulus remained in focus on the participant's computer. Eight participants failed the color question and/or unfocused the stimulus window for a majority of the study time and were therefore eliminated from analysis, leaving 22 participants.

We analyzed the effect of the robot's gaze behavior on participant ratings of the robot personality using repeated-measures analysis of variance (ANOVA). Results indicated that participants did perceive a difference in the personality of the robot in the way that we intended. The extroversion rating of the robot was significantly higher in the extrovert gaze behavior condition (M=3.79, SD=0.54) than in the introvert gaze behavior condition (M=3.53, SD=0.59), $F(1, 84) = 5.09, p = .027$. This result is supported by previous work which demonstrated that participants can accurately recognize a robot's intended personality based on its verbal and nonverbal behaviors [23].

EXPERIMENTAL EVALUATION

The validation study showed that the gaze manipulations indeed resulted in differential perceptions of the robot's personality. Next we present a more comprehensive study of the effect of using these personality-expressing gaze behaviors in motivational interactions with human users. The goal of this study was to test the effect on compliance of matching or mismatching the robot's personality with that of the user.

Hypotheses

Three hypotheses were developed that predict the effect of matching the personality of the robot—expressed through gaze—to the personality of users, as well as the potential effect of users' intrinsic motivation.

Hypothesis 1—Matching the robot's personality to the user's personality will improve the user's subjective ratings of the robot's performance.

This hypothesis follows from similarity-attraction theory, which predicts that a person will be more attracted to others who match their personality than to those whose personalities do not match [22]. Thus, we predict a strong interaction effect between user personality and robot personality.

Hypothesis 2—Matching the robot's personality to the user's personality will improve compliance with the robot's requests to engage in the task for a longer period of time.

This hypothesis also predicts a strong interaction effect between user personality and robot personality and follows from similarity-attraction theory. Previous work in socially assistive robots found a similar interaction effect on compliance between user personality (extrovert or introvert) and robot therapy style (challenging or nurturing) [44]. Our own data collection, which we presented earlier, also lends some preliminary support for this hypothesis, as the two personality-matching dyads participated in the puzzle task longer than both personality-mismatching dyads.

Hypothesis 3—The user's intrinsic motivation for the task will interact with the personality-matching effect on compliance. Users with low intrinsic motivation will be more affected by personality-matching than users with high intrinsic motivation.

If a user has high intrinsic motivation for the puzzle-solving task, they would inherently find the task interesting or enjoyable and thus would not respond to external motivation attempts from a socially assistive robot [38].

Participants

We recruited 40 participants for this experiment (16 Female, 24 Male) from a university campus. Participant ages ranged from 20 to 58 (M = 30.6, SD = 9.4). For feasibility purposes, all participants were healthy adults without need of physical or cognitive therapy, a strategy that has been employed in previous research on socially assistive robots [44]. Participants' countries of origin included France, the United States, China, Romania, and Tunisia, and came from both technical and non-technical backgrounds. The experiment was implemented in both English and French (including the script of both the experimenter and the robot), and participants were allowed to choose the language with which they were most comfortable (10 chose English, 30 chose French).

Study Design & Procedure

The study followed a 2×2 between-participants study design, with participant personality (extrovert or introvert) and robot personality (extrovert or introvert) comprising the two factors. The study contained four total conditions representing each of the four personality combinations, with ten participants recruited for each of these conditions. The robot's gaze behavior was the only difference between robot personality conditions; experimenter instructions and the content of robot speech were held constant for all conditions.

All participants were asked to complete and submit the Big Five personality inventory prior to participation to determine their position on the extroversion-introversion spectrum [19]. These items, as in the human-human task, took the form of five-point rating scales. We used a median split to separate participants into two groups. All participants with an extroversion score less than or equal to 3.0 were labeled as "introverted," with participants scoring higher than 3.0 labeled as "extroverted." Participants were also asked to complete and submit a questionnaire to assess their global motivation toward activities in their life. This questionnaire contains 28 items assessed on a seven-point scale, with constructs for both intrinsic motivation and extrinsic motivation [15].

Participants were randomly assigned to interact with either the extroverted or introverted robot. After receiving informed consent, the experimenter introduced the participant to the Meka robot and explained the task. Participants were told that they would be completing the Tower of Hanoi puzzle under the supervision of the robot, and that the robot would provide all the necessary instructions for the rules and for progressing through the various stages of the puzzle. Participants were seated in front of the robot, facing it at eye-level, with a table between them. The physical Tower of Hanoi puzzle was placed on the table between the robot and participant (as illustrated in Figure 1). The participant was clearly instructed that it was their decision as to when they wanted to terminate the interaction and that they could indicate this to the robot at any time they wished. A headset microphone was used for capturing the speech of the participants, while the robot's speech was projected through its own speakers.

The experimenter then started the system implementation and left the participant to interact with the autonomous robot. After initial introductions, the robot carefully explained the goal and rules of the puzzle and asked the participant to complete it. After the participant's first successful completion, the robot explained that it would be asking the participant to complete the same puzzle several times and reminded the participant that it was up to them to decide when they would like to stop. During the execution of each puzzle task—the *in-task phase*—the robot monitored the task and provided help if the participant got stuck or explicitly asked for help. Following the successful completion of each puzzle—the *between-task phase*—the robot first provided positive feedback and then asked the participant if they would like to continue. If the participant agreed, the robot indicated a new puzzle goal and asked the participant to begin another iteration of the task.

Three levels of difficulty were implemented for the puzzle. The easiest difficulty required the solution of the three-disk version of the puzzle; the medium difficulty used four disks; and the hardest difficulty involved five disks. The least number of disk movements that can be made for each level of the puzzle are 7, 15, and 31, respectively. When the participant completed the puzzle eight times at the same difficulty level (starting with the easiest), the robot asked them to increase the difficulty by adding another disk. If a participant reached the hardest difficulty level, they stayed at this difficulty until they decided to terminate the interaction.

When the participant indicated that they wished to terminate the interaction, the robot thanked and instructed them to fill out a follow-up questionnaire at a computer nearby. Once participants finished this final questionnaire, the experimenter returned and thanked them once again for their participation.

Measures

The study included three objective measures of participant compliance: total time spent working on the task, total number of puzzles solved, and total number of disks moved across all instances of the puzzle. The follow-up questionnaire contained several seven-point rating scales for assessing the performance of the robot. Five items from this questionnaire were combined into a single construct of *perceived robot performance*,

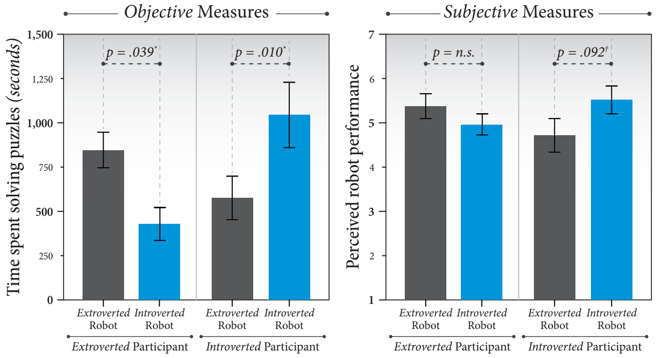

Figure 4. Left: objective results of compliance for total participation time. A personality matching effect predicted by similarity-attraction theory was found. Right: subjective results of perceived robot performance. Introverted participants reported a marginal preference for the introverted robot. (*) and (†) denote $p < .05$ and $p < .10$, respectively.

including questions about the robot's skills as an instructor and motivator, as well as questions relating to the usefulness of the robot's information and advice. This construct was found to have good internal reliability (Cronbach's $\alpha = .75$).

The follow-up questionnaire also included open-ended questions about why the participant chose to participate for as long as they did and why they chose to eventually terminate the interaction. In order to obtain a more task-specific measure of intrinsic motivation, these open-ended responses were coded for explicit mention of the participant's inherent desire to solve the puzzles, without mention of any external motivation coming from the robot.

Results

Analysis of the data was conducted using a between-subjects analysis of variance (ANOVA). Participant personality, robot personality, and the interaction of both were modeled as fixed effects. Participant gender, language (English or French), and previous experience with robots (yes or no), were found to be non-significant covariates on all measures and are not discussed further. Participant background (technical or non-technical) was found to have a significant effect on some measures and it has been retained as a covariate in the statistical model. A Bonferroni correction was employed to control for the experiment-wise error in multiple comparisons.

Compliance—Regarding the measure of total participation time, there was no main effect of either participant personality, $F(1,35) = 0.75, p = .39$, or robot personality, $F(1,35) = 0.16, p = .69$. A significant interaction effect was observed, $F(1,35) = 14.80, p < .001$, with a significant effect of extroverted participants participating longer with the extroverted robot, $F(1,35) = 5.97, p = .039$, and for introverted participants participating longer with the introverted robot, $F(1,35) = 8.97, p = .010$. Participant background also had a significant main effect on participation time, with non-technical participants participating for longer than those from technical backgrounds, $F(1,35) = 7.31, p = .011$.

On the total puzzles solved measure, there was no main effect of either participant personality, $F(1,35) = 0.36, p = .55$, or robot personality, $F(1,35) = 0.57, p = .45$. We found a significant interaction effect, $F(1,35) = 8.07, p = .007$, with a significant effect of extroverted participants solving more puzzles with the extroverted robot, $F(1,35) = 6.51, p = .031$, but no significant effect among introverted participants $F(1,35) = 2.16, p = .30$. Participant background did not have a significant effect on this measure, $F(1,35) = 0.51, p = .48$.

On the measure of total disks moved across the entire interaction, there was no main effect of either participant personality, $F(1,35) = 0.14, p = .71$, or robot personality, $F(1,35) = 1.72, p = .20$. Our analysis found a significant interaction effect, $F(1,35) = 5.42, p = .026$, with a significant effect of extroverted participants moving more disks with the extroverted robot, $F(1,35) = 6.65, p = .028$, but no significant effect among introverted participants $F(1,35) = 0.52, p = .94$. Participant background was not found to have a significant effect on this measure, $F(1,35) = 1.03, p = .32$.

Perceived Robot Performance—On the subjective rating of the robot's performance, there was no main effect of either participant personality, $F(1,35) = 0.25, p = .62$, or robot personality, $F(1,35) = 0.58, p = .45$. We found a significant interaction effect, $F(1,35) = 4.70, p = .037$, with no significant effect among extroverted participants, $F(1,35) = 0.99, p = .66$, and a marginal preference among introverted participants for the introverted robot, $F(1,35) = 4.27, p = .092$. Participants with a non-technical background also expressed marginally higher ratings of the robot's performance, $F(1,35) = 3.10, p = .087$. Results for compliance and perceived robot performance are visually presented in Figure 4.

Motivation—We conducted a regression analysis on the effect of the participant's reported global intrinsic motivation (collected in the pre-test survey) on all measures of compliance. No significant results were found for any of the measures. However, significant effects were observed for the task-specific measure of intrinsic motivation, in which we coded participant responses to the open-ended question: "Why did you participate for as long as you did?" Participants who indicated an inherent interest in solving the puzzle, rather than participating because of the presence of the robot and its feedback, were labeled as having high intrinsic motivation. Twenty-seven participants (14 extroverts, 13 introverts) were found to have high intrinsic motivation. We observed a three-way interaction effect between this measure of intrinsic motivation, participant personality, and robot personality on the compliance measure of total participation time, $F(1,34) = 5.62, p = .006$. Among participants with high intrinsic motivation, there was no significant effect of personality among extroverted participants, $F(1,34) = 1.43, p = .24$, or introverted participants, $F(1,34) = 2.08, p = .16$. However, among participants without high intrinsic motivation, extroverted participants participated for significantly longer with the extroverted robot, $F(1,34) = 15.84, p < .001$ and introverted participants participated for significantly longer with the introverted robot, $F(1,34) = 19.44, p < .001$. The results involving intrinsic motivation are visualized in Figure 5.

DISCUSSION

The goal of the experimental evaluation was to test the effectiveness of matching a socially assistive robot's personality—

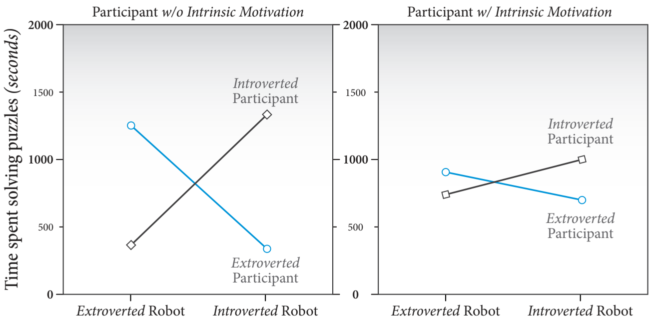

Figure 5. The interaction effect on compliance predicted by similarity-attraction theory is only present for participants that were not found to have high intrinsic motivation for the task.

as expressed via our designed gaze behaviors—to that of the participant in a repetitive task requiring persistent motivation from the robot. The robot's personality was manipulated purely through its gaze behavior, gazing much more toward the participant when expressing an extroverted personality and much more toward the task space when expressing an introverted personality. These behaviors were validated in an online study to express their intended personality, and we were interested in whether an extroverted and introverted robot would elicit more compliance and positive subjective perceptions from extroverted and introverted participants respectively.

Our first hypothesis predicted that, in line with similarity-attraction theory, participants would give higher subjective ratings to the performance of a robot that matches their personality. This hypothesis was partially supported in the experiment, in that introverted participants reported a marginal preference for the introverted robot behaviors. Extroverted participants reported no difference in ratings. Introverts may have been more consciously sensitive to the behaviors of the robot, as previous work has shown introverts have a superior detection rate and perceptual sensitivity than extroverts [7]. In a study involving the rating of other people, previous work has also found that introverts preferred other introverts on the measures of "reliable friend" and "honest and ethical," while extroverts were ambivalent in these measures [16].

The experiment provided support for our second hypothesis, which predicted that participants would comply more with robots that matched their personality. On the measure of total participation time, both extroverts and introverts exhibited significantly greater compliance with the personality-matching robot. However, in the measures of total puzzles solved and total disks moved, only extroverts exhibited significantly greater compliance with the personality-matching robot. Previous work in HCI has shown a similar result in that matching a synthesized voice's personality to a user's personality improved feelings of social presence, but only for extroverts [22].

Our third hypothesis predicted that the intrinsic motivation of participants and the personality-matching effect would interact. We found some support for this hypothesis, but not from the pre-test survey asking participants to rate their intrinsic motivation towards tasks in general. Instead, when we coded participants' open-ended responses to a post-study interview question asking why they participated for as long as they did, we found that some participants were more intrinsically motivated to solve the puzzles, whereas others were more extrinsically motivated by the robot. When we split the participants into these two groups, we found a significant interaction between intrinsic motivation and personality matching. For both extroverts and introverts, the personality-matching robot was most effective in motivating those who were not highly intrinsically motivated to solve the puzzles. We note, however, that splitting our population into groups with intrinsic and extrinsic motivation resulted in relatively small sample sizes and that follow-up work with a larger participant population must be carried out to more conclusively establish this relationship.

Design Implications

This work further demonstrates the importance of designing social technologies that can adapt to user characteristics. We have shown that a robot that matches the personality expressed by its gaze behavior to the personality of its user can improve compliance and subjective perceptions of the robot's performance. These outcomes are particularly critical for socially assistive robots that must motivate their users to engage in physical or cognitive exercises, especially when these exercises are repetitive or boring. Social theories such as similarity-attraction must be leveraged and further studied in human-robot interaction, as they can have powerful implications for the effectiveness of these interactions. We believe that the results presented in this work also extend beyond socially assistive robots and point to similar design considerations for embodied agents—including both robots and virtual agents—in other domains, such as education and companionship.

Limitations & Future Work

A significant limitation of the current work is that the study population was comprised of healthy adults all under the age of 60. This choice was made for the purposes of feasibility in testing a novel idea for socially assistive robots, similar to what has been done in previous work in this domain [44]. We expect our findings to hold for the targeted populations that need socially assistive robots, such as the elderly or post-stroke patients, but this expectation should be tested in future work.

The gaze model presented in this work has a number of limitations due to certain simplifications, including the small sample size it was generated from, the fidelity of included gaze targets, and the specificity to a single task in a controlled environment. These simplifications were necessary and the resulting model was sufficiently detailed for this initial effort and evaluation, but future work should seek to build more sophisticated models that overcome these limitations. While we observed participants in our study to gaze almost exclusively toward either each other or the task space, more complex interactions in less controlled environments will need to take into account more possible gaze targets. More sophisticated models will also need to dynamically adjust to the task state. In our work, we differentiate between on-task and between-task times, but future work will need to include finer-grained task analyses.

We chose to median-split our populations from both the modeling and the evaluation studies to establish "introverted" and "extroverted" groups in order to investigate the effect of matching/mismatching personality categories with balanced sampling. To address the potential limitations of this simplification, future work must model extroversion as a continuum, and the robot should dynamically adjust its behaviors to match the user's location on this continuous spectrum.

In this work, we presented two models of gaze behavior that can exhibit either an extroverted or introverted personality. Previous work has also shown that some aspects of the Big Five model of personality, including extroversion, neuroticism, and openness, have consistent correlations with a person's gaze behavior, as measured by fixation frequencies and durations [35]. However, previous research has also demonstrated that personality and nonverbal behavior are not always linked in simple ways [13]. Personality can be expressed differently in different contexts, group compositions, cultures, and combinations, and this richness should be taken into account in future work to align robot behaviors with user personalities. Additionally, future socially assistive robot systems should detect user characteristics such as personality *in-situ*, rather than requiring the user to explicitly provide this information, e.g., by filling out a questionnaire before using the system.

CONCLUSION

In this paper, we presented the design and evaluation of gaze behaviors for socially assistive robots that allow the robot to match the extroversion dimension of personality to the user, thereby more effectively motivating users to repeatedly engage in a therapeutic task. These robot behaviors were designed by analyzing the gaze behavior of participants in a human-human data collection study, and were validated in an online study to express either an extroverted or introverted personality. The evaluation also demonstrated the importance of taking the user's intrinsic motivation into account when attempting to produce external motivation and increase compliance. In general, socially assistive robots offer a particularly powerful way of improving motivation and compliance in rehabilitation settings due to their physical embodiment and ability to use nonverbal communication channels. By effectively taking advantage of these abilities and designing methods for adapting to the characteristics of their users, these systems can dramatically improve the quality of life for people in need.

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REFERENCES

1. Andrist, S., Tan, X. Z., Gleicher, M., and Mutlu, B. Conversational gaze aversion for humanlike robots. In *Proc HRI'14* (2014), 25–32.
2. Bickmore, T. W., Caruso, L., and Clough-Gorr, K. Acceptance and usability of a relational agent interface by urban older adults. In *Proc CHI'05 Extended Abstracts* (2005), 1212–1215.
3. Bruno, B., Mastrogiovanni, F., and Sgorbissa, A. Functional requirements and design issues for a socially assistive robot for elderly people with mild cognitive impairments. In *Proc RO-MAN'13* (2013), 768–773.
4. Bull, R., and Gibson-Robinson, E. The influences of eye-gaze, style of dress, and locality on the amounts of money donated to a charity. *Hum Relat 34*, 10 (1981), 895–905.
5. Burroughs, N. F. A reinvestigation of the relationship of teacher nonverbal immediacy and student compliance-resistance with learning. *Commun Educ 56*, 4 (2007), 453–475.
6. Christophel, D. M. The relationships among teacher immediacy behaviors, student motivation, and learning. *Commun Educ 39*, 4 (1990), 323–340.
7. Davies, D. R., Matthews, G., Stammers, R. B., and Westerman, S. J. *Human performance: Cognition, stress and individual differences*. Psychology Press, 2013.
8. Emery, N. The eyes have it: the neuroethology, function and evolution of social gaze. *Neurosci Biobehav R 24*, 6 (2000), 581–604.
9. Eriksson, J., Matarić, M. J., and Winstein, C. Hands-off assistive robotics for post-stroke arm rehabilitation. In *Proc ICORR'05* (2005), 21–24.
10. Fasola, J., and Mataric, M. J. Using socially assistive human–robot interaction to motivate physical exercise for older adults. *Proc IEEE 100*, 8 (2012), 2512–2526.
11. Feil-Seifer, D., and Mataric, M. J. Defining socially assistive robotics. In *Proc ICORR'05* (2005), 465–468.
12. Feil-Seifer, D., and Matarić, M. J. Toward socially assistive robotics for augmenting interventions for children with autism spectrum disorders. In *Experimental Robotics* (2009), 201–210.
13. Gifford, R. Personality and nonverbal behavior: A complex conundrum. 2006, 159–179.
14. Goetz, J., Kiesler, S., and Powers, A. Matching robot appearance and behavior to tasks to improve human-robot cooperation. In *Proc RO-MAN'03* (2003), 55–60.
15. Guay, F., Mageau, G. A., and Vallerand, R. J. On the hierarchical structure of self-determined motivation: A test of top-down, bottom-up, reciprocal, and horizontal effects. *Pers Soc Psychol B 29*, 8 (2003), 992–1004.
16. Hendrick, C., and Brown, S. R. Introversion, extraversion, and interpersonal attraction.
17. Huang, C.-M., and Mutlu, B. Robot behavior toolkit: generating effective social behaviors for robots. In *Proc HRI'12* (2012), 25–32.
18. Iizuka, Y. Extraversion, introversion, and visual interaction. *Percept Motor Skill 74*, 1 (1992), 43–50.
19. John, O. P., and Srivastava, S. The big five trait taxonomy: History, measurement, and theoretical perspectives. vol. 2. 1999, 102–138.
20. Kang, K. I., Freedman, S., Mataric, M. J., Cunningham, M. J., and Lopez, B. A hands-off physical therapy assistance robot for cardiac patients. In *Proc ICORR'05* (2005), 337–340.

21. Kidd, C. D. *Designing for Long-term Human-robot Interaction and Application to Weight Loss*. PhD thesis, 2008.

22. Lee, K. M., and Nass, C. Designing social presence of social actors in human computer interaction. In *Proc CHI'03* (2003), 289–296.

23. Lee, K. M., Peng, W., Jin, S.-A., and Yan, C. Can robots manifest personality?: An empirical test of personality recognition, social responses, and social presence in human–robot interaction. *J Commun 56*, 4 (2006), 754–772.

24. Leite, I., Castellano, G., Pereira, A., Martinho, C., and Paiva, A. Modelling empathic behaviour in a robotic game companion for children: an ethnographic study in real-world settings. In *Proc HRI '12* (2012), 367–374.

25. Lippa, R. A., and Dietz, J. K. The relation of gender, personality, and intelligence to judges' accuracy in judging strangers' personality from brief video segments. *J Nonverbal Behav 24*, 1 (2000), 25–43.

26. Marti, P., Bacigalupo, M., Giusti, L., Mennecozzi, C., and Shibata, T. Socially assistive robotics in the treatment of behavioural and psychological symptoms of dementia. In *Proc BioRob '06* (2006), 483–488.

27. Moon, A., Troniak, D. M., Gleeson, B., Pan, M. K., Zeng, M., Blumer, B. A., MacLean, K., and Croft, E. A. Meet me where i'm gazing: how shared attention gaze affects human-robot handover timing. In *Proc HRI'14* (2014), 334–341.

28. Mumm, J., and Mutlu, B. Designing motivational agents: The role of praise, social comparison, and embodiment in computer feedback. *Comput Hum Behav 27*, 5 (2011), 1643–1650.

29. Mutlu, B., Kanda, T., Forlizzi, J., Hodgins, J., and Ishiguro, H. Conversational gaze mechanisms for humanlike robots. *ACM TiiS 1*, 2 (2012), 12.

30. Mutlu, B., Shiwa, T., Kanda, T., Ishiguro, H., and Hagita, N. Footing in human-robot conversations: how robots might shape participant roles using gaze cues. In *Proc HRI'09* (2009), 61–68.

31. Nass, C., Jonsson, I.-M., Harris, H., Reaves, B., Endo, J., Brave, S., and Takayama, L. Improving automotive safety by pairing driver emotion and car voice emotion. In *Proc CHI'05 Extended Abstracts* (2005), 1973–1976.

32. Nikolopoulos, C., Kuester, D., Sheehan, M., Ramteke, S., Karmarkar, A., Thota, S., Kearney, J., Boirum, C., Bojedla, S., and Lee, A. Robotic agents used to help teach social skills to children with autism: the third generation. In *Proc RO-MAN'11* (2011), 253–258.

33. Osterberg, L., and Blaschke, T. Adherence to medication. *New Engl J Med 353*, 5 (2005), 487–497.

34. Peters, P. Gaining compliance through non-verbal communication. *Pepp Disp Resol L J 7* (2007), 87.

35. Rauthmann, J. F., Seubert, C. T., Sachse, P., and Furtner, M. R. Eyes as windows to the soul: Gazing behavior is related to personality. *J Res Pers 46*, 2 (2012), 147–156.

36. Richter, L. A., and Salvendy, G. Effects of personality and task strength on performance in computerized tasks. *Ergonomics 38*, 2 (1995), 281–291.

37. Rutter, D., Morley, I. E., and Graham, J. C. Visual interaction in a group of introverts and extraverts. *Eur J Soc Psychol 2*, 4 (1972), 371–384.

38. Ryan, R. M., and Deci, E. L. Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemp Educ Psychol 25*, 1 (2000), 54–67.

39. Scassellati, B., Admoni, H., and Matarić, M. Robots for use in autism research. *Annu Rev Biomed Eng 14* (2012), 275–294.

40. Segrin, C. The effects of nonverbal behavior on outcomes of compliance gaining attempts. *Commun Stud 44*, 3-4 (1993), 169–187.

41. Staudte, M., and Crocker, M. W. Investigating joint attention mechanisms through spoken human–robot interaction. *Cognition 120*, 2 (2011), 268–291.

42. Takacs, B., and Hanak, D. A prototype home robot with an ambient facial interface to improve drug compliance. *J Telemed Telecare 14*, 7 (2008), 393–395.

43. Tapus, A., and Mataric, M. J. Socially assistive robots: The link between personality, empathy, physiological signals, and task performance. In *Proc AAAI Spring Symposium: Emotion, Personality, and Social Behavior* (2008), 133–140.

44. Tapus, A., and Matarić, M. J. User personality matching with a hands-off robot for post-stroke rehabilitation therapy. In *Experimental Robotics* (2008), 165–175.

45. Tapus, A., Tapus, C., and Mataric, M. The role of physical embodiment of a therapist robot for individuals with cognitive impairments. In *Proc Ro-Man'09* (2009), 103–107.

46. Tapus, A., Tapus, C., and Mataric, M. J. The use of socially assistive robots in the design of intelligent cognitive therapies for people with dementia. In *Proc ICORR'09* (2009), 924–929.

47. Torrey, C., Powers, A., Marge, M., Fussell, S. R., and Kiesler, S. Effects of adaptive robot dialogue on information exchange and social relations. In *Proc HRI'06* (2006), 126–133.

48. Vallerand, R. J., and Reid, G. On the causal effects of perceived competence on intrinsic motivation: A test of cognitive evaluation theory. *J Sport Psychol 6*, 1 (1984), 94–102.

49. Wade, E., Parnandi, A., Mead, R., and Matarić, M. Socially assistive robotics for guiding motor task practice. *Paladyn 2*, 4 (2011), 218–227.