User Personality Matching with Hands-Off Robot for Post-Stroke Rehabilitation Therapy

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Abstract. This paper describes a *hands-off therapist robot* that assists, encourages, socially interacts, monitors and reminds post-stroke users to use the weaker, stroke-affected limb. We investigate the role of the robot's personality in the hands-off therapy process, focusing on the relationship between the level of extroversion-introversion of the robot and the user. The experimental results show the first attempts of mapping between the extraversion-introversion personality dimension and the spectrum of therapy styles that range from challenging to nurturing.

1 Introduction

Research into Human-Robot Interaction (HRI) for *socially assistive* applications is in its infancy. Socially assistive robotics, which focuses on the *social interaction,* rather than the *physical interaction* between the robot and the human user, has the potential to enhance the quality of life for large populations of users [7,12,28]. Post-stroke rehabilitation is one of the largest potential application domains, since stroke is a dominant cause of severe disability in the growing ageing population. In the US alone, over 750,000 people suffer a new stroke each year [22], with the majority sustaining some permanent loss of movement. Stroke patients with hemiparesis or hemiplegia (one-sided deficit) may have difficulty with everyday movement activities. This loss of function, termed "learned disuse", can improve with rehabilitation therapy during the critical post-stroke period. One of the most important elements of any rehabilitation program is carefully directed, well-focused and repetitive practice of exercises, which can be passive and active. In passive exercises, also known as hands-on rehabilitation, the therapist (or the robot) actively helps the patient to repeatedly move a limb as prescribed. In contrast, active exercises are performed by the patient him/herself, with no physical hands-on assistance. The vast majority of existing work into rehabilitation robotics focuses on hands-on robotic systems (e.g., [3, 4, 27]). However, recent results from physical therapy research show that such therapy may not be the most effective means of recovery from stroke, and are certainly not the only necessary type of much-needed treatment [7].

Our work focuses on *hands-off therapist robots* that assist, encourage, and socially interact with patients during their active exercises. Our previous research [7, 12, 15, 28] demonstrated, through real-world experiments with stroke patients, that the physical embodiment (including shared physical context and physical movement of the robot), the encouragements, and the monitoring play key roles in patient compliance with rehabilitation exercises.

In this work we investigate the role of the robot's personality in the hands-off therapy process. We focus on the relationship between the level of extroversion/introversion (as defined in Eysenck Model of personality [11]) of the robot and the user, addressing the following research questions:

1. How should we model the behavior and encouragement of the therapist robot as a function of the personality of the user?
2. Is there a relationship between the extroversion-introversion personality spectrum based on the Eysenck model [11] and the challenge-based vs. nurturing style of patient encouragement?

Examining and answering these questions will begin to address the role of assistive robot personality in enhancing patient compliance.

2 Eysenck Model of Personality

Personality is a key determinant in human social interactions. Research has shown a direct relationship between personality and behavior [6, 8, 20]. In [20], Morris indicated that, to the personality psychologist, the behaviors of greatest importance are those that are: (1) relatively pervasive in the person's life-style in that they show some consistency across situations; (2) relatively stable in the person's life-style across time, and (3) indicative of the uniqueness of the person.

Consequently, personality is also a key factor in human-robot interactions (HRI) [23, 24]. It has been argued that robot personality should match that of the human user [24]. While there is no generic definition of *personality*, our working definition of it is *the pattern of collective character, behavioral, temperamental, emotional and mental traits of an individual that have consistency over time and situations*, consistent with the literature [32, 6, 20].

To date, little research into human-robot personality matching has been performed. In [32], Woods et al. explored the topic, showing that subjects perceived themselves as having stronger personality traits than robots. A similar study, by [16], found that people enjoyed interacting with humorous robots but listened to more serious ones. No work has yet addressed the issue of personality in the assistive human-robot interaction context. This is what we focus on.

Quantification of personality is a controversial topic since there is no universally accepted number of personality dimensions. The Eysenck model of personality (3 model factor - PEN) [9], the Five-factor model of personality (Big5) [19] (extraversion-introversion, neuroticism, agreeableness, conscientiousness, and openness) and the Myers-Briggs model [21] (extraversion-introversion, sensation-intuition, thinking-feeling, and judging-perceiving) are the most used and dominant models in the literature. In this work, we use the biologically-based Eysenck [11] Model of Personality (PEN) that advocates three major dimensions or super-factors in the description of personality: (P) Psychoticism, (E) Extroversion, and (N) Neuroticism. The *extroversion vs. introversion* dimension is related to the social interest and positive affect. Eysenck showed that extraversion-introversion is a matter of the balance of neural "inhibition" and "excitation", since extraversion is based on cortical arousal, measurable through skin conductance. *Neuroticism* or *emotional stability vs. instability* corresponds to the stability of behavior over time and the person's adaptation to the environment. Neuroticism is based on activation thresholds in the sympathetic nervous system, measurable through heart rate, blood pressure, hand temperature, perspiration, and muscular tension. Finally, *psychoticism* is associated with rebelliousness, aggressiveness and impulsiveness and is related to testosterone levels.

We chose the PEN model of personality because of its biologically inspired nature and its explicit treatment of introversion and extroversion within the above space, factors we are specifically interested in studying in the assistive context.

Our preliminary work with stroke patients [7] demonstrated significant personality differences in patient response to the therapist robot. In this study we aim to address those differences directly, by focusing on the extroversion-introversion personality dimension. One of the inspirations for this work is the observed influence of the pre-stroke personality of subjects over the post-stroke recovery. It was noted that the subjects classified as extroverted before the stroke mobilize their strength easier to recover than introverted subjects [14]. Since the extroversion dimension (Figure 1) is comprised of many different factors, habits, and behaviors, in this study we give higher importance to the extroversion-introversion traits, in an attempt to map them to the spectrum of therapy styles that range from nurturing to challenging.

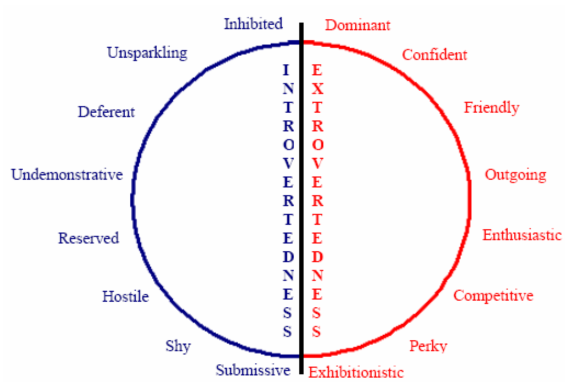

Figure 1: Human Personality: Introvert and Extrovert Adjective Items (from the Eysenck in [11] model of personality)

3 Interaction Design

To the best of our knowledge, none of the existing robotic systems for socially assistive applications integrate the personality dimension in their behavioral model. Inspired by Bandura's model of reciprocal influences on behavior [2], we believe that it is helpful to incorporate the personality dimension so as to improve human-robot interaction (HRI) and behavior selection. Figure 2 depicts our general behavior control architecture, which integrates the Eysenck model.

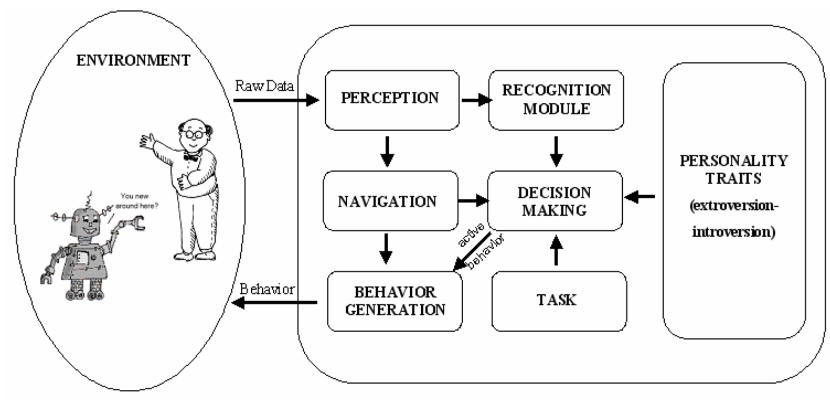

Figure 2: HRI Information Processing using the Personality Model of the User

The extraversion-introversion dimension is based on the observed inter-correlations between traits such as sociability, activity, impulsiveness, liveliness and excitability, all of which strongly influence behavior. In our experimental design, we chose to use two of those traits: sociability and activity, which can be most readily emulated in robot behavior.

3.1 Sociability

Sociability is the trait that most clearly expresses a person's level of extroversion-introversion. A large body of research in *social psychology* has shown that individual behavioral differences are most apparent in social situations [6, 8, 20]. In [18], Harkins, Becker and Stonner empirically illustrated that both the presence of others and their social activities are typically more enjoyed by extraverts than by introverts. In [9], Eysenck described the extravert as sociable, friendly, talkative and outgoing. In contrast, the introvert is quiet, introspective, and prefers small groups of intimate friends (see Figure 1- for additional personality adjectives used by Eysenck). We hypothesize that these are directly related to verbal and non-verbal communication patterns. Hence, we identified proxemics and vocal features (i.e., content, volume, and speech rate) as relevant aspects to be embodied in the robot's behavior. Each is described below.

A. Proxemics: The interpersonal space in human interactions has been widely studied in social psychology, since the seminal paper by Hall [17] who coined the term *proxemics*. Recently, roboticists have begun to use proxemics in social spatial interactions [5, 15, 31]. Hall divided space into four general zones:

- **Intimate:** Up to 0.25m from the body; usually involves contact (e.g., embracing, comforting). Can be uncomfortable and intrusive.
- **Personal:** Between 0.3-1m; typically used for family and friend interaction.
- **Social:** About 1-3m, used in business meetings and in public spaces.
- **Public:** Beyond 4m, e.g., the distance between an audience and a speaker.

Since we use a non-contact (hands-off) HRI approach, intimate space is not applicable. The public distance is also unsuitable since it involves no interaction. Consequently, only personal and social space are considered in this work, as they facilitate our focus on social interaction. Hall [17] linked the human sense of space with behavior and personality type. We posit that extraverted individuals, who like social interactions, may prefer to have the robot physically closer than introverted individuals, who may perceive the robot as invading their space. Therefore, proxemics can be encoded as function of the individual extraversion-introversion level.

B. Verbal and Para-Verbal Communication: Both vocal content and paralinguistic cues, such as volume and speech rate, play important roles in human interactions, and express personality and emotion [1, 26, 29]. The similarity-attraction principle, which assumes that individuals are more attracted to other people manifesting the same personality as themselves, has studied in HCI (e.g. [25]). We designed two interaction scripts, one that displayed an extroverted and one an introverted personality type through the choice of words and paralinguistic cues. The dominant and challenging script is composed of strong and aggressive language (e.g., "You can do it!", "You can do more than that, I know it!", "Concentrate on your exercise!"). Higher volume and faster speech rate are used in the pre-recorded transcript voice, based on evidence that those cues are associated with extraversion [23, 25]. In contrast, the empathetic and nurturing script contains gentler, supportive language (e.g. "I know it is hard, but remember that it's for your own good.", "Very nice, keep up the good work.", "You did a very nice job."). The voice used has lower volume and pitch.

3.2 Activity

In addition to sociability, we also considered the activity trait. [9, 11] showed that people with high activity scores are generally energetic and favor physical activity, while individuals with low scores tend to be physically inactive. High activity is an extravert characteristic, while low activity tends to characterize introversion. In our system, the activity of the robot is correlated/matched to the user's movement and sociability.

4 Hypotheses

Based on the principle of similarity attraction, we experimentally tested the following hypotheses:

Hypothesis 1: Users with extroverted personalities will have a preference for a robot that challenges them during rehabilitation therapy, over one that focuses the interaction on praise.

Hypothesis 2: Users with introvert personalities will prefer a robot that focuses on nurturing praise rather than on challenge-based motivation during the training program.

5 Robot Test-bed

Our experimental test-bed, shown in Figure 3, consists of an ActivMedia Pioneer 2-DX mobile robot base, equipped with a SICK LMS200 laser rangefinder used to track and identify people in the environment, by detecting reflective fiducials worn by the users. We also used a light-weight motion-capture system based on inertial measurement units (IMU) worn by the user and used by the robot to detect and track the user's weaker stroke-affected limb movement.

Figure 3: Robot test-bed

6 Experimental Design

To test our stated hypotheses, we employed the above-described robot system as an experimental tool to be used in human subjects interactions. The study had a

2(sociability) x 2(activity) design. Hence, the robot could manifest (non-) social and (low) high activity traits through its behavior, to express the extraversion-challenging or introversion-nurturing therapy styles.

Before participating in the experiment, each subject was asked to fill two questionnaires: one for determining personal details such as gender, age, occupation, and educational background, and another for establishing the subject's personality traits based on the Eysenck Personality Inventory (EPI) [10].

The experimental tasks were intended as functional exercises similar to those used during standard stroke rehabilitation and consisted of four tasks:

- Drawing up and down, left and right;
- Lifting and moving books from a desktop to a raised shelf;
- Moving pencils from one bin to another.
- Turning pages of a newspaper.

The participants were asked to perform the four tasks in a sequence as part of a predefined scenario, but they could stop the experiments at any time by saying "stop". Each task lasted 5 minutes. If a user continued beyond the end of a task, the robot would verbally advise the user to change the task. At the end of each experiment, the experimenter presented a short debriefing.

Vocal data were collected from the users with a microphone and interpreted through automatic analysis. The robot was capable of understanding the following utterances: "yes", "agree", "no", and "stop". The participants wore a motion sensor on their (weaker, if post-stroke) upper arm and a reflective laser fiducial was strapped around the participants' lower leg, as shown in Figure 4.

Figure 4: The experimental setup: the participant is performing task 4 (turning pages of a newspaper) with the robot at a social distance. The laser fiducial is on the participant's right leg, the motion sensor on the right arm, and a microphone is worn on standard headphones.

In the experimental design, each participant was exposed to two different assistive personalities: one that matched his/her personality according to the Eysenck Personality Inventory (EPI) and one that was randomly chosen from the rest of the options. The participants' responses were recorded. Evaluation was performed based both on user introspection (questionnaires) and experimental observation (videotapes analysis) methods. After each experiment, the participant completed two other questionnaires designed to evaluate their impressions about the robot's personality (e.g., "Did you find the robot's character unsociable?") and about the interaction with the robot (e.g., "The robot personality is a lot like me."). All questions were presented on a 7-point Likert scale ranging from "strongly agree" to "strongly disagree".

5 Experimental Results and Discussions

The pilot experimental group consisted of 12 participants (8 male, 4 female). A small proportion (25%) was under 20 years old, but none younger than 18. Approximately, 33% were 21-25 years old and 42% were 26-30. Most of the participants (except three) were students; 91% came from robotics or technology-related departments (e.g., computer science, electrical engineering).

To test the matching between the user's and robot's personality, we asked the participants to rate on a Likert scale from 1 (strongly disagree) to 7 (strongly agree) whether the "robot's personality was a lot like theirs". Table 1 illustrates the average of the obtained results. The participants tended to match their personality with the robot's. Extraverted users rated the extraverted robot as significantly closer to their personality than the introverted robot (extraverted robot M=4.7143, introverted robot M=3.2857). However, even if the rates of introverted users were less significant, they matched their personality better with the introverted robot (M=4) than with the extraverted one (M=3.8).

TABLE 1: Average of results obtained for testing the matching between the user's and robot's personality (disagreement = 1, agreement = 7).

	Extraverted Robot	Introverted Robot
Extraverted User	4.7143	3.2857
Introverted User	3.8	4

We also analyzed the correlation between the extraversion-introversion personality of the robot and the challenge-based vs. nurturing style of patient encouragement. The users rated the robot encouragement style on a Likert scale from 1 (Nurturing) to 7 (Challenging). On average, the participants classified the introverted robot as more nurturing (M=3.91) and the extraverted robot as performing a challenge-based encouragement (M=5). We also compared the personality of the robot and the robot's personality observed and attributed by the user. The results show that extraverted robots were classified as having an extraverted personality with an average score of 5.83 and that introverted robots had an average score of proper (introverted) classification of 4.25.

None of the 24 trials was terminated by the experimenter. The end of a trial was either a sequence of "stop" utterances from the user or the end of the four exercises. Because of the high sensibility of the speech recognition module, participant breathing and ambient noise were on occasion detected as a "stop" or "no", ending the interaction prematurely. Figure 5 shows the average interaction time (in minutes) spent by the extraverted/introverted users with extraverted/introverted robots, respectively. Introverted participants interacted equally with the introverted (M=6.39 minutes) and extraverted (M=6.24 minutes) robot. In contrast, extraverted users preferred interacting with the extraverted robot (M=7.36 minutes) than with the introverted robot (M=4.84 minutes).

Another interesting finding is that an important percentage of participants (83%) would have preferred to speak more with the robot and to have a more complex dialogue with it. Our future work will enrich the verbal communication between the participants and the robot.

The pilot study thus validated our two hypotheses. The participants with extraverted personalities had a preference for a robot that challenged them during exercises over the one that focused the interaction on praise. Analogously, users with introvert personalities preferred the robot that focuses on nurturing praise rather than on challenge-based motivation during the training program.

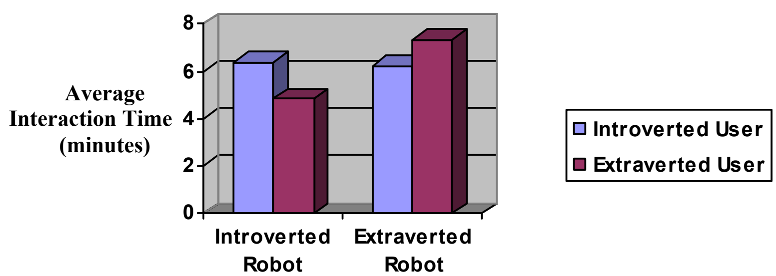

Figure 5: The average interaction time (minutes) spent by introverted/extraverted users with introverted/extroverted robots, respectively

The pilot results show the preference for personality matching between users and socially assistive robots. Further experiments with larger and more representative participant pools (i.e., stroke patients) are needed and are being pursued in our continuing work.

6 Conclusion and Future Works

We have presented a *non-contact therapist robot* intended to assist, encourage, socially interact, monitor and remind post-stroke users to use the stroke-affected weak limb. The role of the robot's personality in the hands-off therapy process was investigated, with a focus on the relationship between the level of extraversion-introversion of the robot and the user. The experimental results have shown first evidence for the preference of personality matching in the assistive domain.

Our work to date demonstrates the promises of socially assistive robotics, a new research area with large horizons of fascinating and much needed research. Our ongoing efforts are aimed at developing effective embodied assistive systems, and extending our understanding of human social behavior. Socially assistive robotic technology is still in its infancy, and the next decade promises assistive robotic platforms and systems that will be used in hospitals, schools, and homes in therapeutic programs that monitor, encourage, and assist their users.

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