User Models for Post-stroke Therapies and Consequences for the Interaction with a Humanoid Robot

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Abstract: In the future, social robots may become a viable help to provide more patient therapy sessions for post-stroke patients. Certain therapies require still another person to work with the patient. If a non-medically skilled helper person could be used, this could dampen the lack of available therapists worldwide. But for this, strategies how robots may best advise a patient and the helper must be found. This paper aims to find a common basis, where to formulate rules how a social robot could react and act in a therapy session. We present the focused therapy and propose our model and give an exemplary idea how to use this framework.

1 INTRODUCTION

A worldwide shortage of medical personnel in all areas is forcing medicine to innovate. In order to cope with the increasing number of stroke patients, research is being carried out in some places on how robots can help patients in neurorehabilitation therapy. Further subdivided, there is the possibility of doing this with a physical aid, in which a mechanical system moves the limbs by a robot and socially assistive robots (SAR). Their task is, among other things, to accompany the patient through verbal instructions and feedback through a therapy session. The main goal of the robot is to let patients perform their training exercises in a good way and to keep the patient motivated throughout the therapy.

An important aspect is a continuously verbal feedback during therapy. This was observed during sessions with a human therapist, but becomes even more important in the case of SAR as the robot cannot provide physical assistance and body contact to the patient. In addition, an intelligent recognition of parameters must already be available for the feedback in order to optimally adapt the feedback with regard to the current therapy situation. While the recognition of a specific therapy session situation represents a multimodal recognition challenge with the use of, for example, several sensors like cameras, sensors for sound or devices analyzing the interaction of a patient.

Based on the sensed situation actions have to be specified that should be activated. Rules can be used for this purpose. They can e.g. specify when the robot should say something to a patient. This aspect of rules will become a topic that we want to discuss in this paper. We will focus on cases with 2 people present, the patient and a helper. Because of the lack of professional therapists, a helper that might come from the family will support the patient.

Most social robot therapies deal with robot-to-patient cases. This works in cases in which the patient can carry out the therapy alone with the robot. In certain forms of stroke therapy, however, the main feature is that the severely handicapped patient's limbs have to be moved by a therapist. Here now adds an idea, to substitute this therapist, with a non-medically skilled "helper", to move the limbs of the patient. For this approach, the robot would then not only have to instruct and motivate a patient, but also this other person.

In order to carry out a suitable spontaneous, helpful feedback strategy, one has to define rules of what to do. Here we look into finding a common basis and a structure, on where rules could be applied to. Thereby we aim to incorporate a way, how we can use a user model and the personality of the therapy participants to consider how the robot provides his

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feedback. The corresponding user models were based on interviews using the Repertory Grid Technique (George A. Kelly, 2001).

The further structure of this paper first shows the related works and then the stroke therapy considered here and then presents a model of when feedback from the robot is appropriate. This is followed by a discussion and a summary.

2 RELATED WORKS

Winkle researched in (Katie Winkle, 2020) how a SAR can be used as a treadmill running instructor and how participants would accept it. She uses an input space of 20 features with different dimensions to monitor a runner approach. It includes features like heart rate, speed, activity level and also psychological traits combined in the Big 5 model.

This is one of the commonly used model to assess the personality of patients as shown by Dwan et al. (Toni Dwan and Tamara Ownsworth, 2019). Coming from the field of psychology, the five personality factors are "Neuroticism", "Extraversion"," Openness to experience", "Agreeableness", "Conscientiousness". A person's factors will be determined through questionnaires.

The Robot has many different actions as a coach for a treadmill like reminding about time or how to correct the pose of the runner. Winkle uses an interactive machine learning approach, whereby a trainer enters during a live-session with a runner new state-action pairs into the system. The robot then improves his next autonomous action from the previously gathered examples from the trainer.

Casas et al. (Jonathan A. Casas, et al., 2019) use a NAO Robot in a therapy setup to increase cardiac function. Patients run on a treadmill and the nearby a robot provides verbal and gestural feedback. Inside their patient-robot interaction they monitor the level of exertion with the "Borg scale" (Bahar Irfan, et al., 2020) and the patient's heart rate. The Borg scale is a method to quantify perceived exertion and aims to make it comparable between individuals. Even with its subjective nature, this method proved to have a good correlation with the level of more measurable effort metrics in diverse application.

Additionally, they watch several cases with these two metrics and switch between different interaction modes. Depending on a "high" or "low" exertion and/or heart rate they ask the patient if he is feeling alright. For cases whereby, the exceeds the heart rate exceeds for too long the normal values, the robot will e.g. be saying: "Doctor, the patient needs help.". This interaction mode then can only be switched off, when the medical staff touches the head of the robot.

A lately, different approach has been done by Irfan et al. (Bahar Irfan, et al., 2020) by measurements with an ECG, Borg Scale entered thorugh the patient via a tablet, a laser range finder and an inertial measurement unit and a tablet camera. Next to predefined phrases at certain points in the session, and alerting the patient and medical staff about a high exertion or Heart rate, the robot will provide prompts if the patient should improve his cervical posture.

A rather different perspective to look on the provision of feedback to the patients comes directly from medical literature. Bachelor et al. (Alexandra Bachelor, 1991) state, that the success of the therapy outcome and the "alliance" between patient and therapist is that the patients perception yields a better prediction of the success than the therapist perception. Furthermore, from a patient's perspective therapist-provided aid, warmth, caring, emotional involvement are factors which truly helped in therapies.

Duncan et al. (Barry L. Duncan, et al., 1994) adds to these findings and states, that in the "alliance" literature, the therapy progresses the most, if the therapist talks about what the patients see as important for them. Additionally the therapist should have chosen methods, that the patient will think, that it helps him to reach the goal specified by the patient.

Because of these finding, we would primarily target the patient's needs and we later present robot actions, which we try to tailor to the findings of Bachelor and Duncan et al.

3 ARM BASIS TRAINING (ABT)

3.1 Classic ABT with a Therapist

ABT has been designed for severe arm impairment. The focus lies on improving the patient's capabilities for selected movements of the patients' arms as displayed in figure 1. The ABT will be done in a structured repetitive training manner with each session to complete a set of arm and hand exercises (Thomas Platz, Bernhard Elsner, and Jan Mehrholz. 2015). The therapy's' movements are starting with joint movements "without" the factor of gravity (step 1), meaning that the therapist is holding the extremity of the patient up and manually assists the movement of the patients arm, hand or finger during the exercise. The next step -after the patient acquires the full range of motion of the movement- is to let the patient do the exercises with gravity (step 2), whereby the patient is

supposed to do single joint movements, while the therapist is still holding the hand or arm, letting the patient focus only on selected joint movements of the rest of his arm. Ideally, the patient performs multiple-joint-movements on his own (step 3). Until then, the supporting therapist needs to hold the weight of the arm and to ensure that the patient does not need a postural control by himself during the exercise.
There is no specific performance-related feedback from the therapist to the patient predefined, so the therapist may engage in feedback as he wants.

In the first session of a patients' therapy, a human therapist will do an intensive assessment and introduce him to the therapy. Only after this, the next therapy session will include the robot.

Figure 1: Three Arm Basis Training exercises with a human therapist. The start- and endpoints for each movement are here displayed (Thomas Platz, 2019).

3.2 ABT with Helper and Robot

This will be the later setup for our robot study and at first adds only the robot to the therapy session. Of course, there needs to be more technical measurement systems like cameras to recognize the movements, the emotional state, body positions and verbal communication.

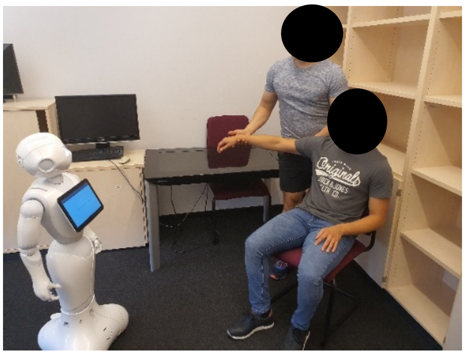

Figure 2: Exemplary execution of the ABT therapy (non-medical envirionment).

It is the idea to check with sensors whether the execution of the exercises is correct. This means e.g. the speed and the extend of the movement.

Figure 3 gives an impression of the models that our analysis software provides. The (upper) image shows what the system calculates with the angles of the limbs. In this one the patient is supposed to do an arm curl. Thereby we analyse the degree of the angle and this may come into consideration of what we would express as feedback e.g. "Move your hand closer to your shoulder."

The lower image displays the situation with a helper from a different perspective. We will provide similar hints

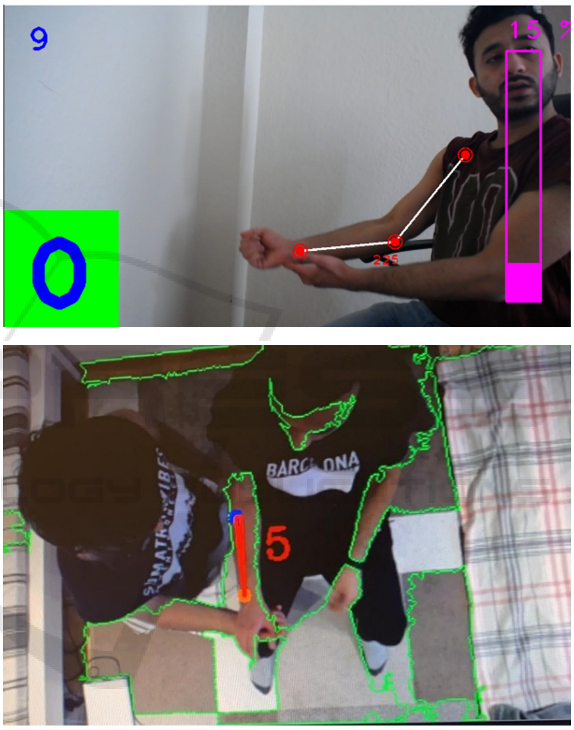

Figure 3: Examples of the visualisation of sensor tracking of arm movements.

Additionally, it is intended to identify the emotions of the patient and the helper. The humanoid robot Pepper provides a quite good solution based on facial expression and voice that works quite well for one person. We did not have a solution for two persons yet. However, in this paper we want to focus on a different aspect, the rule model.

4 PROPOSED RULE MODEL FOR

4.1 Basic Patient/Helper Model

Starting with the basic form of one robot to one patient, we also use an exertion metric with binary values, in this case “low” and “high” engagement. For emotional states we use “neutral”, “unhappy” and “happy.

Table 1: Basic state table.

Emotion	High Engagement	Low Engagement
Unhappy		
Neutral		
Happy		

Table 1 presents 6 different states of a patient, to which a robot could react and provide spontaneous feedback. Note that this is only a general framework for such an arm rehabilitation scenario. More specific feedback for arm posture is not the main focus of this model.

Currently with this table alone, one would only describe the person’s state. We now need to introduce the robot’s possible actions. After this, we can combine both the patient/helper state with the possible robot actions to design a “grid”. With this grid, we have one simple way how to define rules for the interaction. So, in the next subsection we will focus on a model for the action space of the robot.

4.2 Robot Actions

From the robot side we need to model the possible robot actions according to what the robot should achieve. The selection of goals and actions, depicted in table 1 are only a subset of what could be perceived as useful. These actions can be done in different ways, such as “positive”, e.g. to generate a good, confirming way, so that the patient gets confirmed, that what he already does, is good. Otherwise a “challenging” style e.g. tries to tell the person, that he is already ok, but he can do it even better. Styles will be more highlighted in a moment.

For our work here, we identify four important feedbacks for the patient.

“Provide task-related feedback” (PTR) is directly linked how the patient performs his task. “Provide social Feedback” (PSF) aims to motivate the person. Then to make a conversation a bit more memorisable, the robot may “provide small talk” (PST), this is mainly for cases, to improve a therapy scenario, where no one talks and the atmosphere between the two persons may become too uncomfortable. Finally, the robot may ask a person, e.g. to enter how the session is going on today or the current exertion level, we call this action “Request information” (RI). This is the only robot action, where we would not include a positive or challenging style, as the person should only focus on entering data as directly as possible.

We intent to use the systems decision making to determine, if a certain action/feedback should be provided by the robot. If an action has been triggered, the style, “how the robot” should formulate his verbal prompt is determined by the psychological profile of this person.

Table 2: Social robot action space.

Action goal	Action	Style	Example
Improve Performance	PTR	P	“You do well, but you should move the arm higher up in each repetition.”
		N	“move the arm higher”
		C	“Dear <name>, are your arms tiring? Move the patients arm higher up”
Improve Motivation	PSF	P	“Great results with your 40 points, you’re approaching your goal fast!
		N	“You reached 40 points, remember your goal to be able to play again.”
		C	“With 40 points, I’m sure you’re still holding back your performance”
relax interaction	PST	P	“We’re halfway through the exercises, you are a good team!”
		N	“We’re halfway through the exercise.”
		C	“I think we as a team can work harder to achieve a better performance! There is only half of the exercises left to prove it!”
Ask for user data (only to Patient)	RI	P	-
		N	“Please enter your exertion level.”
		C	-

The column “style” means “feedback style”, which will be either “neutral” (n), “positive” (p) and “challenging” (c). We use the “Big 5” or “OCEAN” Model as the foundation to decide in which conversation style the robot’s action should be formulated.

In this manner, for a person being less “open to experience” new things according to the “Big 5” model, we may not use the challenging style often, whereby a more open person may find this style more engaging than others.

The idea, is, that a robot will always say the same, when providing a certain action, but the patient profile will determine, which feedback style will be used.

4.3 Patient + Helper Model

The main point here is that we try to look on both persons separately. Therefore, we have two user models. However, in this paper we focus on the models for patients only. For helpers the structure of the model looks similar. However, the spoken phrases of the robot are different.

If we try to summarize the possible states of a participant's states (table1) with all possible robot actions (table 2), we have 72 state and action combinations. This means, that the robot says one or several phrases for each of these states. Additionally, for the aspect of engagement of either person, the robot could integrate a more precise answer for task-related feedbacks, since the patient is the more passive one and the helper will be the more active executor in the first stage of the therapy. But this would result in even more sentences and more detailed feedback, which need to be prepared beforehand and also be recognized.

4.4 Patient and Helper Attributes and Metrics and Its Role for the Feedback Style

As mentioned before we base our decision which feedback style the robot should use on the Big 5 Model, as briefly explained in section 2. The arm and hand speed of the participants detected by devices are what we specifically want to use for the low/high engagement. Since the whole therapy is based that the patient's arm and hands should be moved by the helper and later by the patient alone, this will be the main metric for engagement. This will be a dynamic value recognized by sensors and cameras.
For the static values of the Big 5 factors, both the patient and helper should fill out a questionnaire before the first therapy session.

4.5 History of Previous Commands

The previously performed actions as "chain" of actions can be added. In theory, the robot should take his previous actions into account, of what to do next. Saying e.g. for the fourth consecutive time, that the helper should better his performance, might be an annoying for him and the patient.

To prevent this, a chain of previous actions can be added to each patient or helper state and add rules basing on them as well. On the other hand, this temporal aspect could become unnecessary if a robot action is triggered at a certain time.

A verbal utterance could only be triggered once e.g. 10 or 15 seconds. It needs to be evaluated how the frequency of feedback should be.

5 DEFINING THE RULES

The next step would now to define the rules that, when a certain action happens, which style of the feedback should be used. This will mostly due determined by the style of the clinicians and or system designer when to use what and when a high or low engagement has been detected.

For the exemplary case we defined an exemplary list of rules:

1. The positive Style will not be used on already happy participants with a high engagement.
2. The "challenging" style should only be used carefully and when appropriate. (This feedback style can be perceived as "social pressure".)
3. If the hand/arm movement speed moves below a certain speed X, the engagement level becomes "low".
4. The robot should ask less often for more information about the participant, if he is more introverted (has not so much extraversion).

This list should only show an idea, how the Table 3 can be used, especially if this framework would be used for other therapies, different therapies involving different tasks for patients and helpers. Only rule 1 & 2 are visually shown in Table 3.

Phrases within a style and the patient's engagement are the same for the sake of simplicity. In contrast to our example, individual phrases can be determined for each different patient state. On the other hand, depending on the application, there are many other opportunities where spontaneous feedback can be given. In the case of the ABT, we have 17 different exercises, which all can be executed wrong in several ways and therefore could integrate multiple correctional feedback options.

Table 3: Exemplary table for an exemplary patient for which we do not want to challenge him/her verbally. In this example we would not use the "challenging" style (**1st rule with purple text)**. Additionally, we wouldn't use the positive style, if the person is already in a happy state (**2nd rule with blue lines**) and highly engaged. Here we regard ABT step 3 (patient trains by himself). Crossed out sentences means that the robot will not use this feedback option.

			Patient/Helper					
			High Engagement			**Low Engagement**		
Action goal	**Action**	**Style**	**Happy**	**Neutral**	**Unhappy**	**Happy**	**Neutral**	**Unhappy**
Improve Performance	Provide Task-related Feedback	Positive	~~"You do well, but you should move the arm higher up in each repetition."~~	"You do well, but you should move the arm higher up in each repetition."	"You do well, but you should move the arm higher up in each repetition."	"You're on a good track, but can you maybe move your arm higher up?"	"You're on a good track, but can you maybe move your arm higher up?"	"You're on a good track, but can you maybe move your arm higher up?"
		Neutral	"Move your arm higher"	"Move your arm higher"	"Move your arm higher"	"Move your arm higher"	"Move your arm higher"	"Move your arm higher"
		Challenging	~~"Dear [name], are your arms tiring? Move your arm higher up"~~	~~"Dear [name], are your arms tiring? Move your arm higher up"~~	~~"Dear [name], are your arms tiring? Move your arm higher up"~~	~~"[name] you are supposed to move your arm higher up"~~	~~"[name] you are supposed to move your arm higher up"~~	~~"[name] you are supposed to move your arm higher up"~~
Keep/Improve Motivation	Provide social Feedback	Positive	~~"Great result with your 40 points, you're approaching your goal fast!~~	"Great result with your 40 points, you're approaching your goal fast!	"Great result with your 40 points, you're approaching your goal fast!	"Awesome results with your 40 points!"	"Awesome results with your 40 points!"	"Awesome results with your 40 points!"
		Neutral	"You reached 40 points, remember your goal to be able to play again."	"You reached 40 points, remember your goal to be able to play again."	"You reached 40 points, remember your goal to be able to play again."	"You reached 40 points, remember your goal to be able to play again."	"You reached 40 points, remember your goal to be able to play again."	"You reached 40 points, remember your goal to be able to play again."
		Challenging	~~"With 40 points, I'm sure you're still holding back your performance"~~	~~"With 40 points, I'm sure you're still holding back your performance"~~	~~"With 40 points, I'm sure you're still holding back your performance"~~	~~"I'm sure in the next round, you can achieve more than 40 points."~~	~~"I'm sure in the next round, you can achieve more than 40 points."~~	~~"I'm sure in the next round, you can achieve more than 40 points."~~
Change interaction climate	Small talk/ Tell a joke	Positive	~~"We're halfway through the exercises, we are a good team!"~~	"We're halfway through the exercises, we are a good team!"	"We're halfway through the exercises, we are a good team!"	"We're already in the 2nd half of the exercises we are a good team!"	"We're already in the 2nd half of the exercises we are a good team!"	"We're already in the 2nd half of the exercises we are a good team!"
		Neutral	"We're halfway through the exercise."	"We're halfway through the exercise."	"We're halfway through the exercise."	"We're halfway through the exercise."	"We're halfway through the exercise."	"We're halfway through the exercise."
		Challenging	~~"There is only half of the exercises left to show everything what you got!"~~	~~"There is only half of the exercises left to show everything what you got!"~~	~~"There is only half of the exercises left to show everything what you got!"~~	~~"Come on, only 8 exercises left to show everything what you got!"~~	~~"Come on, only 8 exercises left to show everything what you got!"~~	~~"Come on, only 8 exercises left to show everything what you got!"~~
Ask for wellbeing	Request for more information	Positive	-	-	-	-	-	-
		Neutral	"Please enter your exertion level."	"Please enter your exertion level."	"Please enter your exertion level."	"Please enter your exertion level."	"Please enter your exertion level."	"Please enter your exertion level."
		Challenging	-	-	-	-	-	-

6 DISCUSSION AND LIMITATION

Finding a common basis to further discuss when to intervene and how that intervention should look like for two persons is a challenging task. We think of our presented work as a starting point of how to formalize the provision of feedback to patient and helper. Additionally, we have to track two persons simultaneously. We will focus on the ideas mentioned by Winkle et. al and the ideas discussed in section 2.

From the work of Duncan et al. and Bachelor and other related works on the subject of the strategic work alliance (section 2), we have taken the paradigm of focusing on the patient. Due to lack of paper space, only one example targeting the patient alone was shown in this work in therapy. Table 3 would also exist in a similar form for the helper. However, it can be argued that the "Request information" action is less important and will not be carried out often, since the helper should be fit for the role as helper and it slows down the therapy session, but the benefit to measure the helper's exertion is rather small. The "relax interaction" action no longer needs to be used, because it is primarily intended for situations when both people no longer interact with each other. If this happens, the robot action will automatically affect the helper. Consequently, the monitoring for this action does not have to be done for the helper.

The actions to motivate the helper and to correct his performance will be changed to suit to his role as supporter. But other than there will be no systematic changes. Also, the feedback styles are used and their usage is derived from the psychological Big 5 profile.

For a practical implementation, one could follow the idea from (Katie Winkle, 2020) and construct an interactive-machine-learning setup. Patient and helper states can be stored as "tuples" of a **<(multi-)state, robot action, (assigned) reward>.** At a given ***t***, one would pick the next best robot action. In this way, a state could then contain the whole patient's profile, engagement level, and the so far elapsed therapy session.

Looking into the limitations, it is clear, that integrating personality traits into the process of choosing the appropriate feedback is a very challenging task. Due to the complexity of this problem, the upcoming evaluation could be viewed only as a preliminary study with the ideas presented here. The results of that study might show that a different approach might be more suitable.

Furthermore, the introduction of more states in the user model can describe the therapy situation better, but adds more complexity for the robot's action space. It is yet not clear whether this is really necessary. Currently, we have the opinion that six states are appropriate. However, this has to be evaluated with patients and helpers.

If we use the same framework for helper and patient, we would also need to consider to add a suitable robot action and or phrase for him as well. More importantly, there should be variation inside every robot action to avoid a therapy experience and situations where patients and helper perceive the robot as boring or monotonous, especially, if these robot actions get triggered more often than others.

It might be necessary to specify more than one sentence in each situation and implement an arbitrary selection of one of those phrases. Thus, the actual number of predefined sentences or general vocabulary increases and also the work behind that. In table 3 we briefly showed the case with 2 examples per robot action, depending on low and high engagement. But in reality, one should aim for several utterances more, since the therapy may take several weeks of daily sessions.

One may argue, that certain sentences or phrases displayed here are not particularly positive. But for a first evaluation, we wanted to let the whole utterance sound "positive" and focus on exact words later.

Finally, we have to consider the extent to which a regular big 5 questionnaire can be used for stroke patients and may instead use a big 5 questionnaire specifically for stroke survivors.

7 CONCLUSIONS

In this paper we introduced a framework of observable states of patient and a non-medically skilled helper to execute a post-stroke therapy for arm and hand rehabilitation. The training tasks are guided by a social humanoid robot Pepper. This framework is intended to be used as a user model of a patient and a helper. The frameworks are based on the Big 5 Model and further therapy-specific attributes. The model supports the decision when to take an action by the robot and also how the feedback should be expressed. We concentrated on six states for each person, determined by a high or low engagement that is analysed from the data of the patient that were created after an initial interview with a human therapist. Additionally, the emotions unhappy, neutral or happy are identified from facial expressions.

Moreover, the robot may take spontaneous actions in different conversation styles, to e.g. challenge or to compliment the users. How the style will be chosen, depends on pre-defined rules to better fulfil the patient's wishes.

We intend to use the framework and define a detailed list of rules, for an ABT-study inside our E-BRAiN (Peter Forbrig, et al., 2020) project. In this project we mainly focus to research how to motivate patients with a social robot in post-stroke therapies.

It is our goal to start with evaluations by patients very soon. This had unfortunately to be postponed several times because of contact restrictions. Even when the restrictions were lowered, patients did not want to come to the hospital. Hopefully, this will change in the near future.

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