Optimizing patients' engagement by a cyber-physical rehabilitation system

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Abstract: Successful rehabilitation of stroke patients is strongly dependent on the engagement of patients. During a whole rehabilitation program, mundane rehabilitation exercises can easily become routine for patients, leading to boredom and as a result to ineffective functional recovery. This has been taken into consideration just by few rehabilitation systems. Engagement in rehabilitation can be decomposed into long term engagement (LTE) and short term engagement (STE) for the reason that their indicators and stimulation strategies are different. This paper proposes various engaging strategies to optimize both LTE and STE of patients. Actually, proposes to combine the strategies concerning the whole rehabilitation program and the strategies to be applied during single rehabilitation exercises. Based on the proposed reasoning model, a cyber-physical computing-based solution for a personalized rehabilitation system is proposed. Various cyber-physical characteristics, such as function augmentation, adaptive and learning control, are being implemented in the system in order to realize the various strategies of engagement.

1 Introduction

Engagement in rehabilitation exercises has been defined as a construct that is driven by motivation and executed through active and effortful participation [LK10]. A positive rehabilitation outcome is strongly associated with high patient motivation and engagement [La11]. Therefore, increased engagement during rehabilitation exercise is essential to achieve good outcomes in rehabilitation.

Researchers have studied long term participation in physical activities after rehabilitation, which is important for the survivors to sustain the benefits from rehabilitation [De06; MW09]. However, few researchers have studied engagement during rehabilitation program. Although stroke patients are required to participate actively during the rehabilitation program, it does not mean that they are mentally engaged. In fact, by definition, engagement extends participation beyond exercise execution and motivation [Ko07]. The difference between engagement and participation in this context is that engagement involves high levels of invested interest [LK10]. Several studies applied virtual reality [Zi13] and serious games [Bu09] in order to increase engagement during rehabilitation training exercise. In our previous study [Li14a], we found that, even if video games are used, the subjects' engagement level will decrease when they become familiar with the games. Therefore, a system which can adapt strategies to engage different patients is needed.

This paper aims at exploring how and why stroke patients engage in both short term and long term, and setting up a system model which can trigger and maintain engagement in short term and long term. The next section introduces the engagement model and the strategies for long term engagement (LTE) and short term engagement (STE). The third section proposes a system model with cyber-physical solutions in order to realize the goal of engaging the patients in both terms.

2 A reasoning model about the forms of engagement

Introduced above, we propose to consider engagement in rehabilitation as a combination of LTE and STE. LTE is defined as engagement throughout a whole rehabilitation program conducted in a hospital or a rehabilitation center, while STE is defined as engagement during a rehabilitation exercise. The reason of suggesting this classification is that their indicators are different, as well as the stimulation strategies that can be used to optimize the patients' LTE and STE. Indicators of engagement can be described in three aspects, which are cognitive, emotional and behavioral [Ai05]. In the context of stroke rehabilitation program, the indicators are striving to recover (cognitive), enjoyment of rehabilitation progress (emotional) and participation in everyday program (behavioral). Indicators of STE can be described as striving to exercise (cognitive), facial expressions (emotional) and intensity of muscle activities (behavioral) [Li14a].

The following figure shows a model about the forms of engagement. To optimize patients' engagement during rehabilitation program, strategies for LTE and STE should be combined. Before rehabilitation exercise, strategies for LTE will be applied. In this way, the patients can have an overview of the whole rehabilitation program. What the patients can expect from the whole program will be clear to them, which will contribute significantly to their willingness to comply with the whole treatment process. Then during single rehabilitation exercises, strategies for STE will be applied.

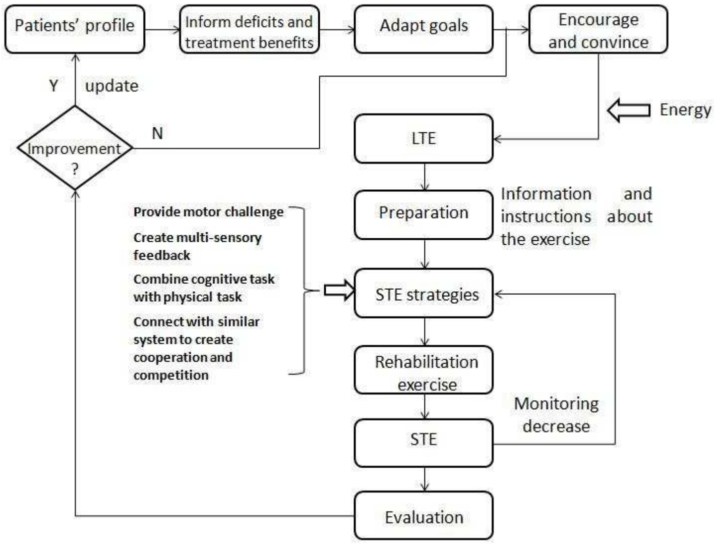

Fig.1 Model of strategies to optimize LTE and STE

LTE strategies can be explained based on the model proposed by Lequerica and Kortte for therapeutic engagement in rehabilitation [LK10]. The first strategy for LTE is informing the patients about their deficits and potential outcomes according to patients' profile. Then the patients can become aware of their own deficits, and this will contribute to their willingness to comply with the treatment and try to reach the goals. The potential benefits of the treatment will also be communicated to them. In this way the patients can know what they can expect and what they can benefit from the rehabilitation program so that they have the motivation to comply with the treatment. Next strategy is setting a proper goal for the patient. A goal, such as completing a task or reaching a Fugl Meyer score, is important because it gives the patients a clear goal and direction to make effort. Patients with different deficits or in different conditions should have different goals. The third strategy is to encourage and convince the patients. Patients' self-confidence or self-efficacy also contributes to engagement in rehabilitation program. To motivate the patients, physical therapists usually encourage them to give them confidence and convince them they have the ability to complete the tasks. Since the rehabilitation program is a long process, patients will be depressed inevitably. Therefore, it is important to encourage and convince the patients through the whole rehabilitation program. The last strategy for LTE is to update the goals. Updating the goals also plays an important role in maintaining engagement. This is because if the previous goal has been achieved, the patients opt to disengage according to the therapeutic engagement model. Therefore, it is of important significance to update the goals to engage the patients continuously along the rehabilitation program.

Strategies for STE have been identified in our previous study [Li14b]. It starts with a preparation stage, in which the patients will be informed about the objective of the exercise, the exercise contents and how to do the exercise. They will apply strategies for providing motor challenge, creating multi-sensory feedback, combining cognitive tasks and physical tasks and providing cooperating and competing training. Engagement level will be monitored using the indicators of STE, such as intensity of muscle activities and facial expressions. Monitoring engagement level will provide information to the system about the engagement level of the patients, and the system can intervene in order to stimulate the patients. Then the maintenance of STE could contribute to LTE by driving and motivating the patients back to do the exercise next time.

3 Cyber-physical based rehabilitation system

3.1 System workflow

The objective of this system is to optimize LTE and STE in rehabilitation. Figure 2 shows the system workflow, which is designed to realize the strategies for LTE and STE. The big loop represents the LTE strategies, and the small loop represents the strategies for STE.

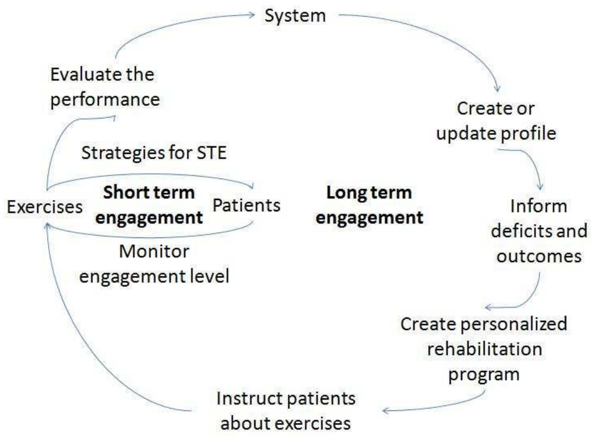

Fig.2 System workflow

3.2 System function

3.2.1 Personalizing rehabilitation program

(1) Create and update patient's profile: Patients' profiles will be the basis of personalized rehabilitation. The profile includes patient's information, name, gender, background, hobby, occupation, side of paresis, Fugl Meyer score for shoulder/elbow and wrist/hand, Motor Power score and Functional Independence Measure. (2) Inform the patient about deficits and potential outcomes: Before the personalized exercises start, the system can use a video or an avatar of the arm to show the patients their deficits and inform them their potential outcomes as well. (3) Generate personalized exercises for different patients: The physical therapist will decide which movements of their impaired limb or

joint should be trained. Then the system will generate personalized exercises for the patients, which are in different contexts. The system will list the exercises that could probably interest them according to their hobbies and backgrounds. (4) Inform and instruct the patient about the exercises: The system will encourage and convince the patients that they are able to do it so that the patients will be confident when they are doing the exercises. Then system will instruct them how to move to complete the tasks.

3.2.2 Monitoring engagement level

(1) EMG: According to our previous research, Root Mean Square (RMS) of EMG signal is found to be related to the subject's engagement level. The system can monitor and analyze the EMG signals of the muscles that are involved in the training exercise in order to be aware of the changes of the subject's engagement level. (2) Facial expression: Facial expression will also be used to indicate the engagement level. According to our previous research, when the subjects are smiling, usually their engagement level is higher [Li14a]. Therefore, the system will also monitor and analyze the facial expression.

3.2.3 Short term stimulation the patients

(1) Provide motor challenge: Every game will have different difficulty levels. If the patient completes the task in a certain level, the system will move to the next level and keep challenging the patientin order to prevent the patient will lose interest and get bored with the exercise. (2) Create multisensory feedback: The system will provide visual, auditory and tactile feedbacks to the patients in order to make them aware of the training exercises. Since some patients prefer certain feedback than others, the system could also provide personalized exercise that focuses on training that certain feedback. For example, if the patient's interest is listening to music, then the system could deliver a training which focuses on auditory feedback. (3) Combine cognitive tasks with physical tasks: The system can combine cognitive tasks and physical tasks in order to engage the patients. To realize this function, game exercises requiring cognitive actions can be delivered to the patients, and at the same time, the patients will be required to move a robotic device integrated with a human computer interface to complete the tasks. In this way the system can combine the two tasks. (4) Connect with similar systems to create cooperation and competition: Similar systems can be connected to create cooperation and competition training for the patients.

3.2.4 Training by learning

(1) Evaluate and memorize the results: After each exercise, the system will evaluate the stimulation strategies for the subjects and evaluate the performance of the patients in each game. The stimulation strategies will be evaluated by the changes of the engagement level after the stimulation strategy is used. If the engagement level increases, then it means this strategy works for this patient. Similarly, the performance of the patients will be evaluated by the game score of the patient. These results will be memorized in the system and updated in the patients' profiles. (2) Learn from the history: When another patient comes the next time, the system will apply a stimulation strategy which has been proved to be successful for a patient having similar background and the same hobby, so that the system can avoid the trial and error period in order to be more effective to engage the patient. The system could also make the game available with the proper difficulty level for the patients with similar FM scores.

4. Conclusion

This paper demonstrates that LTE of a whole rehabilitation program and STE during single rehabilitation exercises are both related with rehabilitation outcome and should be achieved in different ways for the reason that their indicators and stimulating strategies are different. Based on the reasoning model and the engaging strategies, framework for a cyber physical rehabilitation system is proposed with the intention to optimize the patients' engagement in both long term and short term. Although some systems aiming to engage the patients with game features have been introduced before, we found that the subjects' engagement level will decrease when they become familiar with the exercise integrated with video games. The proposed system may engage the patients to a higher level and for a longer time because it can provide personalized rehabilitation program and it can be adaptive based on patients' real time engagement level. Implementation and validation of the system is a task to be completed in the future.

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