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# As I am Not You: Accommodating User Diversity through Adaptive Rehabilitation Training for Multiple Sclerosis Patients

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## ABSTRACT

People who suffer from Multiple Sclerosis (MS) are unique individuals with their own characteristics and rehabilitation training needs. The great variation of MS symptoms and severity of the disease elevates a need to accommodate the diversity among its patients and support adaptive personalized training to meet every patient's rehabilitation needs. Our research has focused on integrating adaptivity in rehabilitation training for MS patients. We introduced the automatic adjustment of difficulty levels as a type of adaptation that can be provided in MS rehabilitation training exercises. A user study has been carried out to investigate the outcome of this adaptation. An adaptive personalized training has been provided to MS patients according to their own individual training progress, which was appreciated by the patients and the therapist. The automatic adjustment of difficulty levels is considered to provide more variety in the training and minimize the therapist's involvement in setting up the training.

## Author Keywords

User diversity, adaptivity, rehabilitation, Multiple Sclerosis

## ACM Classification Keywords

H.5.2 [User Interfaces]: Input devices and strategies; I.3.7 [Three-Dimensional Graphics and Realism]: Virtual reality; J.3 [Life and Medical Sciences]: Health

## INTRODUCTION

Owing to the diversity of users, static interfaces that behave in the same way regardless of the individual user, are considered less satisfactory in many cases. Users have uniquely different characteristics (e.g. preferences, abilities, and levels of experience) that may influence their performance in using an interface. Adaptive user interfaces can be considered as one way to accommodate these individual differences and level up users'

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performance in using an interface. Incorporating adaptation in the design of user interfaces improves user interaction with systems by facilitating user performance, easing system use, avoiding cognitive load problems and helping users deal with complex systems (Lavie and Meyer, 2010).

Rehabilitation is concerned with the act of restoring or bringing people back to a former capacity or to a satisfactory state. Within the medical and health care domain, the main purpose of rehabilitation is to restore some or all of a patient's physical, sensory or mental capabilities that were lost due to an injury, illness, or disease. People who are in need of any kind of rehabilitation are individuals with their own characteristics and needs. Although they might be subjected to the same background cause for rehabilitation, the stage of their condition or the severity of their disease may differ between one another which requires different treatments and forms of rehabilitation. For example, patients who suffered from stroke are most likely to have different impact levels of stroke. This calls for a suited, flexible rehabilitation training to meet every patient's needs and abilities, which raises the necessity of adaptive and personalized rehabilitation training to accommodate patient diversity.

People with Multiple Sclerosis (MS) belong to a unique group of patients with regard to their rehabilitation training needs. To date, no cure has been found for MS. Thus, the aim of therapy and rehabilitation for MS patients is slightly different from any other disease. For MS patients, rehabilitation training will not result in their full recovery; however, it may improve their functional mobility and quality of life. In the case of MS, the individual differences among its patients are quite prominent due to the great variation of MS symptoms and the impact levels of the disease. With regard to rehabilitation, the abilities of MS patients which vary differently may bring influence on the course of their rehabilitation training. For example, some training exercises might be difficult, if not physically impossible, for some patients due to their muscle weakness, while others have no problem in performing the exercises.

Providing a personalized training to each MS patient becomes essential to ensure the effectiveness of the

rehabilitation. Each patient progress in different ways, thus the training exercises must be tailored to each individual differently. For example, the difficulty of an exercise should increase faster for those who are progressing well compared to those who are having trouble performing the exercise. Therefore, there is no chance that the same rehabilitation training can be offered to every patient due to the diversity among patients.

To acquire a good result of rehabilitation, it becomes necessary to maintain patient motivation. Generally, rehabilitation involves the same training exercises that should be performed repetitively and for a long period of time. Some patients may feel less motivated when reaching a certain point in the training where they become bored with the exercises. Some patients may also feel less motivated when they find the training exercises to be too easy or too difficult. Therefore, rehabilitation training should be set at an appropriate level of challenge or difficulty to maintain the motivation of patients. This also raises the need of integrating adaptivity in the rehabilitation training which can play a significant role in accommodating patient diversity.

Through our work, we would like to investigate the integration of adaptivity in rehabilitation training for MS patients. This paper firstly describes an overview of adaptation in rehabilitation training, followed by a brief description of our research effort for developing a haptic-based rehabilitation system to support a personalized rehabilitation training for MS patients. Then, we elaborate on one type of adaptation, *automatic adjustment of difficulty levels*, which can be provided in the rehabilitation training for MS patients. Furthermore, we present a user study which was carried out to investigate the outcome of the integration of that particular adaptation.

#### **ADAPTATION IN REHABILITATION TRAINING**

Several studies have focused on investigating the integration of adaptation in rehabilitation training. Jezernik et al. (2003, 2004) studied the adaptation in rehabilitation training of locomotion for stroke and spinal cord injured patients. The patients have to perform the treadmill training as part of their rehabilitation. In manual treadmill training, the patient stands on a treadmill and performs walking-like leg movements with the help of two physiotherapists. To increase the training duration and reduce the physiotherapists' effort, an automated treadmill training system was introduced using a robotic rehabilitation device. The regular treadmill training with the robotic rehabilitation device is performed with a fixed gait pattern that is realized by controlling the position of the patient's joint angle trajectories. However, it is important to ensure that the patient is actively walking by himself and not only passively moving with the help of the device. Training with an adaptive gait pattern promotes active training, which may lead to a better rehabilitation outcome. Therefore, automatic gait-pattern adaptation algorithms were developed to enable patients that have some degree of voluntary locomotor capability to walk in the device actively with a variable gait pattern. A clinical study on six spinal cord injured patients

described in Jezernik et al. (2003) showed that the treadmill training with adaptive gait patterns increases the motivation of the patient and gives him/her the feeling that they are controlling the machine rather than the machine is controlling them. All patients also preferred the treadmill training with gait-pattern adaptation in comparison to the fixed gait pattern.

Kahn et al. (2004) described the integration of adaptive assistance into guided force training as part of the upper extremity rehabilitation for chronic stroke patients. A wide range of arm impairment levels can be observed in the stroke patients, where some patients are able to move through a large range of motion at a high velocity while others have severe range and velocity limitations. Based on the varying degrees of arm movement ability, they developed an adaptive algorithm that individually tailors the amount of assistance provided in completing the guided force training task. The adaptive training algorithm has been implemented with a simple linear robotic device and evaluated with one patient in a two month training program. The result showed significant improvements in the patient's arm function reflected by the performance increase of functional activities of daily living such as tucking a shirt and stabilizing a pillow.

Kan et al. (2011) presented an adaptive upper-limb rehabilitation robotic system for stroke patients which employs a decision theoretic model as its primary engine for decision making. The system accounts for the specific needs and abilities of different patients to allow automatically modifying parameters of the reaching rehabilitation exercises. In the conventional reaching rehabilitation, the therapist manually adapts the exercise parameters by gradually increasing the target distance and the resistance level. Also, whenever the patients show signs of fatigue during the exercise, the therapist asks the patients to rest for a few minutes and then continue with the therapy session. Using the decision theoretic model, the system autonomously facilitates upper-limb reaching rehabilitation by tailoring the exercise parameters and estimating the patient's fatigue based on the observation in his/her compensation or control of movements. The performance of the system was evaluated by comparing the decisions made by the system with those of a human therapist. A single patient participant was paired up with a therapist participant for the duration of the study. Overall, the therapist agreed with the system decisions approximately 65% of the time. The therapist also thought the system decisions were believable and could envision this system being used in both a clinical and home setting. The patient was satisfied with the system and would use this system as his/her primary method of rehabilitation.

These aforementioned studies have mainly investigated the integration of adaptivity in robot-assisted rehabilitation training. The goal of adaptivity mainly aimed at providing a personalized training to the patients according to their individual characteristics, needs and abilities. Besides that, it also intended to facilitate an automated training system to minimize the therapist's effort in manually adjusting the rehabilitation training.

Over the past few years, there is an increasing research interest in the development of virtual environments applications for use in stroke rehabilitation. Virtual environments are considered beneficial in stroke rehabilitation because they enable more precisely controlled training settings, intensive practice with easier repetition of tasks, automatic record of training progress and more enjoyable and compelling interaction for the patients. These applications may also benefit from adaptivity since it allows to dynamically adjust the parameters of the virtual environment as the training tool to provide a suited, personalized training to every patient based on his/her current needs and abilities.

Ma et al. (2007) stated that adaptation is one technique that virtual reality systems for rehabilitation can exploit to benefit a group of patients with a great diversity. They have developed several adaptive virtual reality games for rehabilitation of stroke patients with upper limb motor disorders. Two examples of the games are the catching oranges game, where the patients have to collect randomly falling oranges using a virtual basket, and the 'whack-a-mouse' game, where they have to hit randomly appearing mice using a virtual hammer. In both games, the elements of the game are designed to be adaptive and to change dynamically according to how well or badly the patient is performing. For example in the 'whack-a-mouse' game, the patient's performance is determined by the accuracy metric which is based on the number of mice hit and the number of mice missed. The information of patient performance is used to enable automatic progression between difficulty levels in the game. The game elements, such as the length of time that the mouse is stationary and the locus of mouse and dog, were adapted according to the difficulty in every game level. For instance, when the accuracy rate goes below a certain threshold, the time during which the mouse remains still increases which has the effects of slowing down the game and making it easier. When the accuracy rate exceeds a certain threshold, this time decreases which makes the game harder. In the most difficult level, both a mouse and a dog appear randomly and must be avoided while patients are hitting the mice. Initial feedback from patients was positive since they enjoyed training while playing the game and they felt more motivated as well.

We have seen that some of the previous studies mainly focused on robot-assisted rehabilitation training for stroke patients. In the context of rehabilitation training for MS patients, we have developed a complete haptic-based rehabilitation system, namely *I-TRAVLE*. This system combines robot-assisted rehabilitation and virtual environments technologies, which have been considered to be promising to provide an effective, independent upper limb rehabilitation training (Kwakkel et al., 2008; Burridge and Hughes, 2010).

#### **I-TRAVLE: INDIVIDUALIZED, TECHNOLOGY-SUPPORTED AND ROBOT-ASSISTED VIRTUAL LEARNING ENVIRONMENTS**

To support a systematic and personalized upper limb rehabilitation training for MS patients, the *I-TRAVLE* system was developed. The system consists of a hardware

and software system setup as depicted in Figure 1. The main component of the hardware system is a haptic robot, the MOOG HapticMaster as illustrated in Figure 2, which functions as both input and output devices. As an input device, it allows patients to interact with the software applications that deliver the training exercises. As an output device, it provides haptic feedback during the training by guiding or hindering with exerted forces. The HapticMaster is equipped with a peripheral device, the ADL Gimbal, where the patients' hand is placed and secured using the attached brace while performing the training exercises. A large display, a full HD 40" Samsung TV screen, is used as a visual display to project the training exercises and is placed behind the HapticMaster approximately 1.5 m in front of the patient. A complete description of the I-TRAVLE hardware system with the adjustments made for the context of MS training can be found in (De Weyer et al., 2011).

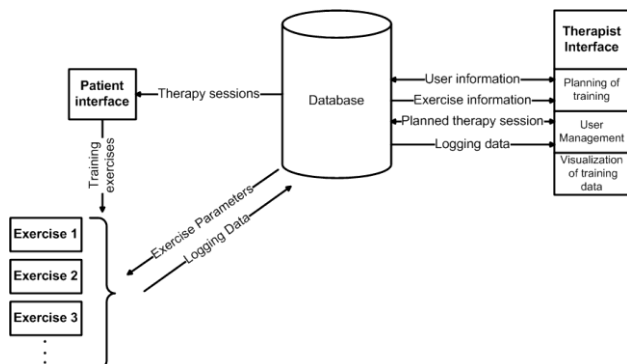


**Figure 1. I-TRAVLE system setup**



**Figure 2. I-TRAVLE hardware system: MOOG HapticMaster and visual display (top), ADL Gimbal (bottom)**

The software system of our I-TRAVLE system is depicted in Figure 3. The main components of the software system are the training exercises, the patient interface, the therapist interface and the central database. A more detailed description of the I-TRAVLE software system can be found in (Notelaers et al., 2010).



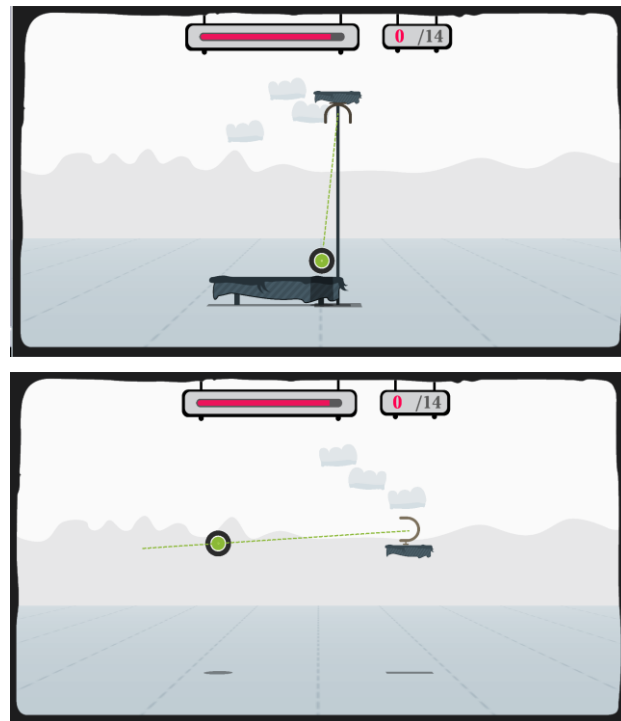
**Figure 3. I-TRAVLE software system**

To keep up the motivation of patients and strive for a successful rehabilitation trajectory, it is essential to give them training exercises that are meaningful in supporting their functional recovery (Woldag and Hummelsheim, 2002). The development of the training exercises were inspired by the T-TOAT (Technology-supported Task-Oriented Arm Training) method, which allows integration of daily tasks into technology-supported training (Timmermans et al., 2009). This method divides an activity of daily living (ADL) into skill components and trains the skill components, first every component separately and later several components combined.

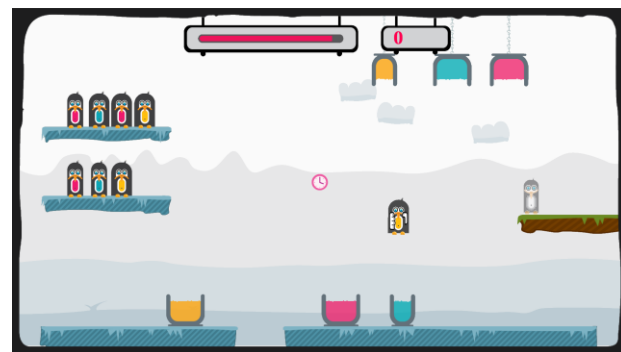
Within I-TRAVLE, the training exercises were designed based on the skill components that patients need to train related to their upper limb rehabilitation. Two types of training exercises were provided, namely basic training exercises which include only one skill component, and advanced training exercises which combine multiple skill components. Figure 4 shows two examples of basic training exercises: *lifting* and *transporting*. In the advanced training exercises, several skill components were combined into a game-like training exercise. Combining the skill components of lifting and transporting, an advanced training exercise, *penguin painting*, was designed as illustrated in Figure 5.

In the penguin painting exercise, the patient has to collect as many points as possible within a certain time period by painting penguins with the right color as many as possible. On the left side, there are two shelves with penguins waiting to be painted. The patient has to select one penguin from a shelf and paint it according to the color of its belly. To paint, the patient needs to bring the penguin to the corresponding buckets, first by dipping it into the bottom bucket to paint the lower part of the penguin and then continuing into the top bucket for the upper part. While painting, the patient must hold the penguin long enough to effectively apply the color. At

some points during the exercise, a devil that tries to capture the penguin, appears and must be avoided in order to not lose the penguin already in hand. Every time the patient finishes painting a penguin, the colored penguin must be transported to the exit platform on the right side.



**Figure 4. The basic training exercises for upper limb rehabilitation: *lifting* (top) and *transporting* (bottom)**



**Figure 5. The advanced training exercise for upper limb rehabilitation: *penguin painting***

#### **AUTOMATIC ADJUSTMENT OF DIFFICULTY LEVELS**

Training duration and training intensity are key factors to a successful rehabilitation (Kwakkel et al., 1999). Rehabilitation training exercises mostly involve performing the same movements repetitively and for a long period of training time. In order to maintain patient motivation, rehabilitation training should be set at an appropriate level of challenge. Patients can get bored and feel less motivated when reaching a certain point in the

training where they find the difficulty level of the exercise to be less challenging. Patients may also feel less motivated when they get frustrated because the difficulty level is above their current abilities. We also have to take into account that every patient progresses differently. This raises the need of adaptation of the difficulty level to be integrated in the training exercises. Usually, the therapist will manually increase the level of difficulty in the therapist interface to present suitably challenging, individualized rehabilitation training exercises. However, this dependency can be minimized and tailoring the training challenge can be provided in the right time without a conscious effort from the therapist.

To achieve an optimal training experience for MS patients, we would like to refer to the Flow Theory of Csikszentmihalyi (1990) which came about in the psychology field around the 1960s. Inspired by the Flow Theory, we find it important to keep the balance between difficulty level and patient performance to ensure that the optimal flow of training experience is achieved. As illustrated in Figure 6, we would like to make sure that a patient stays within the “optimal training zone”, where the difficulty level of exercise given to a patient is balanced with his current performance. In the optimal zone, the patient will not experience *overtraining* or *undertraining* (O’Toole, 1998). Overtraining happens when the patient is asked to perform the exercises with a high difficulty level while his/her performance is still low, thus the patient is most likely to find the training too difficult and may not be able to perform the training. On the other hand, undertraining happens when a low difficulty level is given to a patient who has a high performance which makes the training not that challenging anymore.

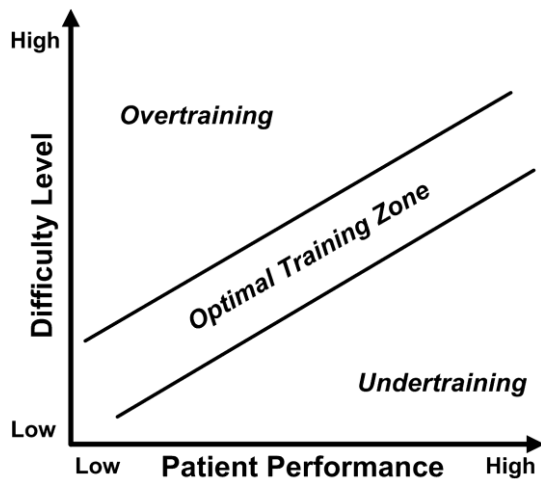


Figure 6. Balancing the difficulty level and patient performance

As an optimization strategy to achieve such personalized training, we propose providing the ability to automatically and dynamically adjust the difficulty of the exercise to avoid boredom, provide suitable challenge and minimize the therapist’s involvement as well.

This can be done by creating automatic difficulty adjustments according to the patient’s performance and progress in the exercise. For this purpose, we need to capture the patient’s performance metrics (e.g. task completion times, scores, errors) during the exercises to observe the short-term training progress of the patient and determine when the difficulty adjustment is necessary.

Providing an adaptive difficulty level adjustment involves the establishment of a user model based on the patient’s performance during the training exercises. We acquire the user model by collecting information about the patient regarding his/her performance in the training exercise and making use of that information to infer the short-term training progress of the patient. This can be considered as a sort of performance-evaluation mechanism. Once established, we can put the user model into practice by applying it to enable adapting the difficulty level whenever necessary. Based on the information from the user model, we can adjust the difficulty of the exercise by making it harder or easier.

To determine the patient’s progress, we evaluate five performance metrics as follows:

- (1) **Task completion time:** How much time does the patient take to complete one task (i.e. select and transport a penguin)? How much is the slope of task completion times in one training session?
- (2) **Score:** What score does the patient achieve in one game session?
- (3) **Error:** How many times does the patient make errors (i.e. hitting the devil, painting with the wrong color)?
- (4) **Pause:** How many times does the patient make pause actions (i.e. motionless period between steps for longer than 2 seconds)?
- (5) **Distance:** What is the distance traveled by the patient to complete one task (i.e. select and transport a penguin)? How much is the slope of the distance traveled in one training session?

To adjust the difficulty levels, we alter the following exercise parameters accordingly:

- **Size of penguin:** how big the penguins are (small - large)
- **Speed of devil:** how fast the devil moves (slow - medium - fast)
- **Frequency of devil:** how frequent the devil appears (infrequent - normal - frequent)
- **Length of stabilization:** the time required to hold the penguin still (short - normal - long)
- **Obstacle wall:** addition of an obstacle wall along the way (no - yes)
- **Amount of coloring buckets:** how many coloring buckets exist (2 - 3 - 4)
- **Width of coloring bucket:** how big the coloring buckets are (narrow - wide)



- **Exit platform:** addition of another exit platform which requires patients to place the colored penguins to the size-corresponding platforms (no - yes)

Based on these parameters, we define seven difficulty levels ranging from very easy to very difficult, as can be observed in Figure 7. At the beginning of the training, every patient starts from an initial level as depicted in Figure 5. The patient's performance of each training session is calculated and compared over the last two training sessions, as a function of the five aforementioned performance metrics, which then indicates the progress of his/her training.

If no significant difference of the performance is shown between the training sessions, it is considered that the patient is training on an appropriate level and adaptation will not be triggered. If the patient shows a decrease in his/her performance between the sessions, a lower difficulty level will be automatically offered to the patient in the next session. On the other hand, if an increase of the patient's performance is shown between the training sessions, the system will automatically provide a level with a higher difficulty in the next session.

## USER STUDY

We have integrated the adaptation of automatic adjustment of difficulty levels in the penguin painting exercise. This results in seven difficulty levels which differ in the exercise parameters as described earlier. We expect that supporting adaptive difficulty level adjustment of the training exercises will not only deliver a personalized training to each MS patient, but also provide suitable challenge, enable less boredom and minimize the therapist's involvement. Therefore, we carried out a user study to investigate the outcome of integrating an automatic adjustment of difficulty levels into the penguin painting exercise.

## Participants

We recruited 8 patients of the Rehabilitation and MS Centre in Overpelt (Belgium) who all suffer from upper limb dysfunction due to MS. They were 5 males and 3 females with an average age of 59 years, ranging from 47 to 64 years old. The duration of the MS diagnosis varies between 3 and 30 years, with an average of 18.8 years. Five of them used the left hand to operate the HapticMaster in training, while the other three used their right hand. Table 1 shows the personal information of each MS patient participating in this research. To have an overview of the severity of their upper limb dysfunction, we obtained their clinical measures as shown in Table 2: upper limb strength (Motricity Index (Wade, 1989)), upper limb functional capacity (Action Research Arm Test (De Weerd, 1985)) and arm motor function scores (Brunnstrom Fugl-Meyer proximal and distal (Duncan et al., 1983)).

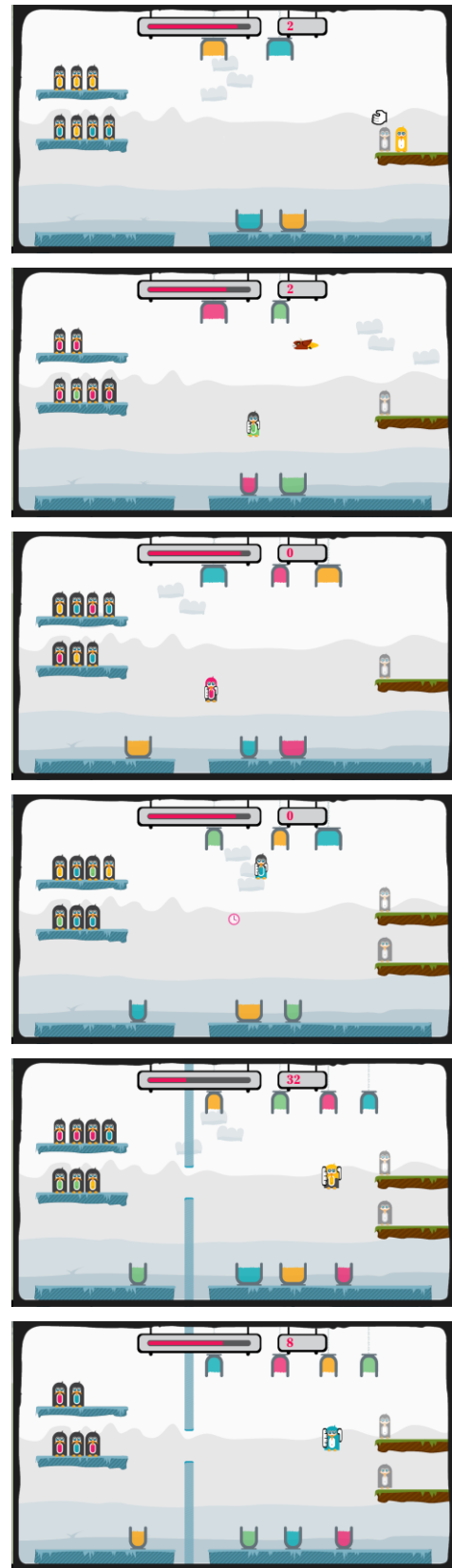


Figure 7. The levels in the penguin painting exercise: from the easiest, Level -3 (top) to the most difficult, Level 3 (bottom)

Patient	Gender	Age (years)	Diagnosis duration (years)	Training hand
1	Male	64	14	Left
2	Female	58	3	Left
3	Male	71	10	Right
4	Female	47	14	Right
5	Male	57	27	Left
6	Male	55	27	Left
7	Female	64	25	Right
8	Male	56	30	Left

**Table 1. Personal information of MS patients in the user study**

Patient	MI (max=100)	ARAT (max=57)	BFM-prox (max=66)	BFM-dist (max=66)
1	76	41	25	40
2	83	56	36	29
3	84	46	32	28
4	76	56	36	30
5	55	41	23	21
6	47	7	18	24
7	72	18	31	25
8	60	30	27	24

**Table 2. Clinical characteristics of MS patients in the user study**

### Procedure

The user study consisted of seven sessions: two elicitation sessions and five adaptive sessions, all took place on the same day. In the elicitation session, participants were asked to perform the penguin painting exercise in the initial level. After two elicitation sessions, the performance metrics of the participant were calculated to determine the progress of his/her training. Based on the information about the training progress over these elicitation sessions, it will be determined for the first adaptive session whether or not the difficulty level should be adapted. Throughout the adaptive sessions, participants were offered an adaptive personalized training in terms of the adjustment of difficulty levels. Three possibilities can happen over the course of five adaptive sessions: *stay at the same level*, *go one level lower* or *go one level higher*.

The duration of each session is 3 minutes. After each adaptive session, participants were asked to rate their subjective perception on enjoyment, boredom, challenge, frustration and fun, on a 5-point scale rating (e.g. *I not at all* to *5 very much*) based on their experience of performing the adaptive penguin painting exercise. Averagely, the user study lasted for about 30 minutes per participant. Figure 8 illustrates the setup of this user study.



**Figure 8. The setup of the user study**

### Results

We have applied the adaptation of automatic difficulty level adjustment in the penguin painting exercise, which provided an adaptive personalized training for each participant. Consequently, the training trajectory was different for every participant during the five adaptive sessions. For each session, the participant can experience staying at the same difficulty level, going to a lower level or going to a higher level, depending on his/her individual performance. Figure 9 shows the personalized training trajectory for each patient as a result of integrating the adaptive difficulty level adjustment in the penguin painting exercise. As can be observed, no patient had the same trajectory as the other patient due to the fact that every patient progressed differently.

Further, we analyzed how these conditions of adaptation influenced the subjective perception of patients on enjoyment, boredom, challenge, frustration and fun, across the sessions. Due to the small number of samples and observations in this user study, we used the nonparametric methods for the statistical analysis.

Based on the patients' subjective responses, we calculated the average ratings of enjoyment, boredom, challenge, frustration and fun, for the three conditions of adaptation as shown by Figure 10. Kruskal-Wallis test showed that no significant differences were found for *Enjoyment*, *Frustration*, and *Fun* between the different conditions of adaptations. This indicates that patients perceived the same level of enjoyment, frustration and fun even though the system introduced an automatic adaptation of difficulty levels in the training exercises. Patients rated a high level of enjoyment and fun (above 4) and a low level of frustration (below 2) in all the conditions.



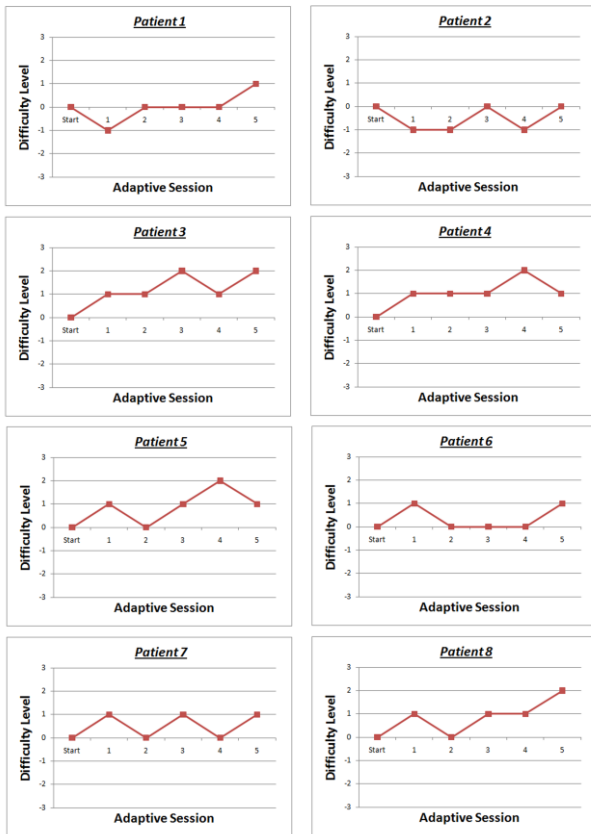


Figure 9. Adaptive personalized training trajectory in the penguin painting exercise

However, there is a significant difference found for Boredom ( $H(2) = 15.651$ ,  $p < 0.001$ ; 2 for condition 1, 1.33 for condition 2 and 1 for condition 3) and Challenge ( $H(2) = 24.376$ ,  $p < 0.001$ ; 2 for condition 1, 2.89 for condition 2 and 4.25 for condition 3). Mann-Whitney pairwise comparison tests showed that patients felt significantly less bored and more challenged when the training was adapted to a higher level compared to when they had to adapt to a lower level or stayed at the same level ( $p < 0.001$ ).

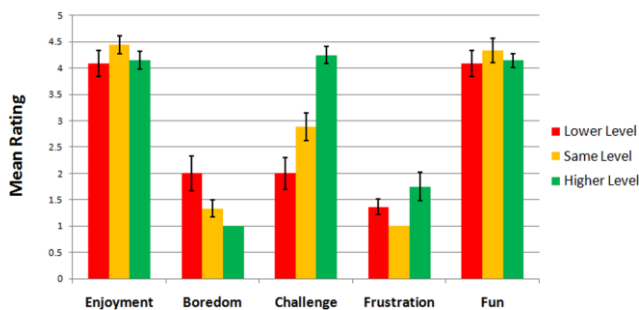


Figure 10. Patient's subjective rating with respect to adaptation

Furthermore, we observed that some patients have noticed the automatic adaptation to be related to their training progress and they liked the diversity of difficulty levels. A couple of therapists appreciated the automatic adaptation as it provided the patients with more variety in the training and also gave them more freedom to train on their own without any interference from the therapist to manually adjust the exercise parameters. This kind of adaptation could be useful to determine an appropriate level to start training on a certain day according to the patient's condition on that day, thus less determined by the previous training or the therapist.

## CONCLUSIONS AND FUTURE WORK

We have presented our investigation to integrate adaptivity into rehabilitation training for MS patients. We have discussed and implemented the automatic adaptation of difficulty level adjustment in the penguin painting exercise. A user study has been carried out to investigate the outcome of this adaptation. Overall, we can conclude that providing adaptive difficulty level adjustment of the exercises has delivered a personalized training to each MS patient according to his/her own individual training progress. The changing of difficulty levels has resulted in less boredom and more challenge during the training, while maintaining the high enjoyment and fun during training. Patients and the therapist have appreciated the automatic adaptation of difficulty levels and considered it to provide more variety in the training and minimize the therapist's involvement in setting up the training.

It is not our focus to carry out an in-depth investigation on the adaptation algorithm used in this user study. We were more interested to observe the patients' response with respect to the automatic adjustment of difficulty levels. We realize that a more accurate and well-defined algorithm should be provided. Therefore, further investigation is needed to optimize the adaptation algorithm which also matches the judgment of therapists on the trigger and timing of adaptation.

Our next step is to extend our investigation of integrating adaptivity into MS rehabilitation training to other types of adaptation that may help patients during the course of their training. For example, automatically adjusting the assistance level based on the detected muscle fatigue. In some cases, the muscle fatigue might develop during long training thus it might be necessary to provide the patients with some assistance to help them performing the task and continue their training. Exploring adaptation in collaborative rehabilitation training for MS patients, where the training exercises involve more than only a single MS patient, is also intriguing. This not only may provide a personalized training but also support social interaction between the patient and his/her training partner.

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