# Towards Guidelines for the Design of Patient Feedback in Stroke Rehabilitation Technology

Lilha Willems, Daniel Tetteroo and Panos Markopoulos

*Eindhoven University of Technology, Den Dolech 2, 5612 AZ Eindhoven, The Netherlands*

Abstract:     Feedback is known to play a key role for the effective rehabilitation of patients after stroke. Although general guidelines exist for UI design for people with physical and cognitive disabilities, and feedback systems have been evaluated with non-disabled persons, little is known about how best to design feedback for interactive technologies supporting rehabilitation after stroke. This paper describes the iterative design process of a feedback module for TagTrainer, a tangible interactive tabletop technology supporting arm-hand training. Based on the evaluation of this technology with seven stroke patients, we propose five guidelines for the design of patient feedback for stroke rehabilitation technology.

## 1 INTRODUCTION

Stroke prevalence is on the rise, due ageing of the population (Hochstenbach-Waelen and Seelen, 2012; Krebs et al., 1998; Timmermans et al., 2009). As a result, the health system is under severe pressure due to an increasing ratio of stroke patients to therapists. It has been suggested that patients could receive better healthcare and have a higher quality of life by using interactive technologies for rehabilitation. According to (Timmermans, 2010) the use of technology in the rehabilitation has four main benefits:

- It can create opportunities for patients to train more often

- It can provide a variety of exercises

- It can enable the patient to practice in absence of the therapist

- It reduces workload of the paramedical staff

Additionally, interactive technology is well suited for motivating, involving, and immersing stroke patients in their rehabilitation (Burke et al., 2009). Interactive technology has been an area of research for getting stroke patients more involved in their rehabilitation, which they may otherwise find tedious and not stimulating due to its intense and repetitive nature (Lövquist and Dreifaldt, 2006).

One way interactive technologies can get stroke patients more involved and motivated to perform exercises is by incorporating the use of feedback (Burke et al., 2009; Wulf et al., 2010). It has been shown that in game design feedback plays a crucial role in achieving more effective engagement (Burke et al., 2009). Feedback makes users aware of their progress towards goals and how their actions impact their progress. It provides users with a means to accomplish their goals and when this information is provided effectively, it enables users to independently learn and improve their performance. In addition, (Winstein, 1991) has shown that feedback enhances learning and self-efficacy when it is positve and encouraging.

The use of effective feedback is therefore an important means for improving stroke rehabilitation and enabling patients to practice independently. Research suggests that the (extrinsic) feedback provided by technology carries special importance for stroke patients due to their compromised intrinsic feedback system as a result of the stroke (Timmermans, 2010; Van Vliet and Wulf, 2006). Extrinsic feedback, when provided properly, can improve stroke patients' learning and increase their active involvement, motivation, confidence and self-efficacy (Timmermans, 2010; Wulf et al., 2010).

Although the positive effects of feedback on the stroke recovery process are somewhat understood, the design of feedback systems targeted specifically at stroke patients is an underexplored, but emergent and important area of research. Therefore, we present an investigation into how to provide

effective feedback to stroke patients using different options for feedback content and modality. We addressed this question by performing an exploratory case study with seven stroke patients using the TagTrainer system (Tetteroo, 2013). In this paper we present the design process of a feedback module for TagTrainer. Finally, we present guidelines for providing feedback with stroke rehabilitation technology that have been derived from the design and evaluation of this module.

# 2 RELATED WORK

## 2.1 Recovery after Stroke

There is ample research on the effects of feedback on motor learning in non-disabled persons. However, to which extent these findings apply to stroke patients is largely unknown. For one, the intrinsic feedback system of stroke patients is impaired (Timmermans, 2010; Van Vliet and Wulf, 2006; Winstein, 1991), while this system plays an important role in motor learning of non-disabled persons. In addition, it has been suggested by (Krakauer, 2006) that stroke may cause learning deficits in the patients. This suggestion implies that stroke patients require a different approach for learning motor skills; a task that is simple for a non-disabled person may be complex for a stroke patient.

Movement recovery after stroke is usually attributed to two mechanisms (Cirstea and Levin, 2007; Krakauer, 2006):

- True recovery: this occurs when the same muscles for a certain activity are once again used as before the stroke.

- Compensation: this occurs when alternative muscles are used as a strategy, different than before the stroke, to perform an activity.

According to (Krakauer, 2006) learning is required for both mechanisms to occur and in order to achieve this, rehabilitation should emphasize on learning different techniques to reach a certain goal and not just repetition of the same movements.

## 2.2 Feedback in Stroke Rehabilitation

In general there has been little research on the effects of feedback in motor learning following stroke. Depending on the impairments caused by the stroke, different feedback is needed to accommodate the patients' capabilities and to facilitate motor

learning. The feedback should be adjusted to the patient's stage of learning (Timmermans, 2010).

It is commonly accepted that three factors play an important role in transmitting feedback to stroke rehabilitation patients: focus of attention, feedback content and feedback scheduling (Van Vliet and Wulf, 2006).

(Cirstea and Levin, 2007) conducted a study with the objective to determine if the manipulation of the attentional focus may lead to arm motor recovery during a repetitive pointing training intervention. In their experiment participants were either provided with Knowledge of Results (KR) that directs attention to performance outcomes (external focus of attention) after every 5th trial, or with Knowledge of Performance (KP) that directs attention to arm movement patterns (internal focus of attention), concurrently and on a fading schedule. The results showed that the motor improvements in stroke patients whom received KP reflect true recovery, in contrast with those who received the KR feedback. This suggests that if the goal of rehabilitation is true recovery, stroke patients may benefit more from KP feedback. However, in their review study, (Van Vliet and Wulf, 2006) found research that suggests that feedback inducing external attentional focus may be more effective to improve performance of task execution after a stroke. In the same study, (Van Vliet and Wulf, 2006) found that additional verbal KR is redundant when KR information is inherent to the task. When this is not the case, they found that summary or average feedback benefits motor learning of stroke patients.

For stroke rehabilitation, (Burke et al., 2009) believe that feedback concerning failure should be more conservative, and successful engagement should be rewarded and encouraged. Furthermore (Timmermans, 2010) argues that it is important to give feedback concerning motor control as this enhances learning, positively influences motivation, self-efficacy, and compliance. Correct performance feedback increases motivation while incorrect performance feedback facilitates learning.

As for feedback scheduling, (Van Vliet and Wulf, 2006) found that providing reduced feedback to stroke patients may enhance learning. Apart from this finding, little is known on how feedback scheduling influences learning in stroke patients.

## 2.3 Designing for Impaired Persons

Older people form the majority of stroke patients. In the U.S. nearly 75% of stroke patients are over the age of 65. In fact after the age of 55 the chances of

stroke doubles with every decade (Krakauer, 2006). Given these statistics it is important to consider how older people interact with technology, as they generally experience a decline in sensory, cognitive, and motor functions that can interfere when interacting with technology (Ijsselsteijn et al., 2007; Kurniawan and Zaphiris, 2005). In addition, even though stroke is prominent in older people, it can occur at any age and its consequences can also induce cognitive- and motor impairments amongst younger stroke patients.

The study of (Kurniawan and Zaphiris, 2005) yielded several guidelines for designing websites for older people. When applying those guidelines for use in arm-hand rehabilitative technology the following guidelines need to be considered:

- Language should be simple, clear, and to the point. Important information should be highlighted. Irrelevant information causes too much distraction for users with cognitive impairments.

- Text design should be static, and presented in a readable format with high contrast. With age the color- and contrast sensitivity declines (Ijsselsteijn et al., 2007).

- Graphics should relevant and easy to understand.

- Navigation cues should clear and provide current location of the page.

These guidelines contribute to dealing with limitations in vision and cognition, by which stroke patients are often affected. Especially for cognition it is important that the interface is simple and intuitive, and to contain the proper affordances to reduce the workload of information processing (Ijsselsteijn et al., 2007).

In their study, (Ijsselsteijn et al., 2007) also recommend providing the same, redundant information using different modalities in order to compensate for visual and auditory limitations. In addition to these limitations, during stroke rehabilitation redundancy is also necessary for cognitive limitations. It is not uncommon for therapists to repeat instructions to their patients and/or actively guide patients' attention towards important information.

To determine how to provide effective feedback to stroke patients, a feedback module system for stroke rehabilitation technology was designed and evaluated with stroke patients in a case study involving the TagTrainer stroke rehabilitation platform.

# 3 CASE STUDY: PATIENT FEEDBACK FOR TAGTRAINER

## 3.1 TagTrainer

TagTrainer (Tetteroo, 2013) is a technology for arm-hand training in stroke rehabilitation. It allows patients to manipulate physical objects (e.g. lift, place, rotate) on one or more interactive tabletop surfaces – called 'TagTiles' – that are connected to a computer. TagTrainer allows therapists to use objects of daily life for rehabilitation training, since the TagTiles are able to detect the presence, position and orientation of these objects as long as these are tagged appropriately with RFID tags. TagTrainer guides patients through an exercise by lighting up areas on the TagTile boards where objects have to be placed, moved or picked up from. Furthermore, the system provides both written and spoken instructions. Finally, TagTrainer collects quantitative performance data (e.g. speed of execution, number of repetitions) through the RFID sensors in the TagTile boards, as well as qualitative performance data (torso compensation, shoulder compensation, accuracy of object placement on the TagTile boards) through the RFID sensors in the board and accelerometers attached to the patient's torso and shoulders.



Figure 1: A patient and therapist using TagTrainer in arm-hand rehabilitation therapy.

An example TagTrainer exercise would ask a patient to repeat a few times the following steps:

- Pick up a cup with her left hand and place it on a TagTile.

- Pick up the cup from a TagTile and raise it to the level of another TagTile, positioned at a 90-degree angle to the first TagTile.

- Touch the upper TagTile with the cup and put it back on the lower TagTile.

While rich performance data is collected by TagTrainer, none of this information is currently presented to patients. Therapists still have to manually guide patients through exercises and provide feedback about their performance (see Figure 1). Given the importance of feedback for the recovery process of stroke patients, we set out to develop a patient feedback module for TagTrainer based on existing literature and user research.

## 3.2 User Research

In order to get a better idea of how rehabilitation sessions are set up, how patients are instructed and supported by therapists, how therapists determine appropriate feedback, and how feedback is currently provided to patients, we conducted two unstructured interviews with stroke rehabilitation therapists and observed an arm-hand training session at a stroke rehabilitation clinic (Adelante Centre of Expertise in Rehabilitation and Audiology, Hoensbroek, NL).

### 3.2.1 Interviews with Therapists

Two unstructured interviews were performed with stroke rehabilitation therapists at the before mentioned rehabilitation clinic. The goal of the interviews was to get insight into how therapists set up training sessions for their patients, and how they guide and work with them during these sessions.

At Adelante, the rehabilitation process is strictly patient-centered. The therapist sits down with the patient and asks the patient about the problems (s)he encounters. Together with the patient, the therapist will determine the goals the patient wants to achieve. According to one therapist establishing goals helps to keep the patient focused. When the patient's goal cannot be achieved straight away, the therapist will divide it into smaller sub-goals that are easier to achieve.

During training sessions, therapists usually provide encouraging verbal feedback. Additionally, they may make use of mirrors, physical guidance or other materials if the situation requires it. Therapists do not apply a systematic approach in giving feedback because of the differences between individual patients. Feedback that works for one patient may not be suitable for another. Therefore, feedback is tailored to the patient by employing a trial-and-error approach. Finally the feedback given differs amongst the therapists and is based on their previous experiences (i.e. observed best practices).

One therapist indicated that during rehabilitation it should be clear to patients why they must invest in certain tasks, and that feedback should primarily concern the quality (speed, fluency, and trajectory) of movement. The other therapist stressed the importance of keeping patients motivated with feedback. Both therapists agreed that it is important that patients experience success and are able to achieve their goal. Therefore the therapists would sometimes relax on giving 'negative' feedback and give more encouraging feedback instead.

### 3.2.2 Observation of Arm-hand Training Session

The first author embedded herself in the Adelante stroke rehabilitation clinic to observe a one-hour arm-hand training session. During the training session, one therapist attended to five patients. Three of them were practicing daily tasks independently and did not receive feedback from the therapist.

The other two patients practiced different tasks that were repetitive in nature. These patients received more attention from the therapist, who helped them in placing a harness around their affected hand. Once the patients started performing their exercises, the therapist predominantly gave positive verbal feedback on their performance. Other times, the therapist gave tips on how the patients could execute the task more easily.

At the end of the training session, the therapist requested the patients to rate their performance on a scale from 1 to 10. In addition to that, patients needed to make and write down a plan of which exercises they planned to practice with their affected arm over the coming weekend. The plan needed to be very specific on time, location and duration of the exercises. The overall goal was that they would use their affected arm at least one hour a day during the weekend.

### 3.2.3 Design Implications

From the user research, we distilled the following implications for the feedback module design:
- For patient involvement and motivation the goal and purpose of the exercise performed should be clear to the patient.
- Provided feedback should be primarily positive and tailored to the patient's needs.
- The design should allow for trial-and-error approach for giving feedback.

## 3.3 Designing Patient Feedback

Although TagTrainer supports stroke patients in

their training by providing them with instructions for the execution of exercises, the current system does not offer them feedback on their performance. Therefore, we designed a patient feedback module for TagTrainer that would provide stroke patients with relevant feedback on their performance. Here we present the final design, and then discuss relevant experiences gathered during the design process and from evaluations.

### 3.3.1 Method

The feedback module was designed in a user-centered iterative process consisting of three consecutive design-implement-evaluate cycles. Initial design choices were based on suggestions from previous research involving non-disabled persons (e.g. (Shea and Wulf, 1999; Van Vliet and Wulf, 2006)) and older people in general (e.g. (Ijsselsteijn et al., 2007)), and the user research reported on earlier in this paper.

During the evaluation sessions, patients performed an exercise on the TagTrainer board. The exercise required the participants to trace a diagonal line 5 times with the affected arm using a small (2x2x2 cm) wooden cube. While the exercise was performed, the feedback module was presented on a separate display in front of the user. The same exercise was used throughout the design process.

After executing the exercise, the participants were asked in an open interview questions concerning their understanding of the displayed information, which information felt to be missing or redundant, and the perceived value of the information presented.

### 3.3.2 Participants

The feedback software was evaluated with seven stroke patients undergoing general arm-hand rehabilitation at the Adelante Centre of Expertise in Rehabilitation and Audiology, Hoensbroek, NL. The age of the participants ranged between 50 and 83 years. The time since their stroke and the evaluation ranged between weeks to a couple of months. All participants were affected in their motor skills, mostly affecting their upper extremities and gate, and some participants were affected in their balance, memory and visual capabilities.

### 3.3.3 Design

The feedback module designed aims to provide

relevant feedback throughout the patients' training session. A session consists of a movement activity that a patient needs to practice repeatedly for either a fixed number of times, or for a given duration. Sessions consist of individual trials: single units of meaningful movement that the patient needs to repeat during the session (e.g., the exercise described above).

The feedback module was designed to guide patients during the entire exercise session and thus consists of four main screens. These screens are shown 1) before the start of an exercise session, 2) during the session, 3) after every block of 5 trials, and 4) at the end of the session respectively (see Figure 2).

The screen shown at the start of the session (Figure 2-A) contains the exercise instructions and its benefits. The instructions are presented as a series of short sentences that are formulated in simple language and displayed in a readable font. Benefits are shown here because the therapists interviewed during the initial design phase suggested that it will motivate users to engage in the exercise.

While the patient is executing a block of 5 trials, the feedback module shows the patient instructions for the exercise and the patient's progress in completing the block (Figure 2-B). The reduced feedback scheduling of 5 trials was chosen for providing feedback during the session, because (Cirstea and Levin, 2007) reported it to work well for stroke patients.

After each block of 5 trials the feedback module shows bar graphs with performance information about those 5 trials (Figure 2-C). The bar graphs denote the duration of every trial, and shoulder- and torso-compensations performed during the trials. The time measure was included because therapists indicated that it will challenge and motivate patients who are doing well in their rehabilitation. However, for those who are not, the therapists fear it will demotivate patients to perform the exercise. Shoulder- and torso compensation measures were included as they are major factors in arm-hand rehabilitation. However, as is the case for the time measure, these measures do not always apply to all patients. The graph type denoting the performance measures was decided upon together with the therapists. The actual numbers of the performance measures are not shown, as it is the pattern of the results that gives the most important information, according to the therapists interviewed in the initial design phase. Textual KP-feedback is given for each performance measure that either tells the user to keep doing what he is doing, or how he can improve
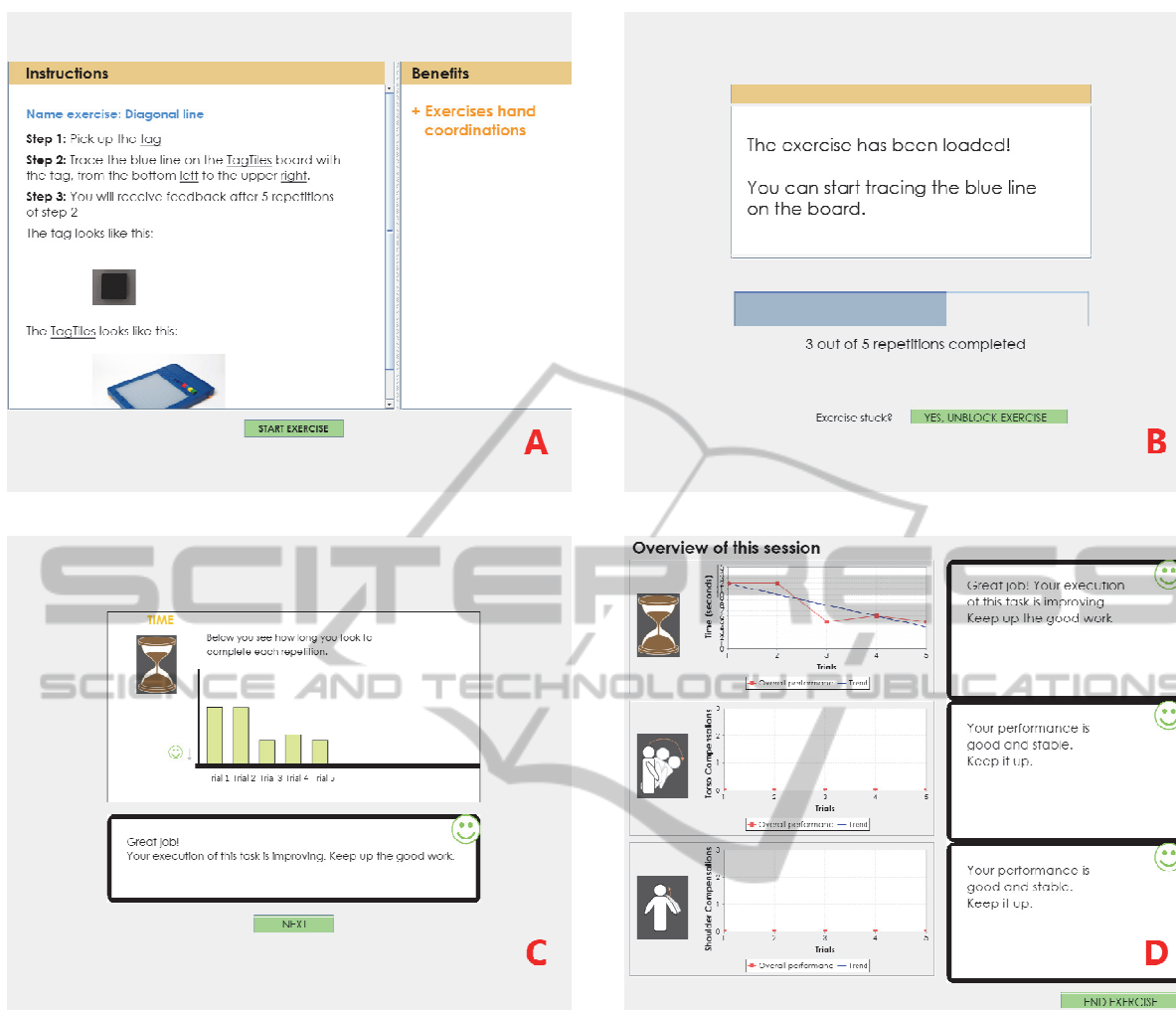
Figure 2: Screenshots from the feedback module: A) before the start of a session, B) during exercise execution, C) after each block of 5 trials, D) at the end of the exercise.

his performance. In telling the user how to improve his performance it only gives feedback concerning the desired outcome and not how the user should perform the movement to get to the desired outcome. This induces an external locus of control and should lead to enhanced learning (Shea and Wulf, 1999; Van Vliet and Wulf, 2006; Wulf and Lewthwaite, 2010).

Finally, after a patient completes the entire session, (s)he is presented with an overview of their performance on execution time, shoulder- and torso-compensation throughout the session, as well as with appropriate KP-feedback (Figure 2-D).

### 3.3.4 Evaluation Results

Three factors play an important role in transmitting feedback to stroke rehabilitation patients: feedback content, feedback scheduling and focus of attention

(Van Vliet and Wulf, 2006). Given that the focus of attention and scheduling of the feedback were not varied in our study, we will not further report on these. However, in addition to 'traditional' feedback that is provided by therapists directly, we have used several modalities for transmitting our feedback to the participants and hence also report on results concerning this factor.

#### 3.3.4.1 Feedback Content

In the initial design of the screen shown before the start of the exercise, performance results of earlier sessions were included to show progress and hence increase patient motivation. However this information was found to be irrelevant and distracting by the users as they were only concerned with the task at hand: performing the exercise.

Therefore, the information in this screen was limited to the exercise instructions.

Instructions are shown again on the second screen, in case the patient does not remember exactly the nature of the task. The instructions on this screen are presented in a condensed form, in an attempt to reduce the amount of information the patient needs to process while performing the exercise. However, condensing the information comes at the expense of less clarity of the instructions and as a result one patient did not know anymore how to perform the exercise.

After each block of five trials, the patients are presented with graphs visualizing their performance for those 5 trials. Initially the graphs were all shown in one screen. However, during the evaluations one participant indicated that he did not understand the feedback information on this screen, even after explanation. When the participant was prompted to comment on the individual components on the screen, including the bar chart, it turned out that the participant did actually understand the information, despite his initial claim of not being able to do so. The problem was one of information density, and it was decided to spread the information by giving each graph its own screen that the users can leaf through. This adjustment was included in the final prototype and five participants indicated to perceive less problems understanding the information on the screen, compared to previous versions.

### 3.3.4.2 Feedback Modality

During the evaluations we observed that the system at times failed in directing the users' attention properly. Two participants were reading the instructions on the start screen and tried to execute the exercise on the TagTrainer board before they pressed the button to start the exercise. More generally, most participants were confused about when to look at the screen, and when to look at the TagTile board. One participant mentioned that he would prefer having the feedback on the TagTile board instead of a separate computer screen. He explained that during training he was focused on the exercise task on the board and did not feel inclined to constantly look back at the computer screen for performance feedback.

For six participants it was not immediately clear what was represented with the feedback shown as bar graphs (see Figure 2-C). Participants found the icons depicting the different types of feedback were not self-explanatory enough. In addition, participants reported that they felt the information shown should

be related to their personal context. It should explain, for example, why certain feedback information is important for them to know and what it says about their performance. During the evaluation five participants explicitly mentioned a desire for information about their performance that is relevant to their current situation.

Despite the participants not fully understanding the graphs, the accompanying summary text (i.e. KP-feedback) was clear. The participants stressed the importance of the text containing information about what is good or not good about their performance. However, written information posed a problem for four participants, as they were unable to comprehend the written information due to poor eyesight and cognitive limitations. However, once the written information was vocalized, these participants were able to grasp its meaning.

## 4 TOWARDS GUIDELINES FOR PATIENT FEEDBACK

Based on experiences from the design process and the results of the evaluations, we identified the following set of design guidelines for feedback in interactive stroke rehabilitation technology:

- **Provide Multimodal Information**: Account for sensory impairments that stroke patients might have. E.g., vocalizing textual information for the visually impaired (Ijsselsteijn et al., 2007). In addition, providing multimodal information enhances understanding and learning. E.g., during the evaluations vocalizing textual information made it easier for stroke patients to understand the information.

- **Provide Stepwise Guidance**: Providing a stepwise guidance through exercise instructions alleviates the workload on the memory as it provides information in more digestible bits. Furthermore, providing a stepwise guidance through the feedback will also improve a patient's understanding of the system.

- **Provide Context Related Information:** The feedback information presented should be relevant to the patient's situation and performance. If the information is not relevant, the patient will lose motivation.

- **Prevent Information Overflow:** It is easier for stroke patients to process information when it is provided to them in smaller bits. A means of doing this is by only showing information that is

relevant for the task at hand and by using short sentences and simple language.

- **Allow for Customization:** There is a great variety in the disabilities that stroke patients may have, and thus their individual needs for feedback show an equal variation. Therefore, it is crucial that feedback systems allow for customization of feedback modality, scheduling and content. So even though a stepwise guidance, short sentences, and simple language are recommended in general, there are patients who want and can understand more complex and related additional information about their performance. By tailoring feedback to the needs of individual patients, their motivation and involvement in the exercise can be increased (Timmermans et al., 2009).

## 5 DISCUSSION

In this paper we have presented the design and evaluation of a patient feedback module for the TagTrainer rehabilitation technology. Although our evaluations have been performed with a limited number of participants, we believe that the experiences from our design process and the findings from our evaluations provide useful pointers to developers of interactive technologies for stroke rehabilitation.

Although we believe that our guidelines contain useful pointers for designers of interactive stroke rehabilitation technology, we realize that the list of guidelines is probably not complete. That is, these designers should also take into account guidelines that have been specified for other, related target groups such as older people (e.g., (Ijsselsteijn et al., 2007)).

The system that we have presented can be used to further explore and research the effects of feedback on stroke patients. The setup can also be used in practice, as it allows therapists to employ their trial-and-error approach in finding out what works for their patient.

## 6 CONCLUSIONS

Providing feedback to stroke patients about their performance in therapy is crucial to their recovery process. However, due to cognitive damage sustained by stroke, stroke patients' information processing is often impaired and their retention

limited. The contributions of this paper are the design of a feedback module for TagTrainer, an interactive stroke rehabilitation technology, and a set of design guidelines for interactive stroke rehabilitation technology that are based on experiences we had, and evaluations we performed during our design process.

These design guidelines address the specific needs and account for the cognitive limitations that stroke patients might have. We invite the community to extend and validate these guidelines, in order to improve the quality of technology supported stroke rehabilitation, and eventually the quality of the lives of people who are affected by stroke.

## ACKNOWLEDGEMENTS

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