International Conference on Virtual Rehabilitation 2011
Rehab Week Zurich, ETH Zurich Science City, Switzerland, June 27 - 29, 2011

Introducing an user-tailored rehabilitation system for patients in their home and work environment

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***Abstract*—Due to the increasing number of patients who need orthopedic interventions, current research focuses progressively more on individualized physiotherapy and postoperative treatment. The restoration and therefore unrestricted movement are strongly connected to the accomplishment of physiotherapeutic exercises (form, repetitions and reproducibility of movement). If exercises are performed at home, less consultation with the therapist and high personal responsibility of the patient is required. In this paper an intelligent cheap and user friendly training system for use in home environment is presented. It evaluates the physiotherapeutic exercise using objective parameters by guiding the patient through the exercise and analyzing his reactions. The system itself was evaluated with 46 persons who performed standard physiotherapeutic exercises. The results show a significant increase in reproducibility of the exercises at home using the training system.**

I. Introduction

Medical rehabilitation and postoperative care is focused on restoring body or organ functions with physiotherapeutic and ergotherapeutic methods. The addressed patients require adequate and individualized therapy according to their needs to improve the chances of continuing to live independently and to quickly regain a good and efficient quality of life [1]. But such physiotherapeutic treatment is time-consuming and expensive because of the high number of exercise units which must be performed under supervision of physicians. An optimized amount of training with concurrent decrease of treatment costs can only be achieved if the execution of the exercises is done by the patient self dependently at home. So there is need of a cheap and easy to use training system which guides and controls the patient in his or her home environment

II. Methods

A. *Conception*

A training system for home rehabilitation should enable the patient to perform his rehabilitation exercises on his own responsibility but controlled at home. Analogue to classic rehabilitation, the physiotherapist assesses the individual needs of the patient and defines appropriate training exercises and a resulting training plan. The exercises are then trained together with the patient. In this phase, the patient's movements are supervised by the therapist and simultaneously recorded with the training system to serve as reference. For each exercise a reference movement is chosen from the recorded training and stored together with the training plan in the training system. In

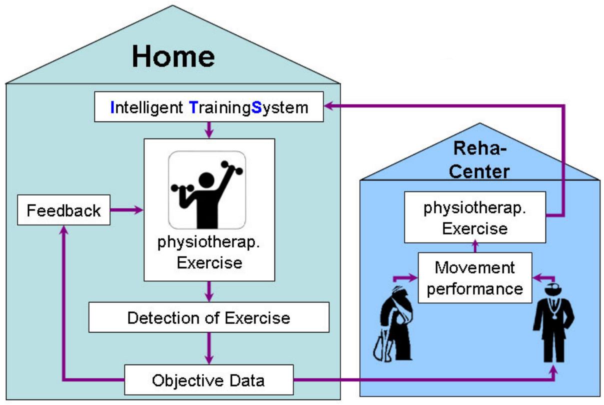

Figure 1. Concept of Home Rehabilitation

the self dependent training situation at home the system is attached to the private PC and presents information about the exercise that has to be performed according to the training plan. The training movements are being assessed quantitatively and compared to the reference movements that were defined previously. Adequate visual feedback is displayed on the computer screen to help the patient to identify possible variances in his movements and helping him to correct them (Figure 1). The assessed quantitative data should also be stored or transmitted to the therapist for later review. In the end the goal must be ensuring a training of the desired movement patterns.

B. The Training System

The Training System is based on resistive elements like gymnastic bands or tubes which are often used in physiotherapy [2]. They are cheap, easy to use and allow resistive training at home. To characterize a physiotherapeutic exercise, the movement path amplitude and speed of the extremities must be assessed. Since the moved extremities lengthen the resistive element, the resulting force within the element is proportional to the amplitude and range of motion. The range of motion can therefore be estimated by measuring the force of the resistive element with an adequate force sensor.

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C. Feedback

The feedback is presented as an oscilloscope-like visualization (Figure 2). The user sees the given force path and can anticipate its progression over time including amplitude, path, speed and number of repetitions. The resulting force of the actual movement is presented as a moving cursor that draws a path on the screen, while the user pursues his training movements. By comparing the given forth path with the actual performed one the user can identify errors and correct them. This kind of feedback contributes to the learning curve, as it helps the patient to evaluate his performance and update his movement schema in case of errors.

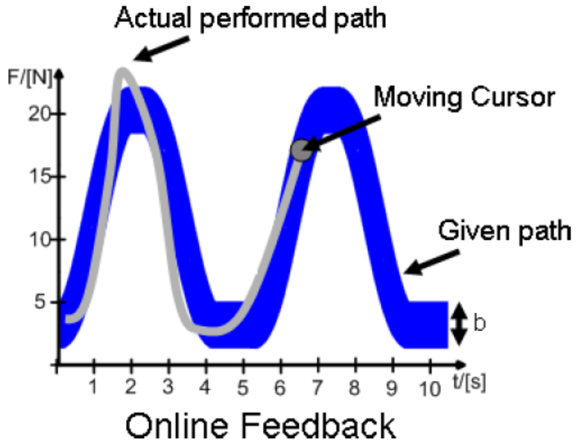

Figure2. Visual Online Feedback: Visual Feedback of the given force path of two repetitions with 5 seconds per movement, a maximum amplitude of 20N and an allowed corridor of the width b. The moving Cursor represents the actual force and its path is displayed as well.

III. EVALUATION

For a proof of concept and to strengthen the hypothesis that users benefit from visual feedback in the attempt to reproduce the rehabilitation movements defined by a physiotherapist, the system was evaluated in a study with 46 young and healthy subjects. The subjects were divided randomly into two groups. The first group consists of 10 men (26.8 ± 5.3 years) and 6 women (26.7 ± 4.5 years) and received no visual feedback from the system. The second group consists of 10 men (27.6 ± 4.7 years) and 20 women (25.1 ± 6.3 years) and received visual feedback.

A. Method

All subjects were right handed and held the handle of the training device with the right hand and pulled against resistance while the other end was connected to the foot. The occurring forces were between 18N and 24N for all subjects. For each subject it was decided randomly if a either an abduction/adduction movement or a diagonal PNF pattern should be performed. All subjects were measured in 2 sets of 12 repetitions. The movement patterns were taught directly prior to the measurements. One group was provided with additional visual feedback (Feedback-Group) and the other group had to perform without visual feedback (Control-Group). The subjects performed the movements in two sets with 12 repetitions leading to 720 movement repetitions with visual feedback and 384 without. The movements were examined by using the cross correlation coefficient, the relative amplitude error (i.e. the relative difference between the locale maximum and given amplitude in one repetition) and the relative duration error (i.e. the relative difference between the length of the actual movement and the given movement in one repetition). Since all parameters were calculated relative to the pre-set amplitude and given duration, the results for the two movements were combined to compare both groups. For all parameters, the mean values as well as the variances were calculated. For evaluating the differences in the parameters among different groups, analysis of variance (double-sided T-TEST with unbalanced variances) was used and calculated. Differences with $p < 5 \cdot 10^{-5}$ were considered to be statistically significant.

B. Results

On the basis of the recorded force data, the cross correlation coefficient was calculated for each movement repetition. The reproducibility was then determined with a mean value of 0.93 ± 0.06 for the Control-Group and 0.99 ± 0.01 for the Feedback-Group. The differences were significantly different with a p-value of $1.2 \cdot 10^{-9}$. The results regarding the correlation between the given ideal movement and the actually performed movements were significantly better in the Feedback-Group than in the Control-Group. The about 10 times smaller standard deviation underlines this impression. This implies that the feedback significantly improves the capability of the subjects to reproduce the given force path.

The relative amplitude error is significantly smaller in the Feedback-Group (0.03 ± 0.03) than in the Control-Group (0.06 ± 0.03) with a p-value of $7.6 \cdot 10^{-7}$. This proves that besides the form of the force path also the amplitude of the force and with it the desired range of motion could be reproduced more accurately than in the Control-Group.

The relative duration error of the Feedback-Group (0.09 ± 0.13) was significantly smaller than for the Control-Group (0.33 ± 0.26) with a p-value of $p = 2.22 \cdot 10^{-17}$. The subjects of the Control-Group seemed to have fallen into an individual movement speed and maintained that speed quite steady, what is reflected in the small standard deviation of 0.26.

IV. CONCLUSION

A Feedback Training System has been introduced that allows home rehabilitation with resistive elements and provides the patient with guidance and control. It is cost effective, movable, easy to use and assures a higher quality of movements performed in comparison to an uncontrolled unguided home rehabilitation.

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