Autonomous Training Assistant: A System and Framework for Guided At-Home Motor Learning

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ABSTRACT

We present a novel framework and system for at-home rehabilitative exercise in the absence of a physical therapist. The framework includes metrics for assessing motor performance on a wide variety of exercises. We present our system, the Autonomous Training Assistant, which utilizes this framework and a low-cost accessible exercise device called the Intelligent Stick to deliver feedback as a user trains at home. We evaluated the system's multimodal feedback mechanism in a case study whose results indicate that individual preference may have a significant effect on modality assignment for optimal learning. We conclude with ideas for future work.

CCS Concepts

• Human-centered computing → Human computer interaction (HCI) → Interaction techniques.

Keywords

Rehabilitation; Human-Computer Interaction; At-Home Training; Motor Learning

1. INTRODUCTION

One of the many focuses in rehabilitative research is at-home exercise. This research aims to address the drop-off in compliance over time in at-home rehabilitation that results from a lack of therapist presence. In this work, we address guidance environments for home exercise in upper-extremity rehabilitation with a focus on unsupervised motor learning, or the improvement of motor function in the absence of a real therapist. The challenge is to develop a system which can assess performance, provide feedback, and guide the user through an exercise routine in the same manner as a physical therapist, while proving a meaningful abstraction of the exercises themselves to engage the user over a long period. To achieve this, we developed a framework for motor guidance and a system for at-home rehabilitation with a focus on three elements: assessment, feedback, and serious game design.

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Figure 1. Intelligent Stick Design Sketch

2. RELATED WORK

As the volume of work related to at-home rehabilitation is extensive, we review some of the common approaches applied in recent work. Approaches toward rehabilitation systems range from virtual reality [2] to serious games developed using commercial hardware [3]. Several studies have yielded a series of common requirements for games developed in this space: they should be adaptable to a wide variety of individuals, easy to use/minimally intrusive, offer frequent and explicit feedback on performance, and adapt well to more complex motor tasks [1]. While many of these systems have offered encouraging results when used by subjects in rehabilitation, often the choice of feedback mechanisms and game archetypes in these systems is arbitrary, and as a result they are more effective for some users than others. To address this challenge, we first define a framework that links assessment and feedback in motor learning. We then present a system which implements this framework in practice, and discuss how game design can make use of this framework to optimize both learning and engagement.

3. MOTOR GUIDANCE FRAMEWORK

In previous work, we developed a framework which formalizes the process of motor assessment and motor feedback for use by an autonomous system [6]. To achieve this, we observed physical training sessions between trainer and trainee and derived three categories for motor assessment which describe any motor action: "posture" and "progression" in the spatial domain, and "pacing" in the temporal domain. We also described how these elements can be quantified and evaluated against a dynamic goal template managed by a trainer for each individual, such that our framework is person-centered. For simple single degree-of-freedom motions, these can

Figure 2. ATA Training Interface.

be measured using the rotational range of the primary limb or limbs involved in the motion, as well as the time required to complete a single iteration of the motion.

We then determined how to deliver feedback on motor performance. We had three channels through which feedback can be delivered during exercise: audio, visual, and haptic (vibrational). The goal of this phase was to determine how to map these channels of feedback to the categories of assessment listed above in a way that optimizes motor learning. As an initial point of guidance, we referred to a review by Sigrist et al. [4] on motor feedback which indicates how modalities can be assigned such that the system scales well with increasing motor task complexity.

4. AUTONOMOUS TRAINING ASSISTANT

With this framework in mind, we propose a system for at-home unsupervised motor learning entitled the “Autonomous Training Assistant” (ATA). This system consists of training software for at-home exercise including a virtual avatar for visual feedback, a Kinect camera for monitoring an individual’s body posture, and a rod-shaped training device called the “Intelligent Stick” which includes an accelerometer for motion capture and vibrational motors for haptic feedback. The stick includes a modular design with flexible grip size which allows users with a wide variety of grip strengths to adapt the design to their needs. The design sketch for the Intelligent Stick prototype is shown in Fig. 1.

The software utilizes our motor guidance framework to interpret data from the Intelligent Stick and Kinect camera during exercise. For each motor exercise, a set of major joints is monitored by the system through the Kinect’s joint tracking data for postural information, while accelerometer data from the Intelligent Stick is used to determine a user’s motion range (progression) and speed (pacing). Trainers can input new motion exercises into the software using authoring software, which we described in previous work [5]. For each individual user, a profile containing the goals for that user in each category is provided and maintained remotely by the trainer over cloud storage. The ATA uses this information on each session to evaluate and provide feedback to the user. A virtual avatar acts as the visual representation of the trainer by demonstrating exercises on-screen and mirroring the user’s motion to provide a visual point-of-reference. This interface is depicted in Fig. 2.

5. CASE STUDY: MULTIMODAL FEEDBACK

To determine how an individual’s learning may be impacted by the modality assignments in our framework, we evaluated the system in a case study with an individual with hemiparesis resulting in

impaired function in one arm. The subject used the ATA interface to perform a series of three exercises assigned by the subject’s physical trainer: umbrella, witik and twirl. For each exercise, we generated a random selection of modality assignments. After a 1-minute calibration period, the user then repeatedly performed the motor task over a period of 2 minutes. Pre- and post-performance scores were determined in each category to provide a basis for improvement in each modality assignment. These results were compared to a control condition in which the user completed the exercise with no feedback from the system, and a condition in which the user chose the modality assignments by preference. In the preference condition, the user’s performance significantly outweighed performance in the other conditions. This suggests that individual preference can have a significant impact on the optimal assignment of modalities in at-home training, although further evaluation is necessary to provide conclusive evidence.

6. CONCLUSION AND FUTURE WORK

Through a case study, we indicated in previous work that the system is capable of capturing and remotely managing a trainer’s feedback and assessment protocol as well as a training regimen with a variety of upper-extremity motor exercises [6]. We also indicated that it may be important to consider an individual’s preference for certain modalities when delivering feedback on motor performance, though future evaluations with multiple users will serve to validate this claim. We are currently in the process of designing games for rehabilitation using a spectrum of motor tasks of increasing complexity and an assignment of game archetypes to those tasks. This will add a layer of interactivity to make motor tasks more meaningful and interactive and is the subject of future work.

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