HOMER: An Interactive System for Home Based Stroke Rehabilitation

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ABSTRACT
Delivering long term, unsupervised stroke rehabilitation in the home is a complex challenge that requires robust, low cost, scalable, and engaging solutions. We present HOMER, an interactive system that uses novel therapy artifacts, a computer vision approach, and a tablet interface to provide users with a flexible solution suitable for home based rehabilitation. HOMER builds on our prior work developing systems for lightly supervised rehabilitation use in the clinic, by identifying key features for functional movement analysis, adopting a simplified classification assessment approach, and supporting transferability of therapy outcomes to daily living experiences through the design of novel rehabilitation artifacts. A small pilot study with unimpaired subjects indicates the potential of the system in effectively assessing movement and establishing a creative environment for training.

CCS Concepts
Information interfaces and presentation (e.g., HCI)

Keywords
Stroke rehabilitation, interactive neurorehabilitation, home based care, assistive technology, health, aging

1. INTRODUCTION
Stroke is the leading cause of disability in the United States and the most common neurological disorder worldwide. Although large-scale studies point to the effectiveness of long-term therapy in facilitating recovery, the cost, availability of facilities and experts, and issues with reliable transportation, limits the amount of supervised therapy that stroke survivors can receive in the clinic [5]. In response, home-based unsupervised therapy has emerged as a possible viable alternative, which can be effective in conjunction with therapy in the clinic or even as the primary mode of therapy [1]. Pervasive health technologies present rich opportunities for leading and supporting efforts here, although considerable personal and technical challenges remain, including patient non-compliance and adherence, reproducing a supervised therapist experience without the therapist present, and technology or design related issues including system size, system complexity and robustness, and home privacy intrusion. Building on our prior interdisciplinary work in creating large-scale rehabilitation systems for hospitals and clinics [2], we present our approach in developing an interactive system for unsupervised upper extremity stroke rehabilitation in the home. The HOMER system is designed to occupy a small footprint in the home, capture and analyze the most significant movement features, and motivate use through a set of therapy objects that promote problem solving capabilities.

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2. RELATED WORK
Home based interactive rehabilitation therapy can be defined as computer-assisted therapy with limited engagement of the therapist (either through remote supervision or a limited number of visits to the home). Recent developments using low-cost interactive technologies such as tablet computers and the Kinect increase the possibility of long-term, affordable home managed care through tangible, augmented, virtual, and mixed reality applications [2, 3, 4]. In tandem with these technical developments, therapeutic approaches to stroke rehabilitation have also evolved considerably in the last decade, with an emerging focus on patient use of goal-driven, active problem solving strategies, and therapist experimentation with activities of everyday relevance [5]. Integrating these advancements, our goal is to produce a robust and affordable interactive system oriented towards creative problem-solving through the use of "enriched" therapy objects that align carefully with activities of everyday living [6].

3. HOMER SYSTEM
Our interactive rehabilitation system for the home consists of an inscribed mat (see Fig 1a), six custom designed therapy artifacts and their container (see Fig 1b and 1c), a table mounted Kinect camera, a mini-computer module clamped underneath and a tablet device with a custom web application (see Fig 1a). The system is designed to fit on typical tabletop surfaces found in the home, such as a kitchen, dining room, or computer/office table. The mat (laid out on a table) acts as a stage on which the user performs each rehabilitation activity using the objects individually or in combination. The Kinect is integrated into a modifiable table–mounted stand which allows for maximal visibility of the upper body of the user. The tablet device hosts the interactive web application presenting the training protocol, including the activity instructions.

The set of objects in our system are designed to support cross-mapping and generalizable activity strategies through their open-ended affordances, combinatorial possibilities, and perceived correlation with diverse artifacts of daily living (e.g. drinking from a glass, turning a key, unscrewing a jar etc.). The current system set consists of three base objects (tapered can, hourglass, covered tripod), and three tops (teardrop, checker, round ball) that can be used individually or variously combined by stacking, or in the case of the can and teardrop top, screwing together. The objects can be grasped and manipulated in a wide variety of ways

Figure 1. a) The HOMER system including mat, objects, tablet and Kinect; b) set of 6 objects; c) combining two objects

corresponding to the primary identified hand grasps, (see Fig 1c) thus lending themselves to rich cross-mapping opportunities.

We use the Kinect 2 camera to passively measure hand movements and train grasp classifiers for the three primary hand grasps (medium wrap, power sphere and precision pinch). We also use the Kinect 2 SDK body tracking algorithm to track the positions of both shoulders as a proxy for torso movement. This combined approach provides coverage for the key movement features as defined by our prior work [2], namely: 1) end effector activity over time and space (reach time, trajectory, velocity profile); 2) hand shape (grasp analysis); 3) torso compensation; and 4) object behavior. Our movement assessment module aims to judge the quality of the activity by identifying six key types of performance errors typically observed by the therapists on our team during therapy including low speed; indirect movement path; dropped object; misplaced object; incomplete task; and torso compensation.

4. PILOT STUDY

We tested the feasibility of the current version of the system through a small pilot study with 15 healthy subjects engaged in completing tasks developed by the team therapists, using unimpaired and simulated impaired movements. Our goal with this study was to safely identify and eradicate any system errors that could potentially confuse, frustrate, or possibly injure vulnerable users in a forthcoming clinical trial.

Participants were instructed to use the web application on the tablet device to access and move through the activity protocol by themselves, and at their own pace. Participants were instructed to complete 12 distinct reach/grasp/transport activities using the set of 6 objects, with each activity repeated 4 times. For the first two repetitions for each activity, the participants were instructed to complete the activity as accurately as they could and at normal speed. For the third and fourth repetitions, the participants were instructed to complete the activity, but each time with one of the 6 performance errors noted above.

5. FINDINGS AND DISCUSSION

The system functioned smoothly throughout the study, with no technical hardware failures and correct communication maintained between the various system devices. All 15 participants completed the study within the assumed 1-hour timeframe and all demonstrated observable growth in fluency and confidence with the system as they progressed through the activities. Overall our system was able to detect 5 of the 6 performance errors (>0.7 recall), which suggests that our current movement assessment implementation is able to identify a particular simulated performance error with decent accuracy. In debrief interviews after the study, participants also noted how the objects and protocol tasks reminded them of various everyday activities, with one stating that they liked how the objects didn't obviously "give away" what they could be, or what they could be used for, indicating that the setup succeeded in prompting them to think creatively during the exercise. Building on these insights, we are currently extending our approach beyond functional error detection to support a broader capture and analysis of the participant's action goals. This revised system will be used in an upcoming trial with 10 stroke patients, which will help us further assess the potential of our approach.

6. REFERENCES

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