Designing Modular Rehabilitation Objects for Interactive Therapy in the Home

Aisling Kelliher
Virginia Tech
Blacksburg, VA 24060, USA
aislingk@vt.edu

Andrew Gibson
Virginia Tech
Blacksburg, VA 24060, USA
drewgan5@vt.edu

Eric Bottelsen
Virginia Tech
Blacksburg, VA 24060, USA
beric@vt.edu

Edward Coe
Virginia Tech
Blacksburg, VA 24060, USA
eoccoe@vt.edu

TEI '19, March 17–20, 2019, Tempe, AZ, USA

ACM ISBN 978-1-4503-6196-5/19/03.
DOI: https://doi.org/10.1145/3294109.3300983

Abstract

Interactive home based rehabilitation therapy is a promising treatment development for stroke survivors. As the impairment characteristics of each stroke survivor are unique, interactive rehabilitation systems need to be customized to the functional and movement quality outcome goals of the patient, and adaptable over time as therapy progresses. In this paper, we present our iterative co-design process creating a set of modular therapy objects and a rehabilitation protocol for upper extremity stroke survivors. Our objects and training protocol are adaptable components within a computer vision based interactive system that captures and analyzes stroke survivors completing rehabilitation activities. We report on findings from a pilot study with nine stroke survivors and a workshop with five physiotherapists where we highlight challenges in designing objects for impaired grasps, opportunities for aligning objects with activities of everyday living, and the responsibility of design sensitivity.

Author Keywords

Home based therapy systems; interactive stroke rehabilitation; interaction design; human centered design

CSS Concepts

• **Human-centered computing~Interface design prototyping; Participatory design**; Interaction devices; People with disabilities

Introduction

Worldwide populations are increasingly aging, meaning that in many countries, including the US, there is an increasing need for effective and accessible rehabilitation services for debilitating illnesses and injury such as stroke and progressive arthritis [7, 11]. Globally, stroke is the most common neurological disorder and while long-term therapy in the clinic has proven effective in facilitating recovery [12], the challenges of financial cost, effort of traveling to a clinic, and overall availability of therapists can be prohibitive. Unsupervised home based therapy has emerged as a potential solution, but here issues of system cost, intrusion and maintenance, in addition to patient motivation and adherence, present new problems to address.

The Interactive Neurorehabilitation Lab at Virginia Tech focuses on developing robust and motivational interactive systems for semi-automated home-based therapy for upper extremity stroke survivors. Our system combines computer vision and machine learning approaches for capturing and assessing patient movement during therapy. As the industrial and interaction designers on the team, we are particularly focused on interrogating the role of design in supporting patient motivation, aligning training experiences with activities of daily living, and creating artifacts that are pleasing and evocative for humans, while also supporting the computer vision and analytical requirements of our team's semi-automated approach. In this description of our current work in progress, we detail our iterative design process in crafting a series of customized modular objects in close collaboration with a team of physiotherapists, rehabilitation medicine experts and the computer vision members of our team. We present findings from a pilot study with nine stroke survivors and discuss ongoing work with our therapist, engineering, and patient collaborators.

Motivation and Background

Technology assisted rehabilitation in the home is emerging as a key avenue for improving health and wellness outcomes with the potential for reducing costs [1]. However, home based therapy faces considerable challenges in terms of cost, intrusion, supervision and patient motivation [3]. There are a number of successful individualized approaches [2, 8], although outstanding challenges remain in terms of scalability, data collection, and reliable automation. Our current work builds on the approach of Kyto et al. and others, in that we aim to develop a low-cost, scalable solution with training objects and therapy tasks purposefully targeted towards supporting the daily life activities of stroke survivors [9].

Approaching the design of objects for interactive therapy

In order to understand the scope of the design space for home based rehabilitation, we conducted a study of important gold standards, spanning therapy objects, activities, and computational analysis of human movement performance of significance to our project. We began by examining the household objects (e.g. pen, paper clip, towel etc.) used in the Wolf Motor Function Test (WMFT), a key standard for evaluating

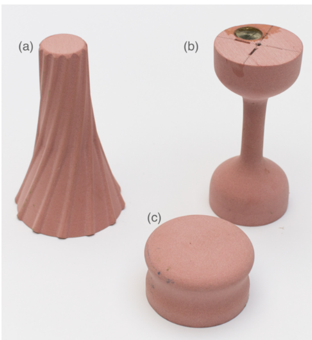

Figure 1: Preliminary object prototypes handmade from composite materials. The objects contained holes where weights could be placed to increase or decrease object stability. 1a approximates a can, 1b could be used as a glass or makeup brush, 1c could be picked up like a large checker piece with a power sphere grasp

upper extremity movement [12]. We next analyzed the activities of daily living examined in the Motor Activity Log (MAL), which compromises a set of questions designed to elicit measurements and understandings about the effects of therapy on an impaired limb during everyday life [11]. Finally, we reviewed the GRASP taxonomy as it is considered useful for assisting in the computer vision recognition and assessment of hand grasps [5]. Table 1 presents our primary findings from this comparative analysis, identifying a proposed set of the most significant and potentially useful grasps, object types, and activities that can be combined in the widest variety of ways to support concrete cross-mapping between rehabilitation training tasks and activities of everyday living.

Object	Grasp	Activity
Basket Checker	Power Sphere	Use towel Put on makeup
Can	Medium Wrap	Pick up glass Hold book
Towel Key in lock	Precision Pinch	Button up clothes Grasp fork or spoon

Table 1. Primary commonalities between objects, grasps, and everyday activities.

Based on our analysis, we created a set of handmade preliminary object prototypes produced using a variety of materials. Figure 1 depicts three of the objects we made from composite materials (we also used wood and foam). We presented our objects and suggested related training tasks (see Fig 1 sidebar for examples) at a workshop for 14 doctors, physical and occupational therapists, biomedical researchers, and engineers from six of our partner academic and medical institutions. In-depth discussions with these participants about the objects and the proposed training protocol helped us further solidify the final object design. Key feedback considerations from this event included: 1) a need to include soft/squishy material objects to assist with grasp release; 2) a need to consider object stability and/or potential roll away from the training area; and 3) a need to better consider the assigned movement task and the combination of objects within a problem solving activity framework.

In response, we modified our object designs and worked closely with the physiotherapists on our team to develop a series of 6 custom designed objects and 12 related activities for the upper extremity. In order to promote active problem solving (i.e. the patient needs to work out how to engage the object), we adopted a defamiliarization [4] approach, where we created objects that were close to, but not quite, recognizable household objects. We wanted to create objects that could be grasped and manipulated in a wide variety of ways corresponding to the primary identified grasps, thus lending themselves to rich cross-mapping opportunities.

We 3D printed a set of three base objects (tapered can, hourglass, contained tripod), and three tops (key-top, checker piece, squishy doorknob) that can be used individually or variously combined by stacking or screwing together (see Fig 2). The activities designed for manipulating the objects include reach (e.g. reach and lightly touch two objects); reach and grasp (e.g. reach and grip one of the tripod object legs), reach, grasp and transport (e.g. reach and lift the can object up towards the participant's face); and reach, grasp, transport, and manipulate components (e.g. reach and hold the can object with the left hand and reach and pick up the tear drop object with the right hand, then screw the tear drop object into the can object).

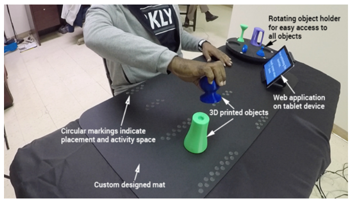

Figure 3. A participant in our study stacks one of our therapy objects on top of another during a “tidying” therapy task


Figure 2. The six objects are stored in a numbered rotatable container to facilitate object identification, object access, and object replacement (each storage slot is unique to each object)

The activity tasks scaffold in complexity (from simple reaching exercises with single objects, to two-handed multi-stage manipulations with two objects) and are crafted to map (and extend) to various activities of daily living, including those featured in the MAL set.

Pilot Study with Impaired Users

We conducted a pilot study of our therapy objects and activities with nine stroke survivors (two women, seven men; two with moderate impairment, and seven with mild impairment). The study tasked the participants with completing four repetitions of the twelve activities developed by our team. The participants used our interactive system, shown in Figure 3, which consists of the objects, a customized tabletop mat, a camera and a computer running the computer vision system, and a tablet interface that delivered the study protocol (i.e. instruction videos depicting what objects to use and how to move them for each task [7]. This IRB approved study took place at the Emory University Rehabilitation Hospital and was supervised by a physiotherapist. The participants were compensated for their participation and for their travel to the hospital. At the conclusion of the activity part of the study, the participants participated in a debrief interview with the research team, discussing their experience using the system, their opinions about the objects, and the types of daily activities they wanted to improve at.

Study Findings

Six of the participants were able to complete all of the activities, while three of the more impaired participants struggled to complete the more complex movement tasks. Different patient profiles (e.g. level of impaired sensation, increased spasticity, limitations in shoulder range of motion etc.) influenced the abilities of the patients to engage with some of the objects. For example, P2 had limited finger extension and found the green hourglass object slippery and had difficulty releasing the purple tripod object.

The participants spoke movingly about the types of activities they would like to be able to do at home including holding a baby’s rattle, washing baby bottles, toweling after a shower, buttoning a blouse, loading the dishwasher, and opening a bag of chips. Several participants noted that our system did not include knife and fork objects as this was something they struggled with both at home and in public. P5 expressed enthusiasm for the squishy object and found it helpful in thinking about the doorknobs they encountered in their everyday live. P2 wanted to hear a click sound or some other audio or tangible feedback when they screwed two objects together, a concern echoed by P5 who was worried about screwing the objects together too far. P1 critiqued our approach in conducting all the activities sitting down and laughingly asked if we too "brushed our teeth sitting down?". P8 was the only participant who objected to the design of the therapy objects themselves and thought there were "like toys for 5 year olds".

The participants had mixed reactions to our proposed set of connections between the objects/tasks and specific activities of daily living. While some made sense to them (lifting the can object towards your face as a drinking motion), others activities, especially those with the hourglass object were not as clear to them. The physiotherapist supervising the study noted that because of their different grasp abilities, the participants could agree that the activity reminded them of some activity, but it may just be different from what we anticipated. The physiotherapist also critiqued our overly open-ended design approach and suggested that we should be clearer about the goal of the perceived affordances of the objects. We found the input of the physiotherapist to be very helpful in assisting us in analyzing our approach and the patient activities and in response, we created an online survey to interrogate our approach more closely.

Physiotherapist Survey Evaluation

Survey Method: We conducted a survey with five physiotherapists, (three of whom were unfamiliar with the project up until then), to assess their interpretation of the therapy tasks and their perceived relation to the intended activities of daily living. The survey was administered online and consisted of two sections. In the first section, the physiotherapists were shown the instruction videos for the twelve therapy tasks. After viewing each video, they could choose one of three possible named activities of daily living (ADL) that in their opinion, best resembled the activity they had just viewed. The options to choose from included the intended ADL, another intended ADL featured in the twelve tasks, and another unrelated activity. The therapists could also submit a different daily activity if they thought that none of the three options were applicable. In the second survey section, the therapists were asked if they could think of any important ADLs that were not represented in the videos, in addition to questions about the sequencing order of the tasks, the complexity of the task, and the impairment characteristics that could influence task order.

Survey Results: The intended ADL was selected by all five therapists for four of the tasks and was selected by four of the therapists for five of the tasks, meaning that the majority of the therapists associated the intended ADL with their own interpretation for nine of the tasks. The remaining three tasks received agreement from three of the therapists, while two differed in their assessment. For two of these tasks, one of the therapists suggested a different task (e.g. "brushing teeth" or "wiping"). In the second section of the survey, the therapists collectively suggested ten additional ADLs to consider including cutting food, reaching across the body (e.g. with a towel), reaching above the shoulder (e.g. to brush hair or stack plates), buttoning a shirt and dealing with pericare after toileting. In addition, they drew specific attention to three grasps or finger movements that they found lacking in the current tasks, specifically a task requiring a hook grip

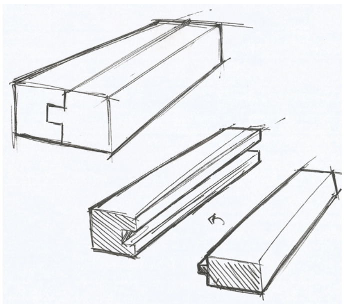

Figure 4: Sketch of chopstick pairs that can also function as a single object, to facilitate use for eating activities, or perhaps as a toothbrush

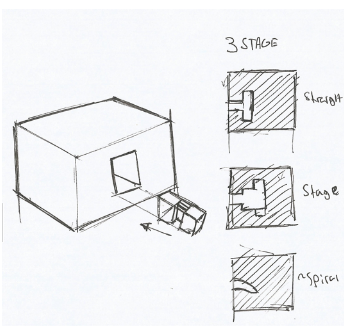

Figure 5: Sketch of a proposed staged lock and key mechanism to give patient physical feedback and a more challenging activity experience

for carrying objects, a lateral pinch grasp to hold a key, and a task specifying individuate finger movements for typing on a keyboard. The therapists agreed that the sequencing order of the tasks according to degree of challenge was correct.

Survey Findings and Follow Up Workshop

The survey results prompted us to more closely examine the objects and tasks that seemed either too generic or not well aligned with the intended tasks. We were also interested in looking further into the objects/tasks that were interpreted most differently as perhaps with specific design tweaks or modified instructions there could be opportunities to expand our task series. In our study, we used the hourglass object as a proxy for a fork or knife while eating, and as a pencil while writing. These two tasks were associated with three different possible ADLs in the survey. A clear issue with the eating task is that we did not create a bimanual activity (an important feature noted in [9]) while the form of the object itself did have enough perceived affordances to be consider by all to be a pen. We also noted that some of our tasks did not give the users the type of feedback typical in an ADL, such as the satisfying click of attaching two objects together, or the pushback from a key that has snapped a lock.

Therapist and Designer Workshop

We reflected on these findings and in response, worked on creating a number of sketches and preliminary mock-ups of additional ADL objects and tasks. One month after the survey, the 5 physiotherapists joined the entire interdisciplinary team for a 3-day workshop at Virginia Tech. As part of the activities on day 3 of this workshop, we collectively reviewed the survey results and discussed them in depth. We also presented our sketches for critique and received detailed feedback from the therapists present. They suggested some new objects such as weighted spoons that could be used for eating motions, in addition to doubling as a hairbrush for top of head mobility. They also challenged the simplicity of our horizontal button designs, observing that most buttons encountered in everyday life are vertical, and suggesting that making the top of the button squishy would give better feedback to the patient.

Conclusions and Future Work

Designing for stroke survivors requires sensitivity to their condition, and creating artifacts considered infantilizing or bizarre is problematic. In our case, creating objects with more muted palettes could help, while being more direct with the ADL intent of the object/activity pairing could help remove confusion or the sense that the system is trying to trick the participant through unnecessary obfuscation. Stroke survivors grasp objects in a way that makes sense for their unique impairment. For computer vision based movement assessment systems like ours, this requires capturing more data of stroke survivors manipulating our objects to train our assessment algorithms. Later this year, we are conducting studies at two clinics aimed at capturing 1000 activity videos. We plan on incorporating the proposed objects in Figs 4 and 5, as well as creating a heavy and a light set of objects to accommodate participants with different patient profiles. We are modifying our checker/button object to have a squishy/flexible center and will experiment with vertical placement activities, as in the lock and key example. We will continue to conduct regular critique sessions with our research team, medical collaborators, and network of stroke survivors.

References

[1] Craig Anderson, Sally Rubenach, Cliona Ni Mhurchu, Michael Clark, Carol Spencer, and Adrian Winsor. 2000. Home or hospital for stroke rehabilitation? Results of a randomized controlled trial: I: Health outcomes at 6 months. *Stroke*, 31(5): 1024–1031, 2000

[2] Madeline Balaam, Stefan Rennick Egglestone, Geraldine Fitzpatrick, Tom Rodden, Ann-Marie Hughes, Anna Wilkinson, Thomas Nind, Lesley Axelrod, Eric Harris, Ian Ricketts, Susan Mawson, and Jane Burridge. 2011. Motivating mobility: designing for lived motivation in stroke rehabilitation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '11). ACM New York, NY, 3073-3082

[3] Michael Baran, Nicole Lehrer, Margaret Duff, Vinay Venkataraman, Pavan Turaga, Todd Ingalls, W Zev Rymer, Steven L Wolf, and Thanassis Rikakis. 2015. Interdisciplinary concepts for design and implementation of mixed reality interactive neurorehabilitation systems for stroke. *Physical therapy*, 95, 3 (2015), 449 - 460

[4] Genevieve Bell, Mark Blythe, and Phoebe Sengers. 2005. Making by making strange: Defamiliarization and the design of domestic technologies. ACM *Trans. Comput.-Hum. Interact*. 12, 2 (June 2005), 149-173

[5] Thomas Feix, Roland Pawlik, Heinz-Bodo Schmiedmayer, Javier Romero, and Danica Kragic. 2009. A comprehensive grasp taxonomy. In *Robotics, Science and Systems: Workshop on Understanding the Human Hand for Advancing Robotic Manipulation*, pp 2–3, 2009.

[6] Mostafa Haghi, Kerstin Thurow, and Regina Stoll. 2017. Wearable Devices in Medical Internet of Things: Scientific Research and Commercially Available Devices. *Healthc Inform Res*, 2017. **23**(1): p. 4-15.

[7] Thanassis Rikakis, Aisling Kelliher, Jinwoo Choi, Jia-Bin Huang, Kris Kitani, Setor Zilevu, and Steven L. Wolf. 2018. Semi-automated home-based therapy for the upper extremity of stroke survivors. In *Proceedings of the 11th PErvasive Technologies Related to Assistive Environments Conference* (PETRA '18). ACM, New York, NY, USA, 249-256.

[8] Pedro Kirk, Mick Grierson, Rebeka Bodak, Nick Ward, Fran Brander, Kate Kelly, Nicholas Newman, and Lauren Stewart. 2016. Motivating Stroke Rehabilitation Through Music: A Feasibility Study Using Digital Musical Instruments in the Home. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (CHI '16). ACM, New York, NY, USA, 1781-1785

[9] Mikko Kytö, David McGookin, Wilfried Bock, Héctor A. Caltenco, and Charlotte Magnusson. 2018. Designing Bimanual Tangible Interaction for Stroke Survivors. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction* (TEI '18). ACM, New York, NY, USA, 245-252.

[10] Alexandros Pantelopoulos, and Nikolaos Bourbakis, A Survey on Wearable Sensor-Based Systems for Health Monitoring and Prognosis. IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), 2009. **40**(1): p. 1-12.

[11] Edward Taub, Miller NE, Novack TA, Cook EW III, Fleming WC, Nepomuceno CS, Connell JS, Crago JE. Technique to improve chronic motor deficit after stroke. *Arch Phys Med Rehabil*. 1993;74:347–354

[12] Steven L Wolf, Pamela A Catlin, Michael Ellis, Audrey Link Archer, Bryn Morgan, and Aimee Pia-centino. Assessing wolf motor function test as outcome measure for research in patients after stroke. *Stroke*, 32(7):1635–1639, 2001.