PT Viz: Towards a Wearable Device for Visualizing Knee Rehabilitation Exercises

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ABSTRACT
We present a wearable sensory display for visualizing knee rehabilitation as part of an in-home physical therapy program. Currently, patients undergoing knee rehabilitation have limited ways of assessing exercise form and extent of movement at home. To address this issue, we developed an exploratory wearable electronic prototype to visualize knee bend. We evaluated the device with physical therapy patients to get feedback on the design and to help us understand some of the challenges they face. We discovered that our current design is better suited for patients recovering from surgery as opposed to patients with chronic conditions.

Author Keywords
Knee rehabilitation; wearable display; user interface device

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION
Physical therapy is an essential part of recovery for patients suffering from injuries or musculoskeletal disorders. This labor intensive process requires patients to regularly consult physical therapists for targeted exercises to recover mobility and strength. Apart from periodic visits to the rehabilitation clinic, the patient must perform exercises regularly at home. While the therapist can monitor proper form and extent of movement in the clinic, patients have little feedback when performing the therapy exercises at home. This could lead to a longer path towards recovery for the patient.

Our research focuses on the recovery process at home for patients undergoing knee rehabilitation. Since there are many exercises for knee rehabilitation, we limit our design space by focusing specifically on the the knee extension exercise. To better understand the needs of patients, we explored the design of a wearable electronic device that utilizes an electroluminescent (EL) display as a feedback mechanism with

Figure 1. Physical Therapy Prototype for Knee Rehabilitation. Inset shows extended leg with view of the bend sensor.

patients who have or are currently attending physical therapy for knee rehabilitation. The specific contributions of this note are:

1. A preliminary design of a wearable knee rehabilitation device, PT Viz, that provides users with a visualization of exercise performance.
2. User study results that identify the needs of rehabilitation patients and how it could help patients improve the quality of in-home sessions.
3. Exploration of how PT Viz could improve patient-therapist communication.

RELATED WORK
There has been substantial work in both commercial and research areas on automated bio-monitoring systems. In the commercial space, the bioPLUX Clinical System (plux.info) device measures and displays muscular activity during rehabilitation sessions. While this device is compact and capable of transmitting data wirelessly, it is primarily designed for physical therapists as a medical device to be used in the clinic. With the advent of motion tracking peripherals in entertainment consoles such as the Nintendo Wii and Microsoft Xbox Kinect, researchers have designed applications that support stoke [8] and balance [6] rehabilitation. These systems require an investment in peripherals and software.

Healthcare researchers have studied wearable sensors to monitor therapy, with solutions that classify movement [4], analyze motion [1], and measure physical activity in specific populations [10]. Most of these biomedical solutions focused on particular technical aspects such as algorithms or sensors. Studies explored body sensor networks (BSNs) for both local [5] and remote physiotherapy treatments [3], but these systems require users to place invasive sensors throughout the body and are focused on communicating information to the therapist. While there has been work on interactive methods [9, 11], few have combined the needs of both the therapist and patient. Most notably, Thera-Network [7], describes an electronic knee brace as part of a conceptual networked system to help patients monitor progress and recover from knee pain. Though similar in concept, PT Viz differs in that it is self-contained, ergonomic, and employs a flexible Neoprene based bend sensor. Additionally, PT Viz takes a bottom up approach and explores the issues surrounding knee rehabilitation using one possible implementation.

METHODS

We used PT Viz as a probe to evaluate a particular design while exploring the broader design space of in-home rehabilitation. As such, the probe was used to elicit feedback from patients regarding their needs and challenges in a real use context while exploring an EL wire based design. PT Viz was a focal point for critique that highlighted possibilities, explored interaction mechanisms, and fostered discussion.

Exploratory Prototype - PT Viz

PT Viz, shown in Figure 1, consists of an enclosure for the upper thigh with embedded electronics, an enclosure for the calf, and a bend sensor. The enclosure for the upper thigh is a curved piece of Neoprene that is lined with polyester on one side and Spandex on the other. One end of the neoprene is attached to a double-slit plastic buckle. The enclosure for the calf is similar to the thigh enclosure, except it is smaller. Our implementation provides full knee visibility and unhindered mobility. The bend sensor, made of Neoprene, Velostat, and conductive thread (kobakant.at/DIY/?p=20) runs across the back of the knee and connects to Velcro strips on the thigh and the calf enclosures; this accommodates varying leg sizes. Knee angle can be approximated by measuring the resistance of the bend sensor which linearly changes as the knee bends. The electronics consists of a small lithium ion battery, a microcontroller, circuit components, and a light based display using electroluminescent (EL) wire. We employed EL wire because it is low power, cool to the touch, and flexible. As the user bends the knee, the bars of EL wire light up until they are all lit, indicating full knee bend.

Study Design

The study consisted of a background questionnaire and a usability session with the prototype, followed by a semi-structured interview. The background questionnaire collected demographic information, information about technology use, rehabilitation history, and physical therapy experiences. For the usability session, we employed the think aloud protocol, where participants were given components of the wearable prototype and a set of tasks to complete. The tasks involved putting the prototype on and performing a common knee extension exercise, which consisted of sitting on the edge of the chair and slowly extending the leg until straight (repeated 10 times). Following the usability session, we conducted a semi-structured interview to better understand user experiences while using the device, what aspects they found useful, what aspects could be improved, and their thoughts on sharing exercise data with therapists. Each session lasted approximately 65-75 minutes. We video recorded the usability testing and the semi-structured interview portions of the study. The study was approved by our university's human subjects review board.

Participants

We screened for participants who were currently attending or had attended physical therapy for knee rehabilitation to assure pertinent feedback. We recruited 6 participants (age range 20-37 years old), 2 males and 4 females, from local rehabilitation clinics and the general campus population. Participants received a $15 USD gift card.

RESULTS AND REFLECTIONS

By using PT Viz as a probe, we discovered specific patient-centric insights into issues such as wearability, portability, the importance of various rehabilitation metrics, the potential sharing of information, and the utility of other pervasive technologies in the rehabilitation process.

Patient Types

We identified two types of knee rehabilitation patients in our study: those who had undergone surgery as a result of injury (4 participants) and those who had chronic conditions (2 participants). One of the chronic group participants performed physical therapy for over 1 year and the other for over 3 years. Three of the four surgery participants had attended physical therapy on average 6-11 months with one participant having attended for over a year. The combined participants reported rehabilitation clinic visits lasting once or twice a week for 30 to 45 minutes. The prescribed home exercise sessions, however varied among the participants depending on the severity of the injury or condition with sessions ranging from everyday for 25 minutes to 3-4 times a week for an hour. We employ the prefixes S and C to help identify surgery and chronic group participants in this paper (e.g., S1, C2).

We highlight these two patient types because we discovered consistent opinions between participants in each group throughout the study. For example, participants who had undergone surgery had few motivation issues to perform home exercises, whereas participants who had chronic conditions were often delinquent in their home sessions and reported the exercises as being "boring." While it is hard to generalize based on 2 participants, we hypothesize that the needs and the physical therapy characteristics of the two patients types are very different. In the surgery group, patients were motivated to recover their mobility quickly, having had full mobility in the past. Whereas in the chronic group, patients viewed physical therapy as a way to improve existing mobility. Furthermore, as surgery patient S1 informed us, a second surgery is sometimes necessary if the knee does not heal properly - a warning that motivated him to perform exercises regularly. The two chronic group participants also confirmed that motivation and compliance were more salient issues in their recovery process. These differences between the two patient types however, need to be further explored.

Is PT Viz needed?

When we asked participants if and how PT Viz might support performance of physical therapy exercises, all of them highlighted the necessity of feedback when performing exercises at home. As S1 stressed,

"Well with a physical trainer he is giving you feedback and he is a professional so you know what he is telling you is probably on track, so having something else tell you that you are doing something right gives you more confidence when doing the therapy by yourself at home."

However, we discovered that which aspects the participants considered useful depended on the patient type. Patients recovering from surgery found PT Viz especially useful since it gave immediate feedback on range of motion. S2 highlighted how the physical therapist would push her beyond what she thought was possible and how PT Viz would be useful in knowing how far to bend at home. Similarly, S3 added that the device would be useful in increasing bodily awareness and assuaging her fears about overexerting. Patients suffering from chronic conditions found PT Viz somewhat useful, reporting that while it was easy for them to sense the angle of the knee, they appreciated knowing when the leg was totally straight and that it may encourage them to hold their leg straighter for longer. Participants with chronic conditions reported difficulties understanding long-term therapy progress, where mobility improvements can be separated by months.

The coarse granularity of PT Viz seems better suited for surgery patients as opposed to chronic patients. This may be because surgery patients initially have greater improvements over a smaller period of time, counter to chronic patients' experiences. Regardless, we need to consider the recovery processes of patients in future designs.

Wearability

Participants did not encounter any issues identifying and wearing the two enclosures during the usability session. However, half the participants had difficulty in attaching the bend sensor. This was because we had provided Velcro strips as connection areas and they were expecting specific connection points on the enclosures. C2 mentioned that connecting the sensor could be easier if paired connection points were appropriately color coded.

Aspects of the PT Viz design that worked well included the ergonomically curved two-piece enclosure design. S2 commented,

"I do think the separate pieces would be a lot easier to put on. Even now when my knees are hurting me...I'll pull on a neoprene sleeve and if my knee is particularly swollen, it would be hard to pull on. I can see how right after a surgery, your knee is really swollen and you don't want to put on a sleeve."

Similar sentiments were echoed by S3 and S4. S4 added that a patient would not have to remove her shoes to wear PT Viz, a difficult activity post surgery. An unintended beneficial aspect of the design that surfaced during the study was the portability of the device. While PT Viz was never designed with portability in mind, four participants remarked how they could easily wrap it up and carry it with them. S3 commented,

"It is really small. I already have to carry around Therabands and ankle weights and stuff like that and this is no bigger than anything else I already have."

When we questioned participants about where else they performed their exercises apart from home, we discovered that participants' rehabilitation practices also extended to gyms, offices, and labs. While we acknowledge that this was probably because our participants were mostly students, it still highlights the need to consider the lifestyles of users when designing physical therapy devices. Considering users' lifestyles affects the design of these devices since we need to balance parameters, such as size, power, functionality, comfort, and portability.

Visualization

Participants found the EL wire bar graph visualization immediately intuitive and successfully correlated knee angle with the light pattern. The power indicator (the blue outer EL ring) was only obvious to half the participants. C2 remarked that the power indicator distracted her from the main bar graph visualization. We can improve this design by replacing the current ring-like power indicator with a single traditional LED in the corner. This modification makes the design simpler and reduces the power requirements.

The overall perceived usefulness of the visualization varied depending on patient type. The four surgery participants found the visualization more conducive to their recovery processes than the two participants with chronic conditions. S4, who was currently attending physical therapy for a torn ACL, found the visualization immediately helpful. When using the device, she remarked,

"I can't bend it all the way back yet so it is good that it is telling me...this might make me work harder."

S2 agreed that PT Viz could motivate patients by helping them set goals and measure progress through the EL wire indicators. The visualization however, was less meaningful to participants suffering from chronic conditions. While C2 appreciated the greater focus and being able to physically see improvement, she suggested we increase the number of bars used to represent knee angle. She remarked how staying in one level for weeks would be less of a motivator.

Participants suffering from chronic conditions also suggested tracking metrics such as sets, reps, and hold time to improve the utility of PT Viz. C2, whose physical therapy lasted 3 years, was keen on tracking these metrics across exercise sessions to see progress over time. While surgery participants were not averse to the idea of tracking progress over time (especially knee angle), they were more interested in the immediate exercise session; they requested hold time and reps as the two additional metrics. This introduces new design considerations for being able to track discrete versus continuous health metrics on wearable systems.

The immediate question that arises is if it is possible to combine the needs of both patients in a single visualization. A smart phone could serve as the paired wireless visualization platform for PT Viz, however participants dismissed the idea as impractical. They listed difficulties that might arise such as: the need to prop up the phone, losing focus on the exercise, having an extra device, being distracted by incoming texts, and the phone battery dying. Perhaps one solution would be to implement a hybrid approach where we maintain the existing visualization but refine it by adding more EL wire lengths for granularity and extra representations for hold time and reps. Additionally, PT Viz can store all the metrics for each session locally before transferring them to the smart phone at a later time.

Sharing and Concordance

The far reaching goal of our research is to promote patient-therapist collaboration so that rehabilitation is a shared process where both patient and therapist make health goals together. This process, known as concordance, leads to better health outcomes when compared to enforcing compliance [2]. Knee rehabilitation is ideal for the concordance process because patients decide how much better they want to be without mortal consequences. Wearable technology plays the role of a mediating artifact between therapist and patient by providing therapists insight into the recovery processes at home.

Towards this end, we studied the acceptability of concordance from a patient-centric perspective by examining participants' attitudes towards sharing PT Viz session data with their therapists. Participants were immediately accepting of this idea, however their reactions were less consistent when we reminded them that the device would also track and report lapses in exercise sessions. S1, who we considered to be our most motivated participant, commented that no one really wants to tell their physical therapist that they are not serious about rehabilitation. Others felt that sharing data would hold them accountable while also acknowledging that it may be uncomfortable when lapses occur. S2, went so far as suggesting that sharing be made mandatory by the physical therapist and likened the process to grading homework. While it is important to integrate patient generated data into clinical decision-making, mandatory sharing could precipitate feelings of embarrassment, decrease patient autonomy, lack of adoption, and system abandonment.

We recognize that there are social factors that our research might not be always be able to address. Still, we are hopeful, since two of our participants naturally suggested sharing as a way to promote collaboration. This was best illustrated by C2 who commented,

"I think it is ok [sharing after missed sessions]. If [the exercises] aren't working for somebody then the physical therapist can work with them to see what does work."

CONCLUSION

In PT Viz, we explored one simple staged visualization to help patients quantitatively see the effort of their knee movement. While this particular visualization was intuitive to participants, we need to explore alternative visualizations that could be tailored beyond a simple linear mapping, and on the body feedback mechanisms (e.g., audible or vibro-tactile) that also track individual exercise session parameters like reps and hold time. Regardless, wearable technology designs in this space may need to accommodate the patients' different recovery processes. We also need to work with therapists to extract metrics that they can use to evaluate patient progress and create intuitive exercise data visualizations. In this case, a future design may allow both patient and therapist to jointly set goals towards full recovery.

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