Design Research Methods to Understand User Needs for an eTextile Knee Sleeve

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ABSTRACT

Knee replacement surgery is dramatically increasing in the United States for people over the age of 45 and rehabilitation after surgery is a necessary step for the success of the replacement. Rehabilitation requires regular access to a wide variety of resources and personnel. Currently, there are no self-care tools to enable tracking a patient's rehabilitative progress at home. As such, there is an opportunity to design and develop sensing technology tools to help alleviate the healthcare system and empower people in the knee rehabilitation process. The purpose of this paper is to describe the design process for a wearable, home rehabilitation device for knee replacement: an eTextile Knee Sleeve. More specifically, it describes the design research methods undertaken to understand user needs, including expert interviews, rehabilitation observation, and a participatory design workshop, to leverage advancements in technology and the field of eTextiles.

Categories and Subject Descriptors

H.5.2 [**Information Systems**]: User Interfaces – *evaluation/methodology, input devices and strategies, prototyping, theory and methods, user-centered design.*

General Terms

Human Factors, Documentation, Design, Reliability, and Experimentation.

Keywords

Rehabilitation, Older Adults, Human Centered Design methods, user research, observation, expert interviews, and participatory design workshop.

1. INTRODUCTION

Knee replacement surgery is dramatically increasing in the United States for people over the age of 45 (1, 2). One of the main reasons for the rise in surgeries is because it is an inexpensive and effective method for treating degenerative joint diseases (3-5). Knee replacement surgery is a method for treating diseases, such as Osteoarthritis, Rheumatoid Arthritis, and Post-Traumatic Arthritis. After surgery, rehabilitation requires regular access to a large variety of resources and personnel, such as isokinetic devices, physical therapists, and primary physicians (6). As the demand for post-operative, rehabilitative care increases, the ability to marginally relieve the healthcare system by offloading resources to the patient is necessary.

Advancements in technology have introduced electronics into wearable products, and within the past 20 years, have engendered the new field of smart textiles, or eTextiles (7, 8). eTextiles enable digital components and electronics to be embedded into the fabric, providing additional functionality to wearable products. eTextile research into the medical fields have focused on the monitoring of motor functions, patterns, ambient sensing, and the integration into orthotics, prostheses, and mobility assistive devices. However, few studies have been done to understand the wearability of technologies within the medical field and their feasibility as a consumable product (9, 10). Furthermore, research has not approached the problem from a fully integrative perspective, encompassing healthcare professionals and patients as feedback mechanisms in the iterative design processes.

The purpose of this paper is to describe the design process for a wearable, home rehabilitation device for knee replacement. More specifically, it describes the design research methods undertaken to understand user needs. This project utilized design ethnography tools such as expert interviews, rehabilitation observation, and a participatory design workshop, to leverage advancements in technology and the field of eTextiles. It investigated the product feasibility and acceptance of discreet on-body sensors to provide a product that enables patients to better perform rehabilitation on their own, but also to allow for a feedback loop for physicians and therapists to view patient progress.

2. RELATED WORK

Within the past 20 years, the medical industry has popularized sensing technologies as a feedback mechanism for physiology, motion, and mobility. In relation to tracking knee movement, a variety of methods have been used, but without full product success. As an example, Gibbs and Asada (11) used an array of single conductive fibers around the knee and hip joints on a pair of spandex pants to detect expansion and contraction of said joints. While successfully detecting flexion, as the sensor warmed up, their results provided less accurate results each time the pants were worn. In the same realm of biofeedback devices,

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Munro et al (12), developed a knee sleeve with a fabric sensor placed over the kneecap in order to track the degree of knee flexion for athletic training improvement. Functional testing however, showed that consistent feedback was not found due to sensor instability.

Additionally, current research looks at more complicated methods to track movement, in which, bulky goniometers in stabilizer braces help track flexion and extension or use the Kinect to estimate angles based on bodily protuberances. However, using new sensors on the body can provide more accurate data. While placing sensors on the body produces a lot of noise in the data collected, the closer a sensor is to the information being sensed, the easier it is for the information to be accurate. This accuracy is integral to biofeedback systems – users will not tolerate inaccuracy. Rhodes (13) and Starner (14) have a "two-second rule" for devices. If a device consistently takes longer than two seconds to activate, users will ultimately stop using the device. The same can be translated to user information. If the information users receive is consistently inaccurate or inaccessible to them, they will find a more suitable device to meet their needs.

Even though the aforementioned methods are necessary to develop sensing technology tools, they fail to incorporate user needs. These methods focus on involving users later on in the development process as they do user testing. There exists an opportunity to involve key product stakeholders early on in the process to provide real-time user feedback during design and development (15). The next sections describe in detail the different methods used in order to understand user needs for designing a wearable home rehabilitation device for knee replacement.

3. USER RESEARCH

This project utilized three main methods as part of a design ethnography approach. These methods included: 1-expert interviews; 2- observations; and 3- participatory design workshops. Together, the three methods contributed to the understanding of user needs to leverage advancements in technology and the field of eTextiles.

3.1 Expert Interviews

Semi-structured expert interviews were conducted with three Physical Therapists, an Applied Physiologist, and two Total Knee Replacement patients. A total of 6 expert interviews were conducted to discover the sentiments that surrounded rehabilitation and potential opportunities that existed. Each interview lasted approximately 30 minutes to an hour and addressed questions such as, "Tell me more about the rehabilitation process," "How does rehabilitation change from person to person?," and "What do you think would help encourage rehabilitation in the home?" Major findings for the expert interviews were compiled with the observational analyses. The goals of the interviews were to learn more about the process of rehabilitation, how it has changed throughout the years, and to understand what the stakeholders envisioned for the future.

3.1.1 Expert Interview 1

An Applied Physiology Professor at the Georgia Institute of Technology was interviewed. The expert provided an overview of physical therapy before offering insightful directions for the project.

Resistance training and balance exercises are the two main parts of knee rehabilitation. The earlier you start rehabilitation after surgery, the more extensive your range of motion will be in the future. There are different types of knee rehabilitation devices, but the better ones provide feedback on your range of motion, such as Isokinetic devices.

Isokinetic devices, such as the ones produced by Kin-Com and Cybex, are typically used during rehabilitation because they quantify and validate the amount of movement by measuring knee motion and the forces your knee can manage. They also bend the knee to the degree specified by the physical therapist, therefore ensuring proper rehabilitation results.

Following, she provided a few areas for further research.

3.1.1.1 Compression stockings

The expert suggested the integration of the sensors into compression hose. Older adults typically use compression hose to alleviate swelling in their legs, but doctors also recommend them because they are known to prevent blood clotting.

3.1.1.2 Hip and Knee Alignment

The expert also talked about the high instance of hip surgeries and potential areas of concern, such as the importance of hip and knee alignments. The possibility of integrating a means to detect ankle alignment in respect to the knee is important for the older generation because it ensures that other surgeries have been done properly.

3.1.1.3 Stimulation

It was also suggested integrating a stimulation device to enhance physical therapy. It isn't just about the quantity, but also about the quality of rehabilitation. Stimulation provides better rehabilitation by inciting a muscle to activate. The expert particularly suggested stimulating the Vastis Medialis, the muscle next to the patella that helps control bending, because it might be beneficial.

3.1.1.4 Temperature

Finally, the expert directed attention towards whether warmth provided a knitted structure would provide a better-perceived rehabilitation experience, as opposed to the traditional one. The expert postulated whether this allowed the user to do more movement, and asked how a device such as this would this affect the pain scale?

3.1.2 Expert Interview 2 – Physical Therapist Coordinator

A licensed physical therapist and the coordinator for the physical therapists in a local rehabilitation center was also interviewed. After providing a rundown of the facilities and the timeline of the process, the expert talked about the importance of range of motion within therapy and patient accountability during rehabilitation. Physical therapists often know when patients do not perform their rehabilitation at home and often get frustrated when the patient does not perform it properly. When the patient gets to the facility, their range of motion is approximately 90 degrees and, typically, their goal is to get the person to bend to 110 degrees. In the beginning of rehabilitation, they use the other knee as a baseline for the range of motion.

3.1.3 Expert Interviews 3 & 4 – Physical Therapists

Interviews were also conducted with two additional physical therapists. They stated that the majority of patients are arthritic

patients or ones who have pain, but Patella femoral syndrome is another big reason people have surgery. Furthermore, the two biggest problems people face after knee surgery are to have to go back to the hospital for a manipulation or an infection. A manipulation is when scar tissue build-up starts to limit the range of motion and a patient has to go back into surgery to get it removed. Rehabilitation is painful for many reasons, however, it's primarily painful because the scar runs right over where you're stretching. Initially after surgery, patients will receive a brace, but both patients and physical therapists discard them because they are not useful and because they limit the range of motion.

Potential opportunities for device features were discussed, such as vibratory feedback. They said it might help to activate the Vastis Medialis, but they hadn't seen any studies on it. Because the brace limits range of motion, physical therapists are wary of anything that goes over the knee and suggest using two Velcro straps above and below the knee. They offer that using Velcro straps allows the technology to be passed from one patient to the next, while the Velcro can be disposed of. All three therapists confirmed that placement of the sensors is incredibly important and, if accelerometers were going to be used, they would have to dissect the leg in order to get a proper reading of the degree.

3.1.4 Expert Interviews 5 & 6

Interviews using directed storytelling techniques were also conducted with patients at the facility to better understand their experiences and their needs. Directed storytelling is a method used to easily gather rich stories of lived experiences from participants. It is rooted in the social science method of narrative inquiry. Directed storytelling was leveraged for two reasons. The first was to trigger conversations between the researcher, the user, and their Physical Therapist for analysis and feedback on the overall rehabilitation process (16, 17). Secondly, it was used to understand product and service opportunities that were lacking or needing improvement (18-20). When coupled with shadowing techniques, as used during observation, researchers have the ability to gain a true sense of the user's actions, decision patterns, and routines.

3.1.5 Patient 1

P1 had undergone surgery 4 months prior. P1 recently (1 month ago) had to have a manipulation done to the previous surgery because they had accumulated scar tissue buildup in the knee and it had to be removed. The primary cause of this was due to failing to perform rehab after surgery. P1 said that it was scary to go through surgery and rehabilitation, and that it was easier to go through it the second time because P1 knew what to expect. During the rehab, P1 spoke about how hard it is to go through rehab, how they cheat at rehab when they are at home. P1 also spoke about physical therapists as being very encouraging when going through the whole process. "It's really painful, but they motivate you to push you further."

3.1.6 Patient 2

P2 had the surgery done on Dec. 31, 2012 and was hopefully in the last month of therapy. P2 had the left knee done 4 years prior and knew what to expect when going through it this time. P2 was impressed at how much better the technology had gotten and appreciated the shorter time both the operation and rehabilitation took. For the first knee replacement, P2 had gone to a class at the hospital that walked future patients through all the steps. The process for P2 was a stay in the hospital for 3 days after the surgery and then P2 went straight to the aforementioned rehabilitation clinic. After being there for a few weeks, P2 went home and a therapist came to see P2 2-3x a week for about 10-12 sessions. P2 said that the CPM machine was really beneficial, except that it left their knee very bruised afterwards.

When asked about what P2 thought the tool might use to motivate P2, P2 responded with "When you see you're making progress, that's motivation. It would be good, though, to know how far away you are from the end goal."

In terms of a user interface for patients, write everything down on a 5th grade level, not too simple, but simple enough. Use photos of exercises and provide information on what the different exercises will get you. ("This exercise would help me achieve three degrees" or "this exercise will make the hamstring stronger") The goal is to walk you through the exercises like a therapist would.

3.2 Observation

Not only is there a difference between what people say and what they do, but Carrillo (21) found that dialogues across different fields and, more importantly, within the same field, are more robust when engaged as a group, and shift the dialogues from assumption to reflection, and from individuals to the collective. Observation was also conducted to see how patients and Physical Therapists interacted. Five individuals were recruited for this phase, 3 Physical Therapists and 2 patients. The study was conducted in two-hour blocks for each patient, where the patient underwent 1 hour to 1.5-hours of physical therapy sessions. The major findings that came out of the observation were:

1. Rehab is slow. Not only is it an arduous process to go through, but the physical act of movement is slow and spasmodic.

2. Rehab is hard. Without the physical therapist present, users have a tendency to forego their rehab at home.

3. There is a disconnection between Health Professionals and Patients. Not only is there a lack of communication between them, but also there is a lack of tools and rehabilitation aids for patients.

3.3 Analysis

Affinity maps were created during the analysis of the observations and interviews. Affinity mapping is a tool used to group data and information by their natural relationships.

3.3.1 Affinity Map - Baseline

Using Affinity Maps, two chief directions emerged from the observational studies. First, the Affinity Map was organized based upon consistent themes that arose during the observation. These themes can be found in Figure 1 and are:

1. Physical therapy is difficult to properly be performed at home, is typically neglected, and often leads to surgical manipulations or infection in the future.

2. The role of the Physical Therapist is both an educator and a motivator.

3. The various tools used in the rehabilitation center, such as heating pads during initial stretching, home exercise sheets, and resistance training.

Figure 1. Observational Analysis.

Key observations using Figure 1 concluded that, despite understanding that they were being held fully accountable for their rehabilitation, the patients felt it was "too hard" to perform proper rehabilitation, which was performed 3 times daily for 15 to 30 minutes in the home and often led to regression in their rehabilitation at home. Despite patient problems, physical therapists often responded in direct correlation to the amount of effort the patient wanted to put in – e.g. the more a patient pushed themselves, the more the physical therapist pushed the patient. Attitude about rehabilitation was very important.

The process of rehabilitation typically started with a heating pad being used during stretching. In order to make up for the regression, physical therapists would slowly build up the exercises during their sessions to push the patient to their limit, which often led to the patients closing their eyes throughout and bracing themselves while the physical therapist worked on their knee. Additionally, simple language, analogies, and metaphors were frequently used to encourage patients. A patient's progress was determined using a goniometer to measure the degree of flexion and extension of the knee. The placement of the goniometer was crucial to determining the angle, as it bisected the leg.

3.3.2 Affinity Map – Patient & PT Disconnection

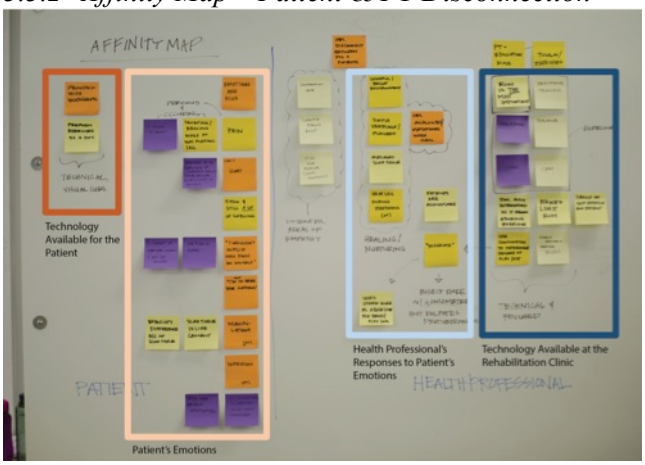

Figure 2. Observational Analysis: Patient / Physical Therapist Disconnection.

Additionally, rehab is very emotional. The Affinity Map was re-arranged to show the disconnection between the technology-centric Physical Therapist and the emotion-centric patient. The darker orange (see Figure 2) corresponds to the amount of technology available for the patient to use in the home, while the dark blue outlines the technology provided at the rehabilitation clinic. Additionally, the light orange refers to the emotions that the patients consistently brought up during the rehabilitation session, while the light blue outlines the tools used by the physical therapists to mediate those emotions. Figure 2 clearly shows the difference in technology between patient and physical therapist and shows how under-prepared physical therapists are to handle the patient emotionally and physically.

4. PRODUCT IDEATION WORKSHOP

Participatory design is a rising research method for product development and human computer interaction (22). Its value stems from examining the "third space", or region of overlap between researchers and product end-users. By engaging both end-users and designers, this method blends their collective knowledge into new insights and plans for action (23). A variety of techniques to encourage the "third space" are available, such as workshops, and were utilized within this study.

Two well-known formats for these workshops are the Future Workshop (24, 25), where participants "critique the present, envision the future, and develop their ideas" as a group, and Sander's conceptual "say-do-make", where participants use "generative tools" to explore past experiences and what they envision for the future (20, 26) . Leveraging these two frameworks, this study used four tools to explore the present and future for a better rehabilitation product. First, a "mind map" technique was used. It is a word association tool that was used both as a primer, to engage participants in the workshop, and used to understand how different stakeholders perceived the current state of rehabilitation by using central themes identified from ethnographic research. Secondly, a creative matrix was used to promote divergent thinking. By juxtaposing categories related to stakeholders with categories related to possible, future solutions, a large number of ideas are created that are related to different product aspects. This creative matrix was coupled with a technique called the Kano Analysis, whereby the participants are asked to categorize the concepts and attributes as either a required, desired, exciting, neutral, or an anti-feature. The Kano Analysis was done to understand the positive and negative features of the future product. Lastly, the workshop ended with a design and build activity using physical materials as a way for participants to explore features that would enhance the rehabilitation experience using eTextiles.

4.1 Workshop Analysis

The goal of the participatory design workshop was to understand the needs of the users through the evaluation and design of an ideal feedback device. Six people familiar with rehabilitation were recruited for the participatory design workshop, three females and three males, from a variety of different backgrounds. Table 1 showcases the demographics of the participants involved.

	Gender	Occupation	Age	Injury
1	M	Product Designer	>40	MCL Tear and Rehab, Both Knees
2	F	Architecture Student	<40	Broken Wrist, Rehab
3	F	Architecture Student	<40	ACL, MCL Patellar Tear and Rehab
4	F	Homemaker	>40	Knee Pain
5	M	Architect	>40	Knee, Ankle - Currently in Rehab
6	M	Senior Research Engineer	>40	MCL Injury, Rehab

Table 1. Workshop Participant Demographics

Key findings from the workshop provided a glimpse into product features people valued, focused around invisibility, and moved the product away from appearing as a technology product. Results from the mind map showed that people view rehabilitation as an arduous, uncomfortable, expensive, yet required process. In contrast, wearable products were supposed to be comfortable, light, and breathable, but they had to be careful as to not be itchy, heavy, or difficult to put on or take off. Moreover, technology was perceived as confusing, modern, bionic, advanced, complicated, and even expensive. Participants pushed for a tool that would provide feedback, but would not appear to use technology.

While the mind map was slightly abstract, the KANO analysis provided a clear set of features for the product. Users ranked features such as invisibility and reliability as required, while comfort and colors were ranked lower, only being considered desirable features. On the other hand, audible feedback and reminders to perform rehabilitation were considered anti-features (see Table 2). Interestingly, one participant wrote down habit-forming as a desired feature, yet two others ranked it as an anti-feature.

Required Features	Invisible, Reliable, Tracking, Customizable, and Easy to Use
Desired Features	Fits under Clothes, USB Capable, Tracking, Variety of Colors, Neutral Colors, Modern, and Not Geeky
Exciter / Delighter	Comfortable, Washable, Have a Long Battery Life, and FUN
Neutral Features	None
Anti-Features	Noise, No Immediate Feedback and Tracking, and Reminders to Perform Rehab

Table 2: Product Ideation Workshop: KANO Analysis

During the design and build phase of the workshop, participants had a chance to propose new ideas. Most participants developed products that were hidden in everyday wearable products, such as belt loops, socks, jean seams, and kinesthetic tape. The participants additionally provided a wide range of technologies to be considered, such as multiple accelerometers, microwaves, sonar, IR, and stretch sensors.

5. CONCLUSION

This paper described the design research methods undertaken for understanding user needs in the design and development of a wearable e-textile rehabilitation knee sleeve. It provided insight into the development of a socially acceptable and wearable knee rehabilitation device. Interviews, observation and participatory workshops were utilized to delve into understanding knee replacement rehabilitation. Interviews highlighted issues within the process of rehabilitation, such as the amount of information, or lack thereof, about the user's experience throughout the process. More research needs to be conducted on how to alleviate the user's struggle and encourage proper rehabilitation in the home. The observations provided an in depth understanding of the problem area and directions for improvement. While the physical therapists are well-prepared to tackle rehabilitation, from both emotional and physical standpoints, the users are not provided with the tools they need. Lastly, the Participatory Ideation Workshop provided novel and unique insight into hierarchal design criteria for a knee rehabilitation device. While the required features were straightforward, the Anti-Features were insightful and helped to provide a clearer design direction. Overall, the aforementioned process provided a solid basis for understanding user perceptions of what wearable technologies for knee rehabilitation should be and what should ultimately be communicated to the user. However, a longer, more comprehensive study into how the product would be used in situ over the course of a few months is necessary. A study, as such, would allow for validating user needs and to understand how the tracking of rehabilitation in the home would influence the overall experience of rehabilitation and allow for more substantial data and insight into the user's experience.

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