Remote Recovery Monitoring after Anterior Cruciate Ligament Reconstruction using Wearable Sensing (Technical Project)

Exploring the Relationship between Clinicians, Patients, and Wearable Health Sensors (STS Project)

A Thesis Prospectus
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By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

Anterior cruciate ligament (ACL) injuries are a popular injury amongst athletes and those who partake in physical activities and exercise. Due to the frequency and damage of an ACL injury, many studies and projects have occurred to optimize ACL recovery. The University of Virginia Department of Kinesiology has begun researching how wearable sensors can be used to monitor early ACL recovery. My systems engineering capstone team aims to identify the optimal location to place these sensors and analyze the data that they collect. We are using signal processing and machine learning to clean this data and identify key features that can indicate a patient's recovery status both early after surgery and throughout the entire recovery phase.

The focus of my STS research paper, exploring the relationship between clinicians, patients, and wearable health sensors, relates to my technical project in the sense that they both focus on how wearable sensors play a role in a patient's recovery process. However, whereas my technical project aims to understand how sensor data can monitor a patient's ACL recovery, my STS research takes a different approach. The STS research paper will analyze the relationship between patients, clinicians, and wearable sensors, and how the addition of these sensors has changed, both positively and negatively, the relationship between clinicians and patients. In addition, this research will not be limited to sensors that monitor ACL recovery or are strictly placed on a patient's knee, but any wearable sensor that a patient uses to monitor his or her injury recovery and health status.

Technical Topic

Anterior cruciate ligament (ACL) injuries occur in the center of the knee and are common amongst athletes who play sports with sudden stops and changes in direction. The ACL is essential for stabilizing a person's knee, and when torn or damaged that knee will become unstable. In order to properly recover, patients must reconstruct the ligament through surgery. Despite a successful surgery, nearly 20% of these patients will later experience an ACL reinjury. In addition, ACL patients are vulnerable to altered movement patterns. While early detection of altered movement patterns is important in improving the rehabilitation process, it requires patients to employ maximum muscle usage through activities such as running and jumping (Trulson et al., 2015). These activities cannot be conducted by patients who are early into the recovery process, given the strain that they put on one's knee. Thus, new methods for monitoring the early ACL recovery of a patient are needed.

The University of Virginia Department of Kinesiology and my capstone team, consisting of seven systems engineering undergraduate students, one systems engineering PhD student, and one systems engineering professor, are investigating how wearable sensors can be used to assist the medical decision making in ACL reconstruction. Our study consists of twenty human subjects: ten who are healthy and ten who recently underwent an ACL surgery. The UVA Department of Kinesiology has recruited the subjects and will begin data collection in the coming weeks. Subjects will be evaluated with two different types of sensors: an EMG and an accelerometer. They will wear two Delsys Trigno Wireless EMG sensors, one on their left leg and one on their right leg, and these EMG sensors have a built in triaxial accelerometer. The data collection for healthy subjects takes place on Wednesday afternoons and for post ACL surgery subjects takes place on Monday, Tuesday, and Thursday afternoons.

My capstone team team's responsibilities are to identify the optimal location to place the sensors on a patient's knee and also find important features in our data that can indicate a patient's recovery status. My individual responsibilities are to assist the UVA Department of Kinesiology in data collection and conduct feature extraction on our data set using both R and Python. Specifically, I will extract features that have been used in past research involving ACL recovery and wearable sensors, such as the mean, maximum, and standard deviation of energy exerted during difference exercises (Tedesco et. al, 2020). In order to find these features, we will first need to clean the data through a procedure known as signal processing. Next, we will extract features from the data and develop machine learning models, specifically classification models such as random forest and decision trees, to show how healthy a subject's ACL is. Our aim is to develop a predictive model that can indicate where a patient currently stands in the recovery process. In other words, how "healthy" the patient's ACL and knee are. By providing patients with this insight, they will be capable of returning to full activity as quickly as possible while minimizing the risk of a reinjury.

In the past, similar studies have been conducted, such as using wearable sensors to capture differences in muscle activity and gait patterns for ACL recoverees (McGinnis et al., 2018), quantifying joint kinematics for high-speed tasks with wearable sensors (Di Paolo et al., 2021), and using wearable sensors' biofeedback mechanisms for ACL rehabilitation (Senanayake et al., 2012). Our research differentiates from others in two major ways. First, we are using a Delsys Trigno Wireless EMG System, which has not yet been experimented to monitor ACL injuries and predict recovery. Secondly, current monitoring methods are relatively short term, whereas we aim to conduct continuous monitoring of the subjects' ACL.

STS Topic

Over the last decade there has been an emergence of wearable health devices and sensors as a result of both advancements in technology and an increasing interest in personal health and wellness. Popular wearable devices, such as smartwatches and wristbands are expected to increase in demand and dominate the consumer market, while healthcare practitioners are using wearable devices to assist them in investigating a patient's health and wellbeing. Wearable devices offer clinicians significant advantages, such as improvements in the quality of health monitoring, reduction in patient costs, and potentially faster patient recovery time for certain injuries. In addition, these health sensors, along with artificial intelligence, can be used to assist decision-makers and healthcare systems in providing more personalized recommendations and prescriptions. Unfortunately, however, these devices can also be responsible for less favorable outcomes. Patients are vulnerable to unintended changes in their behavior, increase in anxiety concerning their health, and lack of data accuracy and privacy. The doctor-patient relationship has traditionally consisted of a patient seeking assistance and a specialized doctor using his or her training to assess the patient's health and identify potential treatment plans. While this relationship has evolved over time with the emergence of new technologies, practices, and knowledge, personalized recommendations and prescriptions have always remained a difficult task. Now, with the assistance of these devices and sensors, this feat is possible and as patients turn to wearable technology to interpret their individual health and recovery status the doctor-patient relationship undergoes inevitable changes. This paper explores the relationships between clinicians, patients, and wearable sensors, and the effect that these sensors have on how patients' health and injury recovery are monitored.

Actor Network Theory (ANT) is an approach to social theory that describes the phenomenon of an ANT network, which is a "heterogeneous amalgamation of textual, conceptual, social, and technical actors" (Ritzer, 2004). In this methodology, both humans and nonhumans can be analyzed as actors within a specific network, where the acts performed by an actor affect the stability and organization of the network. Through this paper, the network consisting of clinicians, patients, and wearable health sensors will be examined. Specifically, readers will have a firm understanding of how this network is organized, how it is "increasingly transportable", and how the actors have become "functionally indispensable" (Ritzer, 2004).

Body-worn sensor systems can be defined as "non-invasive systems that are worn to obtain clinically relevant information" (Bergmann & McGregor, 2011). Past research has found that clinicians are both more willing to use healthcare body-worn sensor systems and have higher expectations for improved health management through these sensors than the general public (Lee & Lee, 2020). Clinicians and patients not only interpret these sensors differently, but also prioritize different features of the technology. Clinicians are primarily interested in the sensors' data collection methods and accuracy, such as their limited recording time, how they should be properly placed on a patient, and the ability to quickly receive data in real-time. All medical professionals, be it physicians, nurses, or psychologists, have the responsibility of "interpreting recommendations, educating and motivating patients, monitoring responses to recommended behaviors, and providing feedback" (Miller et al., 1997). Therefore, they must prioritize the functionality and efficiency of the sensors in order to mitigate error in their recommendations and feedback to the patients. Patients, on the other hand, are more interested in a sensor system that is "compact, embedded and simple to operate and maintain" (Bergmann & McGregor, 2011). Patients share strong beliefs on the design and usability of the sensors and believe that the technology should not alter their daily behavior and routine (Bergmann & McGregor, 2011).

Self-tracking health monitors encourage behavior change most commonly through "nudges." There are two common ways in which these devices send nudges: the first can be through physical contact (Gilmore, 2017) such as a vibration, and the second can be visually via an alert or message. The nudges aim to both encourage the user to pursue a certain action and notify them when they have reached some sort of target. For example, an Apple Watch may notify its user that they have reached 10,000 steps that day, or that they have only reached 5,000 steps and are below the daily target. This type of notification acts as "a sort of compass to help individuals navigate a world of choices" (Schüll, 2016). Users are compared to a standard value and the nudges encourage them to meet or exceed that value. In a study conducted in 2020, middle-aged male and female participants used a variety of wearable health sensors over the course of four to six weeks and researchers analyzed their response to the sensors' nudges (Toner et al., 2021). Rather than blindly adhere to the advice of the nudges, participants actively made sense of the notifications and information they were receiving and developed their own interpretations as to whether they should act on that advice or not. Participants also believed that they did not need to consistently know how they compared "in relation to some arbitrary ideal" and were dismissive of the data when it conflicted with their own knowledge of their body. In some cases, the nudges actually resulted in participants feeling anxious and confused, and they consciously disregarded the information. Without the supervision of a medical professional, nudges serve as the only communication source between the sensor and user, and the frequency that they are delivered in, the data that they are providing, and the timing of the notification can all negatively affect a user's willingness to act from it.

The two most common methods for outpatient monitoring are patient reported outcome measures (PROM) and telemonitoring. PROM involves a patient self-reporting their perspective via a descriptive analysis sent to the clinician, whereas telemonitoring passively tracks physiological data by using information technology which can be viewed by the patient and clinician. In addition to the fact that PROM collects subjective data, it also poses shortcomings by only gathering a person's symptoms periodically as opposed to continuously, and also requiring great effort from the patients to provide accurate and thorough descriptions (Maldaner et. al, 2019). Telemonitoring, on the other hand, is limited to the quality of the wearable sensor and the accuracy of the data. Quantifying self-hybrid models (QSHMs) intersects these two, as it accounts for both a patient's qualitative assessment and the quantitative variables from the sensors. Most wearable sensors are monitored using telemonitoring, however QSHMs offer the advantage "combining subjective symptoms with objective criteria" (Appelboom et al., 2014).

Next Steps

For my STS Topic, my next steps include further exploring wearable sensors as an intermediary between clinicians and patients, and I believe that QSHMs are a rich space to explore how clinicians use both the inputs of patients and sensors to make recommendations. In addition, I want to explore how QSHM's fit into "patient-centeredness," an ideology where clinicians "try to see the illness through the patient's eyes by exploring patients' feelings and expectations" (Krupat et. al, 2000). A third area I would like to explore is how QSHMs fit into the relationship of patients who are athletes and clinicians who are associated with a team or professional organization. I would like to understand how these clinicians weigh the subjective data of a patient versus the quantitative data collected from the sensor.

Week #	Date	Capstone Objective	STS Objective
1-2	9/22 - 10/6	Project definition and literature review	
3-5	10/7 - 10/27	Pilot data collection and analysis with test patient	-Complete Prospectus Draft and conduct peer reviews
6-11	10/28 - 12/1	-Clinical trials with patients -Test 4 patients per week for 5 weeks -Must be finished collecting data by end of December	-Submit Prospectus to STS Professor and Capstone Advisor
12-13	1/19 - 2/2	Data Cleaning/Pre-processing -Deliverables: • Cleaned, labelled dataset	
13-18	2/3 - 3/9	Data Analysis -Deliverables: • Statistical models identifying key indicators of ACL recovery • Data Visualizations	-Complete a draft of the research paper

18+	3/10 - 5/1	Interpretation of Analysis -Deliverables: • Findings related to how sensors can be used to predict ACL recovery	-Submit final Thesis Portfolio

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