A Smartwatch-Based Service Towards Home Exercise Therapy for Patients with Peripheral Arterial Disease

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***Abstract*— Utilizing a consumer-grade smartwatch in conjunction with a prescribed exercise therapy plan can help to reduce the patient-level entry barriers into programs designed for patients with peripheral arterial disease, which affects millions of people worldwide. Currently the alternative to this physical therapy plan is surgical therapy which costs between $3 and $5 billion annually. This paper presents the development and testing of WalkCoach app, a smart service system integrating a consumer-grade smartwatch (Polar M600) in the monitoring of supervised walking exercises. By monitoring a participant's baseline activity and improvements with time, it will be possible to provide personalized exercise prescriptions that can be easily modified or personalized to adjust and optimize for improved walking ability as the therapy progresses. This paper demonstrates the accuracy of the smartwatch-based WalkCoach app in a pilot cohort study of 10 healthy older adults (>65 yrs) who were recruited to perform a 400m overground walking task. Results are promising and show that the consumer-grade smartwatch accurately measures steps (step count = 637) compared to a video/manual step count (650 steps; Pearson's r = 0.96, P <0.001). In the future, WalkCoach will be improved to produce granular analytics on a patient's compliance and performance to the supervised walking exercises.**

Keywords*— *Telehealth services, Telemedicine, Smartwatch, Physical therapy, Supervised exercises.

I. Introduction

Peripheral arterial disease (PAD) is the buildup of plaque (consisting of fat, cholesterol, calcium, and other substances) in the lower limb arteries that results in reduced blood flow [1]. PAD affects 8-12 million people in the US [2] and more than 200 million people worldwide [3]. At least half of those diagnosed with PAD experience various degrees of leg muscle pain during physical activity, known as intermittent claudication (IC), which occurs from restriction of blood flow. The corresponding therapeutic guidelines from the American Heart Association [4] indicate supervised exercise therapy (SET) as a first line therapy for IC. However, there are a host of barriers to using SET including a lack of facilities that offer this, inconsistent reimbursement and no support for maintenance therapy despite demonstrated benefits such as improvement in quality of life [5]. The barriers to patient acceptance of SET include narrow and inconvenient times for SET sessions, as well as economic barriers related to transportation and time commitment.

A. Current Lifespan SET Program

Home exercise therapy (HET), was developed as an alternative to address these patient-level entry barriers to SET, and has been shown to be effective in improving the symptoms of claudication [6] but is neither reimbursed nor widely available. Moreover, there is currently little ability to track patient compliance, symptoms and physiologic data during HET.

Surgical therapy (either endovascular therapy or open reconstruction) instead of SET translates to an estimated >300,000 cases annually in the US, at a cost of $3-5 billion [7] with no clear benefit over SET. Thus, an effort to effectively implement HET for those with IC would be an innovative step toward reducing healthcare costs with a lower risk intervention.

B. Smartwatch-Driven Services for HET

Our initial approach to effectively implement HET is in developing a novel WalkCoach app using a consumer-grade activity tracker/smartwatch for feedback and support, rather than simply as a data collection tool [8]. The utilization of technology-based prompts to initiate exercise sessions, give feedback and reward for completion of treatment, and provide information on improvements is a significant innovation in the potential treatment of IC. This has potential to match the results seen in clinical studies of exercise therapy without the requirement of study staff for daily phone calls, recording of activity, and other labor-intensive and costly tasks, as well as patient barriers.

By monitoring a participant's baseline activity and improvements with time, it will be possible to provide

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A) Peripheral Arterial Disease

B) The PAD Exercise Tracker App for Smartwatch

C) Services for Home Exercise Therapy

Figure 1: a) a conceptual diagram describing the pathology of PAD, 2) WalkCoach App with a smartwatch, and 3) proposed services for supervised walking exercises.

personalized exercise prescriptions that can be easily modified or personalized to adjust and optimize for improved walking ability as the therapy progresses. The application will work through software development to ensure that the smartwatch app framework is user-friendly, and optimized to promote adherence. This paper demonstrates the accuracy of the smartwatch-based WalkCoach app in a pilot cohort study of 10 healthy older adults (>65 yrs) who were recruited to perform a 400m overground walking task. The objective of the study was to measure the accuracy of the smartwatch's capability to count steps. The study involved video recording of the participants' walking. The video-recordings were analyzed by kinesiology domain experts to count the steps. Later, the results from smartwatch-generated steps were compared with the human-counted steps for all the participants.

II. BACKGROUND

A. Peripheral Arterial Disease (PAD) & Intermittent Claudication (IC)

PAD is a prevalent form of cardiovascular disease which reduces blood flow to the legs; the most common clinical manifestation of this is leg cramping and/or fatigue with physical activity known as intermittent claudication. While this does not commonly result in limb loss, it does often negatively impact health-related quality of life and physical function. Structured exercise programs have consistently been shown to effectively treat IC, with little to no morbidity. There are several proposed physiological mechanisms by which exercise therapy may accomplish this. However, despite its proven safety and efficacy, it is rarely used in the US because of a number of barriers including lack of access to facilities capable of administering supervised exercise therapy (SET) and barriers to patient compliance with attending SET. Therefore, in current practice, surgical revascularization is often used to treat IC instead, despite its associated costs and potential risk.

B. Smart Services for HET to Treat IC

There is a plethora of research activities which focus on the use of smartwatches/smartbands for monitoring general health and wellness [9,10,11]. However, few studies [12; 13] have been conducted in this population and none have been done using a platform specifically designed for those with IC. Those that have been done using smartwatch technology have not used the devices as a therapeutic tool, but simply as an adjunct to more traditional advice and instruction [14].

The smart services can specifically be designed to measure and encourage walking in older adults who have peripheral artery disease (i.e. vascular disease of the leg arteries) and experience intermittent claudication (IC). WalkCoach attempts to overcome many of the traditional patient-centered barriers associated with SET. WalkCoach has the potential to transform how patients with IC are treated by automating and individualizing the exercise treatment plan and escaping the traditional barriers of a supervised setting. This may also reduce unnecessary surgical procedures and medical costs.

C. Economic and Societal Impact

1. Quality Assurance: Once the WalkCoach has been validated for accuracy, it offers quality assurance by virtue of its objective quantification of physical activity and compliance with prescribed exercise therapy. This quality assurance mechanism is superior to self-reported measures of compliance with prescribed exercise therapy commonly used in HET. Patient self-report is limited by recall bias and response bias. WalkCoach generated reports of physical activity and compliance with prescribed exercise can be monitored and assessed by the treating physician. The quality assurance provided to the physician as well as the patient can assist in identifying areas of need within the care plan.

2. Coordinated Care: Developing proper care plans for patients requires a team who all interact with the patients through various outlets. As each of these health care professionals have different areas of focus, their ability to communicate and understand the therapies and treatments being asked of the patient can help to mitigate areas of overlap or conflict.

3. Cost Reduction: Through the ability to have quality assurance with a coordinated care team, a patient is more likely to flow smoothly through the therapeutic process and continue on with their normal daily living. The more effective the care plan the faster the patient can become independent in their use of exercise therapy which in turn reduces the need for surgery and frees up more time for the health care professionals to attend to other patients. Furthermore, by providing a patient with education and feedback about their disease and the therapy prescribed, the less likely they are to return with the same problem.

III. PATIENT-CENTERED SMART SERVICES

A. Smartwatch Service Architecture

Reminders, encouragement, instruction, and feedback which are automated through WalkCoach assist patients in adherence to their health regimen which can potentially reduce clinic costs. The effectiveness of reminders for adherence has grown in power over the years across most mediums such as text messages, phone calls, alerts, reminders

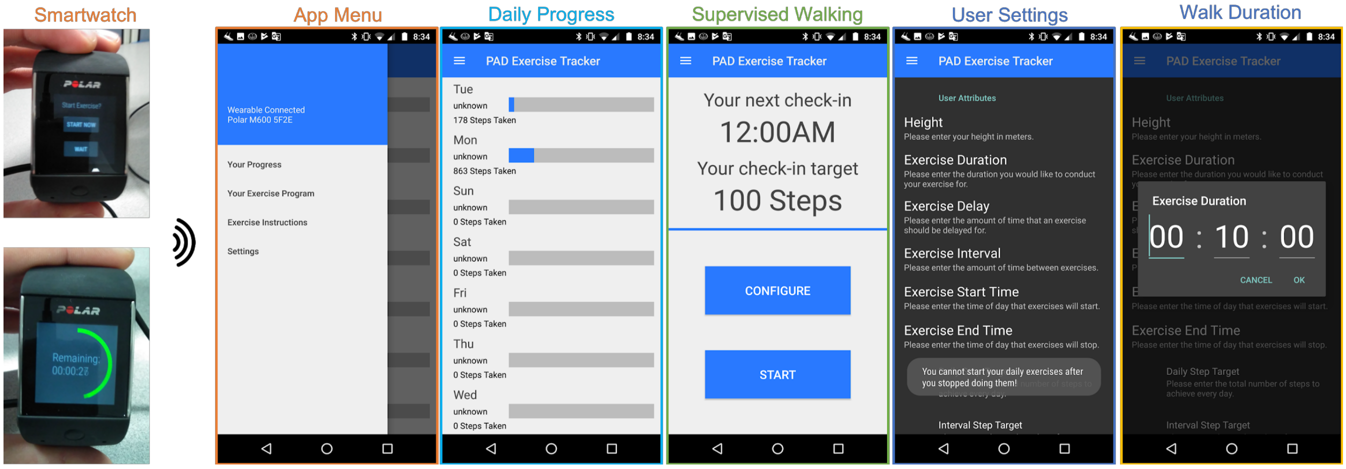

Figure 2: WalkCoach App and its services.

amount others [14,15,16]. WalkCoach focuses on using notification prompts from the app to remind the patients of their exercise goals.

The application allows the user control of when to exercise and what to use for daily step targets. They are given access to this through a menu that is initially presented to the user when they open the application. From this menu the user has the ability to select four options, “Your Progress”, “Your Exercise Program,” “Exercise Instructions,” and “Settings.” The user is also provided with the status of the wearable device.

Settings allows the user to customize and personalize their exercise program to their specific needs. Currently there are six parameters the user can use to configure their exercise program:

1) *Height* is used during the exercise to estimate walking distance.

2) *Exercise duration* is used to specify how long measured exercise events should last.

3) *Exercise delay* is used to determine how how long the app should wait to notify the user again after the exercise has been snoozed. Exercise interval is used to determine how often the user’s exercise progress should be check throughout the day.

4) *Exercise start and end times* specify what time interval in the day the user should be exercising.

5) *Daily step target* specifies how many steps the user should make in a day. The interval step target specifies how many steps the user should make between alarm updates. The Daily Progress displayed to the user provides information about their progress for the past week based on these settings.

6) *Performance Composition Analysis* (to be developed) will assess exercise time and rest time performed during the exercise period, a major component of an app designed to treat IC.

The sensor data used is gathered from the smartwatch which provides the primary method of communication with the user. The functions of the smart watch include telling the user when they need to perform an exercise and giving them feedback on their exercise performance. During a measured exercise event a sensor manager provides access to both low- and high-level sensors such as accelerometers and step counters for data analytics on the performance. In the app the step counter is used to measure the steps made by the user during the exercise.

An example of an exercise test which is commonly used for the IC patient is the six-minute walk test. During this exercise the goal is to walk at a comfortable pace for six-minutes and then report on pain levels. Incorporating this test into the app will allow the patient and treating physician to monitor progress and adjust exercise prescription.

B. Value-Added Services

Services for Walking Rehab Programs benefit from an assessment of the human services and the tracked compliance with national treatment guidelines for the duration of the program. These analytics and insights are given more granular datasets to identify problem areas when technology is incorporated[9, 13].

The goal of duplicating the SET experience and quality into HET can be improved when instruction and feedback mechanisms are given to the patient [17]. Allowing, the periodic surveying for leg pain ratings due to IC can help the care team to make informed decisions.

Table 1: Participant Demographics Information

ID	Age (years)	Gender	Height (cm)	Weight (kg)	BMI
1	72	F	172.7	74.1	24.8
2	70	F	156.2	57.6	24
3	67	F	170.2	73.5	25.4
4	67	F	160	74.1	28.9
5	68	M	171.5	78.9	26.8
6	75	M	177.8	96.8	30.6
7	75	F	156.2	73.6	30.1
8	72	F	167.6	62.3	22.1
9	67	F	167.6	73.6	26.1
10	79	F	163.2	65	24.4

IV. EXPERIMENTS & RESULTS

A. Methodology and Experimental Design

Figure 3: Experimental results: A) comparison between smartwatch step counts and true step counts (human rater), B) Duration for the 400m walk task, and 3) gait speed for the 400m walk task.

WalkCoach was developed to utilize a commercial-grade smartwatch (Polar M600) to track steps. In fall 2018, 10 relatively healthy older adults (age=71, S.D. = 4 yrs) without IC were tested in a 400 meter walk test to evaluate the validity of our initial app version to measure steps.

The healthy older adults were instructed to walk in one direction for 20 meters then come back 20; this was repeated 10 times. Tape was placed on the floor to denote the spot to turn. They were instructed to take wide turns, as pivoting to turn can lead to difficulties in calculating steps even on the video. During the walk they wore the smartwatch. The walk was also video recorded from two separate angles. The video records provided the gold standard for the true number of steps. This number was compared to the number calculated by the smartwatch.

B. Results & Discussions

Results show that the consumer-grade smartwatch (Polar M600) accurately measures steps (step count = 637) compared to a video/manual step count (650 steps; Pearson's $r = 0.96$, $P < 0.001$). The charts shown in Figure 3 provide a comparative information on how participants vary in their total step count for 400m walk. For example, Participant #8 walked 826 steps. This number is highest among all the participants. The gait speed of Participant #8 was 0.83 m/sec that is lowest among all. The same participant had the smallest step length of 0.48m. Participant 8 took longest time to complete the 400m walk. In contrary, Participant #3 demonstrated the fastest gait speed and had a very long step length.

In the future, we plan to create an analytics tool for clinicians to make such comparisons from WalkCoach data. Clinicians are more interested in analyzing the progress of each patient. Instead of inter-patient comparison, clinicians would want to see how each patient is doing in regard to their walking exercises when they are at home.

V. CONCLUSION AND FUTURE WORK

We have found that the smartwatch can track general walking behaviors but with limited granularity. It is limited in its ability to track the intensity of the walking exercise session. This type of data in conjunction with the self-reported pain rating may prove insightful about the progression and location of the claudication being experienced.

To further enhance WalkCoach reminders; instructions, encouragement, and feedback on the performance of an individualized exercise program that complies with national treatment guidelines [4] and duplicates the SET experience will be surveyed. Further aspects of the interface that need to be added and refined include 1) developing an "at home" six-minute walk test with a survey about leg pain ratings due to IC, 2) adding a 30-60 minute daily walking session limited by pain, with a reminder to do the walking session and an option to "snooze", 3) weekly summaries to provide individualized feedback about the volume (i.e. duration, intensity and frequency) of walking done at the end of each week, and 4) improvement from baseline six-minute walk test results.

WalkCoach Version 2 will be developed to be user-friendly, with appropriate patient safety and educational interfaces, and compliance with HIPAA regulations. This version will continue with the collaboration with kinesiologists, vascular surgeon, gerontological nursing, and biomedical engineers to personalize WalkCoach to a specific exercise therapy program aimed for at-home study. The "at-home" six minute walk test for distance with a small group of older adults using the WalkCoach will provide a valid assessment of this well-recognized test that predicts health outcomes in older adults [18].

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