Using Wearable Sensors in Stroke Rehabilitation

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Abstract

Stroke is one of the major causes of disability worldwide, and patients with residual neurological deficits are recommended to undergo rehabilitation. Besides baseline medical conditions, many other factors play a role in rehabilitation success, including patient engagement and medical complications. Wearable technology allows objective and continuous monitoring of body functions and behavior. Furthermore, wearable sensors could detect the risk of adverse events such as falls, infection and mood disorders. In the past, we gained experience using wearable sensors for stroke gait analysis. For example, we have evaluated algorithms to quantify gait patterns using inertial measurement units (IMUs) data and demonstrated that we can quantify and visualize changes in gait patterns in both healthy and stroke populations. As a next step, we aim to combine multiple wearable sensors and data modalities to further assess patient performance in rehabiliation. This planned study aims to investigate the efficacy of wearable devices, including, continuous glucose monitoring (CGM), and smartwatch devices. We will not only investigate the potential of wearable devices in quantifying the improvement in neurological function and reducing complications during the early stroke rehabilitation process, but also assess the effects of using wearables in improving patient engagement and motivation during early stroke rehabilitation.

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1 Introduction

Stroke is the second most common cause of death and among the most common causes of disability globally [1]. Post-stroke disabilities such as impairments in the sensory and motor functions can have an impact on patients' mental states, eventually leading to an array of psychosocial issues [4]. Although disabilities might be reversible, the right form and dose of rehabilitation coupled with patient engagement is crucial. As marked in the literature, patient motivation in post-stroke rehabilitation is a major determinant of rehabilitation outcomes both mentally and physically [9].

The need for tools that enable remote patient monitoring led to the emergence of wearable sensors [5]. According to a study conducted in the USA, 30% of the general population and 25% of the patients with high cardiovascular risk reported using wearable devices [3]. The use of wearable sensors in post-stroke rehabilitation can impact the course of patients by improving motivation and helping medical professionals develop individualized, realistic and sustainable rehabilitation strategies [7]. Furthermore, new digital biomarkers can be identified which predict rehabilitation outcomes. inertial measurement units (IMUs) are devices that measure acceleration and rotation rates. They are commonly used in gait and motion assessments. Continuous Glucose Monitorings (CGMs) are sensors used to measure blood glucose levels based on the interstitial fluid and can also be used to detect glucose levels, which is believed to have a deteriorating effect on stroke outcomes [6]. Finally, smartwatches have the ability to capture multiple health-related parameters, including but not limited to heart rate, respiratory rate, activity levels, and step counts.

In our previous work, we have proposed methods to select IMUs for mobility assessment [11], validated the performance of gait quantification algorithms using IMU data and opto-electric and pressure sensor-based reference systems [8], and demonstrated that we can quantify and visualize changes in gait patterns in both healthy and stroke populations [10, 13]. Figure 1 shows the attachment of the IMUs sensors on the shoes of a participant.

Figure 1: IMU sensors that are attached to the laces at the top of shoes to measure spatio-temporal gait parameters.

However, it is worth emphasizing that a holistic approach that captures different aspects of a patient's health status is needed to comprehensively evaluate the stroke rehabilitation progress. Therefore, additional sensor modalities are necessary as a next step.

In a future clinical study planned to be conducted with the Charité–Universitätsmedizin Berlin, we will implement the intervention of equipping patients with wearable sensors (IMU, CGM, and smartwatch) and providing them feedback about the data collected by the sensors in terms of daily and weekly reports in a designated mobile application. Further, we will let patients choose a personal rehabilitation goal and record their reflections and perceived progress as well as their setbacks in the mobile application. We hypothesize that receiving feedback and setting personal goals will increase patient engagement and motivation during stroke rehabilitation. This innovative approach aimed at improving the level of motivation can counteract disengagement from stroke rehabilitation and can be a milestone in stroke rehabilitation.

2 Wearable Sensor Data Collection

Recording multiple sensor modalities simultaneously usually requires individual mobile applications for each sensor modality. To reduce the burden of having too many applications and to ensure good data quality, we rely on a mobile application that runs on a smartphone (Android OS). The initial development of this software was initiated at the research group Digital Health–Connected Healthcare at the Hasso Plattner Institute under the name SensorHub [2]. Now, the software is developed, provided, and managed by the non-profit organization D4L data4life gGmbH under the name D4L Collect. The mapping between the data collected through the native application and the clinical data is handled outside the application, ensuring that no PII (personally identifiable information) is accessible to anyone outside the medical team. All data collected by the mobile application are encrypted at rest and in transit and only stored on servers hosted in Germany, adhering to applicable data privacy laws. In the context of the study, the app will be used to connect to a Samsung Galaxy Watch 6, CGM device (Dexcom G7), and IMUs (Movella Dot). Figure 2 shows a screenshot from the D4L Collect application running on an Android smartphone.

The mobile application further allows for creating questionnaires that are exposed to the study participants, either one time at the beginning of the study, or in regular intervals during the study. Possible use cases for the planned study could be the assessment of patient's mood or motivation. In combination with the smartphone application, Data4Life developed a research platform to allow the design of study protocols, including planned questionnaires and mobility tests, and enables the configuration of sensor modalities such as acceleration and angular velocity of IMU sensors. Moreover, the platform has an integrated dashboard to display information about the ongoing study, including the number of participants enrolled, the results of the questionnaire uploaded and the recording sessions of sensors. The recorded sensor data can also be downloaded directly through the research platform.

3 Preliminary Data Analysis

To comprehensively assess the efficacy of the intervention using the sensors presented, we briefly describe planned data analysis methods that we will conduct on the collected data. We aim to assess rehabilitation progress utilizing subjective and objective measurements. The subjective measurements could be based on questionnaires, including motivation and patient-reported outcome measures. Objective measurements will comprise the assessment of data coming from the smartwatch, CGM, and IMU sensors. Smartwatch data can be used to gain insights into average daily heart rates, sleep, or general activity levels, whereas CGM provide insights into blood glucose levels. IMU sensors will be used to analyze movement of upper and lower limbs, e.g. during walking tasks or standard clinical tasks such as the timed-up-and-go test. For gait analysis, we will use an algorithm established in our previous studies to derive spatio-temporal gait parameters such as walking speed, stride length, and stride time, as well as variation and symmetry measures from these gait parameters [11, 12]. The outcomes of those mentioned above will be collected, and subjective and objective assessments from all planned visits will be used to evaluate the rehabilitation progress based on the longitudinal development of these outcomes and statistical tests for significant improvements.

4 Conclusion

In this article, we have outlined the importance of wearable sensors in the context of stroke recovery. By using technologies like IMUs, CGMs devices, and smartwatches, we build on our experience of past studies and plan to conduct studies in the future to monitor patients' physiological and behavioral data continuously in an in-home setting. With the D4L Collect app, all data shall be collected

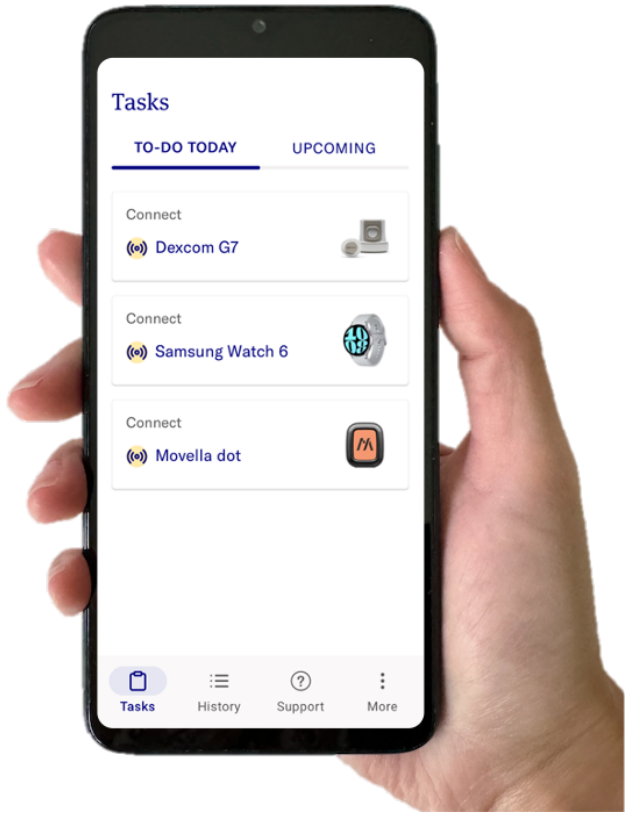

Figure 2: The D4L Collect Android application used to collect data from multiple sensor simultaneously.

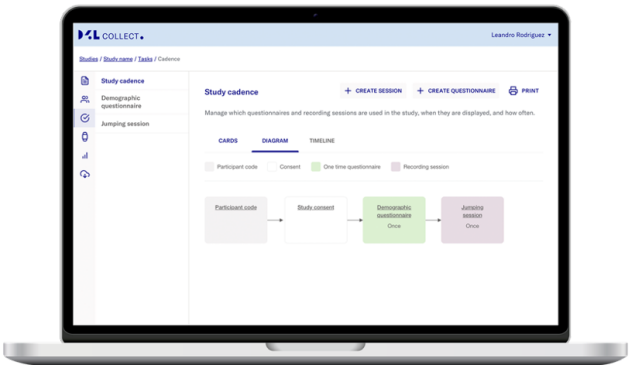

Figure 3: The D4L Collect platform used to design, distribute, and monitor the study progress. Data collected from the participants will also be downloaded through the solution.

through a single device and made available to researchers in a secure and harmonized format. In future studies, we not only plan to assess patients' rehabilitation progress but also want to assess the effect of patient engagement using these wearable technologies. Especially through real-time feedback and personalized health prompts, we hypothesize that this might foster a greater motivation for patient rehabilitation. In addition, these devices might help identify and mitigate complications such as falls and mood disorders.

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