IMU Data Availability and Usability in Post-Stroke Rehabilitation: Preliminary Findings from the Sensor-S Study

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Abstract. Wearable inertial measurement units (IMUs) have become an important technology for objectively assessing motor performance during stroke rehabilitation. However, the reliability of subsequent analyses depends on the quality and completeness of the collected sensor data, particularly in longitudinal studies. This paper presents a preliminary quality assessment of the IMU data collected within the ongoing Sensor-S study. The assessment evaluates recording availability, data completeness, and recording integrity for standardized IMU movement tasks performed during the inpatient and outpatient phases of the study. Representative visualizations further demonstrate the interpretability of the collected signals through various assessments.

The results indicate that the majority of IMU recordings have been successfully acquired and exhibit promising quality for subsequent analysis. The presented examples demonstrate the feasibility of event detection, multimodal sensor integration, and bilateral movement comparison, highlighting the potential of the dataset for developing quantitative digital biomarkers of motor recovery.

This work establishes an initial quality assurance framework for the Sensor-S study and provides practical insights into the acquisition and evaluation of longitudinal IMU data, supporting future research on wearable sensor-based stroke rehabilitation.

Keywords: Stroke Rehabilitation · Wearable Sensors · Inertial Measurement Units · Data Quality.

1 Introduction

Stroke rehabilitation increasingly benefits from wearable sensing technologies that enable objective and quantitative assessment of motor performance. Inertial measurement units (IMUs), in particular, have demonstrated considerable potential for capturing clinically relevant movement characteristics during rehabilitation, supporting continuous and objective evaluation beyond traditional clinical assessments [1,2]. As wearable technologies continue to mature, they are becoming an integral component of digital health applications and personalized rehabilitation strategies [3,4].

The Sensor-S study, introduced in our previous work [5], is a multicenter randomized controlled trial investigating the integration of multimodal wearable sensors into post-stroke rehabilitation. The study combines data collected from multiple wearable devices with standard clinical assessments to evaluate whether objective use of wearable sensors can improve patient engagement and rehabilitation outcomes.

Unlike continuously acquired physiological measurements, the IMU data in the Sensor-S study are collected as active recordings during clinically designed movement tasks [6,7]. These standardized assessments are performed at predefined time points and comprise two distinct study phases. This longitudinal design enables objective monitoring of motor recovery beyond the clinical environment while capturing patient performance under real-world conditions [8,9].

The reliability of wearable sensor analyses depends fundamentally on the quality of the acquired data. Factors such as incorrect sensor placement, incomplete recordings, deviations from standardized movement protocols, synchronization errors, or technical failures may substantially influence signal quality and consequently affect feature extraction, digital biomarker development, and clinical interpretation [10,11]. Early quality assessment further enables the identification of systematic issues in the acquisition workflow before large-scale data analyses are performed [12].

In this paper, we present a preliminary assessment of the quality of IMU data collected throughout the Sensor-S study. Furthermore, we provide a technical overview of the IMU recording pipeline. By documenting both the implementation details and the initial quality assessment, this work aims to support transparent, reproducible, and reliable IMU-based data collection for longitudinal stroke rehabilitation research.

2 Methods

This section describes the methodology used for IMU data acquisition, management, and quality assessment in the Sensor-S study. It first outlines the study framework and IMU assessment protocol, followed by the data collection workflow using the Data4Life Collect platform and the methods applied for the preliminary evaluation of the collected recordings.

2.1 Sensor-S study framework

An overview of the Sensor-S study design, recruitment strategy, and multimodal sensing infrastructure has been presented in our previous work [5]. Figure 1 summarizes the overall study framework. The goal of the study is to investigate the effect of using wearables on patient engagement in post stroke rehabilitation. Participants are randomly assigned to either the intervention or control cohort, with 116 of the target 156 participants recruited at the time of writing. The study consists of an inpatient phase, during which wearable assessments are conducted under clinician supervision following a standardized protocol, and an outpatient phase, in which the intervention group continues the assessments independently at home. This longitudinal design enables the evaluation of rehabilitation progress in both controlled clinical and real-world settings [12].

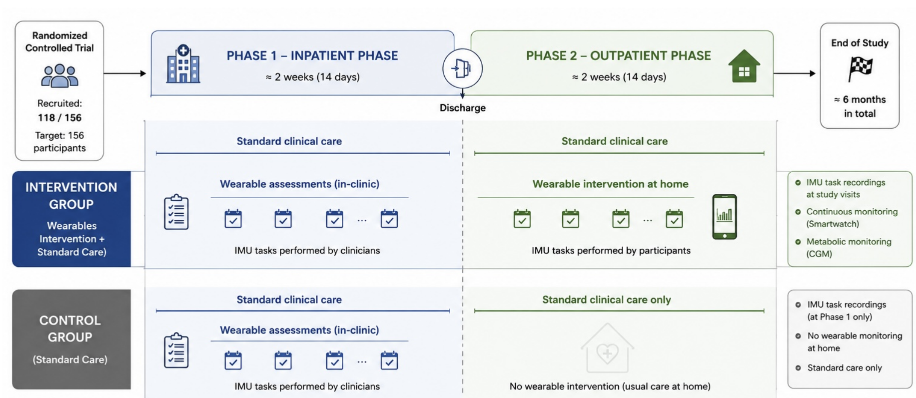

Fig. 1. Overview of the Sensor-S- study framework.

All IMU recordings in the Sensor-S study were acquired using Movella Xsens DOT sensors [7]. The IMU assessment protocol comprises five clinically designed movement tasks targeting different aspects of motor performance: gait analysis, Timed Up-and-Go (TUG), Sit-to-Stand (STS), the Water Task, and a spasticity assessment [1,2,13,14,15]. Gait recordings are acquired at 120 Hz, while all remaining tasks are recorded at 60 Hz, reflecting the different temporal requirements of the respective movement assessments [7,16].

2.2 Data Collection and Management

The Sensor-S study utilizes the Data4Life (D4L) Collect platform as the central infrastructure for wearable data collection and study management. The D4L Collect ecosystem consists of two complementary components: the Research Studio web application and the D4L Collect mobile application. Research Studio is used by researchers to set up, perform and observe studies. Following data acquisition, the platform also provides centralized access to the collected recordings for review and export to subsequent analyses. Figure 2a illustrates the IMU task configuration interface within Research Studio. The D4L Collect mobile application acts as the participant-facing interface for active IMU recordings.

During each assessment, the application establishes the connection to the required IMU sensors, presents standardized task instructions, and visualizes the ongoing recording process in real time. Figure 2b shows an example of an active IMU recording session in the D4L Collect application.

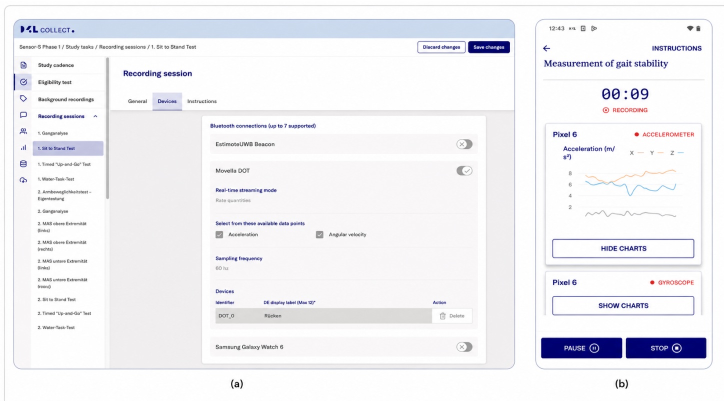

Fig. 2. IMU data collection workflow using the D4L Collect platform. (a) Research Studio (b) D4L Collect mobile application.

Once a recording session is completed, the acquired IMU data are securely synchronized with Research Studio, where they become available for data management and analysis. Beyond serving as a data repository, Research Studio also provides built-in monitoring tools that support quality assurance throughout the study. These include visual summaries of recording completeness that allow researchers to identify potential issues early in the data collection process. Such functionality provides valuable operational feedback during longitudinal studies and serves as an important complement to the dedicated quality assessment presented in this paper. An example of the IMU data quality monitoring interface provided by Research Studio is shown in Figure 3.

3 Results

As participant recruitment for the Sensor-S study is still ongoing, continuous evaluation of the collected data is essential to ensure the quality and completeness of the dataset before conducting large-scale clinical analyses. Early identification of missing recordings, protocol deviations, or technical issues allows the data acquisition workflow to be refined during the study rather than after data collection has been completed, thereby improving the reliability of subsequent analyses [10,11]. To this end, we performed a preliminary assessment of the IMU recordings collected thus far.

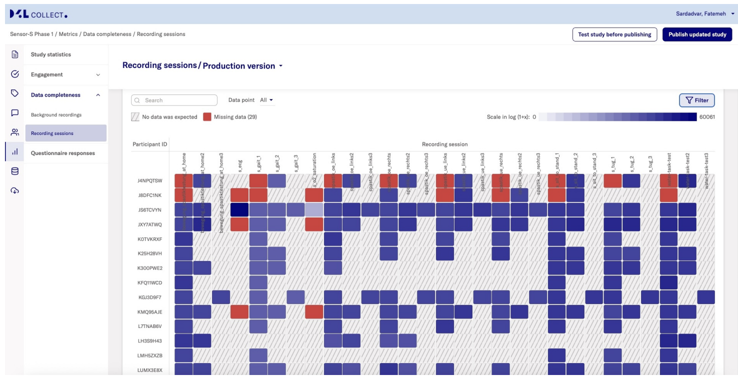

Fig. 3. Research Studio quality monitoring dashboard for IMU recordings. The blue cells indicate available data for each IMU task. The data volume is shown by blue color gradient.

3.1 Overall IMU data availability

The first step in the quality assessment was to evaluate the overall availability of IMU recordings across all movement tasks. For each IMU assessment, we quantified the number of participants for whom at least one valid recording was available and, conversely, the proportion of participants with missing recordings. This initial analysis provides an overview of the current completeness of the dataset and identifies tasks that may require particular attention during the remaining recruitment period.

Figure 4 presents the availability of IMU recordings for each movement task across all enrolled participants. Rather than considering only the total number of recordings, this participant-level visualization allows missing data patterns to be identified, helping distinguish isolated missing recordings from recurring acquisition issues that may indicate protocol- or workflow-related challenges.

To provide a quantitative summary of the observed recording availability, Table 1 reports the percentage of available IMU recordings for each assessment task in the inpatient and outpatient phases. This table provides a comprehensive overview of the current completeness of the IMU dataset.

Table 1. Participant compliance through IMU recording availability for each assessment task during Phase 1 and Phase 2.

Study Phase	**Number of Participants**	**Data Availability per Task**			
		Sit-to-Stand	**Timed Up-and-Go**	**Spasticity**	**Water Task**
Phase 1	108	85%	78%	86%	88%
Phase 2	17	57%	78%	64%	71%

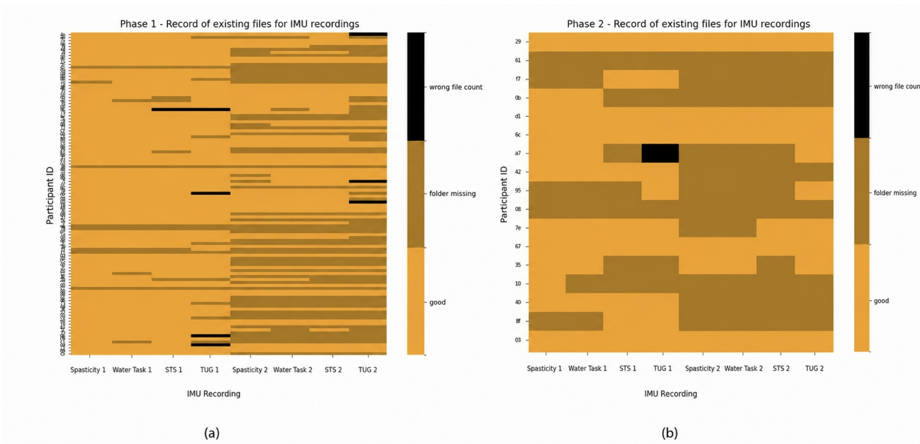

Fig. 4. Overview of IMU data availability across all enrolled participants during (a) phase one and (b) phase two. Each row represents one participant, and each column corresponds to an IMU assessment task in visit 1 and 2.

3.2 Quality Assessment of IMU Recordings

Beyond assessing recording availability, an additional step in the preliminary quality assessment consisted of visually inspecting the collected IMU signals. While quantitative quality metrics provide important information regarding the presence and completeness of recordings, they do not necessarily indicate whether the recorded signals accurately represent the intended movement tasks. Visualizing the sensor data therefore provides an initial validation that the acquired recordings exhibit interpretable movement patterns [11,17]. Although only a subset of the currently available IMU recordings has been analyzed at this stage, the initial results demonstrate promising signal quality across multiple assessments.

Sit-to-Stand Assessment The Sit-to-Stand (STS) task was likewise introduced in our previous work [5] and represents one of the fundamental functional mobility assessments included in the Sensor-S study. As a first processing step, peaks were detected from the IMU signals. The detected peaks correspond directly to the number of completed repetitions in a 30-second recording session and therefore provide a straightforward validation of both recording quality and participant task execution. Figure 5(a) illustrates an example of the peak detection algorithm applied to one recording, while Figure 5(b) summarizes the detected number of repetitions across all participants in phase one for whom valid recordings were available.

Spasticity Assessment The spasticity assessment differs from the other movement tasks in that it is performed separately on both the left and right upper limbs using standardized passive stretching movements commonly employed in

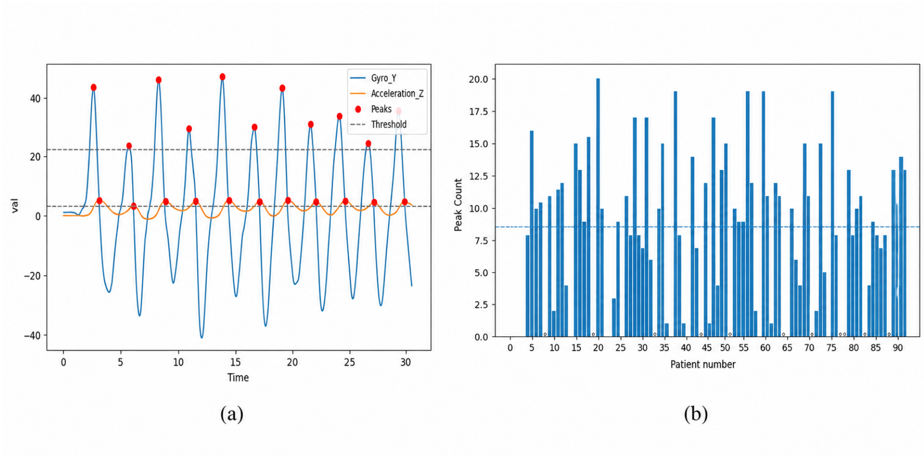

Fig. 5. Sit-to-Stand (STS) analysis. (a) Example of the peak detection algorithm (b) Number of detected repetitions for each participant in phase one. The horizontal line indicates the average number of detected repetitions across all analyzed participants.

clinical spasticity evaluation [18,19]. Since stroke frequently results in unilateral motor impairments, comparing movement characteristics between the affected and unaffected limbs provides valuable insight into asymmetries associated with neurological deficits [1,18]. As a preliminary visualization, the acceleration magnitude obtained from both limbs was compared to illustrate differences in movement behavior. Figure 6(a) presents an example comparison between the right and left upper-limb recordings for an individual participant, while Figure 6(b) summarizes these magnitude differences across all participants in phase one included in the current analysis.

These preliminary visualizations demonstrate that the collected IMU recordings not only exhibit satisfactory availability and completeness but also contain meaningful movement patterns that can be interpreted using established signal processing techniques. As participant recruitment continues, these analyses will be extended to the complete dataset and will serve as the foundation for the extraction of quantitative digital biomarkers describing motor performance throughout stroke rehabilitation.

4 Conclusion

This paper presented a preliminary quality assessment of IMU data collected within the ongoing Sensor-S study, focusing on recording availability, completeness, and signal interpretability. As recruitment is still ongoing, continuous quality assessment enables early identification of acquisition issues and helps ensure the reliability of the final dataset.

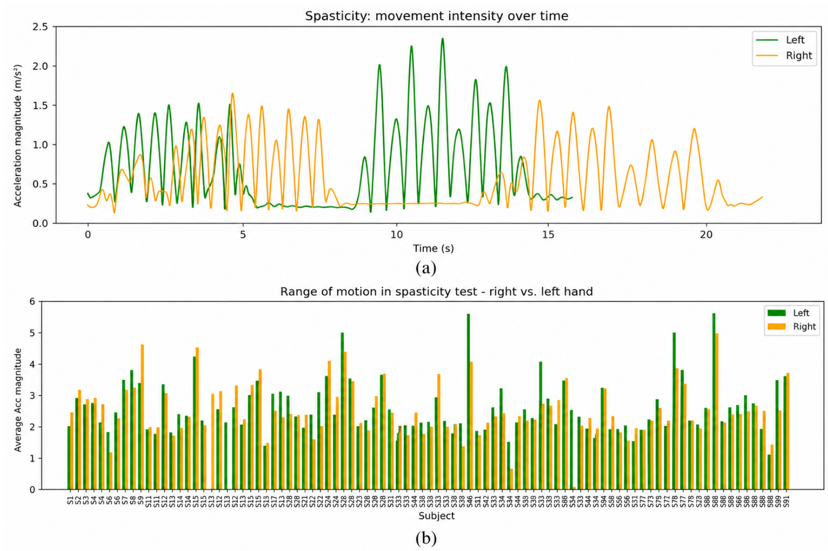

Fig. 6. Preliminary comparison of IMU-derived movement characteristics obtained during the spasticity assessment in phase one. (a) Example acceleration magnitude. (b) Comparison of the average acceleration magnitude between the left and right upper limbs across all analyzed participants.

The results indicate promising overall IMU data quality across the different movement assessments. Beyond recording availability and completeness, representative analyses demonstrate the feasibility of event detection, multimodal sensor integration, and bilateral movement comparison, supporting the dataset's suitability for downstream signal processing and clinical analysis.

This initial evaluation provides a quality assurance basis for the remainder of the Sensor-S study. Future work will extend the assessment to the complete cohort, incorporate additional quality metrics, and investigate automated detection of recording anomalies. Ultimately, these data can support the development of objective movement features and digital biomarkers for monitoring stroke rehabilitation progress.

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