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Data Descriptor

Full-Body Mobility Data to Validate Inertial Measurement Unit Algorithms in Healthy and Neurological Cohorts

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Abstract: Gait and balance dysfunctions are common in neurological disorders and have a negative effect on quality of life. Regularly quantifying these mobility limitations can be used to measure disease progression and the effect of treatment. This information can be used to provide a more individualized treatment. Inertial measurement units (IMUs) can be utilized to quantify mobility in different contexts. However, algorithms are required to extract valuable parameters out of the raw IMU data. These algorithms need to be validated to make sure that they extract the features they should extract. This validation should be performed per disease since different mobility limitations or symptoms can influence the performance of an algorithm in different ways. Therefore, this dataset contains data from both healthy subjects and patients with neurological diseases (Parkinson's disease, stroke, multiple sclerosis, chronic low back pain). The full bodies of 167 subjects were measured with IMUs and an optical motion capture (reference) system. Subjects performed multiple standardized mobility assessments and non-standardized activities of daily living. The data of 21 healthy subjects are shared online, data of the other subjects and patients can only be obtained after contacting the corresponding author and signing a data sharing agreement.

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Dataset License: CC BY-NC-SA

Keywords: biomechanics; IMU; sensors; validation; algorithm; clinical cohort; neurogeriatrics; motion capture

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1. Summary

Mobility is defined as the ability to change and maintain a body position, which is required to perform daily living activities and engage in life [1]. Limitations in mobility can negatively affect independence and quality of life [2,3]. The most common mobility limitations in neurological diseases are gait and balance deficits. For example, gait speed decreases in patients with Parkinson's disease (PD) [4,5], multiple sclerosis (MS) [6] and chronic low back pain (CLBP) [7].

Changes in mobility-related parameters can be used to measure the effect of treatment [8,9] and to track disease progression [10,11]. This information can be potentially used to provide a more individualized treatment. The changes in mobility need to be quantified with sophisticated equipment or algorithms because these changes can be subtle. Stationary equipment is generally very accurate for assessing mobility but can often only be used in the lab or medical institutions. Wearable sensors, such as inertial measurement units (IMUs), can easily be used outside of the lab and even for multiday measurements during daily living. IMUs typically contain accelerometers, gyroscopes and magnetometers. To extract useful mobility parameters from these data, algorithms need to be developed.

After the development, the algorithms need to be validated to make sure the extracted parameters contain the desired information. Since movement patterns change with age [12] and certain neurological disorders [13], the validation should be best performed for these groups separately. During the validation process the results from the IMU-based algorithm should be compared against a very accurate measurement system, such as an optical motion capture system [14].

Often the whole body is involved in mobility-related movements; therefore, even the upper body can provide valuable information about mobility [8,15]. In this dataset, data from the full body when performing standardized clinical assessments as well as non-standardized activities of daily living (performed in the lab) are available. An IMU as well as multiple reflective markers for the optical motion capture system were placed on each body segment. This dataset can be used to develop and validate all kinds of mobility-related IMU-based algorithms. The data can also be used to answer clinical research questions.

2. Data Description

2.1. Subjects

This dataset includes data of healthy (younger) adults (18–60 years), healthy older adults (>60 years), as well as of patients with a neurological movement disorder: PD, a recent symptomatic stroke (less than four weeks ago), MS and CLBP. In addition to these well-defined neurological patient groups, also a small number of patients with rare or unknown neurological movement disorders was measured.

Healthy subjects were recruited via flyers that were placed in public facilities. The neurological patients were recruited from either the outpatient clinic or the University Hospital Schleswig-Holstein neurology ward, Campus Kiel, Germany. Subjects were excluded when they used a walking aid or had a Montreal Cognitive Assessment (MoCA) score <15. Healthy subjects were excluded if they had a movement disorder that was not age related. The patients were also excluded if they had a movement disorder in addition to their primary diagnosis that could affect mobility. An overview of the included subjects can be found in Table 1. All subjects provided written informed consent before the start of the measurement, where they approved that their anonymized data can be shared with collaboration partners. A total of 21 healthy adults agreed to uploading of their data without any restrictions. The ethical committee of the Medical Faculty of Kiel University (D438/18) approved the study. The study is registered in the German Clinical Trials Register (DRKS00022998).

Table 1. Demographics and clinical scores of the subjects.

	Healthy Adults (18–60 Years)	Healthy Elderly (>60 Years)	Patients with PD	Patients with Stroke	Patients with Multiple Sclerosis	Patients with Chronic Low Back Pain	Patients with Other Diagnosis	Total
n [% male]	43 (51%)	24 (50%)	34 (62%)	23 (74%)	21 (38%)	10 (70%)	12 (75%)	167 (58%)
Age [years]	29 ± 8	72 ± 6	65 ± 11	68 ± 16	39 ± 13	64 ± 15	66 ± 17	54 ± 21
Height [m]	1.79 ± 0.09	1.74 ± 0.10	1.74 ± 0.09	1.73 ± 0.10	1.80 ± 0.12	1.75 ± 0.09	1.77 ± 0.09	1.76 ± 0.10
Weight [kg]	74 ± 13	79 ± 17	81 ± 18	79 ± 17	84 ± 24	83 ± 19	85 ± 15	79 ± 17
MoCA (0–30)	29 ± 2	25 ± 4	23 ± 3	22 ± 4	27 ± 3	25 ± 2	24 ± 4	26 ± 4
MDS-UPDRS III (0–132)	1 ± 2	5 ± 4	27 ± 20	6 ± 6	9 ± 8	6 ± 5	11 ± 9	9 ± 14
SARC-F (0–10)	0.14 ± 0.35	0.71 ± 1.02	2.38 ± 2.00	1.33 ± 1.86	1.33 ± 1.32	0.75 ± 1.23	2.83 ± 1.95	1.29 ± 1.73

Note that 29 patients with Parkinson's disease (PD) performed the assessment with dopaminergic medication, 5 without, and 8 during both conditions (on different days). MDS-UPDRS III = motor part of the Movement Disorders Society Sponsored Revision of the Unified Parkinson's Disease Rating Scale; MoCA = Montreal Cognitive Assessment, and SARC-F = strength, assistance with walking, rising from a chair, climbing stairs, and falls.

2.2. Demographic Data and Clinical Scores

The demographic data include gender, age, height, weight, foot size and handedness. The following clinical scales and questionnaires were also assessed and are not included in the uploaded data package. They can be applied to answer specific clinical

questions in collaboration with the data provider (please contact the corresponding author for this purpose): MoCA [16], the Charlson Comorbidity Index [17], European Quality of Life (5 Dimensions 5 Level Version) [18], the Instrumental Activities of Daily Living Scale [19], SARC-F (strength, assistance with walking, rising from a chair, climbing stairs, and falls) [20], German Funktionsfragenbogen (function questionnaire) Hannover [21], the General Self-Efficacy Scale [22], the Fatigue Severity Scale [23], the Visual Analogue Scale [24], and the motor part of the Movement Disorders Society Sponsored Revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS III) [25]. All subjects were also assessed with a tuning fork (Rydel–Seiffer) to obtain their vibratory sensation [26]. For all patients, disease duration and medication type, dose and frequency were recorded. For PD patients, the Hoehn and Yahr stage was also recorded [27]; for MS patients, the Expanded Disability Status Scale [28]; and for stroke patients, the NIH stroke scale [29].

2.3. Equipment

Subjects were measured with at least fifteen IMUs (Noraxon USA Inc., myoMOTION, Scottsdale, AZ, USA). The IMUs contain a triaxial accelerometer (±16 g), a triaxial gyroscope (±2000°/s) and a triaxial magnetometer (±1.9 Gauss). The IMUs were worn on different body segments: head, sternum, upper arms, fore arms, pelvis, thighs, shanks, ankles and feet (Figure 1a). The IMUs were attached to these segments with elastic straps that contained a hold for the IMU. When the subjects had pockets in their shorts, a 16th IMU was placed in the pocket. If subject did not have pockets the 16th IMU was either not used or placed on the lateral side of the right foot, just below the malleolus lateralis (x pointing backwards, y downwards and z lateral). Where this 16th IMU was placed is indicated in the channel names in the data files. More information about the placement and orientation of the IMUs can be found elsewhere [30]. The IMU data were collected with a sample frequency of 200 Hz (except for 12 subjects (pp080–pp091) that were measured with a sample frequency of 100).

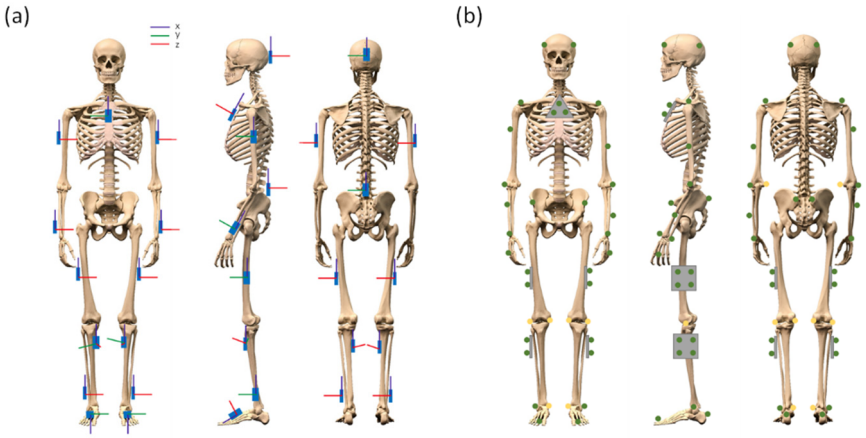

Figure 1. Placement of the inertial measurement units (**a**) and the reflective markers measured by the optical motion capture system (**b**).

An optical motion capture system (Qualisys AB, Göteborg, Sweden) was used as reference tool. At least three reflective markers (19 mm) were placed on each body segment. A total of 47 markers were attached to the body during the assessments. Markers on the sternum, thighs and shanks were fixated as a marker cluster, other markers were placed on the skin or tight-fitting clothes (Figure 1b). During the static calibration in neutral pose, six additional markers were adhered to the body. More information about the exact marker placement can be found elsewhere [30]. The optical motion capture data were labelled with Qualisys Track Manager (Qualisys AB, Göteborg, Sweden). In addition to labelling the marker data, no post-processing was performed (e.g., gap filling and filtering). The optical motion capture system recorded with a sample frequency of 200 Hz. The IMU and

the optical motion capture data were synchronized with each other with the help of a TTL pulse at the start of the measurement.

A treadmill (Woodway, Waukesha, WI, USA) of 2.10 by 0.70 m was used to record longer walking distances. Subjects first chose their own comfortable walking speed on the treadmill and walked at that speed for one minute. Thereafter, the speed of the treadmill was changed to the preferred overground walking speed, which was measured at the start of the assessment with two light barriers (Telemecanique, photo-electronic sensor XULM06031, Rueil-Malmaison, France) standing 5 m apart.

Dual-task assessments during walking were performed on a smartphone (One Touch Pop 2, Alcatel, Hong Kong, China) with a screen size of 4.5 inches. The dual-task assessments consisted of a simple reaction time test and a numerical Stroop test that were developed with Presentation Mobile® (NeuroBehavioral Systems, Berkeley, CA, USA). The results from these assessments (e.g., reaction time and accuracy) are not included in the uploaded data package.

The assessments were recorded with two cameras (GoPro Inc., Hero Session, San Mateo, CA, USA). Since these data contain identifying information, these data will not be shared.

3. Methods

Subjects performed both standardized and non-standardized assessments. The standardized assessments contained clinical tests, several walking assessments, as well as instructed and structured series of movements. At the start of the measurement, a static calibration was performed with a few additional reflective markers on the body. During the static calibration, subjects were measured for a few seconds in a neutral pose. With this assessment, it is possible to determine several joint centers. After the calibration, the standardized and non-standardized assessments were performed in randomized order, except for the MDS-UPDRS III that was always performed first. During all assessments, standardized and non-standardized, data were collected with both the IMUs and the optical motion capture system. When a reflective marker cluster or IMU was displaced, another calibration was performed.

The setup of the lab and the assessments performed during the standardized mobility part are shown in Figure 2a.

Most of the walking assessments were performed on a 5 m walkway. Reflective markers placed at the beginning and the end of the walkway indicated the start and end. Subjects were always asked to start walking at least two steps before the start of the 5 m and to continue walking until two steps after the indicated 5 m. In this 5 m area, the optical motion capture system can capture the full body; however, before the start and after the end of the 5 m, the cameras cannot detect all reflective markers. The cones on the walkway for the slalom walk were also measured with reflective markers, as well as the obstacle during the obstacle walks.

A subset of the healthy young adults (29 subjects) also performed a split-belt walking protocol on this treadmill. During these assessments, the subjects walked one minute at preferred speed, then 2 min with a 25% speed reduction on one side and then another minute at preferred speed. This was performed twice, one for each side.

The non-standardized assessment consisted of activities of daily living. This part was not structured. The subjects were instructed during the assessment which activities they had to perform but could perform it according to their preferences. Every time they finished one task, they were instructed on which task they had to perform next. There was no fixed order in performing the different tasks; therefore, the order of the tasks is different per participant. At the start of the COVID-19 pandemic, tooth brushing was removed from the protocol. The setup of the lab and the activities that were recorded are shown in Figure 2b.

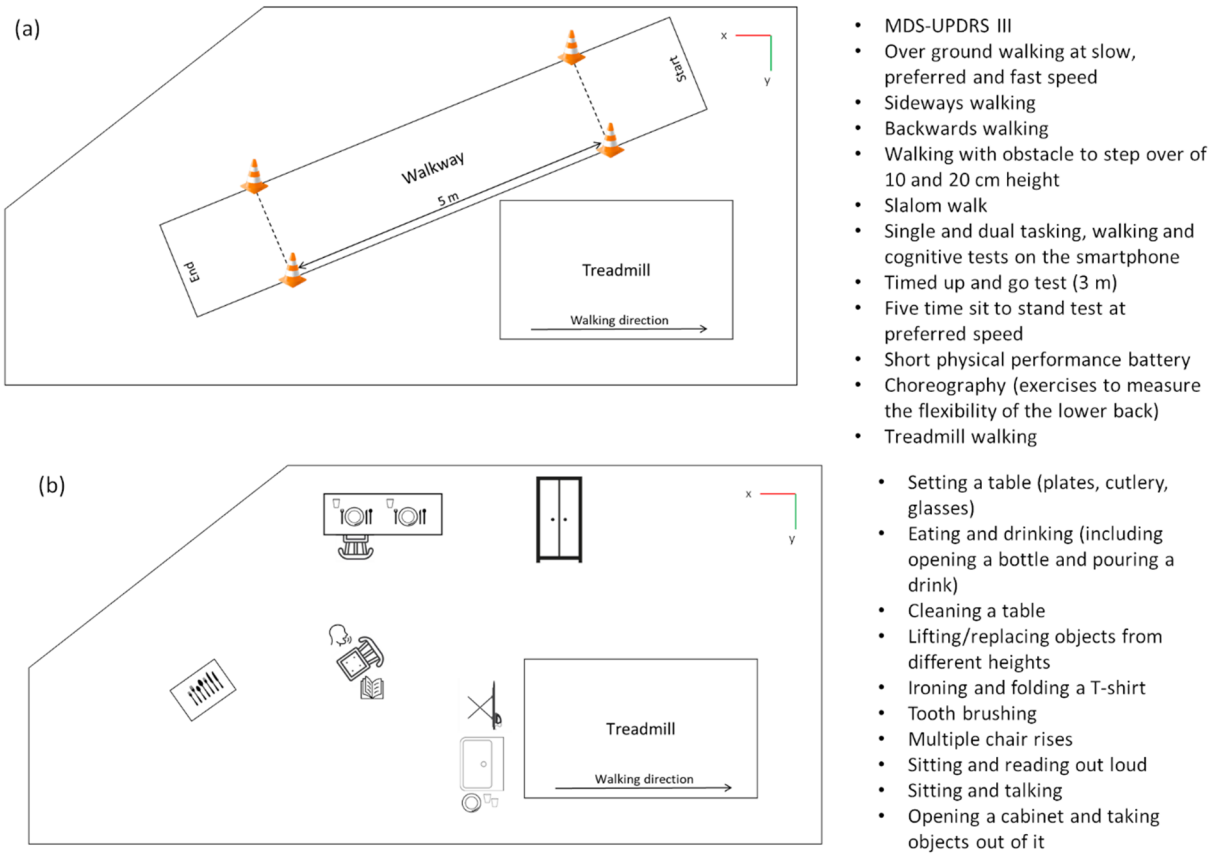

Figure 2. The setup of the lab for the standardized mobility assessments (**a**) and for the non-standardized activities of daily living (**b**). The assessments and tasks that were measured during both parts are described on the right side.

A more detailed description of the assessments and the instructions can be found in [30].

Because of the extensive protocol, not all patients managed to perform all assessments due to fatigue. Therefore, there are some files missing for some patients.

4. Data Records

The data of 21 healthy subjects are made available using Figshare [https://doi.org/10.6084/m9.figshare.20238006]. Data of patients can only be shared after signing a data sharing agreement; please contact the corresponding author for that.

The dataset organization is adapted to the brain imaging data structure (BIDS) format for movement data [31,32]. The folder structure conventions can be found on https://neurogeriatricskiel.github.io/data/ (accessed on 20 September 2022). Data are saved in a tab-delimited text-based format (*.tsv) with the first row serving as a header describing the contents of each data column. The files containing the raw marker or sensor data are named systematically "sub-<label>_task-<label>[_run-<label>]_tracksys-<label>_motion.tsv"; for example, "sub-pp001_task-walkSlow_tracksys-imu_motion.tsv". Where "sub" stands for subject and "tracksys" stands for the tracking system that was used. In addition, each motion data file is accompanied by a separate file describing the data columns, named likewise: "sub-<label>_task-<label>[_run-<label>]_tracksys-<label>_channels.tsv". This channels file holds the following information for each column in the data file:

- The column name ("name");
- The type of data (e.g., "ACC" for acceleration and "ANGVEL" for angular velocity, "POS" for position);
- Which component, (e.g., "x", "y", "z", or "err" for the residual);

- Which tracked point, (e.g., "head" and "sternum");
- Which units, e.g., "mm" or "g";
- Which sampling frequency was used (in Hz);
- The tracking system, that is "omc" for the optical motion capture system and "imu" for the inertial measurement units.

From the IMU data, the acceleration data are stored in g, the angular velocity in °/s and the magnetometer data in Gauss. The optical motion capture data are stored in mm, the fourth column of each marker is the residual.

In terms of the "motion" and "channels" files, for some tasks, there is an "events" file. For the overground walking trials at preferred, slow and fast speed, these events files hold information on the onset of gait events (initial contacts and final contacts of both feet). For the treadmill walking trials, these event files hold information on the start and end of the belt speed. For each subject, a scans file ("sub-<label>_scans.tsv") lists the data files that are available for the given subject. Additionally, this file lists for each task file, which is the corresponding calibration file that belongs to it. In case of treadmill walking, the file holds information on the preferred treadmill walking speed as well as preferred overground walking speed.

An overview of the filenames of the assessments can be found in [30] (Supplementary Materials).

The motion capture system provides data with average errors of less than 0.5 mm and maximum errors of less than 1 mm [14]. Therefore, the reference system itself is very accurate. However, slightly larger errors can be introduced by inter- and intra-assessor differences in marker placement, missing data because of marker occlusion and soft-tissue artefacts. To reduce any inter- and intra-assessor differences, the medically trained assessors received thorough training before they started collecting data. The marker occlusion was minimized by performing most assessments in the middle of the lab to make sure the reflective markers were seen by multiple cameras. Soft-tissue artefacts were minimized by placing the reflective markers as much as possible on bony landmarks. IMUs were also positioned in a way that soft-tissue artefacts were minimized.

5. User Notes

Information and code on how to work with BIDS data can be found on the BIDS starter kit page (BIDS metadata and file formats—BIDS starter kit (bids-standard.github.io)). The data of 21 healthy subjects are made available using Figshare [https://doi.org/10.6084/m9.figshare.20238006].

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/data7100136/s1.

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Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of Kiel University (protocol code D438/18 and 08/05/2018).

Informed Consent Statement: Informed consent was obtained from all subjects involved in this study.

Data Availability Statement: Information and code on how to work with BIDS data can be found on the BIDS starter kit page (BIDS metadata and file formats—BIDS starter kit (bids-standard.github.io)). The data of 21 healthy subjects are made available using Figshare [https://doi.org/10.6084/m9.figshare.20238006].

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