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# A data set with kinematic and ground reaction forces of human balance

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This article describes a public data set with the three-dimensional kinematics of the whole body and the ground reaction forces (with a dual force platform setup) of subjects standing still for 60 s in different conditions, in which the vision and the standing surface were manipulated. Twenty-seven young subjects and 22 old subjects were evaluated. The data set comprises a file with metadata plus 1,813 files with the ground reaction force (GRF) and kinematics data for the 49 subjects (three files for each of the 12 trials plus one file for each subject). The file with metadata has information about each subject's sociocultural, demographic, and health characteristics. The files with the GRF have the data from each force platform and from the resultant GRF (including the center of pressure data). The files with the kinematics have the three-dimensional position of the 42 markers used for the kinematic model of the whole body and the 73 calculated angles. In this text, we illustrate how to access, analyze, and visualize the data set. All the data is available at Figshare (DOI: 10.6084/m9.figshare.4525082 ), and a companion Jupyter Notebook (available at <https://github.com/demotu/datasets> ) presents the programming code to generate analyses and other examples.

# **A data set with kinematic and ground reaction forces of human balance**

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# 13 Abstract

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15 body and the ground reaction forces (with a dual force platform setup) of subjects standing still  
16 for 60 s in different conditions, in which the vision and the standing surface were manipulated.  
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28

# 1 Introduction

The ability to maintain an upright posture is a vital skill needed to perform most of our daily life activities, and this ability is a complex task that is dependent on a rich and fine integration of the central nervous system with the somatosensory and musculoskeletal systems. One of the most basic and easily observable facts related to the maintenance of an upright posture is that our body sways while we stand even if we try to stay as still as possible. To quantify the amount a person sways, the displacements of the segments of the body can be measured, and these measurements can be used to estimate the displacement of the body's center of gravity (COG). A physical quantity related to and that is simpler to measure than COG is the body's center of pressure (COP), which expresses the position of the resultant reaction force applied to the body (to our feet) at the ground's surface. As we sway while standing, both COG and COP displacements vary over time, and these physical quantities are the most commonly used quantities to quantify a person's postural sway in both clinical and research contexts (Duarte & Freitas 2010; Visser et al. 2008).

However, the exact nature of the control mechanisms that allow humans to maintain their balance and the extent of the information that can be extracted from a person's COG and COP, among other issues, are not settled and are still under intense investigation. With the intent of contributing to this investigation, we recently published an article in which we described a public data set with the results of qualitative and quantitative evaluations related to the balance of 163 human subjects (Santos & Duarte 2016). The only quantitative measurement of the postural sway we provided in that data set was COP displacement, which was measured with a single force platform. We now seek to contribute a different public data set with quantitative measurements other than COP displacement to help investigate questions related to human balance. For

example, a person's COP during regular bipedal standing is the net COP of the resultant forces from each foot, and these distinct COP values can be measured with a force platform under each foot (Winter 1995). However, most studies on balance control are based on data acquired from a single force platform setup. Another question that indicates the need for more data to understand balance control is how humans coordinate the movement of their segments while standing; this question has been investigated since the classical observation of the ankle and hip strategies that are used to control balance after a perturbation (Horak & Nashner 1986).

The availability of a public data set on the Internet that presents results of such measurements together with information on how to access and process this data could potentially boost the research on this topic, increase the reproducibility of studies, and be used for training and education, among other applications. The present article describes a public data set with a rich quantitative evaluation of human balance, and in this data set, we measured the three-dimensional (3D) kinematics of the whole body and the ground reaction forces (GRFs) (with a dual force platform setup) of subjects standing during different vision and surface conditions.

## 2 Methods

The data collection was performed in the Laboratory of Biomechanics and Motor Control at the Federal University of ABC, Brazil. The entire data collection for each subject was performed in a single subject with one subject per session, and each session lasted one hour. We conducted pilot studies with four subjects to train with the equipment and to establish experimental protocol. The data of these four subjects is not included in this data set. This study was approved by the local ethics committee of the Federal University of ABC (#1.417.054), and all subjects signed a consent form prior to the data collection.

75

## 76 **2.1 Subjects**

77 A convenience sample of 49 subjects was recruited to participate in this study, and they  
78 were assigned to one of two groups according to their age: Young (15 males and 12 females who  
79 were between 18 and 40 years old) and Old (11 males and 11 females who were 60 years old or  
80 older). The subjects were recruited by word of mouth from local communities and included  
81 students from the university, the local neighborhood, and a community center for older adults.  
82 The subjects were interviewed to collect information about their demographic characteristics,  
83 sociocultural characteristics, and overall health condition.

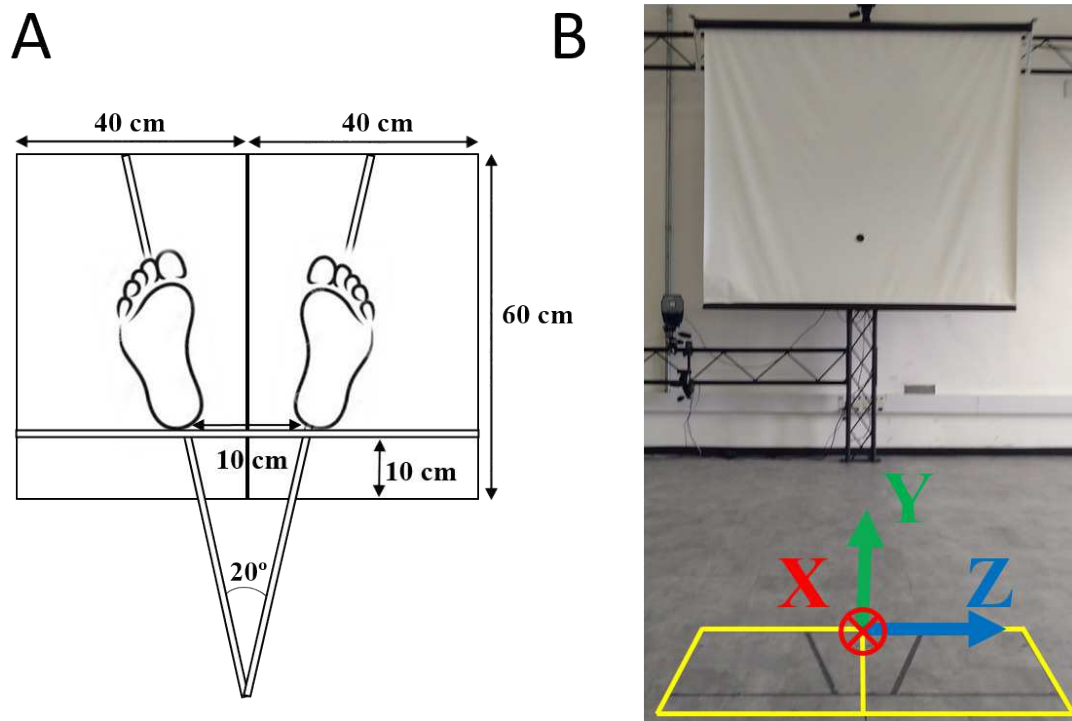
84

## 85 **2.2 Data acquisition**

86 We evaluated the subjects' balance during bipedal quiet standing employing the same  
87 standing conditions as described in Santos and Duarte (2016), but we used a dual force platform  
88 setup and recorded the subjects' full-body 3D kinematics using a motion capture system. Briefly  
89 (for more details, see Santos and Duarte (2016)), we evaluated subjects standing still for 60 s  
90 under four different conditions, in which vision and the standing surface were manipulated: on a  
91 rigid surface with eyes open, on a rigid surface with eyes closed, on an unstable surface with  
92 eyes open, and on an unstable surface with eyes closed. Each condition was performed three  
93 times, and the order of the conditions was randomized. We placed two 40 × 60 cm force  
94 platforms (OPT400600-1000; AMTI, Watertown, MA, USA) under each foot, and under the  
95 unstable conditions, the subjects stood on two 6-cm high foam blocks (Balance Pad; Airex AG,  
96 Sins, Switzerland), one of which was placed on each force platform. In the eyes-open conditions,  
97 each subject looked at a 5 cm round black target placed at the subject's eye height on a wall 4.35

98 m in front of the subject. For all the trials, the subject's feet were placed with an angle of 20  
99 degrees between them, and their heels were kept 10 cm apart by asking the subjects to stand on  
100 lines marked on the top of the force platform (see Figure 1). The trials were conducted in a 11.75  
101 × 9.69 m room with white walls and adequate illumination (see Figure 1).

102



103

104 Figure 1. A: Marks for the subject's feet placement on the force platform. B: Data collection  
105 room for the stabilography (note the 5 cm black target at the wall 4.35 m ahead), the two force  
106 platforms (marked in yellow), and the laboratory coordinate system convention (XYZ vectors).

107

108 We recorded the full-body 3D kinematics of the subjects during the quiet standing trials  
109 using a motion capture system with 12 infrared cameras (Raptor-4, Motion Analysis, Santa Rosa,  
110 CA, USA). The displacement of the head, trunk, pelvis, and right and left feet, thighs, and shanks  
111 were tracked using a marker set model that combined the lower-body and upper-body models



proposed by Leardini and collaborators (2011; 2007) plus four markers on the head and two markers on the iliac crests. In total, 42 reflective markers were placed on the subject's anatomical landmarks (see Figure 2 and Table 1 of the supplementary material). Of note, the upper limbs were not tracked by the motion capture system because each subject was instructed to maintain the placement of his or her arms along his or her trunk during the trials.

The data acquisition of the GRF and 3D markers' positions were performed at a sampling frequency of 100 Hz with the Cortex software version 5.3 (Motion Analysis, Santa Rosa, CA, USA). Using the Cortex software, we exported all the data of each trial to a file in the c3d format (<https://www.c3d.org/>).

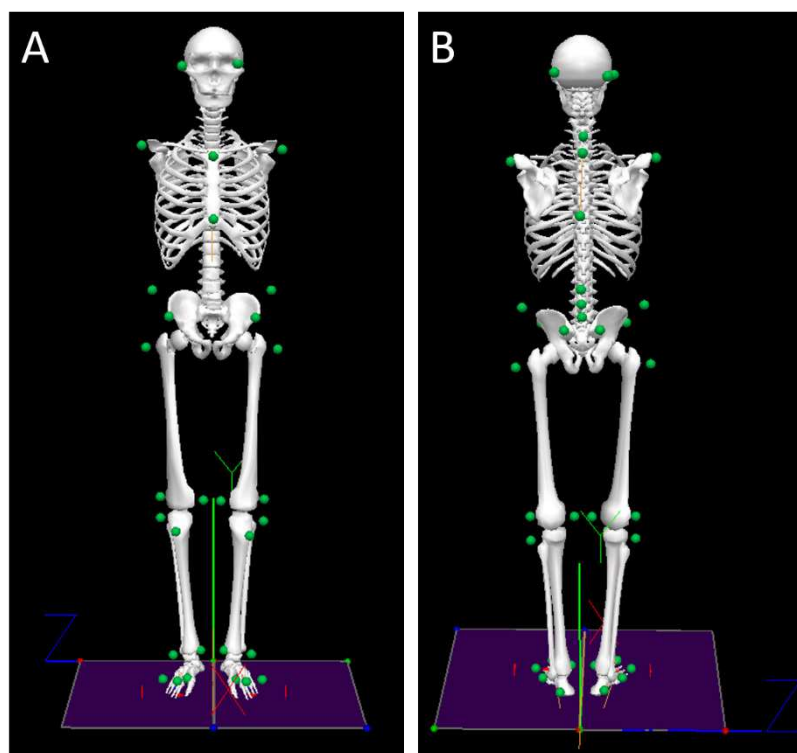


Figure 2. Front (A) and rear (B) views of the biomechanical model of the human body with the marker set convention (represented as green dots).

## 2.2.1 Protocol

The following procedure was adopted for the data collection (based on Santos & Duarte (2016)):

1. The researcher explained to each subject the process of data collection with the force plates and the motion capture system. The subject was informed that during the data collection, he or she would be monitored and that there should not be any verbal communication during the trials but that he or she could interrupt the data collection if desired and that assistance would be given if necessary.
2. After these explanations, each subject was asked to stay barefoot, to change their clothes to tight-fitting clothes, and to place an elastic band around his or her head.
3. The same researcher located 42 anatomical landmarks on the subject's body using palpation, and passive reflective markers were placed on these landmarks with double adhesive tape (see Table 1 of supplementary material for the list of anatomical landmarks).
4. Before the quiet standing trials, each subject was asked to perform a standing calibration trial for the kinematic measurement. A template was used to align the subject's feet in a standardized position so that the long axes of the feet were parallel to the X-axis of the laboratory coordinate system. Then, the markers' 3D coordinates were recorded for 3 s. After the acquisition was completed, the markers at the medial side of the right and left knees and ankles were removed, because they could disturb the subject during the quiet standing trials.
5. After the standing calibration trial, the researcher instructed the subject how to stand on the force platforms according to the task (with open or closed eyes and standing on a firm

or foam surface). The subject's feet were positioned on the marks at the force platforms (see Figure 1). The researcher instructed the subject to maintain the position of his or her arms along his or her body and to stand as still as possible. During the trials with the subject's eyes open, the subjects were told to fix their gaze ahead on the round black target placed on the wall at the subject's eye level. During the trials with eyes closed, the subjects were told to fix their gaze ahead at the same target, close their eyes when they felt ready, and only open them when the researcher indicated that the trial was over.

6. The researcher started the data collection around 5 s after the subject said he or she was ready.
7. At the end of the trial, the subject was helped down from the force platform, and he or she could rest (and sit if desired) for about one minute before the next trial.
8. If the subject was unable to complete the 60-s trial, the test was stopped, and that trial was immediately repeated up to two times if necessary. All subjects completed all trials.

## 2.3 Data processing

Data processing, including biomechanical modeling, analysis, visualization, and exportation of data to text files, was performed using custom programming implemented in the Visual3D software version 6.0 (C-Motion, Inc., USA) and in the SciPy Stack (<https://www.scipy.org/>) for the Python programming language. All the data for the GRF and marker positions was smoothed with a low-pass Butterworth filter with a 10 Hz cutoff frequency, fourth order, and zero lag.

### 2.3.1 Ground reaction force data

The COP position for each force platform was calculated according to the standard formula (Duarte & Freitas 2010; Santos & Duarte 2016), and the GRF data (including COP) was transformed to the laboratory coordinate system using the Cortex software. As result, for each force platform, the data is presented as the X, Y, Z components of COP and force and the free moment (at the Y direction).

From the GRF data of each force platform, we calculated the net (resultant) GRF and the net COP in the anterior–posterior (x-positive is anterior), vertical (y-positive is up), and mediolateral (z-positive is to the right) directions (according to the laboratory coordinate system):

$$GRFNETx = RGRFx + LGRFx$$

$$GRFNETy = RGRFy + LGRFy$$

$$GRFNETz = RGRFz + LGRFz$$

$$COPNETx = \frac{(RCOPx \times RGRFy + LCOPx \times LGRFy)}{GRFNETy}$$

$$COPNETy = 0$$

$$COPNETz = \frac{(RCOPz \times RGRFy + LCOPz \times LGRFy)}{GRFNETy}$$

where L and R represent the left and right force platforms with respect to the subject standing on them.

### 2.3.2 Kinematics data

The use of the anatomical-based protocols for marker placement and segment definition proposed by Leardini and collaborators (2011; 2007) with additional markers placed on the

subject's head allowed us to calculate two-dimensional projection angles based on four points for each joint and 3D Cardan angles with the following convention: the first rotation (flexion-extension) occurred in the mediolateral axis (Z-axis, perpendicular to the sagittal plane), the third rotation (internal/external rotation) was around the longitudinal axis (Y-axis, perpendicular to the transverse plane), and the second rotation (abduction/adduction) was around an axis perpendicular to the previous two axes, which, in the anatomic position, represents the anterior-posterior axis (X-axis, perpendicular to the frontal plane). This is the Z-X-Y convention, and it is frequently used to describe lower extremity rotations in the human body (Cappozzo et al. 1995). See Tables 2-4 of supplementary material for a description of all the angles calculated. To estimate COG position based on the kinematic data, besides using the segments proposed by Leardini and collaborators (2011; 2007), we altered the trunk of their model to a segment that included the head, arms, and trunk and used the mass and moment of inertia from the Dempster anthropometric model adapted by Winter (2009) for this segment and the other segments.

Next, we exemplify how to access, analyze, and visualize the data set. All the programming code used here for such examples is available as a Jupyter Notebook in a GitHub repository (<https://github.com/demotu/datasets>).

### 3 Results

All the data is available at Figshare (DOI: 10.6084/m9.figshare.4525082); the data is stored in ASCII (text) format with tab-separated columns that can be downloaded as a single compressed file that is 6.93 GB large and that is made available under the CC-BY license (<https://creativecommons.org/licenses/by/4.0/>). The data set comprises a file with metadata plus

1,813 files with the GRF and kinematics data for the 49 subjects (3 files for each of the 12 trials plus one file for each subject:  $3 \times 12 \times 49 + 49$  files).

217

### 3.1 Metadata

The metadata file named PDSinfo.txt contains 29 fields about the conditions of the trials and information from the anamnesis of each subject. There are 12 rows for each subject in this file—one row for each of the 12 trials. In these 12 rows, the only columns that have rows with different values are the columns describing the trials. The content of all the other columns is simply repeated over the 12 rows. As a result, the PDSinfo.txt file has a header plus 588 rows with 29 columns. Here is the coding for the metadata (the first word identifies the name of the column in the header):

1. **Trial:** file name of the stabilography trial (PDSXXYYZ, where XX identifies the subject and varies from 01 to 49; YY identifies the stabilography condition and is either OR, OF, CF, or CR; and Z identifies the number of repetitions and varies from 1 to 3).
2. **Subject:** number of the subject (from 1 to 49).
3. **Vision:** visual condition (O: open eyes or C: closed eyes).
4. **Surface:** surface support condition (R: rigid or F: foam).
5. **Rep:** trial number (from 1 to 3).
6. **Age:** subject's age in years.
7. **AgeGroup:** age group (Young: Age < 60; Old: Age ≥ 60).
8. **Gender:** gender (F or M).
9. **Height:** height in meters (measured with a calibrated stadiometer).
10. **Weight:** weight in kilograms (measured with a calibrated scale).

- 238 11. **BMI**: body mass index in kg/m<sup>2</sup>.
- 239 12. **FootLen**: foot length in cm (average of the two feet, measured with a calibrated paquimeter).
- 240 13. **DominantLeg**: preferred self-reported leg for kicking a ball (Right or Left).
- 241 14. **Nationality**: country where the subject was born.
- 242 15. **SkinColor**: self-reported skin color.
- 243 16. **Ystudy**: years of formal education.
- 244 17. **Footwear**: most common type of footwear the subject wears daily.
- 245 18. **Illness**: whether the subject had any illness at the time of the trials, as declared by the subject
- 246 (Yes or No).
- 247 19. **Illness2**: type of illness of the subject (“No” if the subjects did not have any illness).
- 248 20. **Nmedication**: total number of medications the subject takes per day (if any).
- 249 21. **Medication**: name of the medication(s) the subject takes (“No” if the subject did not take any
- 250 medication).
- 251 22. **Ortho-Prosthesis**: whether the subject wears any type of orthosis or prosthesis, as declared
- 252 by the subject (Yes or No).
- 253 23. **Ortho-Prosthesis2**: name of the orthosis or prosthesis the subject wears (“No” if the subject
- 254 did not wear any orthosis or prosthesis).
- 255 24. **Disability**: whether the subject has any disability, as declared by the subject (Yes or No).
- 256 25. **Disability2**: name of the disability of the subject (No if the subject did not present any
- 257 disability).
- 258 26. **Falls12m**: how many unintentional falls the subject experienced in the last 12 months, as
- 259 declared by themselves (from 0 to an unlimited upper limit).

260 27. **PhysicalActivity**: number of days per week the subject practiced physical activity (from 0 to  
261 7).

262 28. **Sequence**: sequence of the four conditions of stabilography (e.g., OR, OF, CF, CR).

263 29. **Date**: date and time of the subject's evaluation (yyyy-mm-dd hh:mm:ss.sss; 24-hour local  
264 time format).

265

266 For instance, when taking the subjects' age (years), height (m), mass (kg), and body-mass  
267 index (BMI, kg/m<sup>2</sup>), the mean and standard deviation values grouped by age can be obtained  
268 with the following Python code:

269

```
270 import numpy as np
271 import pandas as pd
272 pd.set_option('precision', 2)
273 PDSinfo = pd.read_csv('PDSinfo.txt', sep='\t', header=0, index_col=None)
274 info = PDSinfo.drop_duplicates(subset='Subject', inplace=False)
275 pd.set_option('precision', 2)
276 info.groupby(['AgeGroup'])['Age', 'Height', 'Mass', 'BMI'].agg([np.mean, np.std])
```

277

278 which outputs:

	Age		Height		Mass		BMI	
	mean	std	mean	std	mean	std	mean	std
AgeGroup								
Old	67.83	6.14	1.61	0.09	68.66	11.24	26.31	3.13



Young	28.08	4.35	1.71	0.11	70.32	17.81	23.94	4.80
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## 3.2 Ground reaction force data

Each text file with the GRF data is named by the corresponding trial (given at the first column of the metadata file) plus the suffix “grf” (e.g., PDS01OR1grf.txt is the file name for the first trial of the first subject). Each file has a header and 6,000 rows (60 s × 100 Hz) and 21 columns of data with six-digit numeric precision. The header refers to the signal at each column (see section 2.3.1): Time, RGRF\_X, RGRF\_Y, RGRF\_Z, LGRF\_X, LGRF\_Y, LGRF\_Z, GRFNET\_X, GRFNET\_Y, GRFNET\_Z, RCOP\_X, RCOP\_Y, RCOP\_Z, LCOP\_X, LCOP\_Y, LCOP\_Z, COPNET\_X, COPNET\_Y, COPNET\_Z, RFREEMOMENT\_Y, and LFREEMOMENT\_Y. The corresponding units are: time (s), force (N), COP (m), and free moment (Nm).

For instance, Figure 3 shows plots of the COP displacement on each force platform and the resultant COP from a trial of an elderly subject who was standing with eyes closed on a rigid surface. Some of the common variables to quantify the COP displacement during quiet standing used in the literature are (Duarte 2015; Duarte & Freitas 2010): the area of the anterior–posterior COP versus the mediolateral COP plot and the velocity and mean frequency of the COP displacement. The plots for these variables calculated for the resultant COP across the different standing conditions and grouped by the age group are shown in Figure 4. In Figure 4, the group of old subjects presents larger values than the group of young subjects for the calculated COP variables, and both groups present larger values in more challenging conditions (i.e., open vs. closed eyes and rigid vs. foam surface).

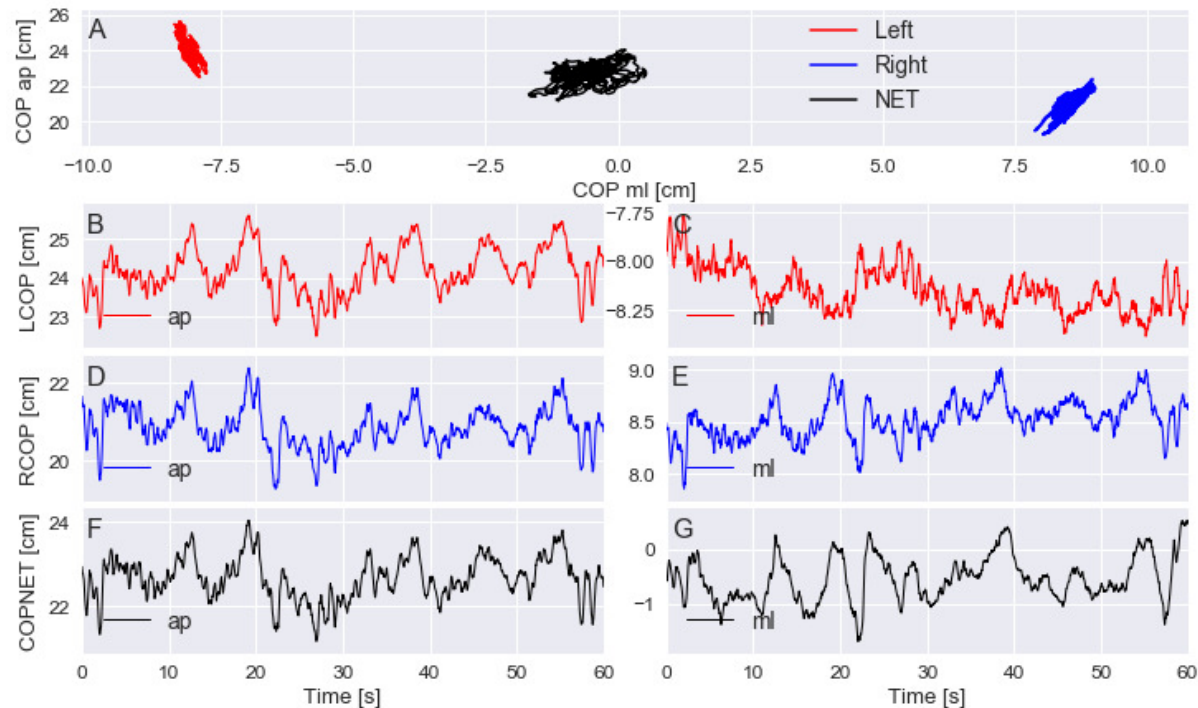


Figure 3. A: exemplary plots of the center of pressure (COP) at the anterior-posterior (ap) direction versus the medio-lateral (ml) direction given by the left and right force platforms and the resultant COP (COPNET). B–G: COP displacement at the ap and ml directions versus time for the left (LCOP) and right (RCOP) force platforms and for the COPNET. Trial PDS13CR1 (elderly subject standing with eyes closed on a rigid surface).

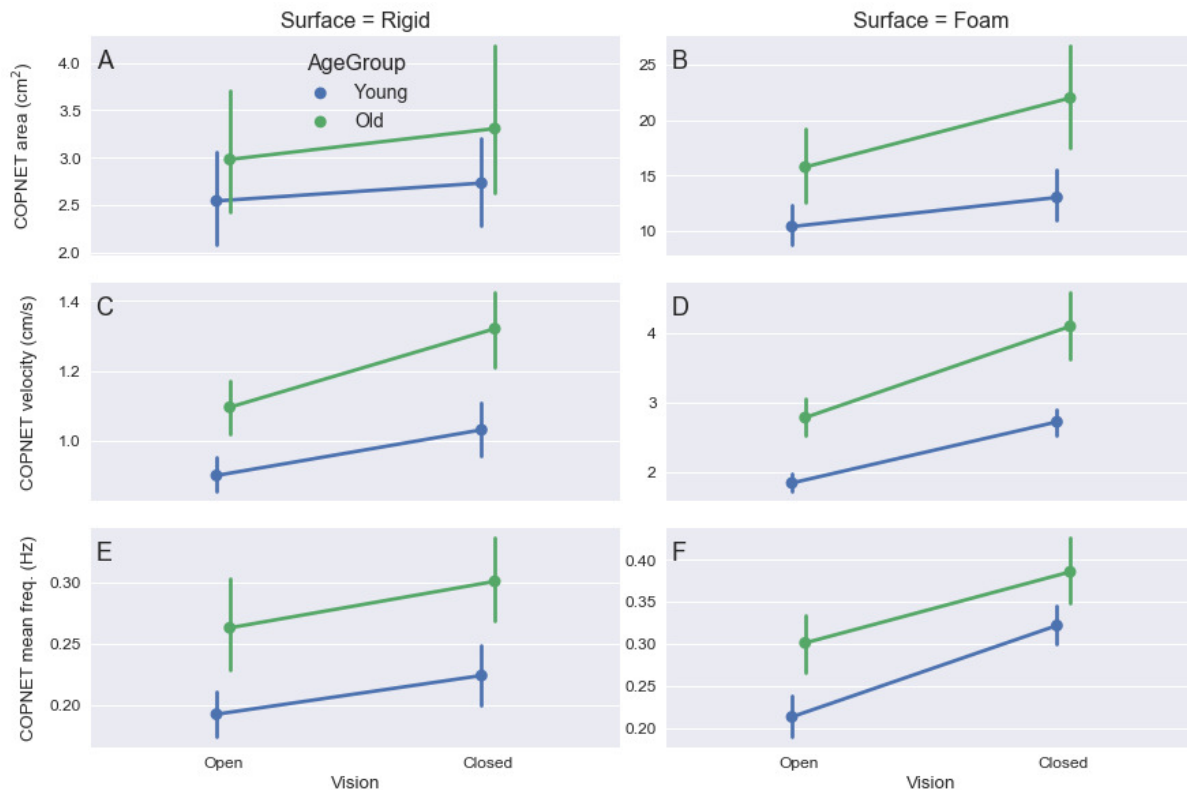


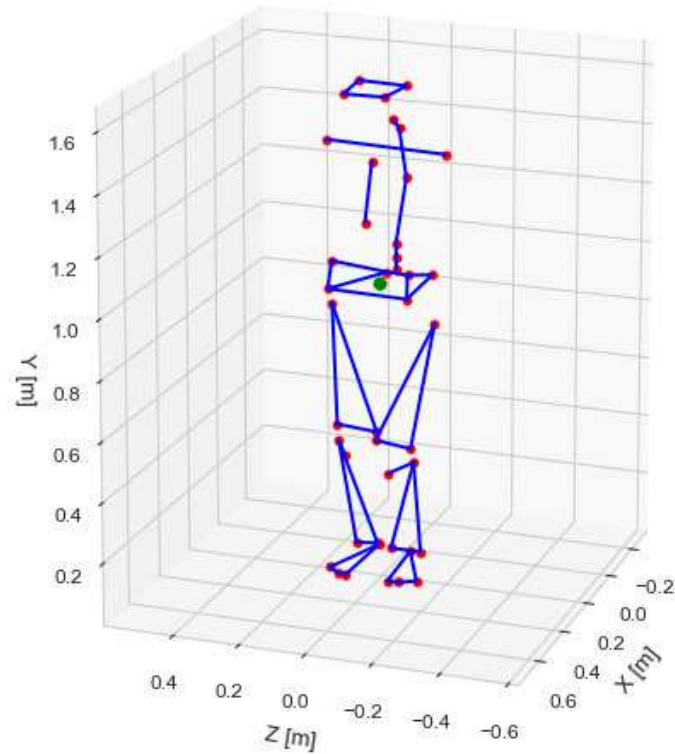
Figure 4. The mean and 95% confidence intervals across subjects of the variables COPNET area (A–B), the resultant COPNET velocity (C–D), and the resultant COPNET mean frequency (E–F) at the different visual and support surface conditions (color coded by age group).

### 3.3 Kinematics data

There are two kinds of files for the kinematics of each trial: a file with the markers and COG positions and a file with the segment and joint angles. Each of these files is named by its corresponding trial (given at the first column of the metadata file) plus the suffix “mkr” for the position data or the suffix “ang” for the angle data. Each file has a header and 6000 rows (60 s × 100 Hz) of data with six-digit numeric precision. The file with the markers and COG positions has 130 columns (a time vector plus the X, Y, Z coordinates of 42 markers and of the COG). The file with the angles has 74 columns (a time vector plus 19 columns for the 19 planar angles plus

54 columns for the 18 3D Cardan joint angles). See the supplementary material for a description of the markers and angles names in the headers. In addition, for each subject, there is one extra file with the markers' positions from the standing calibration trial for the kinematic measurement that contains 300 rows ( $3 \text{ s} \times 100 \text{ Hz}$ ) of data with six-digit numeric precision. This file is named PDSXXstatic.txt, where XX is the number of the subject. With this file, along with the markers' positions and the GRF files, a user of the data set can define a biomechanical model consistent with the marker set we used and calculate any kinematic and kinetic variable (e.g., to calculate the joint moment of force). The corresponding units are: time (s), marker and center of gravity position (m), and angle ( $^{\circ}$ ).

For instance, Figure 5 shows a plot with the average three-dimensional positions of the markers and the COG from a trial of an elderly subject standing with eyes closed on a rigid surface. Figure 6 shows plots of the resultant COP and the COG displacement of the same trial. The COP and COG are very similar at the anterior–posterior direction but not as similar at the mediolateral direction.



336

337 Figure 5. Average three-dimensional positions of the 42 markers (in red) and center of gravity (in  
 338 green) during standing. Trial PDS13CR1 (elderly subject standing with eyes closed on a rigid  
 339 surface).

340

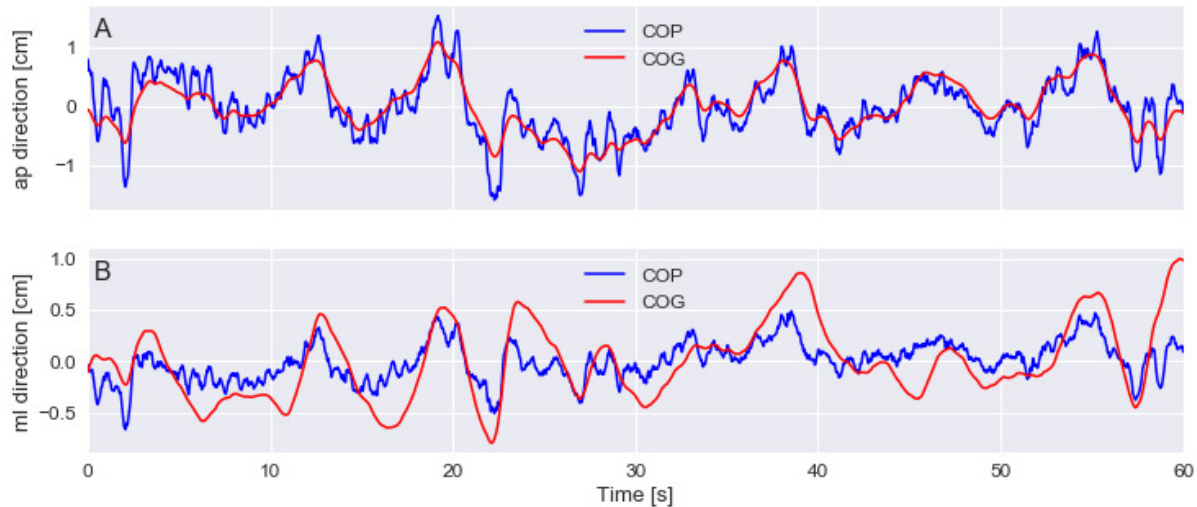


Figure 6. A–B: exemplary plots of the center of pressure (COP) and center of gravity (COG) displacements at the anterior–posterior (ap) and mediolateral (ml) directions. The COP and COG displacements had their corresponding mean values subtracted so that both signals have zero mean. Trial PDS13CR1 (elderly subject standing with eyes closed on a rigid surface).

Figure 7 shows exemplary plots of the Cardan angles at the sagittal plane (flexion/extension) for the hip, knee, ankle, trunk/head, and pelvis/trunk joints during a trial of an elderly subject standing with eyes closed on a rigid surface. The angles for the right and left sides are very similar. Figure 8 shows plots for the mean and 95% confidence intervals across subjects of the amplitude range (maximum minus minimum) for these joint angles averaged between sides for all subjects. The joint angle ranges have similar values for both age groups and for the trials in which the subjects stood on a rigid surface; there is a bottom-up pattern for the joint angle range value that increases as the joint is furthest from the ground and closest to the head, but this pattern cannot be seen in the trials in which the subjects were standing on the foam surface.

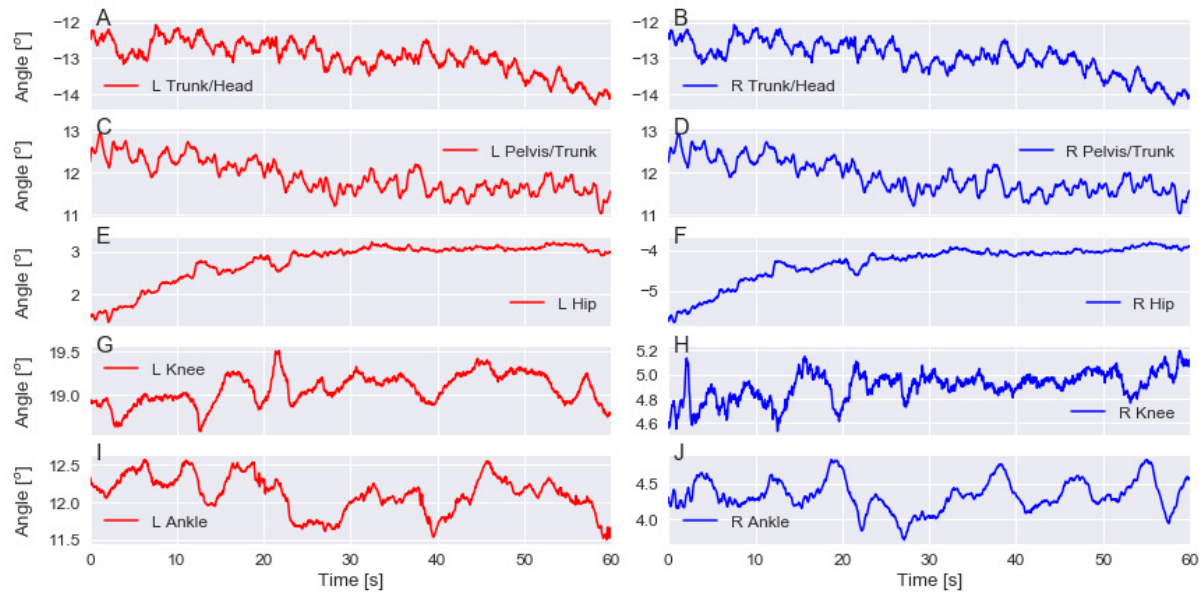


Figure 7. A–J: exemplary plot of the Cardan angles at the sagittal plane (flexion/extension) for the trunk/head, pelvis/trunk, hip, knee, and ankle joints for the left (L) and right (R) sides. Trial PDS13CR1 (elderly subject standing with eyes closed on a rigid surface).



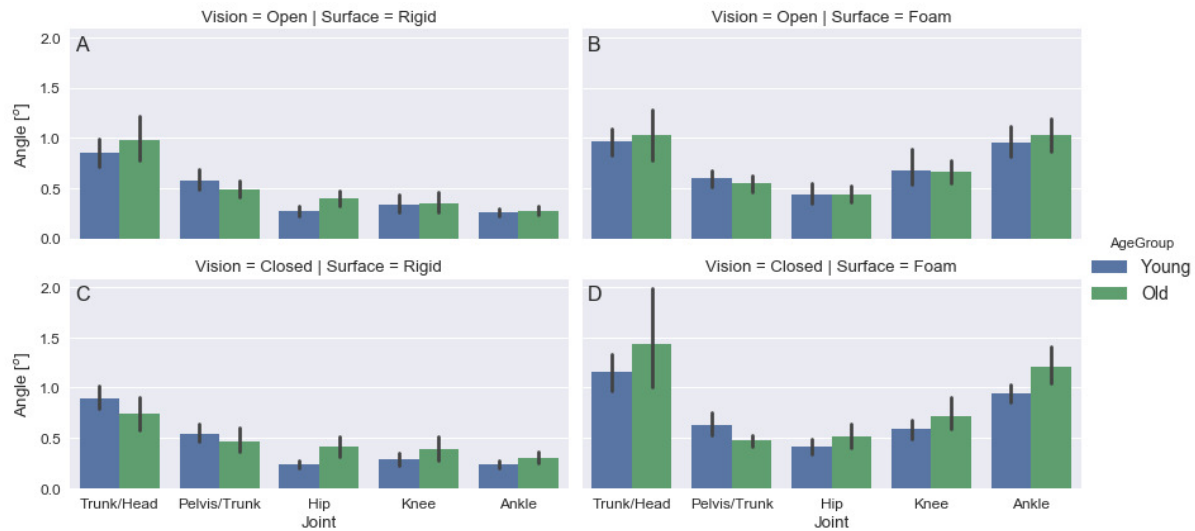


Figure 8. A–D: mean and 95% confidence intervals across subjects of the amplitude range (maximum minus minimum) for the Cardan angles at the sagittal plane (flexion/extension) for the trunk/head, pelvis/trunk, hip, knee, and ankle joints at the different visual and support surface conditions (color coded by age group).

## 4 Discussion

The data set made publicly available at Figshare (DOI: 10.6084/m9.figshare.4525082) and described in this work includes data regarding the three-dimensional kinematics of the whole body and the GRFs (with a dual force platform setup) of 27 young and 22 older adults while standing in different conditions. We also made a file with metadata about the subjects' sociocultural, demographic, and health characteristics available in the same data set.

In this article, we illustrated how this data can be accessed and explored; a companion Jupyter Notebook (available at <https://github.com/demotu/datasets>) presents the programming code to generate such analyses and other examples. The preliminary exploration of the data performed so far suggests that these subjects presented similar basic characteristics to the



characteristics presented in different studies about human balance that employed similar methods (Freitas et al. 2005; Santos & Duarte 2016; Visser et al. 2008; Winter 1995).

We previously created a public data set (Santos & Duarte 2016) with the results of qualitative and quantitative evaluations related to human balance with the same testing conditions employed here. These are the only two data sets related to human balance of which we are aware that are available in the literature. The key difference of the present data set is that this data set has provided the full-body 3D kinematics and the GRF of each foot of the subjects during the standing still trials. These additional measurements are very relevant to the scientific community considering the nature of human posture and the current research about human balance published in the literature.

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