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***Abstract*— The maintenance of balance in upright stance is traditionally evaluated using heavy and expensive force platforms. The aim of this work is to prove the usefulness of a low-cost wearable sensor (an actigraph) to assess postural sway. We compared the performance of the device to a gold standard force platform. We analyzed measurements of postural sway in four conditions differently challenging the subject: with eyes open or closed, while keeping a small or large base of support. We estimated the main postural parameters (ellipse area, medio-lateral and antero-posterior root-mean square, eccentricity, sway path length) considering: 1) acceleration data recorded by the actigraph, and 2) traditional COP data obtained from the force platform. We found that it is possible to clearly distinguish the differences among the postural parameters, obtained in the various balance conditions, also using acceleration data. Our results show that the wearable device allows for obtaining information similar to those achievable by the force platform. This support the use of wearable devices to assess postural balance, in a handy and cheap manner.**

Keywords—Accelerometers; Inertial Measurement Units; IMUs; posturography; balance; postural balance.

I. INTRODUCTION

Posturography is the systematic measurement and description of quantities that characterize the human postural sway in upright stance. It is used, in the clinical field, to assess fall risk in geriatric subjects [1] and to quantify balance-related disabilities [2][3][4][5] and, in sport-science, to assess the postural balance of athletes [6]. The increasing interest towards the study of balance has led to a continuous evolution of the methods used to carry out this examination. Traditionally, posturography is performed using a force platform to estimate the postural sway from Center-Of-Pressure (COP) trajectories [7]. Although force platforms are considered as the gold standard to obtain reliable balance measurements, they are costly and heavy to transport, making them impractical in clinical settings and sport centers. In recent years, inertial measurement units (IMUs) are increasingly being used in posturagraphy [8], but they have not yet become a standard, due to the unknown accuracy of IMU-based measurements with respect to the gold standard. If proven accurate, the use of IMUs for balance measurements would be ideal since they are inexpensive, wearable and easily portable in different environments.

The aim of this work is to prove the usefulness of a low-cost wearable device (an IMU-based actigraph) to assess postural sway, using 3D accelerometric data. We compared the performance of the actigraph to a gold standard force platform, analyzing measurements of postural sway in four distinct conditions, each of which differently challenges postural balance.

II. MATERIALS AND METHODS

We recorded postural sway signals by using the wearable device and the force platform at the same time.

A. Wearable device (actigraph) to measure accelerations

The wearable device is an actigraph (size: $70 \times 45 \times 10$ mm, mass: < 50 g) designed at our lab for human activity recognition [9][10] and now produced by Medical Technology (Italy). This activity tracker is equipped with a Magneto-Inertial Measurement Unit (MIMU) that includes 3-axis accelerometers, 3-axis gyroscopes and 3-axis magnetometers. In the present work, we used the device as a data logger. After each test session, we downloaded the data to a PC through a USB cable. In particular, we were only interested in x-, y-, and z-acceleration data (measurement range of accelerometers: $\pm 4g$). The sampling frequency of the actigraph is 80 Hz.

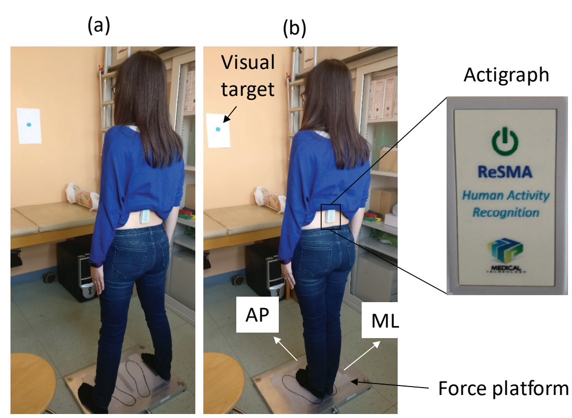

Figure 1. Subject positioned over the force platform with the wearable device (actigraph) attached to her back. The subject gazes at a visual target in the eyes-open conditions. Different balance conditions are represented: (a) Wide base of support (feet apart), (b) Small base of support (feet together).

B. Force platform to measure COP signals

The force platform used is a Kistler type 9286A (Kistler Instruments AG, Inc Winterthur, Switzerland), and the signals were acquired by the system Step32 (Medical Technology, Italy). The initial sampling frequency was 2 kHz. Then the signals were down-sampled to 80 Hz.

C. Protocol

The subject (healthy female volunteer aged 24) stood barefoot over the force platform. The actigraph was attached over the trunk, in correspondence of the 5th lumbar vertebra (L5) using bi-adhesive tape (see Fig. 1). Acceleration signals and COP signals were acquired, at the same time, with the actigraph and the force platform, respectively.

The subject maintained quiet upright stance with arms at her sides. She performed 12 tests, in randomized order, consisting of 3 repetitions in each of the 4 following balance conditions:

- EO_wide - Eyes Open with wide base of support (feet apart)
- EC_wide - Eyes Closed with wide base of support (feet apart)
- EO_small - Eyes Open with small base of support (feet together)
- EC_small - Eyes Closed with small base of support (feet together).

In the two eyes-open conditions, the subject gazed at a fixed target, positioned on the wall in front of the subject at a distance of approximately 2 m from the subject's eyes.

In each test, the subject maintained upright posture for 1 minute and 20 seconds. After each test, the subject could leave the platform and move freely for 1 minute, to avoid fatigue effects.

To synchronize the actigraph and the force platform, during the first few seconds of each signal acquisition the volunteer performed a small hop, rapidly raising the heels from the platform. Towards the end of the acquisition, the subject performed another small hop. Then, only the central 60 s were considered in the analysis.

D. Signal processing

For the synchronization, we used the acceleration along the vertical axis (z) recorded by the actigraph and the force F_z recorded by the force platform, using the signals sampled at 80 Hz.

The x-, and y-acceleration signals were then down-sampled to 20 Hz, low-pass filtered (3th order Butterworth, cut-off frequency: 5 Hz) and the mean value was removed.

A similar procedure was applied also to the mediolateral (ML) and antero-posterior (AP) components of the COP signals.

E. Postural sway parameters

Various parameters are typically derived from COP signals to quantify postural sway, including: ellipse area, root-mean-square amplitude in the medio-lateral (rmsML) and antero-posterior (rmsAP) directions, sway path length (SPL) and eccentricity [3].

For each postural test, we estimated these five parameters, for both acceleration sway (signals from the actigraph) and COP sway (signals from the force platform).

III. Results and Discussion

Figure 2 and Figure 3 show the postural sway measurements obtained with the actigraph (acceleration signals) and the force platform (COP signals), respectively. The first trial recorded in each balance condition is reported.

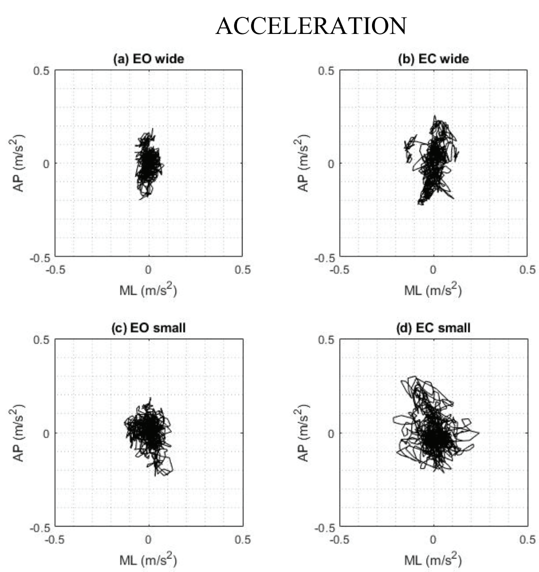

Figure 2. Acceleration sway measured by the wearable sensor (actigraph) in the transverse plane (AP: antero-posterior direction, ML: mediolateral direction), in 4 different postural conditions: (a) Eyes open (EO) and wide Base of Support (BOS), (b) Eyes closed (EC) and wide BOS, (c) EO and small BOS, (d) EC and small BOS.

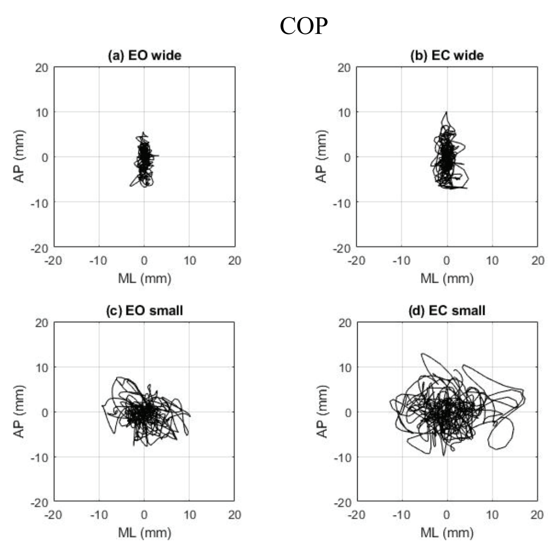

Figure 3. COP sway measured by the force platform (AP: antero-posterior direction, ML: mediolateral direction), in 4 different postural conditions: (a) Eyes open (EO) and wide Base of Support (BOS), (b) Eyes closed (EC) and wide BOS, (c) EO and small BOS, (d) EC and small BOS.

In both Figure 2 and Figure 3, analyzing the sequence of plots from (a) to (d), it can be noticed that the postural sway always increases with visual deprivation, in both feet-together and feet-apart conditions. Furthermore, the shape of the

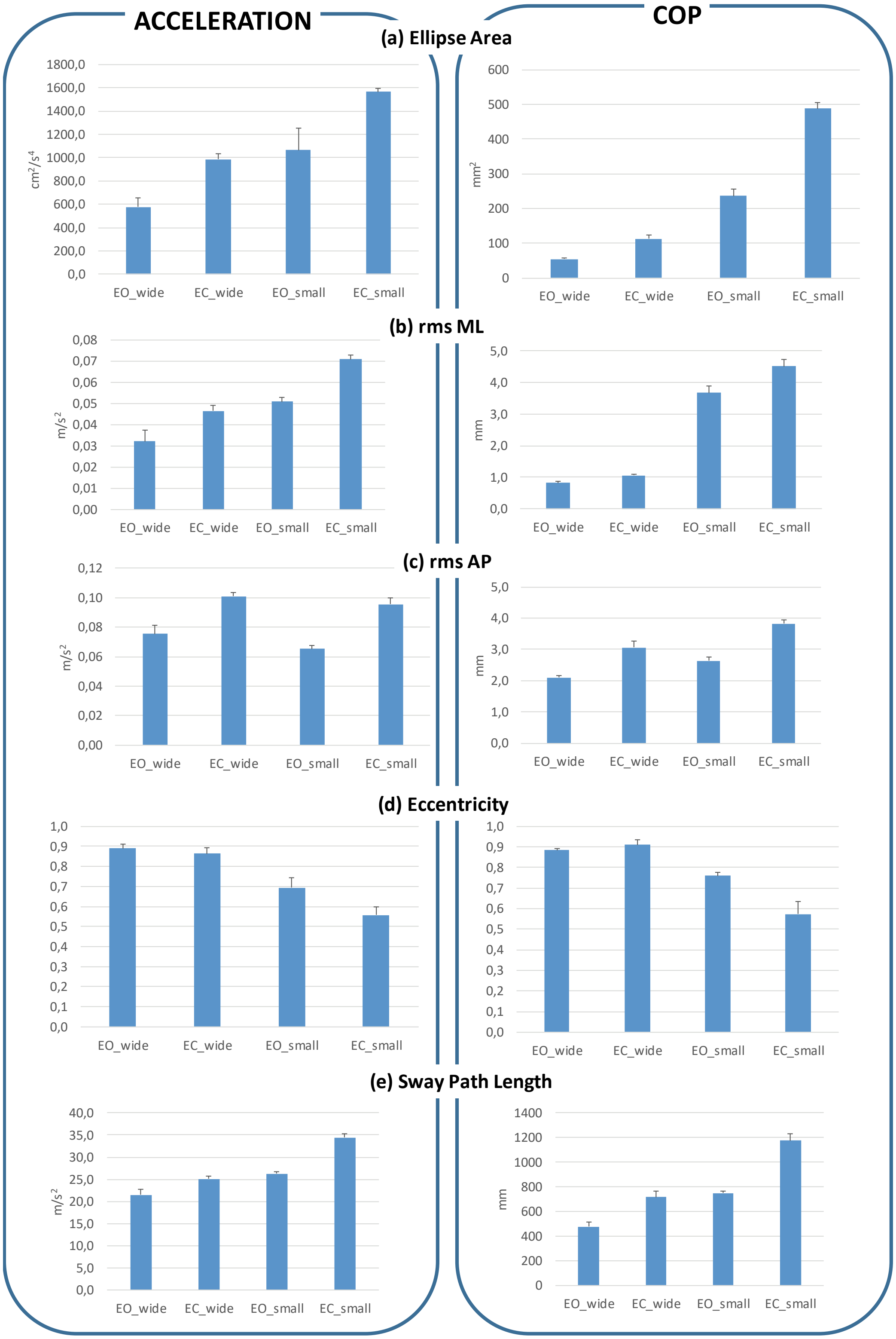

Figure 4. Postural sway parameters from acceleration signals (wearable actigraph) and COP signals (force platform): (a) Ellipse Area, (b) Medio-Lateral root mean square, (c) Antero-Posterior root mean square, (d) Ellipse eccentricity, (e) Sway Path Length. The mean value and standard error across 3 trials are reported, for each balance condition (Eyes Open wide base of support (BOS), Eyes Close wide BOS, Eyes Open small BOS, Eyes Close small BOS).

postural sway markedly changes when reducing the base of support. In particular, an increased contribution of the ML sway can be noticed with a smaller base of support (feet-together), both with and without visual deprivation.

The characteristic features of the postural sway, in the different balance conditions, are evident in both acceleration and COP data. From this perspective, an analogous information can be obtained from the actigraph with respect to the gold standard.

Figure 4 shows, for both acceleration and COP data, the average values and standard errors (across the 3 trials) of the postural sway parameters, in each balance condition. Again it can be noticed that the differences between eyes open/closed conditions and wide/small base of support can be appreciated both with acceleration data from the actigraph and COP data from the force platform.

IV. Conclusion

This work demonstrated the feasibility of using a low-cost wearable sensor to perform posturographic studies with an accuracy comparable to that of a force platform, which is the current gold standard. This is important to assess postural balance, in a handy manner, in different clinical environments and sport centers.

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