IMU-Based balance assessment: alternative or complementary to gold standard GRF-based posturography?

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Summary

The measurement of center of pressure (CoP) trajectory has become the de-facto standard for posturography. Recently, inertial measureament units (IMU) have been proposed as a portable alternative to force plates. Although their demonstrated potential, the functional interpretation of these methods remains limited, and no standard approach exists for inertial signal processing. This work aims to compare ground reaction force (GRF) and IMU-based metrics in characterizing postural performance in healthy participants on varying surface and visual conditions, concurrently analyzing how results are affected by different filtering cut-off frequencies. A 5Hz cut-off frequency resulted to allow noise reduction maintaining 95% of the signal power. Low correlations were found between GRF- and IMU-based metrics and changes detected by the two approaches differed. Although describing the same behavior, GRF- and IMU-based metrics capture different aspects of postural control: based on the inverted pendulum model, GRF-based metrics describe postural adjustments, while IMU-based ones postural performance.

Introduction

IMUs have been proposed as a portable alternative to force plates for posturography, the most common sensor location being on the back at L5 level, assuming to approximate the centre of mass (CoM) acceleration [1]. Understanding how CoP trajectory relates to trunk acceleration (ACC), is essential for the functional interpretation of the results of both approaches. Based on the inverted pendulum model of quiet standing [4], ACC in the horizontal plane is proportional to the difference between CoP and CoM position. Therefore, GRF- and IMU-based metrics may have a similar mathematical formulation, but, being applied to COP trajectory and to (an approximation of) CoM acceleration, respectively, they quantify different aspects of posture, hindering direct comparison between them. Before attempting to provide a physiological interpretation of IMU-based metrics, literature [2] highlights that comparative sensitivity of GRF- and IMU-based metrics to testing conditions must be assessed, and IMU acquisition and processing protocols require standardisation. This work aims to compare IMU- and GRF-based metrics of postural response to variations in visual and surface conditions in healthy individuals also analyzing sensitivity to IMU-signal pre-processing filtering methods.

Methods

Twenty-one healthy participants (11females/10males, 24±3years, 1.71±0.1m, 64±10kg) were asked to maintain static posture under 8 different randomized conditions (4 support surfaces: without-foam, soft-foam (E=33KPa), medium-foam (E=52kPa), rigid-foam (E=139kPa); 2 visual conditions: eyes-open, EO, eyes-closed, EC). Posture data were collected using a force platform (Bertec, USA, 800Hz) and an inertial sensor at L5 level (Cometa, Italy, 200Hz) [1,2]. COP signals were lowpass-filtered at 10Hz. Based on literature review [2], ACC were lowpass-filtered at: 0.5Hz, 3.5Hz, the maximum frequency containing 95% of the signal power (f95max), 2*f95max, 50Hz. Time- and frequency-domain postural parameters [1] were extracted from both COP and ACC with different filtering. As distribution was not normal, Scheirer–Ray–Hare test (significance level, 0.05) was applied to test the effect of surface and visual condition on COP and ACC. Foam-stiffness effect was also analyzed separately for EO and EC (Kruskal-Wallis, 0.05), to evaluate sensitivity to subtle changes.

Results and Discussion

f95max for IMU-signals resulted 5Hz. Correlations between GRF- and IMU-based metrics resulted weak to moderate ($0<|\rho|<0.7$): 3.5Hz- and 5Hz- low pass filtered ACC signals exhibited the highest number of moderate positive correlations ($\rho>0.40$). A 5Hz cut-off frequency resulted the best compromise to allow noise reduction maintaining 95% of the signal power. Both GRF- and IMU-based metrics showed increased postural oscillations on foam surfaces, but opposite behaviors in frequency, with no significant difference among different foam types. GRF-based metrics highlighted higher postural oscillations under eyes-closed conditions, especially on foam, whereas IMU-based metrics showed no significant change except range and root mean square in the medio-lateral direction that decreased with eyes closed.

Conclusions

Present results highlighted differences in GRF- and IMU-based posturography: low correlations between GRF- and IMU-based metrics were found and changes detected by the two approaches differed. These results support the hypothesis that, although describing the same behavior, GRF- and IMU-based metrics target different specific manifestation of postural control that, according to the inverse pendulum approximation [4] can be described as: i) postural adjustments for GRF-based (i.e., the trajectory of CoP); ii) postural control performance for IMU-based metrics (i.e., the CoM-CoP distance, proportional to CoM-ACC [4]).

References

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