Comparison of Plantar Pressure Mapping to Traditional Force Plate for Assessing Imbalance

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DISCLOSURE: Authors Joseph Schwab and Hamid Ghaednia hold patent rights for the optical pressure mapping device used in this study.

INTRODUCTION: Falls in older adults (>65 years) are a major healthcare concern with a critical gap in predictive measures. Despite a range of commercial devices, a lack of standardized, high-resolution, and clinically tested options has limited the clinical standard for qualitative assessments such as the Romberg test [1]. Recent efforts have turned toward quantitative platforms, such as force and plantar pressure mapping (PPM) devices, to address the gap. While force plates are commonly used for balance assessment, they offer limited resolutions incapable of detecting imbalance in healthy subjects [2]. Moreover, they cannot resolve load distributions between limbs or specific regions on the foot, constraining their diagnostic scope. Optical PPM devices by contrast offer high spatial resolutions and the potential for additional parameter extraction. This study compares the sensitivity of PPM devices to force plates in quantitating temporal sway.

METHODS: With IRB approval, 17 healthy volunteers (18-35 years, both male and female) with no neurological or musculoskeletal impairments performed balance assessments on a PPM device that simultaneously functioned as a force plate (Fig. 1A). Participants completed seven 30-second tests per session; a subset repeated the protocol in up to two additional trials, yielding a maximum of 21 recordings per subject. Tests T1-6 of the Romberg poses had participants stand with arms to their sides, extended forwards, or laterally, with eyes open and closed. The final test T7 involved participants fully extending their arms laterally, closing their eyes, and leaning their head back in the purposefully imbalanced vestibular inhibition pose.

The PPM system employed a custom frustrated total internal reflection (FTIR) platform: an elevated glass pane edge-lit by RGB LEDs. Plantar contact disrupted internal reflection and illuminated high-resolution contact patterns captured by camera in real-time. Four load cells beneath the pane provided concurrent force data, enabling direct comparison between FTIR-derived and FS-derived measures.

Center of gravity (CoG) trajectories were calculated independently from both PPM and FS signals. Postural sway was quantified as the absolute mean error of CoG. PPM data were additionally separated into right and left foot contributions for an understanding of sway and weight distribution per limb. To assess signal quality in the absence of a ground-truth variable, CoG trajectories from both systems were evaluated for continuity and predictability of movement. Continuity, here termed smoothness, was defined as the first derivative of the CoG after min-max normalization and outlier removal. Predictability was assessed via autocorrelation analysis. Both systems were evaluated for their degree of compatibility with expected physical conditions of static postural sway.

RESULTS: Initial comparisons of PPM- and FS- derived data evaluated all subjects' sway across test durations (Fig. 1B). In both systems, only the balanced (T1) and imbalanced (T7) poses demonstrated statistical significance in the Kruskal-Wallis test, indicating limited capacity to distinguish between intermediate poses. FS-derived CoG trajectories consistently exhibited magnitudes averaging 5.513 times larger than the corresponding PPM-derived trajectories. Consistent with expectations of greater imbalance in the plane of least symmetry, the sagittal-to-coronal sway ratio averaged 1.571 for PPM and 1.928 for FS signals across all subjects and tests. In analyses of continuity and predictability, PPM trajectories more closely aligned with physical expectations of postural sway. PPM consistently showed reduced CoG trajectory roughness within the 95% confidence interval, compared with increased fluctuations in the FS data (Fig. 1C). Similarly, FS-derived autocorrelation deviated further from short-term predictability of motion, supporting the conclusion that FS measurements are dominated by noise relative to PPM (Fig. 1D).

DISCUSSION: In static postures, CoG trajectories should remain both continuous and short-term predictable. Analyses of rate of change and autocorrelation confirmed that PPM data more closely adhered to these criteria, indicating greater fidelity than FS. By association, FS trajectories inflated CoG values due to noise and overestimated sway magnitude. Beyond improved accuracy, the PPM platform offers distinct clinical advantages. Postural stability depends on the coordinated function of the vestibular, proprioceptive, and visual systems. The balance test series systematically reduced support from these systems, such that T1 served as the balanced reference pose with all systems intact, and T7 as the maximally imbalanced pose with all systems removed. Although sway magnitude alone did not yield statistical distinction across all poses, the richer information available from PPM enables the possibility of pose differentiation through alternative parameters. The optical approach offers not only enhanced sensitivity for balance assessment, but also the potential for further analysis into clinically relevant insights, including peak plantar pressures, inter-foot asymmetry, contact area, and foot morphology.

CLINICAL RELEVANCE: Current force plate devices are limited by resolution and measurement parameters; instead, the fine-tuning of quantitative pressure mapping can allow for higher accuracy diagnoses of known at-risk patients as well as seemingly healthy individuals. Moreover, accurate PPM devices could be utilized for better progress assessment following a range of different musculoskeletal and neurologic diseases.

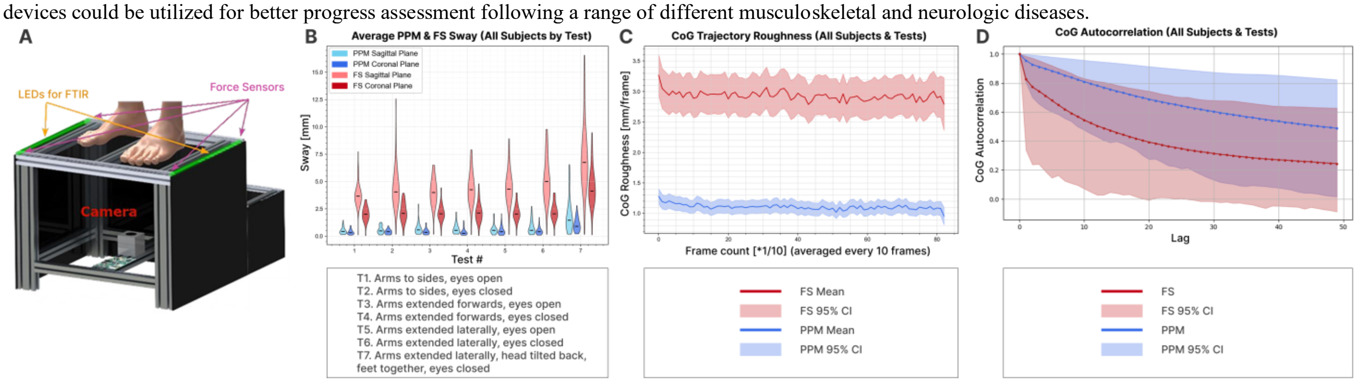

Figure 1. PPM vs FS platform design and comparisons. (A) 3D model of the PPM device built in house [2]. (B) Tracking of PPM vs FS sway magnitudes for all subjects across all tests. (C) PPM vs FS discontinuity of movement. (D) PPM vs FS predictability of motion.

REFERENCES:

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