The spectral content of postural sway during quiet stance: influences of age, vision and somatosensory inputs

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SUMMARY
Maintenance of human upright stance requires the acquisition and integration of sensory inputs. Spatio-temporal measures of sway have had limited success in addressing the complexities and dynamics associated with postural control. Participants performed quiet standing trials from which, ground reaction forces were sampled at 100Hz and then transformed to center of pressure (COP) data in the AP and ML directions. The results suggest existence of two distinct postural control sub-mechanisms operating at different time scales (e.g., slow reorientations and rapid stabilization). Such understanding of age-related adaptation of the postural control system can aid in the design and implementation of effective fall prevention strategies.

INTRODUCTION
The quantification of the performance of the postural control system (PCS) opens perspectives for fall-risk prediction and design of effective fall prevention strategies. Assessments of PCS function have been based upon data obtained during trials of quiet stance. Spatio-temporal and summary frequency measures have been unable to address the dynamics associated with the PCS[1]. Power spectrum analysis (PSA), however, is sensitive to the complexities associated with physiological systems [1]. The use of PSA on sway data can also discriminate between contributions of inputs to the PCS [2]. The aim here was to investigate the effects of visual and somatosensory inputs, and age on the spectral distribution of sway bi-directionally.

METHODS
Sixteen young (aged 18–24) and sixteen old participants (aged 55–65), gender balanced, completed several quiet, bilateral stances in four conditions, involving visual (eyes open & closed) and somatosensory feedback (compliant & hard surface). During trials, ground reaction forces were sampled at 100Hz with participants standing on a force platform. These were transformed to center of pressure (COP) data in the AP and ML directions [2, 3]. FFTs were used to perform PSA for each COP time series, which were normalized to the total power and divided into 50 bands of 0.1 Hz each (5Hz) to obtain mean normalized power (MNP). To achieve normal, homogeneous residuals, MNP values were natural-log transformed prior to statistical analysis. Mixed-factor ANOVAs were used to determine the effects of sensory conditions and aging on the MNPs. Adjustments for multiple post-hoc pairwise comparisons were made by controlling false discovery rates (FDR) [3] with a threshold rate of 0.05.

RESULTS AND DISCUSSION
Main effects of age, surface, and vision (Figure 1; Top) on MNPAP were evident for specific frequencies. Although older individuals had higher values at all frequencies except the lowest, the main effect of age was significant only in one

Figure 1: Log-log plot of MNP vs. frequency in the antero-posterior (AP; Top) and medio-lateral (ML; Bottom) directions showing the effects of vision. Grey areas indicate p < 0.05.
frequency band centered on 0.9Hz. Significant main effects of surface compliance were observed in three frequencies bands (0.1, 0.3, and 0.4Hz), while effects of vision on MNP$_{AP}$ were significant in all bands.

Significant main effects of age, surface, and vision (Figure 1; Bottom) were also observed on MNP$_{ML}$. Older individuals had significantly higher values in several middle and higher frequency bands, whereas surface compliance had significant effects in several frequency bands across the spectrum, including low (0.1Hz), low to middle (0.4 – 0.8Hz), middle to high (2.0 – 3.7Hz), and high (4.1 – 4.7Hz) frequencies. Significant main effects of vision were observed in low and low to middle frequencies (0.1 – 0.5 Hz) as well as several high frequencies (3.2 – 4.9Hz).

Interactive age x gender effects were evident on MNP$_{AP}$ and MNP$_{ML}$ (Figure 2), though these effects occurred at different frequencies. In middle – high frequencies (0.6 – 0.8Hz in AP vs. 1.0 – 5.0Hz in ML), this interactive effect was reflected in a differential influence of age between genders (or vice versa). At these frequencies, the increase in MNP among older individuals was more pronounced in males than in females. In addition, older males showed higher levels of MNP than the remaining three groups at the highest frequencies.

The results here indicate that age, eye closure and surface compliance all resulted in a similar spectral reorganization, with an increase in middle-high frequencies [2], as well as a decrease in the lowest bands. This may be due to an increased reliance on other sensory inputs in the absence of a particular modality, resulting in a tradeoff between the mechanisms of slow reorientations and more rapid corrective actions [4]. The preference towards increased rapid corrective actions, which is consistent with hypothesis of reduced system “complexity” with age[1], is reflected in the broadening of the spectral content of sway under more complicated conditions, suggesting the use of combined hip and ankle strategies [3].

CONCLUSIONS
Perturbing sensory inputs challenges the PCS such that there is increased periodicity (signal related noise) in the COP signal during quiet standing. The current results indicate distinct effects of vision, surface compliance as well as age and these effects were direction dependent. This study not only provides further confirmation for the existence of two distinct postural control sub-mechanisms but also emphasizes that these sub-mechanisms operate at different time scales. The effectiveness of system feedback seems to guide the preference for balance strategy, and could therefore explain changes towards a combined control strategy with aging.