Detecting and Understanding Differences in Postural Sway. Focus on “A New Interpretation of Spontaneous Sway Measures Based on a Simple Model of Human Postural Control”

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Postural sway during quiet standing reflects the interplay between destabilizing forces acting on the body and actions by the postural control system to prevent a loss of balance. Hence, balance impairments caused by altered sensory, motor, or central nervous function related to such factors as older age and pathology (e.g., Parkinson’s disease, peripheral neuropathy) will be reflected in altered characteristics of postural sway. The influence of different factors on postural sway during quiet standing has thus been the focus of much clinical and basic scientific study. Important considerations in such studies are which measures best characterize postural sway, which measures are best for detecting differences in postural sway, and how do differences in these measures relate to the postural control system?

To detect differences in postural sway requires a set of measures that can sufficiently characterize the “random” oscillatory motions that constitute sway. The measures must also be sensitive to variations in the underlying, physiological determinants of sway. Interpreting the detected differences then requires that the relationships of the measures to the underlying determinants be known. There is presently little basis for selecting and interpreting postural sway measures, however. Many and varied sway measures exist, in both the time domain (e.g., the SD of position) and the frequency domain (e.g., the median frequency of motion). Yet few comprehensive investigations have been performed of the relationships between these many sway measures or of the number of independent characteristics that they measure (Kitabayashi et al. 2003; Prieto et al. 1996; Rocchi et al. 2004). The main point of agreement of these studies is that multiple measures are needed to characterize postural sway. Studies of the sensitivities of different sway measures to changes in hypothesized physiological determinants of postural sway have also been few and limited in scope, such as of the effects of sensory noise or muscle stiffness on sway amplitude (Newman et al. 1996; Peterka 2000; van der Kooij et al. 1999; Winter et al. 1998). One reason for this limited study is that sensitivity analyses entail systematically varying one variable and observing the resulting changes in another; the properties of the postural control system cannot be easily manipulated in this manner experimentally.

In this issue, Maurer and Peterka (p. 189–200) take a novel approach to these considerations. They use a simple model of the human postural control system to investigate the relationship between different measures of postural sway and the sensitivity of these measures to changes in the properties of the postural control system. They then demonstrate that this simple model can be applied to experimental data to gain unique insight into the mechanisms underlying observed differences in sway. The model represented the body as an inverted pendulum controlled by an ankle torque that was determined from the angle of the body based on assumed stiffness, damping, and time-integration properties. Also included were a time delay in sensing body angle and a source of random noise added to the ankle torque. The behavior of the postural control system was characterized by five parameters, each having a straightforward physiological meaning and shown by Maurer and Peterka to be reliably estimable from postural sway measures using optimization techniques. Despite its simplified approximation of the postural control system, the model was able to generate simulations of postural sway for which 15 computed sway measures were all consistent with values reported for young and older adults. Such an experimental-based validation to provide support for the model’s basic structure necessarily established credence for the findings.

An important insight relevant to sway measurement emerged: just two independent factors explained 92% of the variance in 14 time- and frequency-domain measures across 59,049 simulations of postural sway. One factor was closely associated with measures of sway amplitude, the other with measures of sway velocity. A third group of measures reflected both factors. The practical implication is that measures of sway amplitude and velocity are both needed, and may in fact be sufficient, to characterize anterior–posterior postural sway.

Another important and novel finding related to sway measurement was that the 14 sway measures considered exhibited widely differing sensitivities to variations in the model parameters that determined postural sway. Interestingly, the most sensitive measures among those related to sway amplitude and those related to sway velocity were from a single class of measures called stabilogram-diffusion function (SDF) coefficients (Collins and De Luca 1993). These coefficients, which describe the relationship between the time interval of motion and the average corresponding change in position, would therefore be recommended for use in characterizing and detecting differences in postural sway. These findings demonstrate the utility of theoretical models in identifying sets of measures that are both sufficient and sensitive enough to detect differences in postural sway.

Also emerging from the sensitivity analysis was that most sway measures were sensitive to multiple parameters of the model. As an example, increases in measured sway amplitude could theoretically reflect either decreased stiffness or increased noise, whereas increases in both stiffness and noise...
might leave sway amplitude unchanged. This would argue that existing sway measures are limited in that they provide no clear indication of the mechanisms underlying differences in postural sway.

Maurer and Peterka therefore propose that their model parameters might be used to gain insights into the underlying mechanisms of observed differences in postural sway. By means of demonstration, identification of their model parameters from 14 measures of sway for young and for older adults led to the interpretation that the postural sway of older adults reflected increases in stiffness, damping, and noise in comparison to young adults. Furthermore, the findings of the sensitivity analysis led to the novel insight that the increased stiffness in the older adults could be an adaptation to counteract the destabilizing effects of increased noise on sway amplitude (at the expense of greater sway velocity). Such potential insight is uniquely made possible by analyzing differences in sway within the framework of a theoretical model. Note also that different models may be constructed based on alternate assumptions regarding the structure and functioning of the postural control system. Analyses using different models can provide corroborating or alternative interpretations of observed differences in sway; for example, might the sway of older adults reflect differences in passive tissue stiffness rather than in active muscle control?

These varied findings illustrate the great power of applying a theoretical model to the study of factors influencing postural sway. Through methods such as those promoted by Maurer and Peterka, the study of factors influencing postural sway may importantly progress from simply describing parametric differences toward identifying the postural control mechanisms responsible for these differences.

REFERENCES


