Measures of Postural Stability During Quiet Stance.

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INTRODUCTION

The control of balance and postural stability has been studied extensively by biomechanists and roboticists, with many interesting results. Postural sway is inherent in all humans during both bipedal and unipedal stance. Time series data of the Center of Pressure (CoP) of a subject on a force plate are most commonly used to analyze postural sway. In this paper we will outline how the time series data may be manipulated to discover what types of process are active, and describe measures that distinguish each series. We follow Zatsiorsky's rambling/trembling concept introduced in [3,4], with particular emphasis given to comparative tests of stability in the elderly. The focus of this paper is to describe the random stochastic movements contained in the tremble component of Zatsiorsky's framework.

METHODS

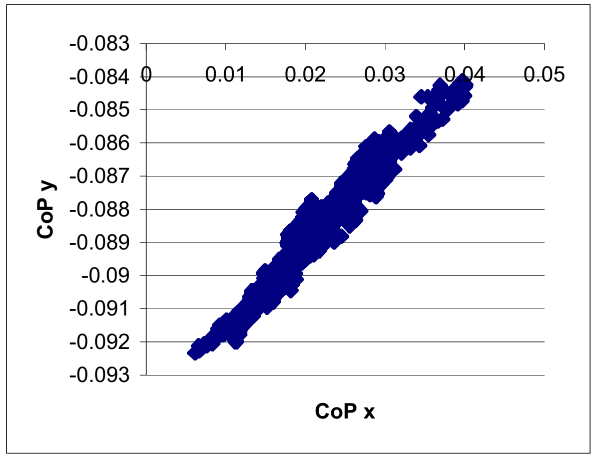
Force plate data were collected at 50Hz from 12 healthy subjects aged over 60. The data were processed to give (x, y)-coordinates of the CoP. After normalization and mean drift removal, we calculated the distribution of CoP movement in both anterior-posterior (AP) and medial-lateral (ML) directions.

We decided to model the migration of the CoP as a random walk in two dimensions, which is analogous to a particle undergoing diffusion. Inspection of the data revealed that the distribution of particle jump sizes was not Gaussian, and in fact, followed a stable distribution. Denoting the probability of finding the CoP at position x at time t by P(x, t), then the fractional diffusion equation, which has the class of stable distributions as solutions, is given by

$$\frac{\partial P(x,t)}{\partial t} = -D\frac{\partial^{\alpha} P(x,t)}{\partial x^{\alpha}} \quad , \qquad (1)$$

where $0<\alpha\leq 2$. In the case $\alpha=2$, the system is Gaussian, and we observe Brownian motion. This equation can be manipulated into an arbitrary dimensionality, with different α's in different directions [2]. The main feature of equation (1) is that the random walk described by this equation has large but infrequent particle jumps that drive the system.

Finally, a method was developed to calculate an individual measure of postural stability, based on existing theory in fractional calculus. For this, the multiscaling fractional advection-dispersion equation, examined thoroughly in [2] was used. Although heavily mathematical, the theory allows simple computation on data sets to obtain a measure of stability based on the exponent α in both the AP and ML directions.



RESULTS AND DISCUSSION

In the data analyzed to date, estimated α values were reduced when subjects moved from bipedal to unipedal stance. There was a further reduction of α when subjects closed their eyes. Figure 1 shows the change in CoP coordinates between consecutive samples for a subject in unipedal stance with eyes closed. Clearly the graph is suggestive of a high correlation between AP and ML movements. Using the multiscaling fractional advection-dispersion equation, we can use this correlation to find the real value of α in each direction.

CONCLUSIONS

From the data collected so far, it is clear that the rambling/trembling framework provides an excellent starting point for describing postural sway. Using the Lambda Model of [1] to describe the main cyclic component of sway combined with the random behavior observed, it is possible to come up with a measure of stability for each subject akin to the concept of Value at Risk (VaR) for a stock portfolio. VaR measures the risk in holding a correlated portfolio of stocks. This would provide a method of indexing subjects according to their relative stability with a minimum amount of a data collection required, which may prove particularly helpful in analyzing changes in stability over time.

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