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Ability of static and statistical mechanics posturographic measures to distinguish between age and fall risk

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Abstract

Traditional posturographic analysis and four statistical mechanics techniques were applied to center-of-pressure (COP) trajectories of young, older "low-fall-risk" and older "high-fall-risk" individuals. Low-fall-risk older adults were active 3 days per week in a cardiac rehabilitation program, while high-fall-risk older adults were diagnosed with perilymph fistula. Subjects diagnosed with perilymph fistula must have experienced two of the following vestibular findings: constant disequilibrium, positional vertigo and/or a positive fistula test. Non-parametric statistical tests were used to determine whether the posturographic measures could detect differences between the young and older "low-fall-risk" groups (age comparison) and between the older "low-" and "high-risk" groups (risk of falling comparison). The statistical mechanics techniques were more sensitive than the traditional measures: detecting significant differences between the young and older "low-risk" groups, while none of the traditional measures were significantly different. In addition, interpretation of the statistical mechanics techniques may offer more insight into the nature of the process controlling the COP trajectories. However, the methods offered slightly different explanations. For instance, the Hurst rescaled range analysis suggests that the movement of the COP is governed solely by anti-persistent behavior, whereas the stabilogram diffusion analysis suggests a short-term persistence balanced by a long-term anti-persistence. These discrepancies highlight the need for a model that incorporates the biological systems responsible for maintaining balance and experimental methods to directly quantify their status and roles. Until such a model exists, however, the statistical mechanics techniques appear to have some advantages over traditional posturographic measures for studying balance control.

Keywords: Center of pressure; Balance control; Stabilogram diffusion analysis; Older adults; Fractal

1. Introduction and background

Falling due to a failure in the postural control system because of aging or a specific pathology is a major problem facing the burgeoning population of older adults (Kannus et al., 1999; Rubenstein et al., 1994). Techniques to determine if an individual is at an elevated risk of falling due to deterioration of their postural control system that are sensitive to small deviations from the norm would provide a means for early detection and intervention. Additionally, the effectiveness of remedial procedures, e.g., balance training, could be evaluated.

A number of methods based on the displacement of the center of pressure (COP) during stationary, upright stance have been used to examine the postural control

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system. Traditional measures quantify the movement of the COP trajectory under the assumption that it is a stationary time series (Murray et al., 1975; Prieto et al., 1996). Statistical mechanics techniques describe the fractal and time evolutionary properties of the COP, and infer additional information about the nature of the postural control system (Collins and De Luca, 1993; Delignieres et al., 2003; Duarte and Zatsiorsky, 2000; Frank et al., 2001; Newell et al., 1997; Riley et al., 1997).

It has been suggested that traditional COP measures (e.g., COP range, sway path length, area) give few insights into the control of posture, since they are no more than summary statistics and they ignore the dynamic characteristics of COP movement (Collins et al., 1995; Collins and De Luca, 1995b). Statistical mechanics techniques have been shown to be sensitive to manipulations in a number of variables related to balance control, including age, touch, vision and subsensory mechanical noise, and additionally, they have been used to develop a conceptual model of postural control (Collins et al., 1995; Collins and De Luca, 1995a; Priplata et al., 2003; Riley et al., 1997; Tanaka et al., 2002). All these studies used a technique developed by Collins and DeLuca (1993) termed stabilogram diffusion analysis (SDA). However, other statistical mechanics approaches have been applied to COP trajectories including the Ornstein–Uhlenbeck model, Hurst rescaled range analysis ($H_{R/S}$) and detrended fluctuation analysis (DFA) (Delignieres et al., 2003; Duarte and Zatsiorsky, 2000; Frank et al., 2001; Newell et al., 1997). The ability of these other techniques to differentiate between individuals who differ in age or fall risk is not clear at this time. Also, clinical measures of balance performance do not always differentiate between "fallers" and "non-fallers" (Laughton et al., 2003). Therefore, identifying analytic techniques that are more sensitive to deterioration in the systems controlling posture is warranted.

The aim of this article is to examine the postural control of three groups of subjects differing in age or "risk" of falling and compare the ability of traditional and statistical mechanics COP analysis methods to detect differences between these groups. In addition, we discuss the insight into the postural control system offered by interpreting these methods. A secondary aim of this article is to document the data reduction and analysis methods for the statistical mechanics techniques.

2. Methods

2.1. Description of the three groups in the study

We examined three groups of individuals able to maintain unassisted upright stance: young healthy active adults (*n:* 10; age: 21–29 years; mean: 24.6), older healthy active adults at a "low-risk" of falling (*n:* 10; age: 68–79 years; mean: 72.6) and older adults at a "high-risk" of falling (*n:* 10; age: 57–80; mean: 69.1). The young and "low-risk" groups were recruited from the campus of Wake Forest University (WFU) and WFU Cardiac Rehabilitation program, respectively. These subjects had no history or evidence of neurological or musculoskeletal problems that would adversely affect postural control. Additionally, they did not report falling in the 3 years prior to data collection and were not presently taking any medication that would likely impair postural control. The "high-risk" adults were recruited from the Department of Otolaryngology at the WFU Baptist Medical Center and were chosen because their postural control system was severely compromised due to perilymph fistula. Subjects diagnosed with perilymph fistula must have experienced two of the following vestibular findings: constant disequilibrium, positional vertigo and/or a positive fistula test. The subjects in the "high-risk" group were asked to discontinue any anti-anxiety therapy at least 48 h before testing. Subjects in both the "low-" and "high-risk" groups were excluded from the study if they had experienced a major cardiovascular event in the last 3 years. The WFU Institutional Review Board approved this investigation and all participants gave their informed consent.

2.2. Experimental procedures and equipment

COP trajectory data were collected at 100 Hz using an Advanced Mechanical Technology Incorporated Model OR-5-1 biomechanics force platform. Subjects stood barefoot in an upright stance with arms relaxed comfortably at their sides with feet abducted 10° and heels separated medio-laterally by 6 cm. Subjects were instructed to focus their eyes on a point on the wall in front of them and stand quietly throughout the test. Subjects stood for 5 s before data collection began for each trial. Data were collected for a series of 10 30-s trials. Rest breaks were provided whenever necessary. During testing, all subjects wore a safety harness attached to support bolts in the ceiling. Pilot data collected on young adult ($n = 5$) and older adult ($n = 5$) subjects, with and without the safety harness, showed that the harness did not alter posturographic results in any measurable way.

3. COP analysis methods

3.1. Traditional static posturographic analysis

Four traditional parameters were calculated for each subject (averaged over the 10 trials). The reader is