INVARIANT DENSITY ANALYSIS OF POSTURAL SWAY AND PROSPECTIVE FALL RISK IN COMMUNITY-DWELLERING ELDERLY

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INTRODUCTION

Falls are one of the most common health concerns facing elderly persons today. About one-third of community-dwelling persons over the age of 65 and nearly one-half of institutionalized persons will fall each year.

Most prior studies have examined fall risk factors based on statistical descriptions of the current behavior of subjects. For instance, traditionally, center of pressure (COP) data have been analyzed using measures that describe the shape or speed of the trajectory. However, these traditional COP parameters represent only the present body sway behavior during the data collection, not in the future. Even though present behavior states may be associated with future falls, there is no *a priori* reason to expect that these traditional measures fully represent the future behavior of COP. That is, traditional measures in themselves are not designed for predicting future events.

A Markov-chain model can be used to determine how the COP behavior will evolve to a stationary distribution, called the Invariant Density. This invariant density analysis (IDA) procedure for examining COP behavior has been found to be successful at distinguishing and providing physiological insight into age-related differences in postural control behavior in a cross-sectional study on healthy young, middle-aged, and elderly adults [1]. In the current study, we propose to validate whether IDA parameters, which predict future states of COP, have the ability to predict fall risk of an elderly cohort of community-dwelling men and women.

METHODS

Experiment

Data were analyzed from the MOBILIZE Boston Study, an ongoing population-based study of 765 community-dwelling older adults [4]. We used data from the first 600 participants. After excluding for insufficient falls follow-up and unacceptable IDA noise level (≥0.5mm), 304 adults were categorized as non-recurrent fallers (< 2 falls) and 140 adults were categorized as recurrent fallers (≥ 2 falls) based on their prospective falls calendars and follow-up phone calls during the first year of study. Anterior-posterior (AP) and medial-lateral (ML) COP data were collected at baseline. Subjects were asked to stand quietly on a force plate for five 30s trials with their eyes open. COP data were sampled at 240 Hz.

COP analysis

IDA is an analysis tool for COP data using a Markov-chain model. IDA assumes that COP data are stochastic, and future COP movement depends only on the present location of the COP. A "state" is defined as the distance from the centroid of the COP stabilogram to the COP current position. (The width of each state ring is 0.2 mm, as determined by the force platform noise level.) The long term movement of the COP is determined by the invariant density, which is an eventual distribution of probability of finding the COP at any given distance away from the center. Invariant density can be computed as the left eigenvector of the transition matrix, which describes the transition probability of the COP from one state to another. Therefore, analyzing the invariant density can give insight to the future behavior of the COP.

Invariant density is characterized by five parameters.

1. *Ppeak*: Identifies the largest probability of the invariant density.
2. *MeanDist* ($\sum_{i \in I} i\pi(i)$): Weighted average state (or average location) that contains the location of the COP. (*I* is the set of all states).
3. *D95*: 95% of the COP data are contained within and below this and all previous states.
4. *EV2*: The second largest eigenvalue of the transition matrix, which corresponds to the rate of convergence of the invariant density.
5. *Entropy* ($-\sum_{i \in I} \pi(i) \log_2 \pi(i)$): Describes the randomness of the system; i.e., low entropy corresponds to a more deterministic system and high entropy refers to a more stochastic system.

In order to compare the IDA parameters to common measures of COP, we also evaluated fall status in terms of traditional descriptive statistical COP measures (TRAD, [2]) and another stochastic-based COP analysis method, Stabilogram Diffusion Analysis (SDA, [3]).

Statistical analysis

One-way analysis of variance (ANOVA) was used to test for differences between non-recurrent (NF) and recurrent fallers (RF), with α = 0.05 (SPSS Inc., Chicago, IL; v15).

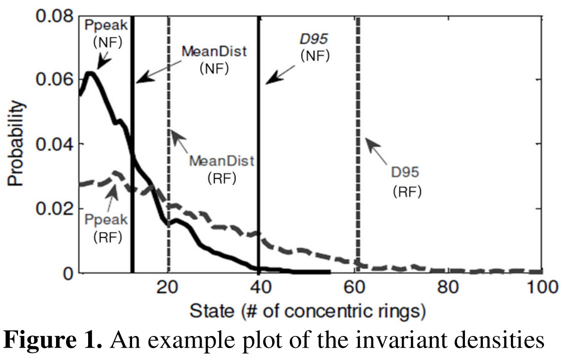

Figure 1. An example plot of the invariant densities of both NF (solid) and RF (dashed) showing the eventual distribution of probability that the COP will be found in a particular state

RESULTS/ DISCUSSION

Significant differences in COP measures were found between recurrent fallers (RF) and non-recurrent fallers (NF) (Table 1).

All IDA measures except *EV2* successfully distinguished recurrent fallers from non-recurrent fallers (Table 1). Only a few SDA and TRAD measures could make this distinction.

Table 1. IDA, SDA, and TRAD parameters with statistically significant differences between NF and RF. Mean±SE

	NF n=304	RF n=140	P
IDA			
Ppeak	0.047±0.0001	0.043±0.001	0.007
MeanDist	3.53±0.06	3.98±0.14	0.001
D95	8.43±0.15	9.56±0.33	<0.001
EV2	0.9992 ± 10^{-5}	0.9993 ± 10^{-5}	0.072
Entropy	5.33±0.025	5.47±0.038	0.001
SDA			
AP_crit dist	20.18±0.92	26.32±2.54	0.005
Rad_crit dist	31.64±1.46	38.90±3.74	0.030
TRAD			
MaxDistRad	14.51±0.24	15.41±0.39	0.043
SD_Rad	5.62±0.09	5.98±0.16	0.042
Range_AP	23.20±0.38	24.68±0.61	0.033
Power_AP	130.90±4.84	153.74±9.62	0.019

Smaller *Ppeak*, larger *MeanDist* and *D95* imply that COP of RF are more likely to stay away from the centroid and tend to wander around wider and more randomly than NF. Larger *Entropy* implies that the COP of RF follow more stochastic paths. This can be interpreted as RF having less degree of active control to keep the COP trajectory closer to the centroid. Finally, even though there were no statistical differences in *EV2* between groups, RF tended to have larger *EV2*, indicating that the COP of RF may converge more quickly to a steady-state behavior than for NF.

In conclusion, the COP of RF were found to fluctuate in a more random behavior than NF. IDA measures provide additional information about balance dynamics that are not captured by traditional COP measures and may provide insights into potential mechanisms of falls.

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