Fall Risk Estimation of Community-Dwelling Elderly Using Invariant Density Analysis

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ASB 2010

INTRODUCTION

- This study investigated the fall risk of community-dwelling elderly adults using Invariant Density Analysis (IDA) [1].
- IDA describes the stochastic process of the dynamical systems aspect of the postural control system (PCS). IDA involves determining the invariant density probability distribution that results from the fluctuations of the center of pressure (COP). Five key parameters associated with this distribution are used to characterize the PCS . Thus the invariant density provides insight into the long-term behavior of COP.
- Traditional COP postural sway parameters with simple statistical description do not capture dynamical systems aspects of the PCS. Stabilogram Diffusion Analysis (SDA) of COP fluctuations only provides summary information about the PCS; it cannot provide specific information about or recreate actual sway behavior.
- Therefore, we 1) investigated the efficacy of the use of IDA to examine the fall risk of community-dwelling elderly adults, and 2) developed a fall risk prediction model using IDA and other postural sway parameters.

METHODS

MOBILIZE Boston Study [2]

- Population-based study of novel risk factors for falls
- 765 community-dwelling elderly adults (age > 70)
- Prospectively followed for falls for 18 months

Subjects

- This study analyzed data from 444 subjects (304 non-recurrent fallers with 0-1 fall, and 140 recurrent fallers with 2+ falls during follow-up year)

Experimental Data

- Baseline test COP from five 30 s quiet standing trials with eyes open. COP data were sampled at 240 Hz.
- Clinical balance parameters: Berg Balance Scale (BBS) and Short Physical Performance Battery (SPPB)
- Retrospective fall history for 12 months prior to baseline testing

Invariant Density Parameters

1) ***Ppeak***: Peak value of the invariant density plot.

2) ***MeanDist*** [$\sum i\,\pi(i)$]: Average location of the COP.

3) ***D95***: 95% of the COP distribution is contained within and below this state.

4) ***EV2***: The second largest eigenvalue of P. This corresponds to the rate of convergence to the invariant density.

5) ***Entropy*** [$-\sum \pi(i)\log_2 \pi(i)$]: 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.

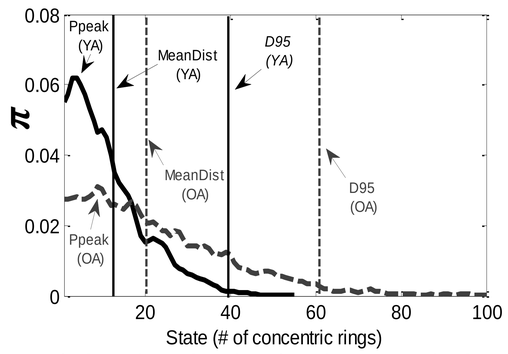

Fig 1. Sample invariant density plots for young (YA) & old (OA) adults

Data Analysis

- Distinguishing group differences using postural sway and clinical measures of balance
  1) Postural sway COP parameters: **IDA**, **traditional** (e.g. COP MaxDisp, StDev, Range, MeanVel, TotalPower, 95%PowerFreq, Ang Dev from AP axis) **and SDA** (short- & long-term diffusion coeff and scaling exp, critical point coordinates)
  2) Clinical balance parameters: **BBS** and **SPPB**
- Correlation analysis to investigate how IDA parameters were correlated with other parameters
- Fall risk prediction model constructed with 2 steps:
  1) Principal component analysis to reduce the number of candidate fall risk factors
  2) Logistic regression analysis to construct fall risk prediction model from balance parameters

RESULTS

Group Differences

Table 1. *IDA parameters mean (± SE) for non-recurrent fallers(NF) and recurrent fallers(RF).*
** t-test results for comparison between NF and RF*

Parameter	NF n = 304	RF n = 140	p-value*
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
Entropy	5.33±0.025	5.47±0.038	0.001
EV2	0.9992 ± 10^{-5}	0.9993 ± 10^{-5}	0.072

COP of:

- Non-recurrent fallers tend to stay within certain state (*Ppeak*)
- Recurrent fallers are likely to sway further away from centroid (*MeanDist*)
- Recurrent fallers wander wider (D95)
- Recurrent fallers sway in more random manner (*Entropy*)

Correlation Analysis

- IDA parameters were strongly correlated (r>0.7) with only a few traditional and SDA parameters (Table 2).

Table 2. *Parameters with strong correlation (r>0.7) to IDA parameters. However, in general, IDA parameters were not strongly correlated with other parameters, suggesting that IDA parameter provide unique information about COP fluctuation and the PCS.*

	Ppeak	MeanDist	D95	EV2	Entropy
TotalPower_AP	-0.60	0.77	0.74	0.40	0.69
MaxDisp_AP	-0.61	0.73	0.71	0.43	0.67
StDev_AP	-0.70	0.80	0.76	0.49	0.77
Range_AP	-0.65	0.76	0.73	0.44	0.71
Area95%Circle	-0.55	0.72	0.69	0.38	0.64

Principal Component Analysis (PCA)

Table 3. *PC coefficients and correlation coefficients between parameters and the corresponding PC. Both rotated and unrotated component matrices were considered for better alignment of variables to PC.*

Unrotated	PC 1 Postural sway (7.40)	PC 2 Func. balance (1.85)	PC 3 Dyn. Aspect (1.11)	Rotated	PC 1 Trad. SDA (4.74)	PC 2 IDA (3.76)	PC 3 Clinical meas (1.85)
Stdev_AP	0.94			**TotalPower_AP**	0.91		
TotalPower_AP	0.93			**CritPointY_AP**	0.86		
MeanDist	0.91			**Stdev_AP**	0.82	0.49	
D95	0.89			**Entropy**	0.42	0.87	
Entropy	0.88			**Ppeak**		-0.85	
Ppeak	-0.79			**EV2**		0.80	
CritPointY_AP	0.75		0.42	**D95**	0.56	0.71	
EV2	0.59		-0.43	**MeanDist**	0.60	0.70	
SPPB		0.89		**SPPB**			0.94
BBS		0.87		**BBS**			0.94

- Top three PCs have eigenvalues greater than one.
- Four candidate factors were found (EV2, Entropy, SPPB, TotalPower_AP).
- Rotated PCA suggests that IDA explains different direction of fall risk from traditional and SDA parameters.

Fall Risk Prediction Model, $ln(\text{Odds Ratio}) = \beta_0+\beta_1x_1 + \beta_2x_2+\ldots$

	β	Odds Ratio	p-value
Entropy	0.74	**2.09**	0.044*
Fall History	0.83	**2.29**	<0.001*
TotalPower_AP	-0.002	0.99	0.228
SPPB	-0.066	0.9	0.246
Age	-0.018	0.99	0.445
Gender	-0.055	0.048	0.259

- Entropy and retrospective Fall History were contributing factors
- Subjects with higher Entropy or retrospective Fall History have about twice the odds to become recurrent fallers
- Model has 33.9% sensitivity, and 93.4% specificity

CONCLUSIONS

- IDA parameters can distinguish recurrent and non-recurrent fallers (Table 1).
- IDA explained different directions (or dimensions) of fall risk, compared to other balance parameters (Tables 2-3).
- IDA Entropy may be an important factor for predicting fall risk of elderly adults (Table 4).

References:

[1] Hur et al. *ASME-SBC* SBC2009(Part B) 915-916, 2009
[2] Leveille et al. *BMC geriatrics* 8(1), 16, 2009

Acknowledgements:

This work is an ancillary study of the MOBILIZE Boston study. This work was funded by the Campus Research Board at the University of Illinois at Urbana-Champaign.