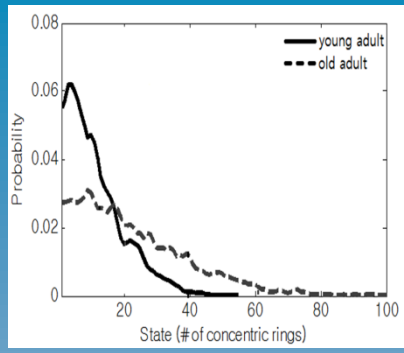
Invariant Density Analysis of Postural Sway and Fall-risk Prediction Model of Community-Dwelling Elderly Adults



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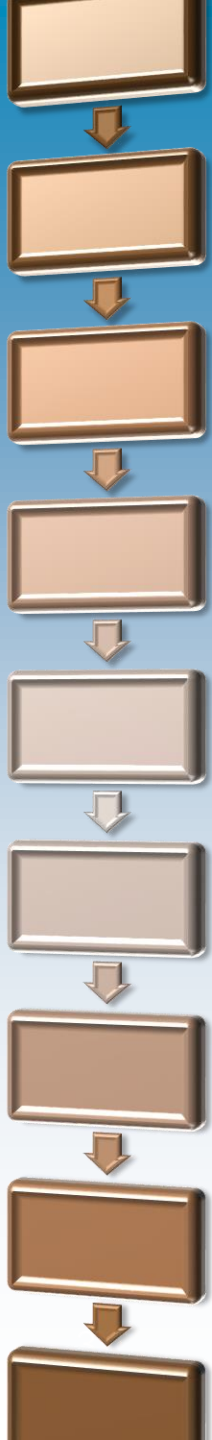
Poor Postural Control => Falls

- Measures of postural function are **descriptive** of sway behavior
  - Amplitude, MPF, velocity, …
- *Markers*, not **Causes**
  - Statistically correlated with Falls
  - Not designed to predict future behavior
  - Temporal evolution of dynamics

How do we predict the future?

- A stochastic approach: Markov Chains
  - Describe temporal fluctuations with **transition probability** from one state to another
  - "**Invariant Density**" π : stationary/steady-state probability distribution => COP behavior over long term

- **How will COP behave in the future?**
- **Do future behaviors explain falls?**

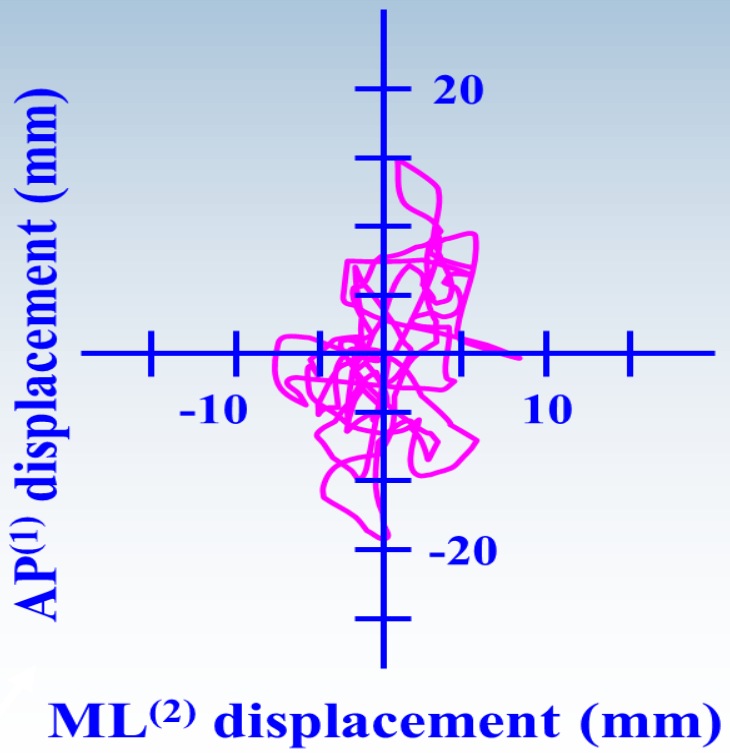


Participants

- MOBILIZE Boston Study
  - Population-based study of *novel* risk factors for falls
    - 765 Community-dwelling older adults
    - Age 70+, MMSE ≥18, English speaking, can walk 6 m
    - 64% Women; 20% Non-white; Mean age 78 ± 5.5
  - Prospectively followed for falls for 6 mo – 3 years
  - Data from 444 were analyzed

Postural Assessment

- Eyes Open
- 5 trials of quiet standing
  - Each trial = 30 seconds

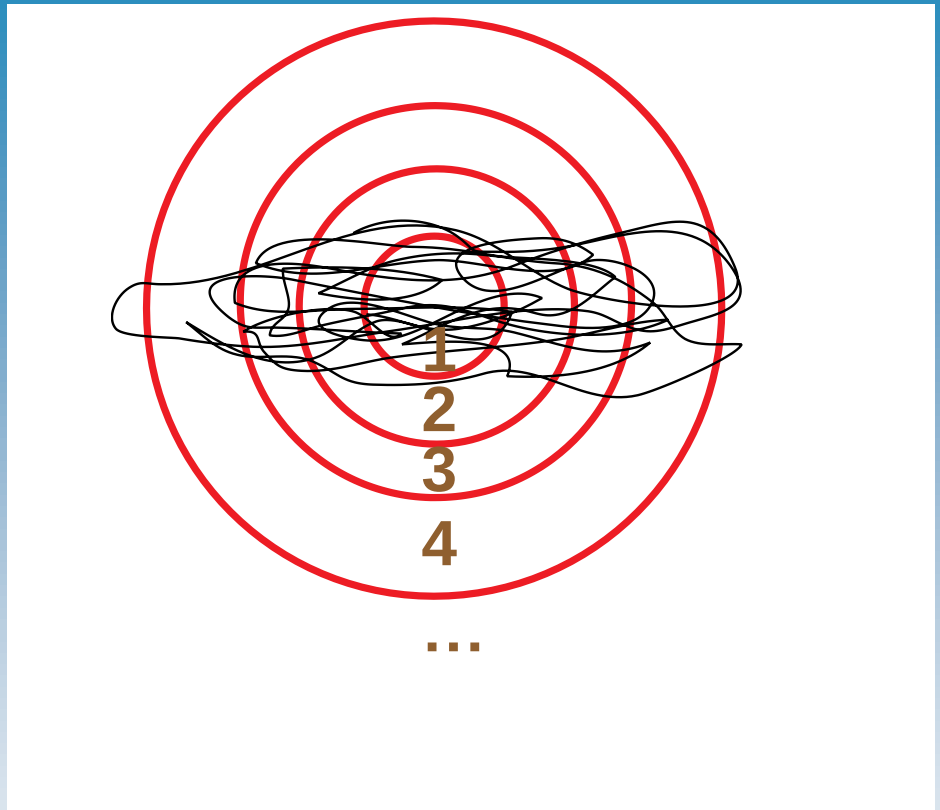


Invariant Density

- **Find centroid of COP**
- **Define states as concentric rings emanating from COP centroid**
  (states separated by 0.2 mm)
- **Construct the transition matrix (P)**

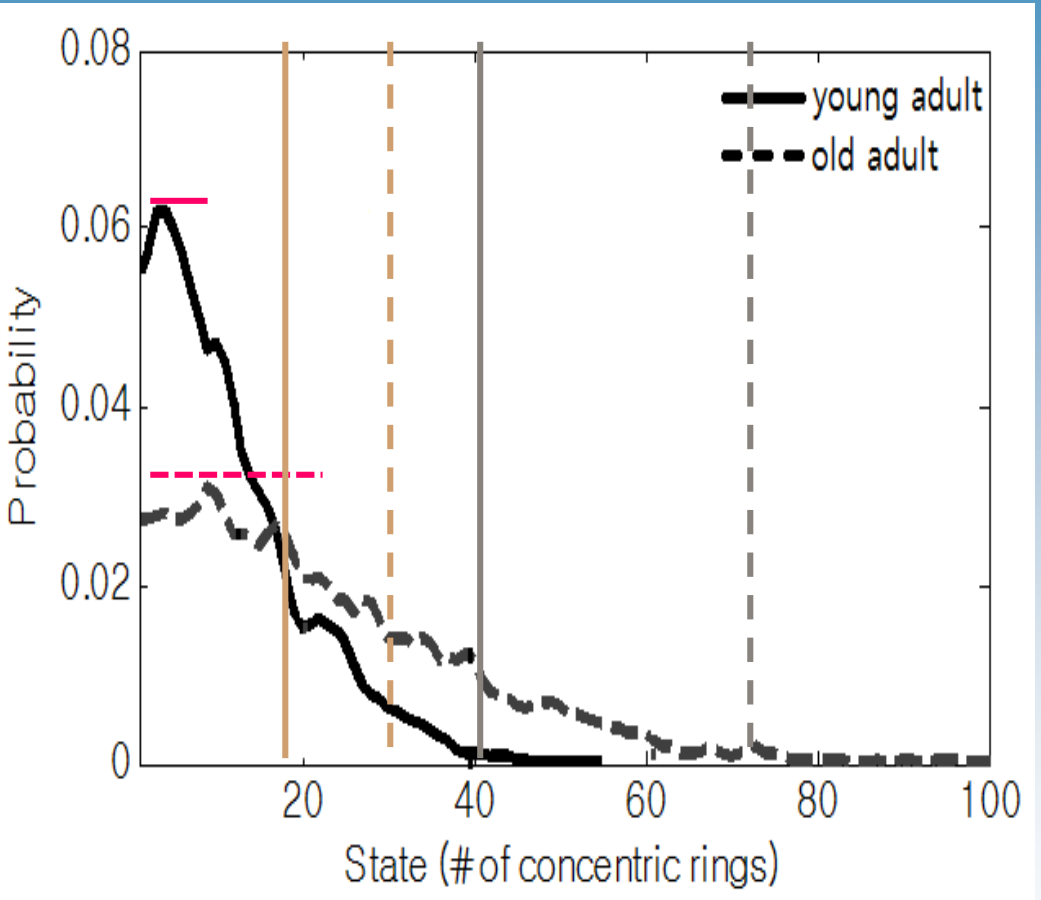
  P contains probabilities of transitioning from one state to another
- **Solve for the invariant density (π)**

  $\pi = \pi \mathbf{P}$



$$\mathbf{P} = \begin{array}{c} \\ \text{Current state} \\ \begin{matrix} 1 \\ \vdots \end{matrix} \end{array} \begin{array}{c} \begin{matrix} \text{Next state} \\ 1 \quad\quad 2 \quad\quad 3 \quad\quad \ldots \end{matrix} \\ \begin{pmatrix} 0.5 & 0.3 & 0.2 & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{pmatrix} \end{array}$$

Methods: Invariant density plot



Plots of invariant density distributions (π) for young and older individuals

Parameters

Ppeak – Probability of being in the state with maximum likelihood

MeanDist – Average state of COP sway

D95 – State where 95% of total COP sway

EV2 – 2nd largest eigenvalue, rate of convergence to π

Entropy – Randomness of system $= -\pi(i)\log_2\pi(i)$,

Falls Assessment

- Mail-in calendar postcards
- staff calls to verify and ascertain circumstances of falls (location, etc.)

–**Recurrent fallers**: 2+ falls within a year of study (*n* = 140)

–**Nonrecurrent fallers**: 0-1 falls within a year (*n* = 304)

INSTRUCTIONS: AT THE END OF EACH DAY, PLEASE PLACE THE LETTER "N" IN THE BOX IF YOU DID NOT FALL, OR THE LETTER "F" IN THE BOX IF YOU DID FALL

February 2008

SUN	MON	TUE	WED	THU	FRI	SAT
1 N	2 N	3 N	4 N	5 N	6 N	7 N
8 N	9 N	10 N	11 N	12 F	13 N	14 N
15 N	16 N	17 N	18 N	19 N	20 N	21 N
22 N	23 N	24 N	25 N	26 N	27 N	28 N

MAIL CARD PLEASE!

- Analysis 1: Are the recurrent fallers different from non-recurrent fallers?

Results: Group differences

	Non recurrent fallers	Recurrent fallers	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

*p-value from independent *t*-test examining differences between groups

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

Results: Distinguishing group differences (cont'd)

	Non recurrent fallers	Recurrent fallers	p-value*
Entropy	5.33±0.025	**5.47±0.038**	0.001
EV2	0.9992 ± 10^{-5}	0.9993 ± 10^{-5}	0.072

*p-value from independent *t*-test examining differences between groups

- **Recurrent fallers sway in more random manner (Entropy)**
  → It may imply recurrent fallers have less degree of active control to keep COP close to centroid

Results: Similar to 'Traditional' Ms.

	Non recurrent fallers	Recurrent fallers	p-value*
Stdev_AP	4.57 ± 0.08	**4.86±0.12**	0.046
Range_AP	23.30 ± 0.38	**24.68 ± 0.61**	0.033
TotalPower_AP	130.9 ± 4.8	**153.7 ± 9.6**	0.019
Area95%Circle	312.3 ± 11.4	**357.4 ± 20.9**	0.041
CritPointY_AP	20.19 ± 0.92	**26.32 ± 2.54**	0.024

*p-value from independent *t*-test examining differences between groups

- **5 traditional and SDA parameters also found that recurrent fallers swayed more**

- Analysis 1: Are the recurrent fallers different from non-recurrent fallers?
  - **YES**
- Analysis 2: Do these new metrics really measure anything different?

Results: Correlation analysis

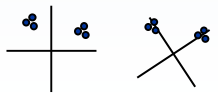
	Ppeak	MeanDist	D95	EV2	Entropy
TotalPower_AP	-0.60	0.77	0.74	0.40	0.69
95%Freq_AP	0.05	-0.11	-0.08	-0.33	-0.10
AngDev	0.19	-0.14	-0.11	-0.16	-0.19
TotalSway	-0.44	0.53	0.54	0.17	0.49
ShortDiff_AP	-0.44	0.50	0.51	0.11	0.47
LongDiff_AP	-0.39	0.34	0.32	0.29	0.42
CritPointY_AP	-0.40	0.62	0.59	0.27	0.48
BBS	0.11	-0.14	-0.14	0.04	-0.13
SPPB	0.08	-0.12	-0.11	0.08	-0.10

- **Some parameters (e.g., TotalPower_AP) were strongly correlated with IDA parameters**

Results – Principal Components

Unrotated	Postural sway (7.40)	Func. balance (1.85)	Dyn. Aspect (1.11)
Stdev_AP	0.94		
TotalPower_AP	0.93		
Range_AP	0.92		
MeanDist	0.91		
D95	0.89		
Area95%Circle	0.89		
Entropy	0.88		
Ppeak	-0.79		
CritPointY_AP	0.75		0.42
EV2	0.59		-0.43
SPPB		0.89	
BBS		0.87	

Rotated	Trad. SDA (4.74)	IDA (3.76)	Clinic. (1.85)
TotalPower_AP	0.91		
Area95%Circle	0.89		
CritPointY_AP	0.86		
Range_AP	0.85	0.42	
Stdev_AP	0.82	0.49	
Entropy	0.42	0.87	
Ppeak		-0.85	
EV2		0.80	
D95	0.56	0.71	
MeanDist	0.60	0.70	
SPPB			0.94
BBS			0.94



- Analysis 1: Are the recurrent fallers different from non-recurrent fallers?
  - **YES**
- Analysis 2: Do these new metrics really measure anything different?
  - Correlated, but something different
- Analysis 3: Which predicts falls better?

Fall Prediction Model

- Multivariate Model: fall risk = f (predictors)
  - Predictors: Entropy, Signal Power
  - Confounders: age, sex, fall history, SPPB

- Logistic regression

$$ln\frac{p}{1-p} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots$$

- p = probability of being a recurrent faller
- If x_1=>x_1+1 then Odds =>Odds x $e^{\beta 1}$
  - $e^{\beta 1}$ = Odds Ratio (OR)
  - OR >1: fall risk increases with x_1
  - OR <1: fall risk decreases with x_2

Results – Multivariate Fall Prediction Model

	β	Odds Ratio	p-value
Entropy	0.74	**2.09**	0.044*
Fall History	0.83	**2.29**	<0.001*
Signal Pwr_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

*factors that significantly contributed to predicting recurrent fallers

$z=\text{Log}(\text{Odds})=\beta_0+\beta_1 x_1+\beta_2 x_2+ \ldots$

- **Entropy and Fall History were contributing factors**
- **The subject with higher Entropy or Fall History has about twice the odds to become recurrent faller**
- **20% of total variance was explained by the model**
- **24.9% miscalculation rate (33.9% sensitivity, 93.4% specificity)**

- Analysis 1: Are the recurrent fallers different from non-recurrent fallers?
  - **YES**
- Analysis 2: Do these new metrics really measure anything different?
  - Correlated, but something different
- Analysis 3: Which predicts falls better?
  - Entropy, after accounting for other measures

Conclusion

- **IDA explained different dimension of fall risk, compared to other balance parameters**

- **Entropy from IDA might be important factor to predict fall risk of elderly adults**

Acknowledgements

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Mobilize Boston
Community Senior Health Study

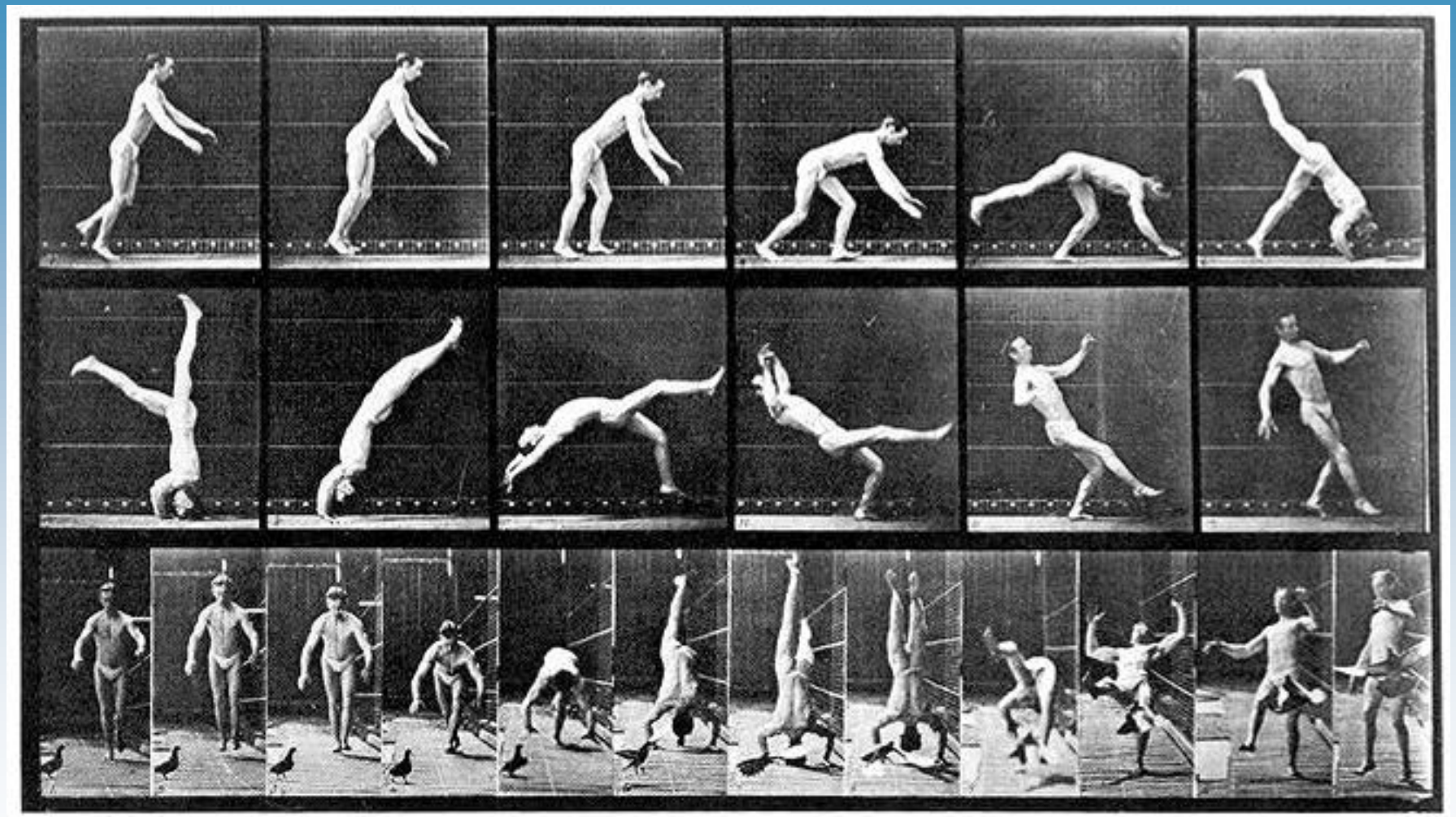
MOBILIZE Boston Research team and study participants

Deterministic model and falls:

- **D4-C-T2.6: Track 2.06 - Orthopaedic Biomechanics**
- **Today: 1545 - 1600 hrs, Room: 308**
- Postural Stiffness, Damping, and Dual Task in Older Adults: The Mobilize Boston Study

- **D5-A-S2.3-8: Sym 2.03-08: Falls - Mechanisms, Injuries and Interventions**
- **Tomorrow: Friday, 6 August 2010, Time: 0900, Room: 310**
- Postrual Stiffness, Damping, and Outdoor Falls in Older Adults: The Mobilize Boston Study

Thank You!



EADWEARD MUYBRIDGE. »Kopfstandüberschlag, eine Taube kommt dazwischen«. 1885. Tafel 365 aus: »Animal Locomotion« Philadelphia 1887. Albuminpapierkopie nach dem Originalnegativ im George Eastman House, Rochester, N.Y.

E. Muybridge