

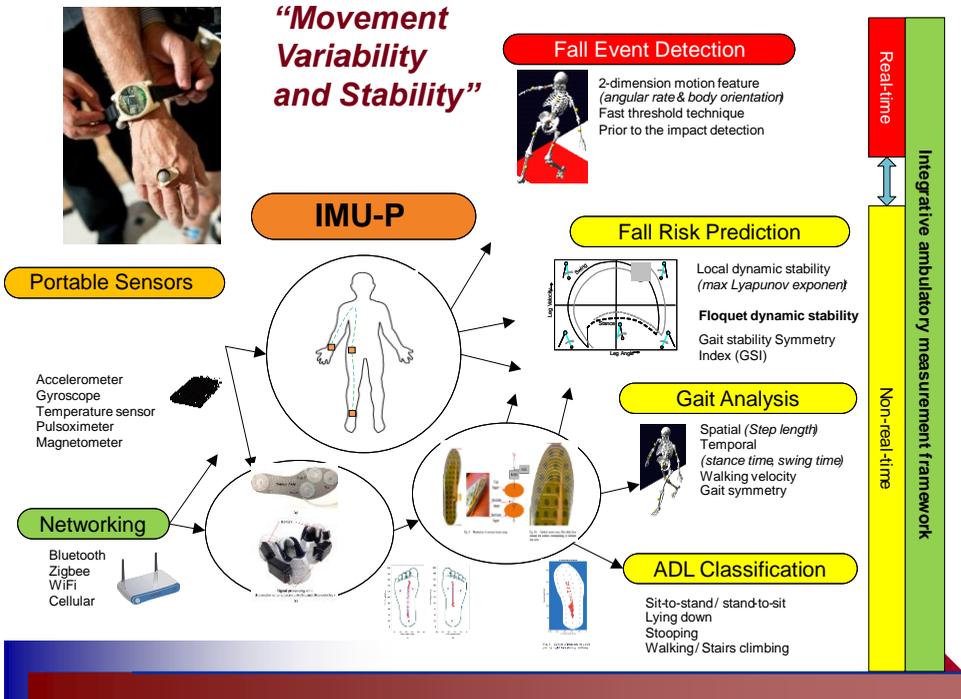
# Nonlinear Methods in Crew Health Performance Monitoring "Behavior and Motor Control"

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"Variability, driving force of nature"



## Why do Older Adults Fall More Younger Adults?



### Factors Influencing Slips and Falls (Intrinsic Changes Associated with Aging)

1. Sensory Degradation.
2. Cognitive Impairment.
3. Muscle Weakness.
4. Gait Adaptation.

**More importantly, extrinsic environmental factors and how those factors interact with intrinsic conditions must be considered.**

What is the relationship between these risk factors and slip and fall accidents in the elderly? **And, how can we use this info to assess fall risk.....**

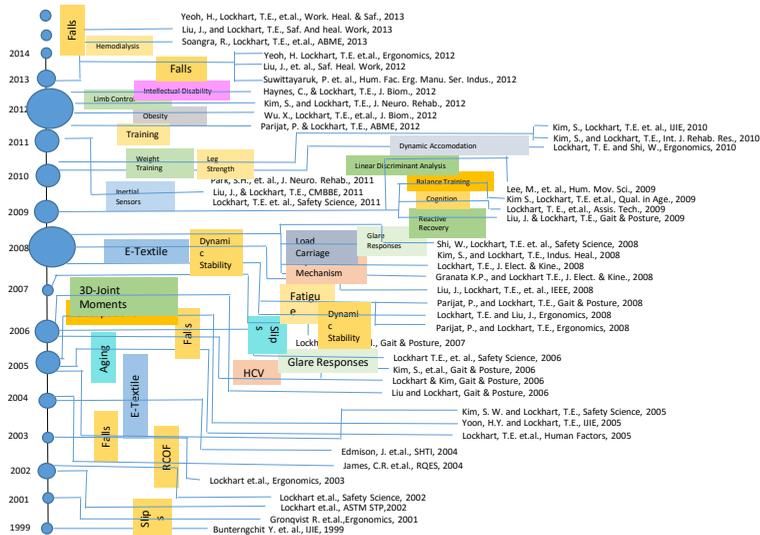
## Slip and Fall Experiments



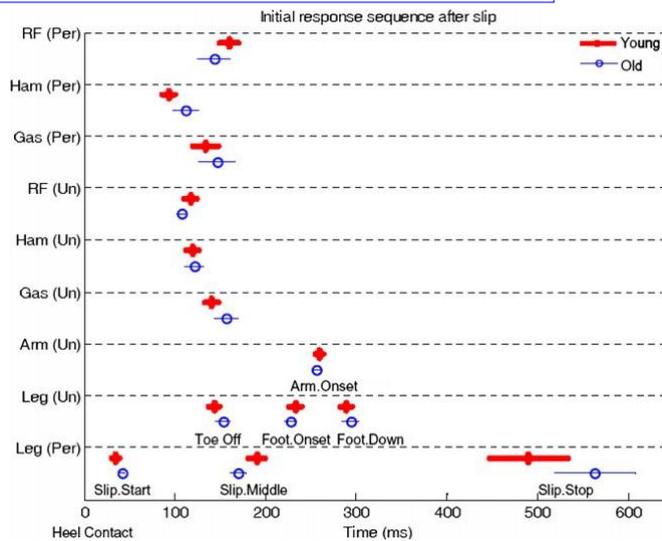
# Trip and Fall Experiments



## Prior Work on Falls and Dynamic Stability



## Bottom Line



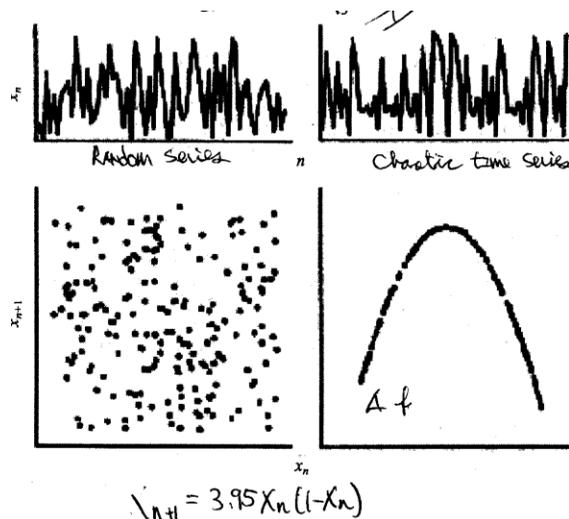
## Summary of Gait Study Results

- **Reactive Recovery Phase** was the most important for the elderly.
- Control systems exhibited a **finite time delay** between the moment a **stimulus was provided (i.e., perturbation)** and the moment the system returned a **response (i.e., nothing happens instantaneously)**.
- In many situations : the responses also depended nonlinearly on the input, such that the evolution of the system in the present depended sensitively on its state in the past (e.g., muscle fatigue).
- This **nonlinear time-delay systems** (autonomic motor control) can be quantified by nonlinear dynamics - stability assessments.

## Predictability and Chaos

- Can having a multiple variables influence predictability?
  - Due to nonlinear dynamical interactions and the phenomenon of chaos (generation of complexity from simplicity).
  - Chaos means that the behavior of a nonlinear system depends sensitively on where a system starts its motion (your birth, etc.).
  - **The solution to such equation look erratic and may pass all the traditional tests for randomness even though they are deterministic.**

## Random and Chaotic



# Rationale

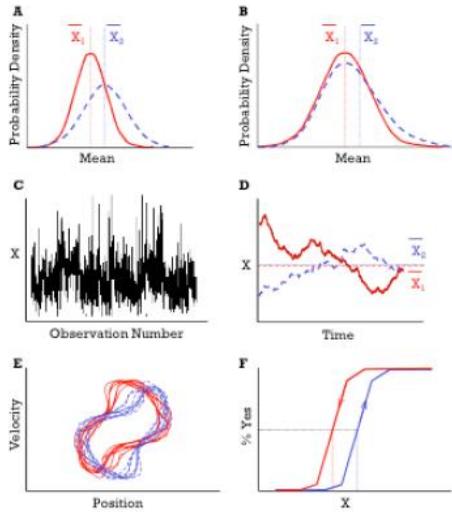


Figure 1.1. (A) Two normal distributions with different means and variances. (B) A normal distribution (solid line) and a distribution with a stretched “tail” (dashed line). (C) A time series. (D) Two time series with identical summary means. (E) Two time-ordered velocity  $\times$  position profiles. (F) Categorical responses with different orders of presentation (indicated by the arrows).

Riley, M. A., & Van Orden, G. C. (2005). Tutorials in contemporary nonlinear methods for the behavioral sciences. Retrieved March 1, 2005, from <http://www.nsf.gov/sbe/bcs/pac/nmbs/nmbs.jsp>

# Physically coupled oscillators

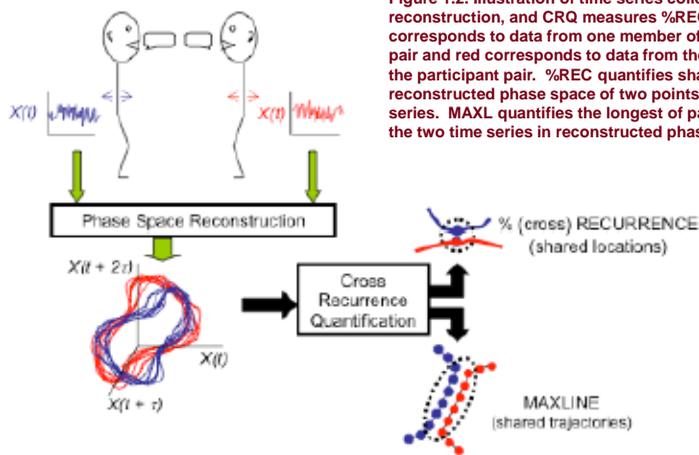


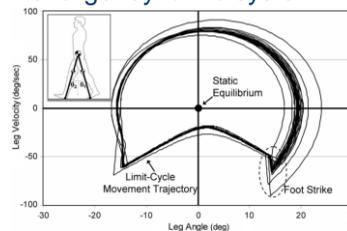
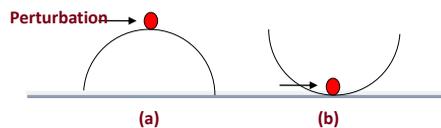
Figure 1.2. Illustration of time series collection, phase space reconstruction, and CRQ measures %REC and MAXL. Blue corresponds to data from one member of the participant pair and red corresponds to data from the other member of the participant pair. %REC quantifies shared locations in reconstructed phase space of two points from the two time series. MAXL quantifies the longest of parallel trajectory of the two time series in reconstructed phase space.

## Stability and Complexity

How can one take advantage of the technique of phase space reconstruction to quantify what appears to be terribly complex postural activity?

## Dynamic Stability

- Based on nonlinear dynamics theory
- Measures the resistance (i.e. stability) of the target dynamic system to small perturbations



### Applications:

- » Dingwell et al. (2000) applied Lyapunov exponents to show that individuals with pathological gait slows down to increase their dynamic stability.
- » Granata and Lockhart (2008) applied limit cycle measures to differentiate fall-prone elderly from their health counterparts.
- » Lockhart and Liu (2008) applied Lyapunov to differentiate fallers and non-fallers.

## Stability and Variability

### Gait variability & Instability



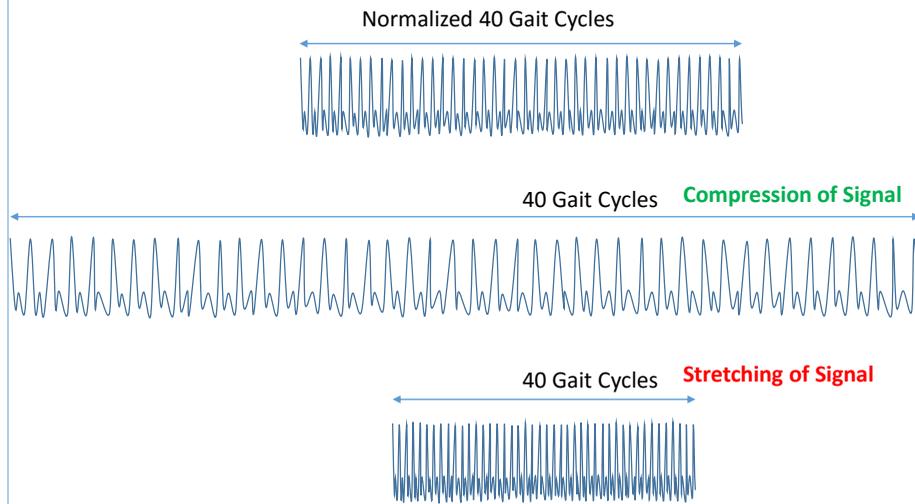
• **Individuals with step variability fell more often than non-fallers.**  
(Guimaraes et al., 1980)

• **Gait variability is demonstrated to be linked to falls in the elderly.**  
(Imms et al., 1979)

## Linear Variability

- Foundation for using linear variability measures to quantify stability is lacking.
- Traditional linear measures mask the true structure of motor variability
  - Averaging procedure - lose spatial information (e.g. average multiple gait cycles)
  - Time normalization - lose temporal information (e.g. 100% gait cycle)
  - Contains little information about the stability of locomotor control system corresponding to perturbations. (Dingwell et al., 2000; Buzzi et al., 2003)

## Gait Cycle Normalized to 100 data points



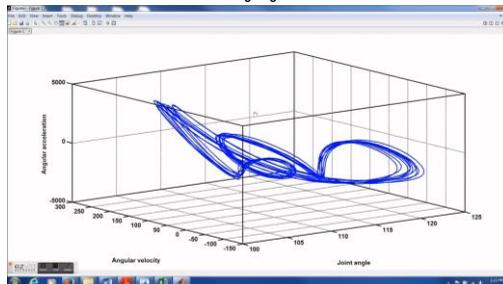
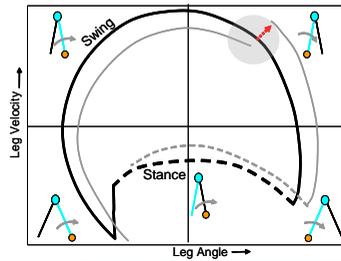
## Dynamic Stability: Floquet

- If no perturbation,  

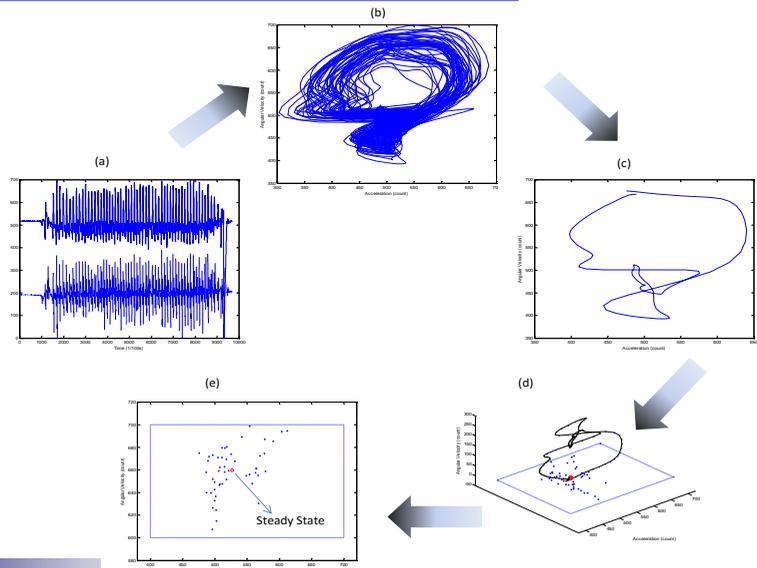
$$x_{i+1} = f(x_i)$$
- If small perturbation,  

$$\Delta x_{i+1} = \nabla f(x_i) \cdot \Delta x_i$$
- After Taylor series expansion  

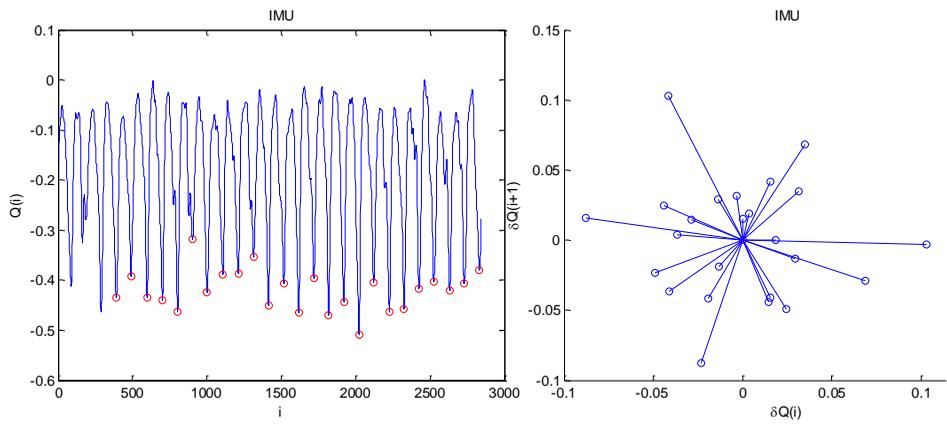
$$\Delta X_{j+1} = J \cdot \Delta X_j$$
- Eigenvalues of J  
 Floquet Multiplier 



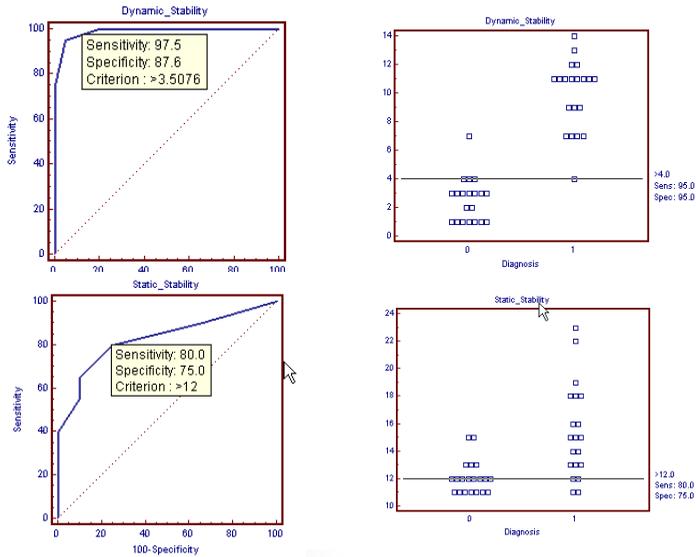
# Data Analysis:



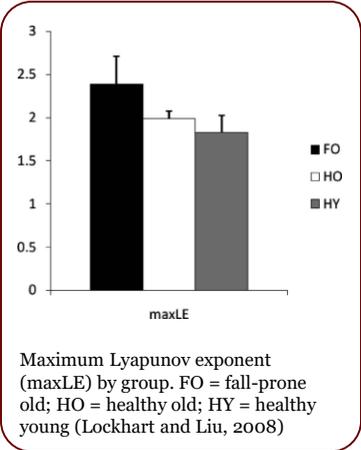
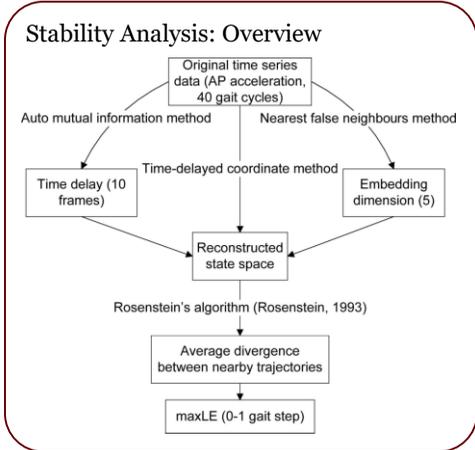
# Normal Walking on Treadmill



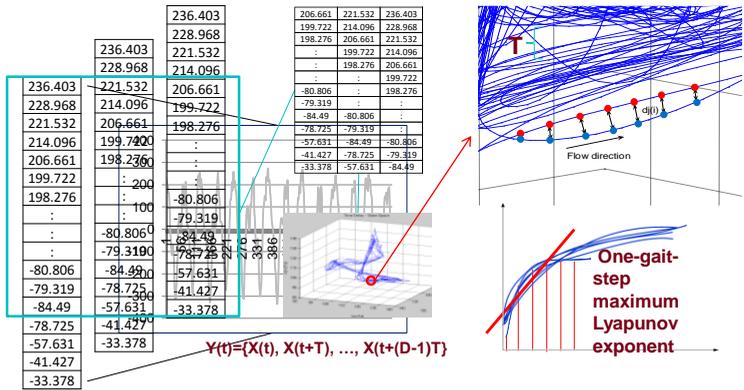
# Data Analysis



# Dynamic Stability: Lyapunov



# Dynamic Stability: Rosenstein's Algorithm for maxLE



# Approximate Entropy: Complexity

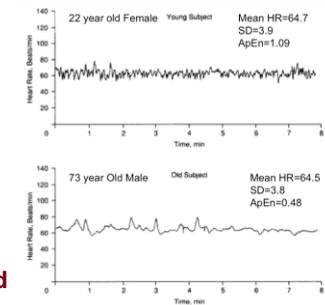
ApEn quantifies regularity and complexity of a system (Pincus, 1994)

Approximate Entropy: It is the logarithmic likelihood that the patterns of the data are close to each other and will not remain close for the next comparison within a longer pattern.

- High ApEn values indicate unpredictability and random variation
- Low ApEn indicates high predictability and regularity of time series data

If  $S_N$  is a time series of length  $N$

$$ApEn(N, m, d) = (N - m + 1)^{-1} \sum_{i=1}^{N-(m-1)} \ln C_i^m(d) - (N - m)^{-1} \sum_{i=1}^{N-m} \ln C_i^{m+1}(d)$$



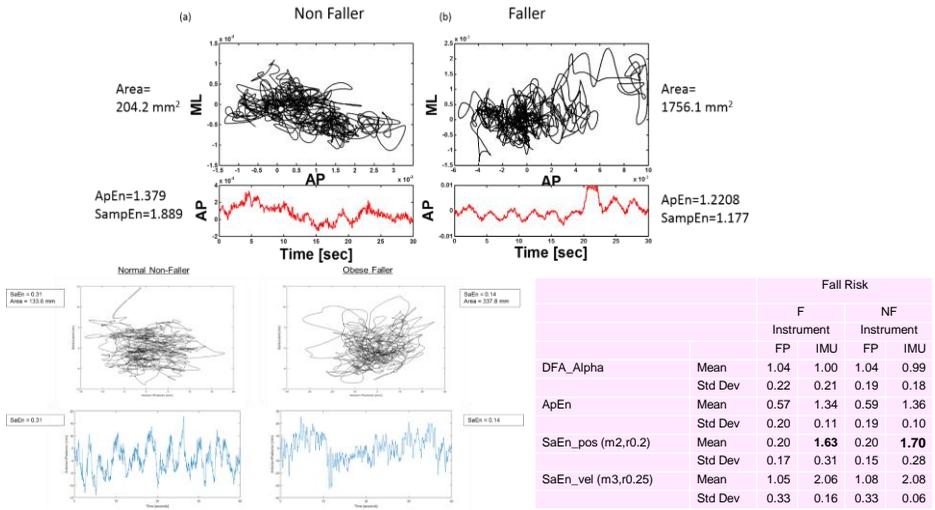
Heart rate signals of old and young participant. Adapted from Lipsitz and Goldberger, 1992

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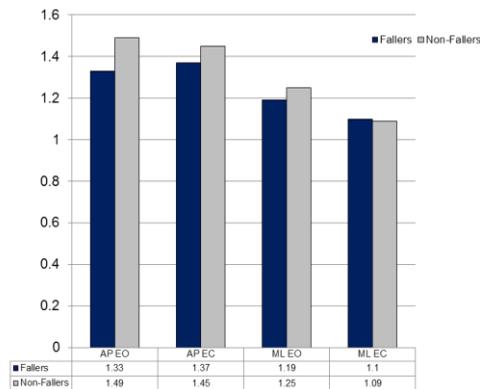
Where  $m$  is the pattern length ( usually chosen as 2) and  $d$  is similarity coefficient (chosen as 0.2 % of SD of time series )



# Complexity of Fallers



# Bottom Line-SE

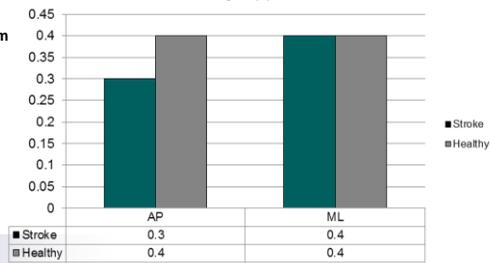
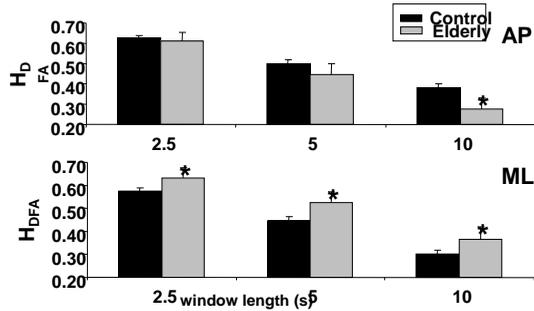


Flexible adaptations to changing demands

## Literature Values - DFA

Fractal time series analysis of postural stability in elderly and control subjects

$0 < \alpha < 0.5$  → Anti-Persistent  
 $0.5 < \alpha < 1$  → Persistent  
 $\alpha = 0.5$  → Uncorrelated/Random



## Depression

