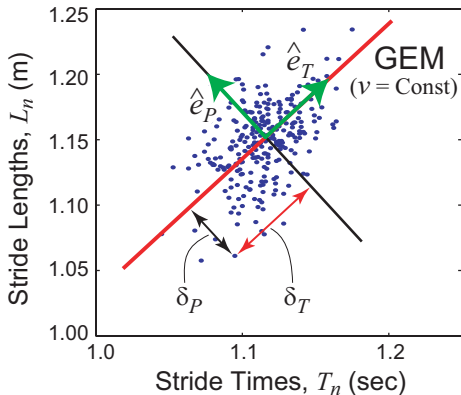


INTRODUCTION

- Greater variability in gait prospectively predicts increased fall risk [1,2]
- But what variable(s) to measure?:
 - Step width, length, or time? [3]
 - Trunk accelerations? [4]
 - Too much or too little variability? [5]
- Which variables are most relevant to achieving the task goal?**
- Do goal-relevant deviations reveal how walking is controlled from stride to stride?**

THEORY

- Understanding how humans control complex redundant movements is a fundamental question in motor control research [6]
- One critical "goal" of treadmill walking is to maintain constant speed, v .
- But many combinations of stride length (L_n) and stride time (T_n) achieve this goal
- All $L_n/T_n = v$ define a "Goal Equivalent Manifold"



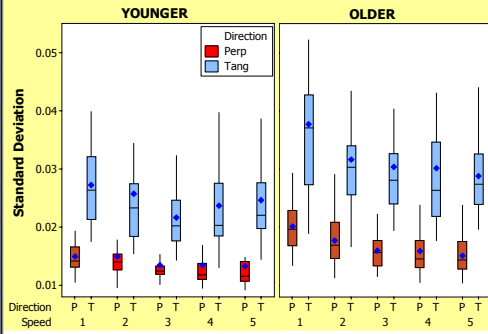
- Where: $\hat{e}_T = \frac{1}{\sqrt{1+v^2}} \begin{bmatrix} v \\ 1 \end{bmatrix}$, $\hat{e}_P = \frac{1}{\sqrt{1+v^2}} \begin{bmatrix} -1 \\ v \end{bmatrix}$
- Deviations along the GEM (δ_T) do not affect speed (v): They are "Goal Equivalent"
- Deviations perpendicular to the GEM (δ_P) do affect speed (v): They are "Goal Relevant"

EXPERIMENT

- 17 Healthy Young & 17 Healthy Older adults [7]
- Walked on a motorized treadmill at 5 different speeds: Preferred, $\pm 10\%$, and $\pm 20\%$ [7]
- Each subject completed 2 trials of 5 min at each speed [7]
- 3D movements of reflective markers attached to their feet were recorded continuously (Vicon, Oxford Metrics, Oxford, UK)
- These data were used to compute stride length (L_n) and stride time (T_n) for each stride, n .
- Each GEM was defined from: $\bar{v} = \langle L_n/T_n \rangle_n$
- Time series of deviations tangent (δ_T) and perpendicular (δ_P) to each GEM were extracted (see Fig. above) and analyzed [8]

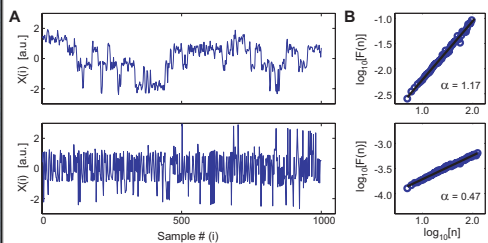
PREDICTION #1

- Hyp. #1:** Variability of δ_P deviations will be much less than variability of δ_T deviations [6,8]
- Variations along the GEM do not matter... Only variations perpendicular to the GEM



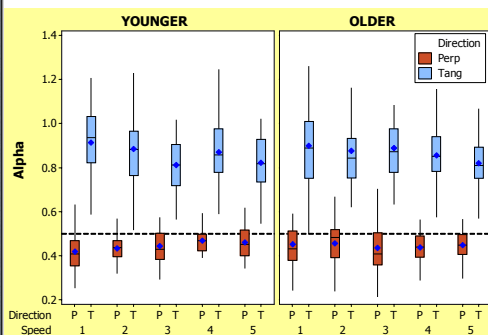
PREDICTION #2

- Hyp. #2:** Temporal fluctuations in δ_P will oscillate faster than fluctuations in δ_T [6,8]
- Detrended fluctuation analysis (DFA) was used to determine the correlation structure of each time series, giving a single value of α for each.
- The exponent α represents the degree to which one cycle is correlated to previous cycles [8]
 - $0.0 < \alpha < 0.5$ → anti-persistence
 - $0.5 < \alpha < 1.0$ → persistent correlations
- Smaller α indicate more rapid fluctuations (i.e., tighter control from stride to stride):



So What did we find?

- Movements were persistent ($\alpha > 1/2$) along the GEM...
- But anti-persistent ($\alpha < 1/2$) across the GEM...
- Consistent with greater control of δ_P deviations



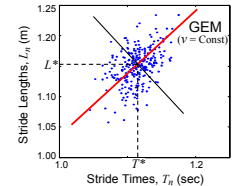
PREDICTION #3

- Hyp. #3:** Variability in speed (σ_v) will scale with variability of δ_P (σ_P) in a very specific way:
- Let $(L^*, T^*) \equiv$ "Operating Point" on the GEM
- Apply a small perturbation & let math "happen":

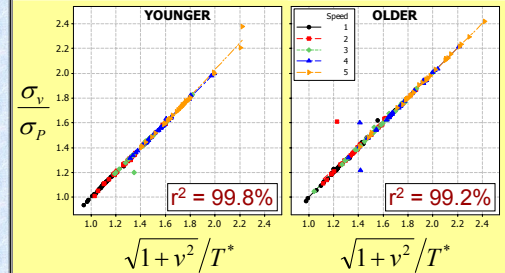
$$v + \varepsilon_v = \frac{L^* + \varepsilon_L}{T^* + \varepsilon_T} \rightarrow \varepsilon_v = -\delta_P \cdot \frac{\sqrt{1+v^2}}{T^*}$$

- This then implies:

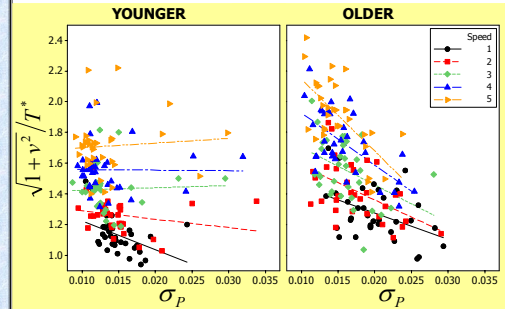
$$\frac{\sigma_v}{\sigma_P} = \frac{\sqrt{1+v^2}}{T^*}$$



- What did we find?:**



- BUT:** Older and Younger subjects achieved this scaling by very different means:



CONCLUSIONS

- All 3 Predictions STRONGLY supported!**
- Younger & Older subjects largely exhibited similar overall performance, but achieved that performance in different ways...
- These differences may suggest specific strategies elderly could use to maintain low σ_v :
- For $\uparrow \sigma_P$, $\downarrow v$ and $\uparrow T^*$ would $\downarrow \sigma_v$: $\sigma_v = \frac{\sqrt{1+v^2}}{T^*} \cdot \sigma_P$

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