The strength-dexterity test quantifies age-related differences in the sensorimotor control dynamics

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Introduction

- The ability to dynamically regulate instabilities with the fingertips is essential during everyday activities [1].
- Assessing and quantifying one's ability to dynamically regulate fingertip forces becomes particularly important to improve and assist clinical intervention.
- The Strength-Dexterity (SD) test consists in compressing a slender and compliant spring prone to buckling. The maximal level of compression (< 300 gf) provides a window into the integrity of the neuromuscular mechanisms for dynamic manipulation [1].
- Preliminary works [2] has demonstrated the nonlinear dynamical behaviors of the combined system of the fingers, spring and neuromuscular system at the edge of instability.

Aim

- We confirm the nonlinear nature of the SD test.
- We investigate for changes in the structure of force regularity due to aging during dexterous manipulation at the edge of instability.
- This choice may be more informative compared to standard linear techniques which assess the amount of variability.

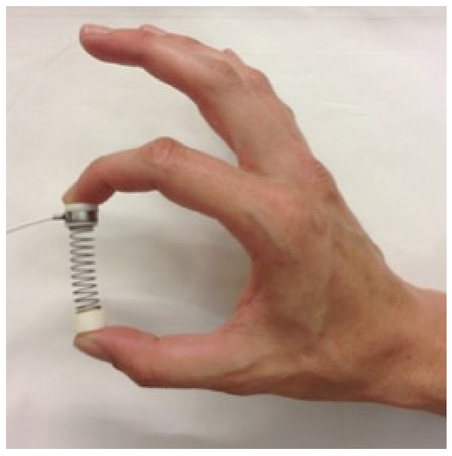
Methods

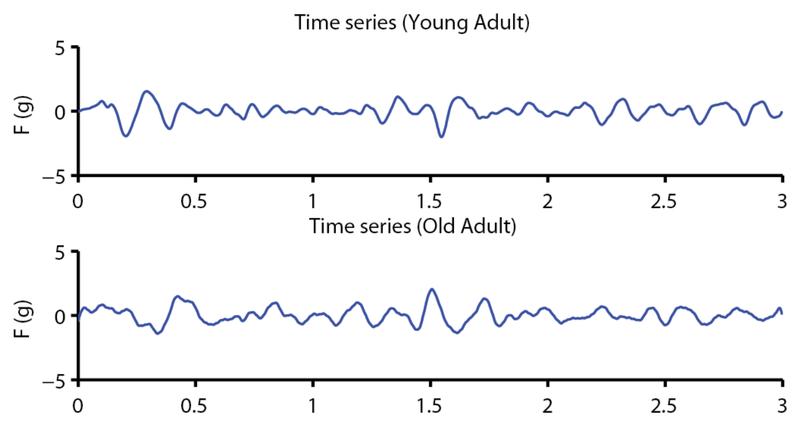
- We analyzed the fingertip forces for **10 young adults** (6F, 4M, mean±SD, 24.1±1.2 yrs) and **10 healthy older adults** (5F, 5M, 65.2±6.7 yrs)
- Participants were asked to compress the spring with only their thumb and index finger to the point of maximal instability they can sustain and maintain a constant level of compression. The force traces from index and thumb finger were averaged and downsampled to 400 Hz.
- We focused our analysis in **two distinct frequency ranges**
  - LF band (< 4 Hz) (voluntary fluctuations).
  - HF band ($4 - 12$ Hz) (involuntary fluctuations).
- We used **nonlinear cross prediction (NLCP)** [3] to detect nonlinearity in the dataset.
- **Sample Entropy (SampEn)** [4] ($m = 2$, $r = 0.2 * \sigma$ [5]) and std were computed to assess the regularity of the force traces in each frequency band.
- We used analysis of variance with a between-subjects factor for group and repeated measures ($p \leq 0.05$).

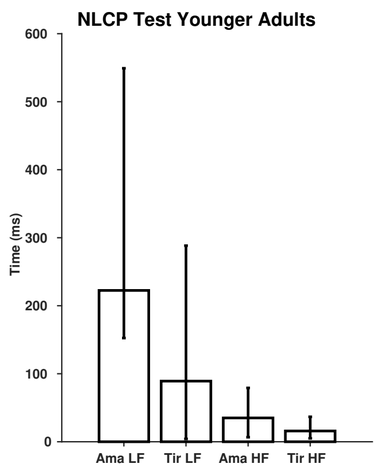
Discussion

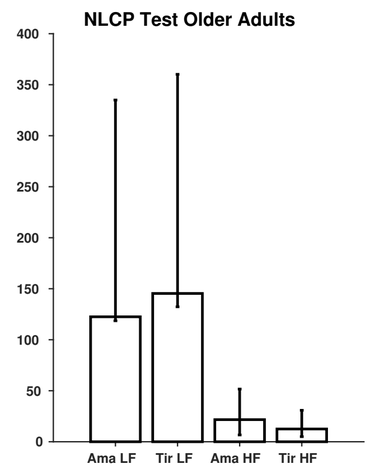
- **Increased irregularity** may hint to the breakdown of correlation properties and the alteration of nonlinear interactions, representing a less complex physiological system (i.e., the **degradation of healthy physiologic control mechanisms**)
- The **increase in short latency unpredictability** likely reflects changes in the nonlinear behavior/controller that may be due to more subtle perturbation in the nonlinear control (e.g., increase of endogenous sensorimotor noise [6])
- This may be a result of the individual/compounded effects of changes in muscle recruitment/rate coding or even structural changes at the level of motor cortex, cerebellum, and basal ganglia (e.g., motor units reinnervation, less efficient transformation of the descending commands from brain to muscles at the spinal cord level).

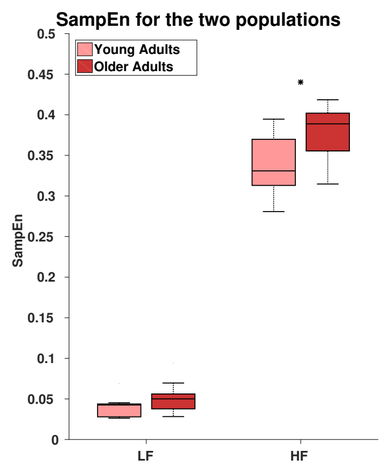
Results

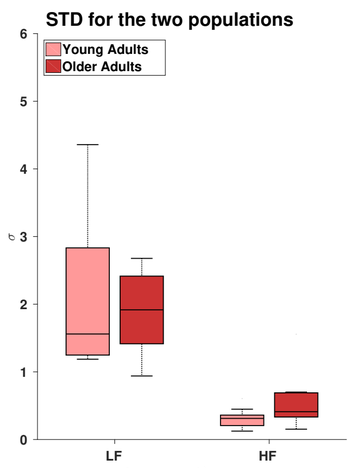












References

[1] Valero-Cuevas FJ, Smaby N, Venkadesan M, Peterson M, Wright T. The strength–dexterity test as a measure of dynamic pinch performance. Journal of biomechanics. 2003;36(2):265–270.

[2] Venkadesan M, Guckenheimer J, Valero-Cuevas FJ. Manipulating the edge of instability. Journal of biomechanics. 2007;40(8):1653–1661.

[3] Stam, CJ and Pijn, JPM and Pritchard, WS Reliable detection of nonlinearity in experimental time series with strong periodic components. Physica D: Nonlinear Phenomena. 1998;112(3):361–380.

[4] Richman, Joshua S and Moorman, J Randall Physiological time-series analysis using approximate entropy and sample entropy. American Journal of Physiology-Heart and Circulatory Physiology. 2000;278(6):H2039–H2049.

[5] Vaillancourt, D. E., Slifkin, A. B., and Newell, K. M. Regularity of force tremor in Parkinson's disease. Clinical Neurophysiology. 2001;112(9):1594–1603.

[6] Sherback, Michael, Francisco J. Valero-Cuevas, and Raffaello D'Andrea. "Slower visuomotor corrections with unchanged latency are consistent with optimal adaptation to increased endogenous noise in the elderly." PLoS Comput Biol 6.3 (2010): e1000708.