The grip force dynamics of static grasp reveals a control hierarchy

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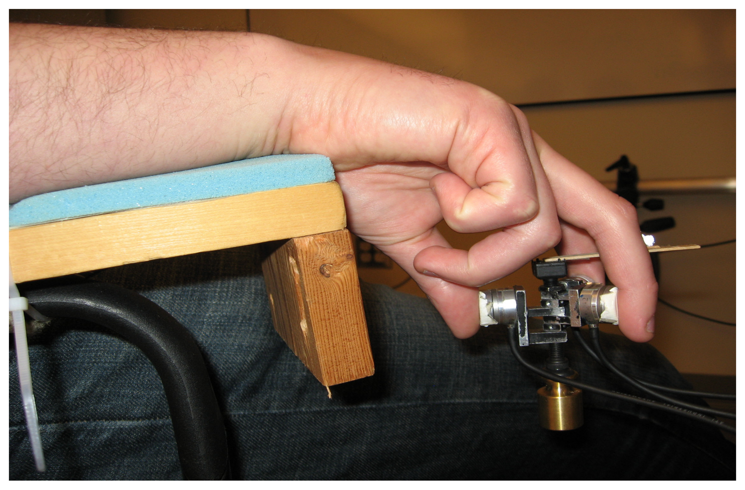
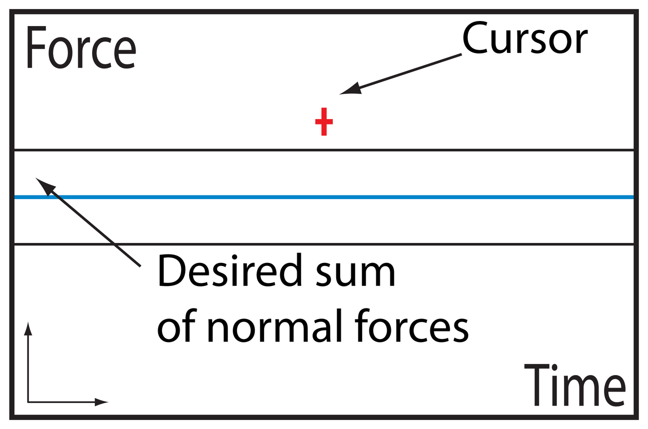
Abstract

- Simple static grasping task: holding against gravity a device with 3 load cells.
- Visual inspection of normal force trajectories reveals structured dynamics, rather than a noise pattern.
- Employed a fluctuation analysis used previously in postural studies [1].
- Detrended Fluctuation Analysis [4] reveals different control strategies over time; multiple scaling regions of displacement as time increases.

Experiments and Data processing

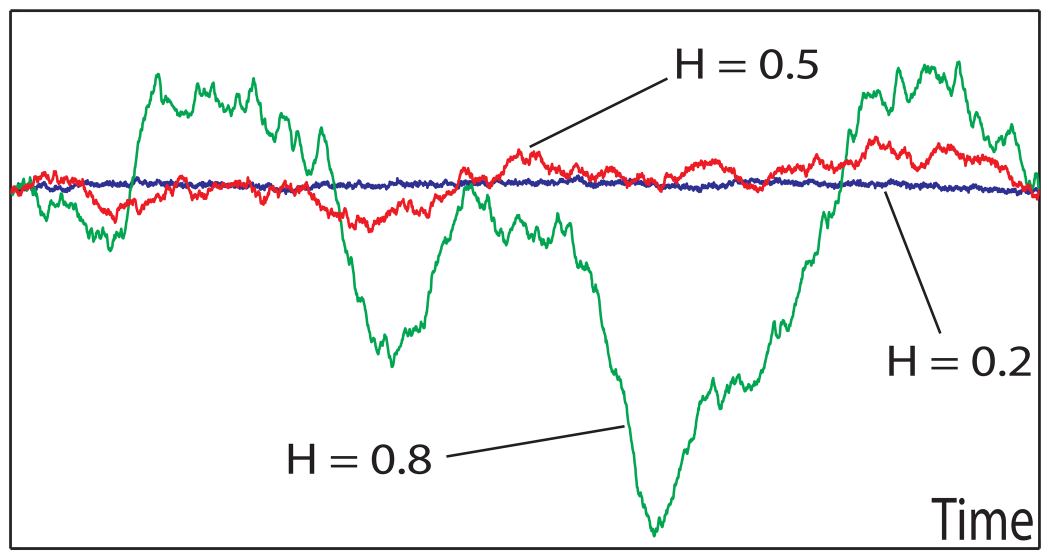


- 5 consenting male adult subjects (ages: 24 - 44 years).
- Task: Holding a device (see left) statically for 2 min with 3 fingers of dominant hand [5].
- Fingertip contact with 6-axis force transducer (ATI Nano 17) sampling at 400 Hz.
- Repeated with 3 weights: 50 g, 100 g, 200 g, with and without visual feedback.
- Feedback (see right): keep sum of normal forces constant.
- Retained first min, downsampled to 100 Hz, then filtered.



Hurst exponent

- Characterizes the tendency of a time series to stay close to the mean or deviate away from it, or, the **scaling of the average displacement over time**:
- **H < 0.5** : Negative correlations, tendency towards mean (see right, blue line).
- **H > 0.5** : Positive correlations, tendency away from mean (see right, red line).



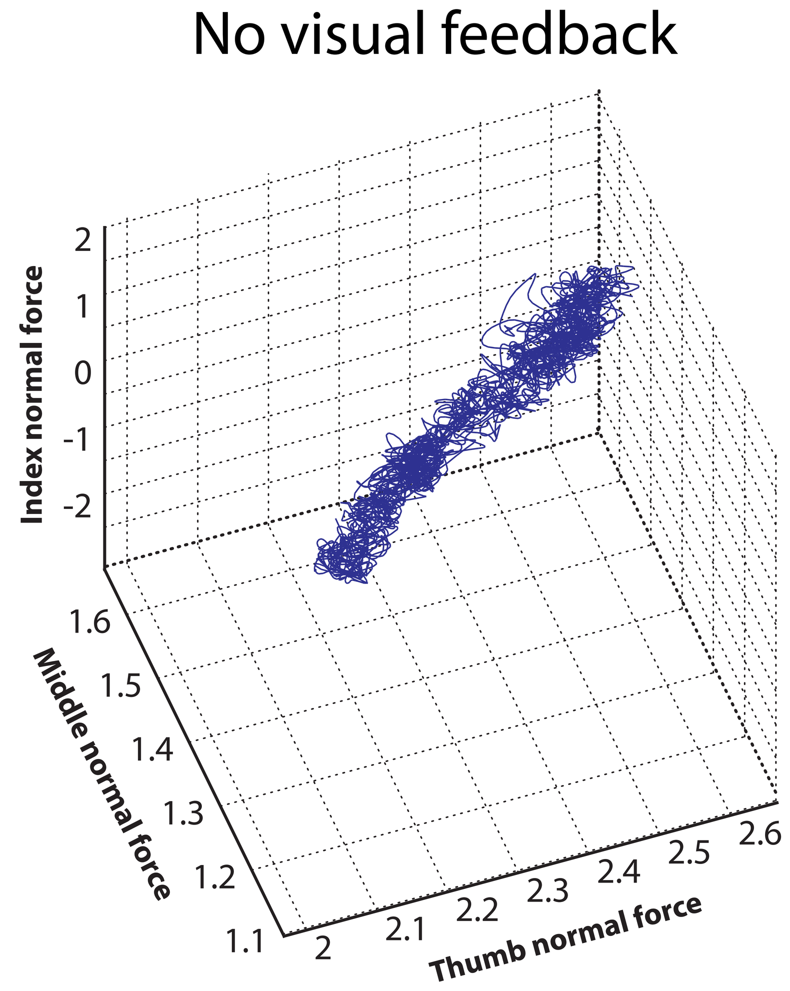
Detrended Fluctuation Analysis

- More refined approach [4] for computing Hurst exponent, which is **less sensitive to trends**, and **detects differential scaling** in small vs. large fluctuations.
- Long-range correlations give rise to power-law scaling, which can be quantified as follows:

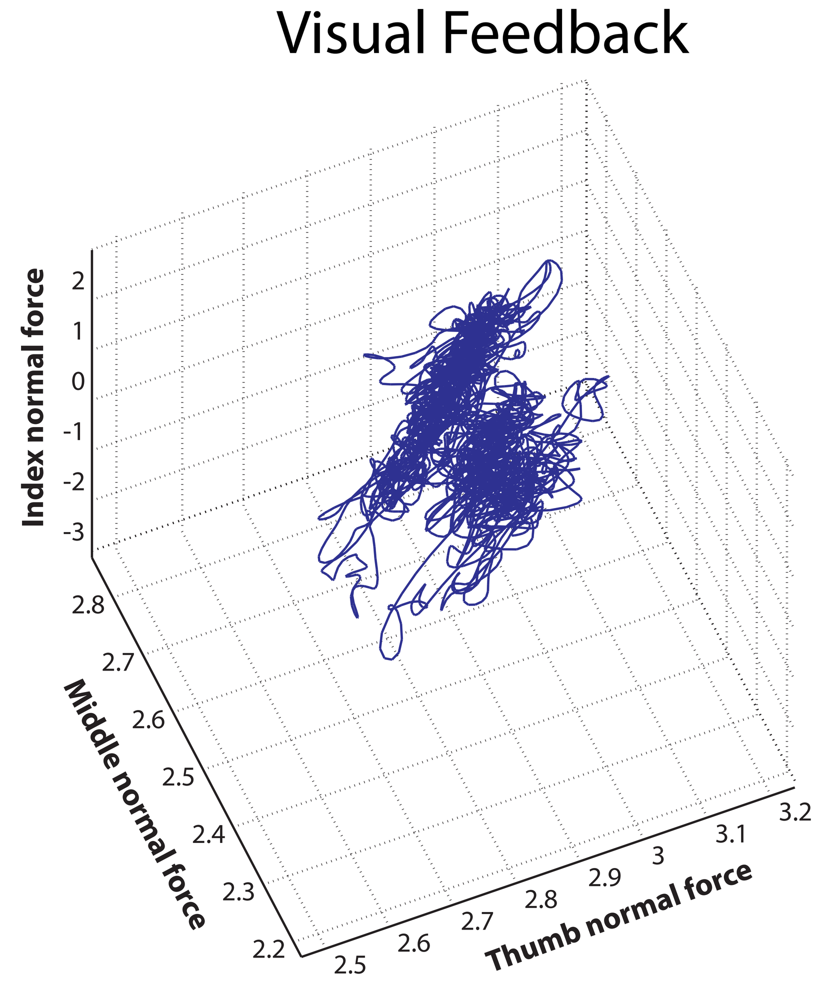
$$F^p(v,s) = \frac{1}{s}\sum_{i=1}^{s}\left(Y\left[(v-1)s+i\right] - y_p(i)\right)^2 \qquad F_q(s) = \left(\frac{1}{N}\sum_{v=1}^{N}\left(F^p(v,s)\right)^{\frac{q}{2}}\right)^{\frac{1}{q}}$$

where *F(v,s)* is the squared mismatch between the *v*-th segment of data *Y*, of length *s*, and the polynomial fit *y(i)* to it, of order *p*. The exponent *q* weights fluctuations according to their size. Doing this for all length-*s* segments and all *s=1,...,N* and averaging, we arrive at the **scaling function** with Hurst exponent *h(q)*: $F_q(s) \sim s^{h(q)}$

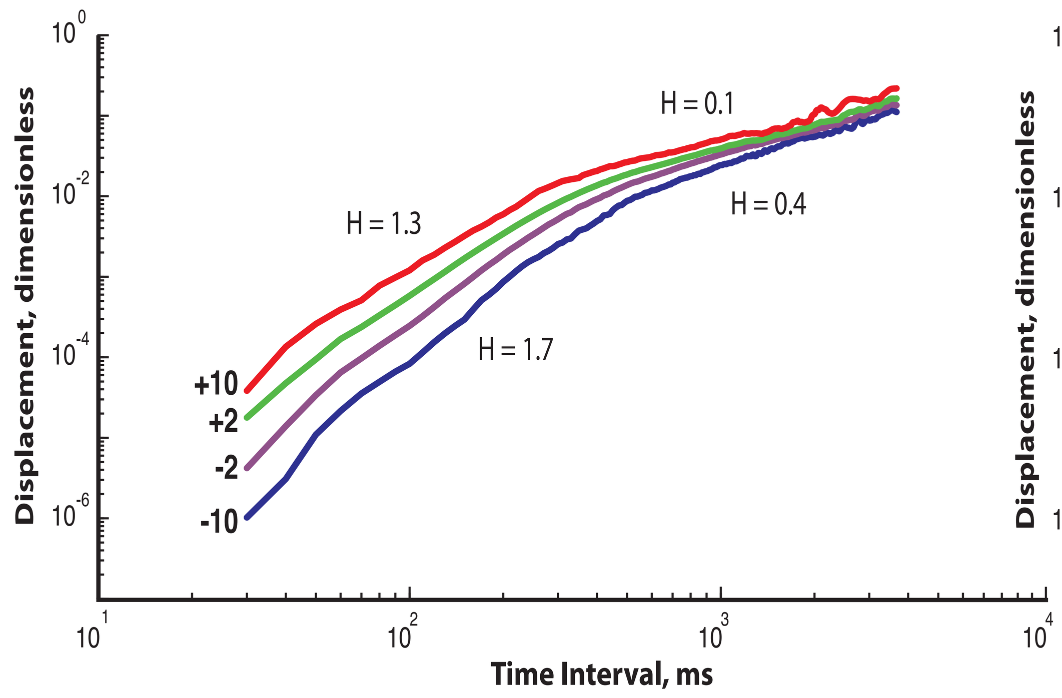
Results

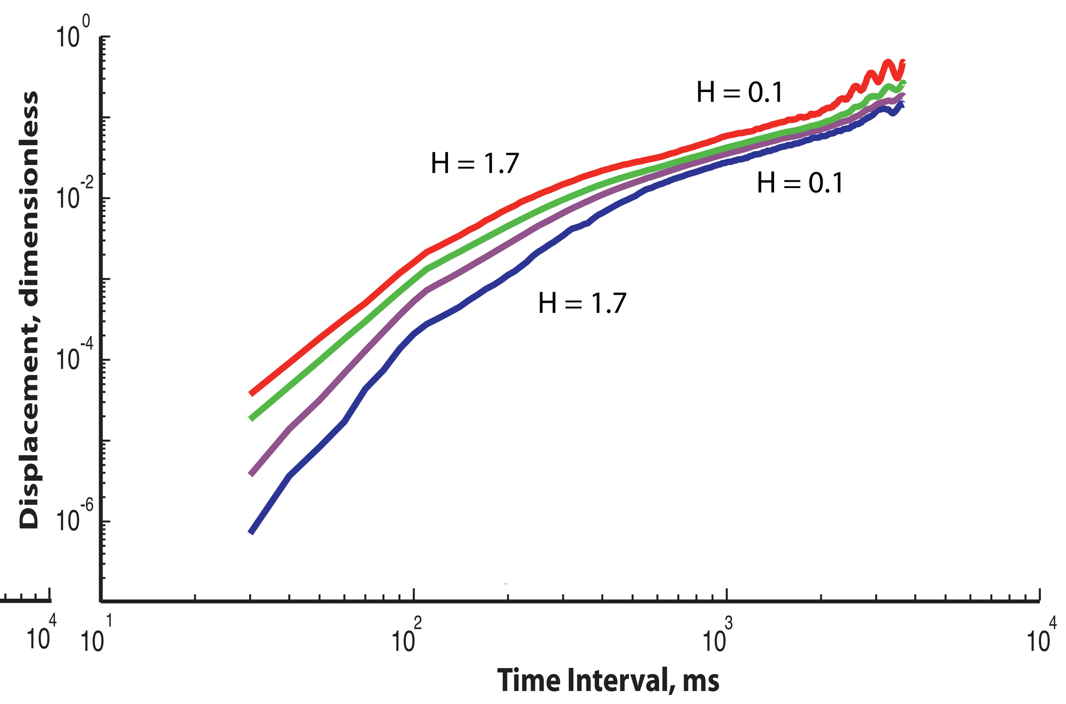


50 g weight. Main axis of variance is [1 1 1].



50 g weight. Main axis of variance is [0 -1 1].





DFA plot exhibits multiple scaling regions, and a switch from positive to negative correlations at approx. 400-800 ms.

Conclusion

- The observed dynamics cannot be solely attributed to noise, but strongly suggest stabilizing control activity.
- The Detrended Fluctuation analysis reveals at least two distinct time scales, with **switching** between correlation ranges occurring at 400-800 ms.
- At **short time scales**, the time series tends to move away from the mean, at **long time scales**, it tends to return, indicative of **stabilization**.
- **Large fluctuations** are more negatively correlated, contributing more to stability.
- These results indicate different control strategies at different time scales, possibly **intermittency** [2], or an effect of **sensorimotor delays** [1].

References and Acknowledgements

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