Uncertain Motor Plans Lower Stability of Current Prehensile Behavior

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Introduction

Traditionally, **motor control research seeks to explain how human movement is stabilized.** When performing repetitive movements such as walking, subjects stabilize their performance so as to best satisfy the demands of the task. **Stability is the ability to reject external disturbances to the current state**, and is associated with successfully executing motor tasks.

In contrast, to transition between motor tasks, the central controller must first lower the stability of the current state [1]. This skill is called **dexterity, and it is the motor ability to achieve flexible motor behavior for any situation and in any condition.** In this experiment, we examine if the expectation of a state change of unspecified timing, magnitude and direction causes significant reduction in the stability of force production by the four dominant-hand fingers.

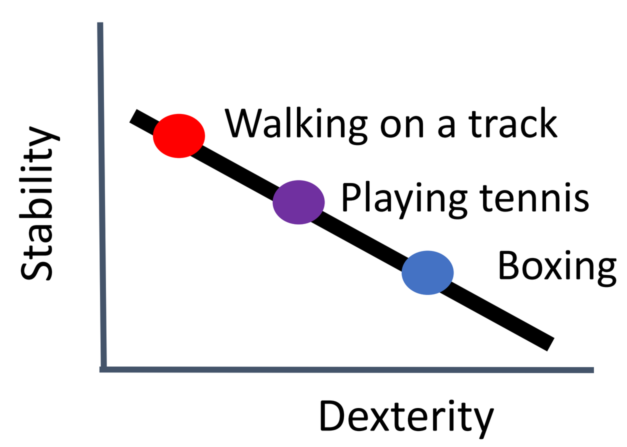

Figure 1. *A highly stable system cannot also be highly dexterous at the same time. Boxing requires more dexterity than walking, therefore is less stable as well.*

Hypotheses

***Hypothesis 1*:** Subjects prepare for expected state change by lowering the stability of the current manual state.

***Hypothesis 2*:** Stability will be reduced more for more difficult tasks.

Methods

- 25 healthy subjects. 6 male, 20.4±2.5 yrs
- Dominant-hand fingers pressed on force sensors
- Task: keep white "X" cursor inside yellow "target" on a computer screen
- Target could move vertically or remained fixed at the center of the screen, at 10% of maximal voluntary contraction (MVC)
- "X" cursor controlled by the sum of the finger forces:

Total Force $F_T = F_{Index}+F_{Middle}+F_{Ring}+F_{little}$

- Three task types, 16 trials each, with 4s+ of constant force (at 10% MVC) in every trial:

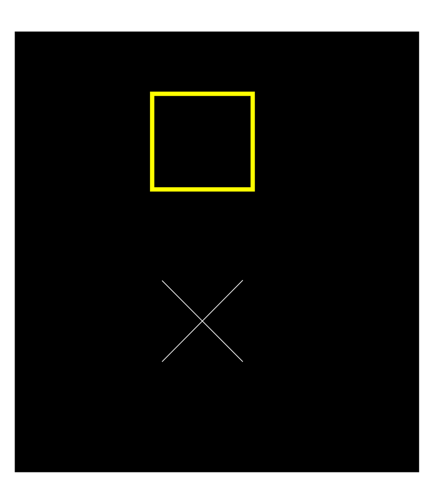

Figure 2. *Subject's view of the X cursor chasing the yellow target*

Stable Task: Subjects know that the target will be 7s of constant force
Slow Dexterous Task: Unpredictable target movement
Fast Dexterous Task: Faster and greater unpredictable target movement

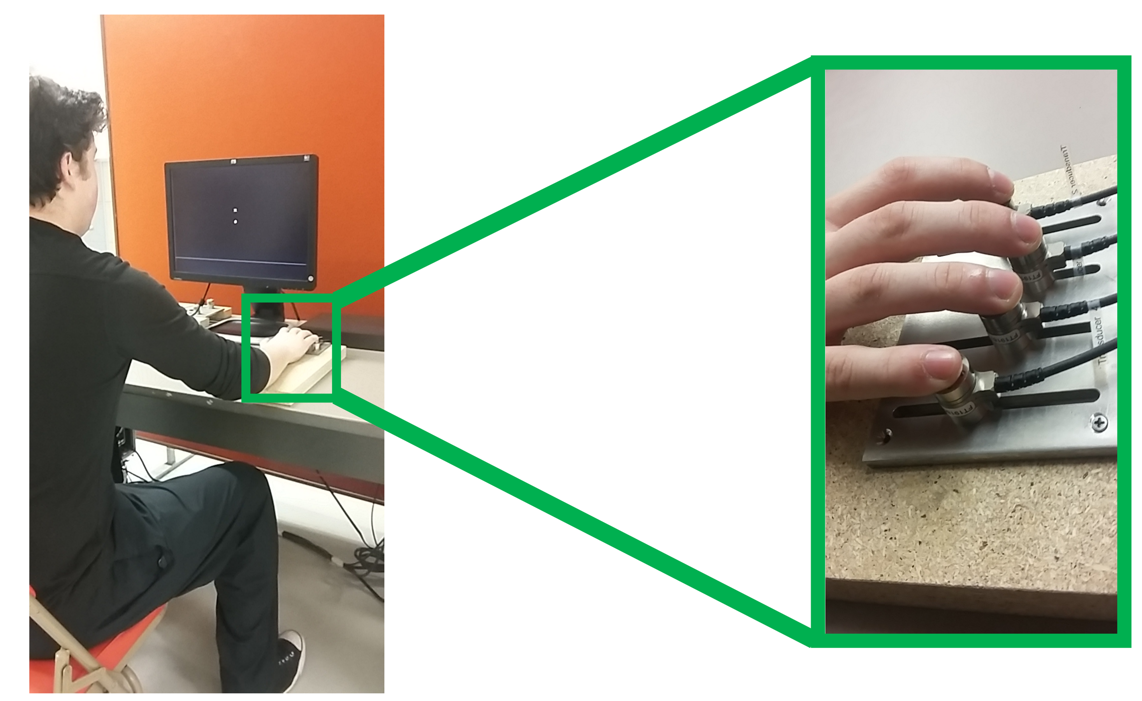

Figure 3. *(L) subject seated at the computer, dominant forearm resting on the table. (R) zoomed in on subject's four fingers on the four force transducers*

Analysis

When performing the same task repeatedly – in this case constant force production - humans naturally accomplish it slightly differently each time. This variability is not an error but a feature of motor control.

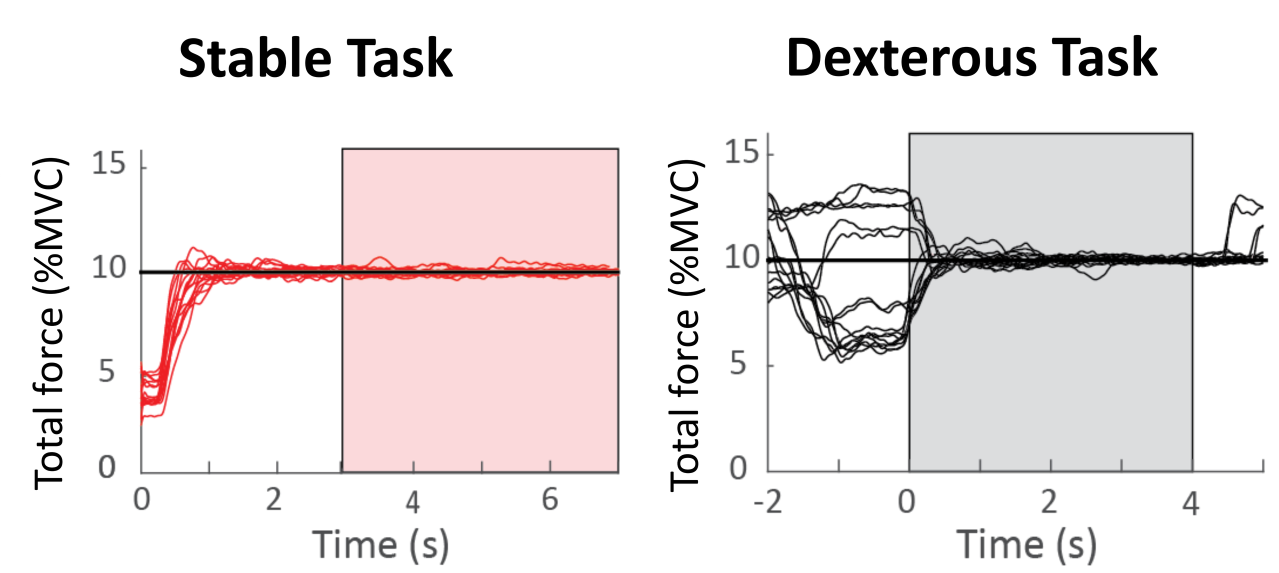

Figure 4. Typical *subject response over 16 trials overlaid. Shaded rectangle is the 4s of constant force to be analyzed.*

Like typical motor systems, our task is redundant with four input finger forces producing just one output total force. Therefore, a total force can be accurately produced with the fingers in infinitely many ways. All valid combinations constitute the ***Uncontrolled Manifold*** (UCM) [2, 3] for this task. Human performance typically shows **good variability** along the UCM where the finger forces compensate for each other while total force remains stable, as well as some **bad variability** that leads to change in the total force.

Variance computed across trials at each time point of the 4s of constant force for each task type. The normalized compensatory covariance (good variance) in the finger forces is a metric for ***task-specific stability of motor action***:

$$C_N = -\frac{\Sigma VarF(i) - VarF(T)}{\Sigma VarF(i)}$$

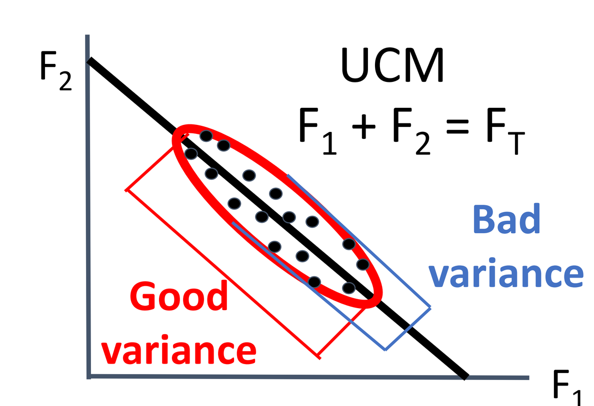

Figure 5. *Downward-sloping UCM for2D version of our task. Data from multiple 2-finger force-production trials is shown.*

Results

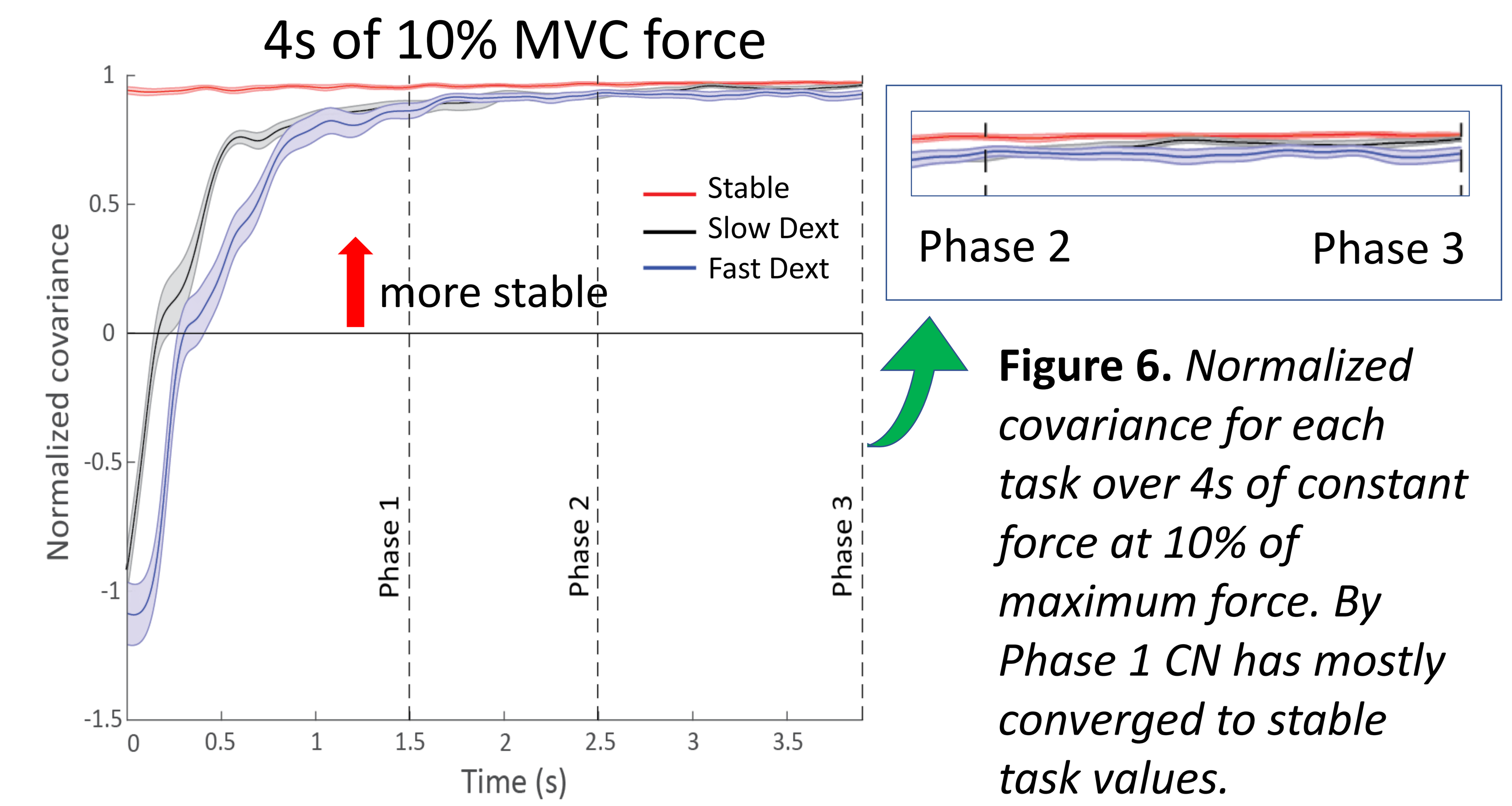

Figure 6. *Normalized covariance for each task over 4s of constant force at 10% of maximum force. By Phase 1 CN has mostly converged to stable task values.*

Task x Phase Repeated-Measures ANOVA on C_N

Hypothesis 1 Supported by **Main Task Effect**: $C_{N\text{-Task 1}}$ (0.96±0.01) > $C_{N\text{-Task 2}}$ (0.91±0.01); $C_{N\text{-Task 1}}$ > $C_{N\text{-Task 3}}$ (0.89±0.02)

Main *Phase* Effect: $C_{N\text{-Phase 1}}$ (0.89±0.02) < $C_{N\text{-Phase 2}}$ (0.93±0.01) $C_{N\text{-Phase 1}}$ < $C_{N\text{-Phase 3}}$ (0.94±0.01)

Hypothesis 2 Supported by ***Task x Phase* interaction**: C_N difference lasted longer for the fast dexterous task.

Conclusion

- This is the ***first demonstration of task-specific stability reduction in hand function solely in response to uncertainty in future motor plans.***
- We observed a ***7% C_N decrease in the expectant conditions compared to the stable task***.
- ***Stability reduction lasts longer for more challenging tasks***.
- Our results have implications for the understanding and clinical assessment of manual dexterity.
- Future research will focus on this mechanism's potential functional benefits with regard to speed and accuracy, as well as its applications in other movements.

REFERENCES

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2. Zhou T, et al. *Exp Brain Res* **226**, 565-573, 2013.
3. Shim JK, et al. *J Appl Physiol* **97**, 213-224, 2004.

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