REDUCTION IN STABILITY OF MANUAL BEHAVIOR IN UNCERTAIN CONDITIONS

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ABSTRACT

We examined changes in Anticipatory Synergy Adjustments (ASA) when controlling the degree of uncertainty of a finger pressing task in college students. We found that young adults are able to prepare for unexpected movement in two stages. Our novel findings suggest that the previously undescribed Stage-1 ASA occurs up to 2s before motor state change. It occurs without a loss of task precision via a distinct mechanism than typical Stage-2 ASA, which results in increased output variability.

INTRODUCTION

Stability is the ability to reject internal and external disturbances in order to maintain the current static or dynamic motor state. ***Dexterity*** is the ability to transition between motor states. How does the central nervous system facilitate the ***stability-dexterity transition*** when switching tasks?

Anticipatory Synergy Adjustments (ASA) are decreases in stability during a transition period up to 400ms before an expected motor state change. Past experiments have demonstrated this phenomenon when the timing - but not the nature - of the upcoming state change is known [3]. For our dexterous tasks, neither the timing nor nature (direction) of the task was known.

With this novel condition we compare the changes in the ***synergy index*** (ΔV) while performing repeated trials of an identical manual (prehensile) motor task across three tasks with varying degrees of certainty. This is called the across-trial ***Uncontrolled Manifold*** (UCM) analysis method [1].

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 (more uncertain) tasks

METHODS

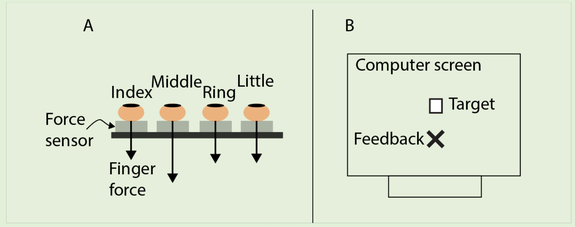

Figure 1. Experimental setup (A). Four fingertips of the dominant hand produce one total force. Feedback of total force and a total force target is provided on the computer screen (B).

- Four finger, isometric force production with dominant hand
- 25 young adults (age = 20.4 +- 2.6 years; 19 female)
- Total force $F_T = \Sigma Fi$; i = {index, middle, ring, little}
- Task to be analyzed is to produce F_T = 10% of maximum voluntary contraction (MVC) in 3 contexts
  1. **Stable:** Trial lasts 7 seconds
     Subjects know that the target is invariant
  2. **Slow Dexterous:** Trial lasts 30 seconds
     Target moves vertically, unpredictably (Figure 2A)
  3. **Fast Dexterous:** Trial lasts 30 seconds
     Faster unpredictable target movement
- 16 repetitions of each condition
- UCM analysis performed on:
  1. Last 4 seconds of the stable task (Figure 2B)
  2. 4 seconds of invariant F_T in dexterous conditions (Figure 2C)

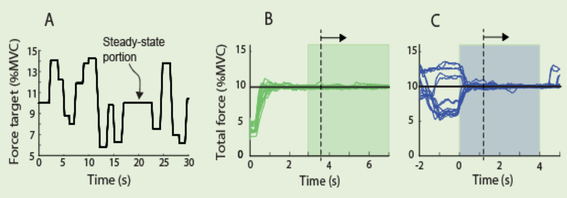

Figure 2. Typical target force profile for a dexterous task (A). Typical performance of the stable task (B). Typical performance of a dexterous task (C). Four-second time windows of 10% MVC steady force requirement are isolated for UCM analysis (B and C).

UCM ANALYSIS

- Can only be performed when # inputs < # outputs which is typical of biological systems' motor tasks [1]
- Across-trial, mean-free finger forces projected onto the 3-dimensional UCM and the 1-dimensional orthogonal (ORT) manifold (Figure 3)
- At each time point t, we computed
  1. Variance in the UCM (V_{UCM}) and the ORT (V_{ORT})
  2. The synergy index (ΔV)
     $\Delta V = (V_{UCM}/3 - V_{ORT})/([V_{UCM} + V_{ORT}]/4)$
  3. The Z-transformed synergy index (ΔV_z)
     $\Delta V_z = 0.5\log([4+\Delta V]/[1.33-\Delta V])$
- Higher ΔVz signifies higher stability of the total force F_T

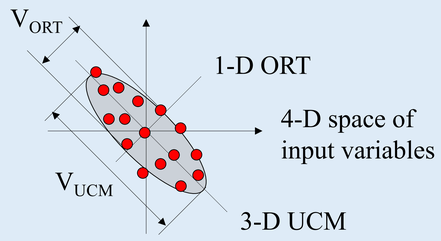

Figure 3. The geometry of the uncontrolled manifold (UCM) analysis. Input F_i data is projected onto the 3-dimensional UCM and the 1-dimensional orthogonal manifolds. Variance in the projections are V_{UCM} and V_{ORT}.

RESULTS

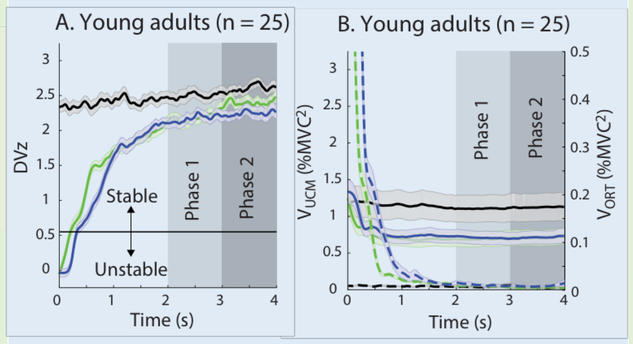

Figure 4. Synergy index time series (A). V_{UCM} and V_{ORT} time series (B).

DISCUSSION

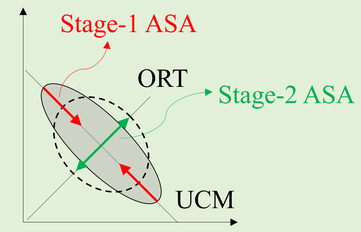

Figure 5. Anticipatory synergy adjustment is a two stage process. Stage-1 ASA occurs in response to a cue, and V_{UCM} decreases. During Stage-2 ASA V_{ORT} increases. Both stages decrease stability (ΔV_z).

- Decreasing eccentricity (ellipse-shape) signifies decreasing stability
- Stage-1 ASA: V_{UCM} decreases in anticipation of transition while V_{ORT} remains unchanged, leading to a more circular distribution
  - Thus stability reduction is achieved without a loss of current performance
- Stage-2 ASA: V_{ORT} decreases, further reducing ΔV_z
  - Associated with performance loss

CONCLUSIONS

- Hypothesis 1 Supported: ΔVz reduces for dexterous tasks by 12%
  $[F(2,48) = 13.794; p < 0.01]$
- Hypothesis 2 Supported: ΔVz reduces more for fast than slow dexterous tasks
  ΔV_z Slow (2.37 ± 0.07) > ΔV_z Fast (2.35 ± 0.07)
- Anticipatory synergy adjustments (ASA) occur in two stages (Figure 5)
  1. ***Stage-1 ASA*:** V_{UCM} decreases in response to a cue, reducing ΔV_z. The cue can be vague.
     - Begins up to 2s before state change
  2. ***Stage-2 ASA*:** V_{ORT} increases, reducing ΔV_z further.
     - Begins up to 400ms before state change [3]

REFERENCES
[1] Scholz and Schoner (1999) ***Exp Brain Res*** **126:289–306**
[2] Cole et al (2010) ***Exp Brain Res*** **201:239-247**
[3] Zhou et al (2016) ***Exp Brain Res*** **226:565–573**

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Solid lines: V_{UCM}
Dashed lines: V_{ORT}

Solid lines: V_{UCM}
Dashed lines: V_{ORT}