On your Mark!
Uncertain motor plans lead to reduced stability of the current state in young and older adults via distinct mechanisms.

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INTRODUCTION

Stability and **dexterity** are functional antagonists. A stable system ensures maintainance of the current state. A dexterous system efficiently switches between states.

How does the central nervous system resolve the **stability-dexterity conflict**? How does aging influence the resolution?

We explored these questions in the context of manual behavior. Four fingertips of the dominant hand produced one total force under isometric conditions. Stability of performance was quantified using the synergy index (ΔV) computed using the **uncontrolled manifold (UCM) method** [1]. Young and old healthy individuals produced one target force as the expectations to produce a quick change in the target force was manipulated across conditions.

HYPOTHESIS 1: Stability (ΔV) of the current state is lower when a quick force change is expected compared to when no change is expected.

The lower stability, presumably, enables faster movements as and when required. Performance on several tests (Purdue pegboard test, nut-and-rod task, etc.) is slower in older adults aged 60 years and over [2]. Therefore,

HYPOTHESIS 2: Compared young adults, older adults show a smaller drop in ΔV when quick force change is expected.

METHODS

* Four-finger, isometric force production with dominant hand
* 25 young adults (age = 20.4 +- 2.6 years; 19 female)
* 6 older adults (age = 72.7 +- 5.7 years; 4 female)
* Total force $F_T = \Sigma F_i$; i = {index, middle, ring, little}
* Task is to produce F_T = 10% of maximum voluntary contraction (MVC) under three contexts:
  1. **Stable**: Trial lasts 7 seconds
     Target is invariant and subjects know that (Figure 2B)
  2. **Slow dexterous**: Trial lasts 30 seconds
     Unpredictable vertical movement of target (Figure 2A)
  3. **Fast dexterous**: Trial lasts 30 seconds
     Faster, unpredictable vertical target movement
* 16 repetitions of each task type
* UCM analysis on
  1. Last four seconds of the stable task (Figure 2B)
  2. Four-second steady-F_T requirement for slow and fast dexterous tasks (Figure 2C)

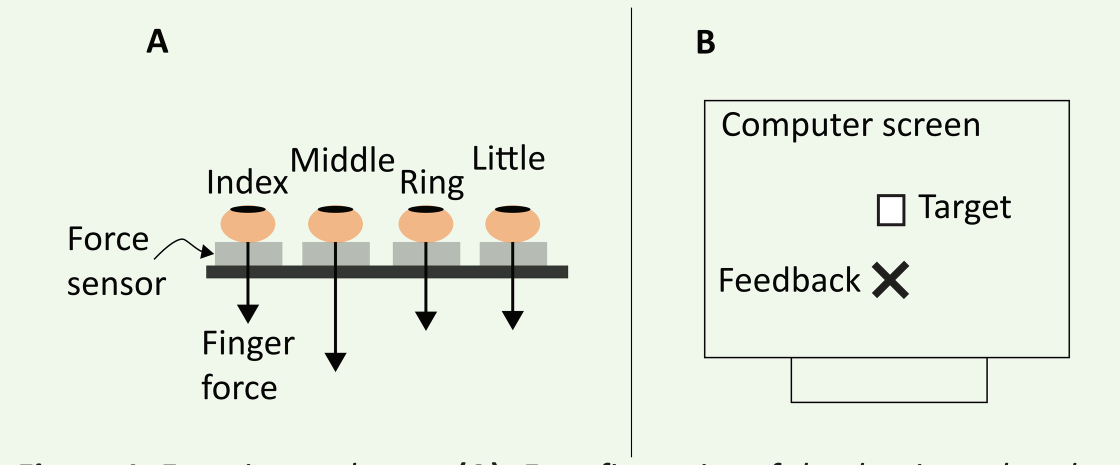


Figure 1. Experimental setup **(A)***. Four fingertips of the dominant hand produce one total force. Feedback of total force and a total force target is provided on the computer screen* **(B)**.

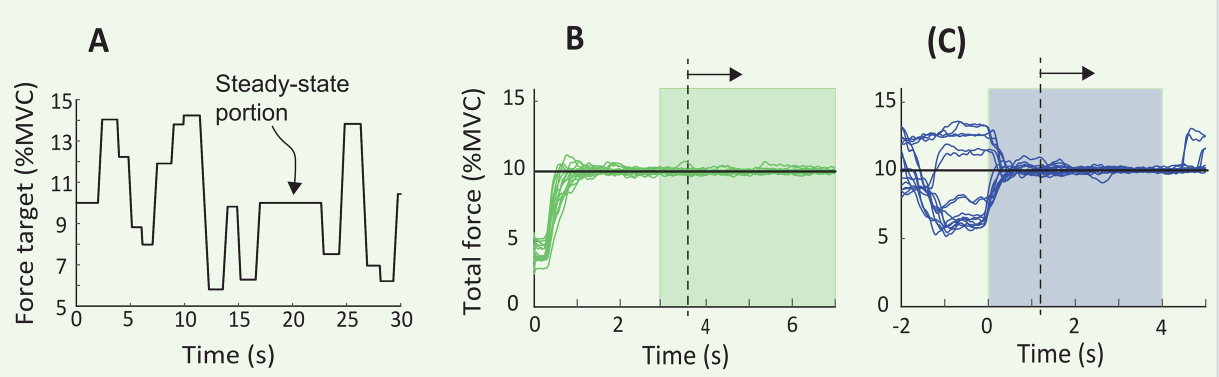


Figure 2. Typical target force profile for a dexterous task **(A)***. Typical performance of the stable task* **(B)***. Typical performance of a dexterous task* **(C)***. Four-second time windows of 10% MVC steady force requirement are isolated for UCM analysis* **(B and C)**.

UCM ANALYSIS

* **Redundant systems** (# inputs > # outputs) afford abundant solution spaces, i.e., solution manifolds to motor tasks [1].
* The central nervous system channels noise into the UCM to ensure stability of motor performance [1].
* Across-trial, mean-free finger forces projected onto 3-dimensional UCM and the 1-dimensional orthogonal (ORT) manifold (Figure 3).
* At each time point *t*, we computed:
  1. Variance within the UCM ($\mathbf{V_{UCM}}$) and within the ORT ($\mathbf{V_{ORT}}$)
  2. The synergy index $\Delta V = (V_{UCM}/3 - V_{ORT})/([V_{UCM} + V_{ORT}]/4)$
  3. z-transformed synergy index
     $\Delta Vz = 0.5\log([4 + \Delta V]/[1.33 - \Delta V])$
* Higher ΔVz implies higher stability of the task variable.

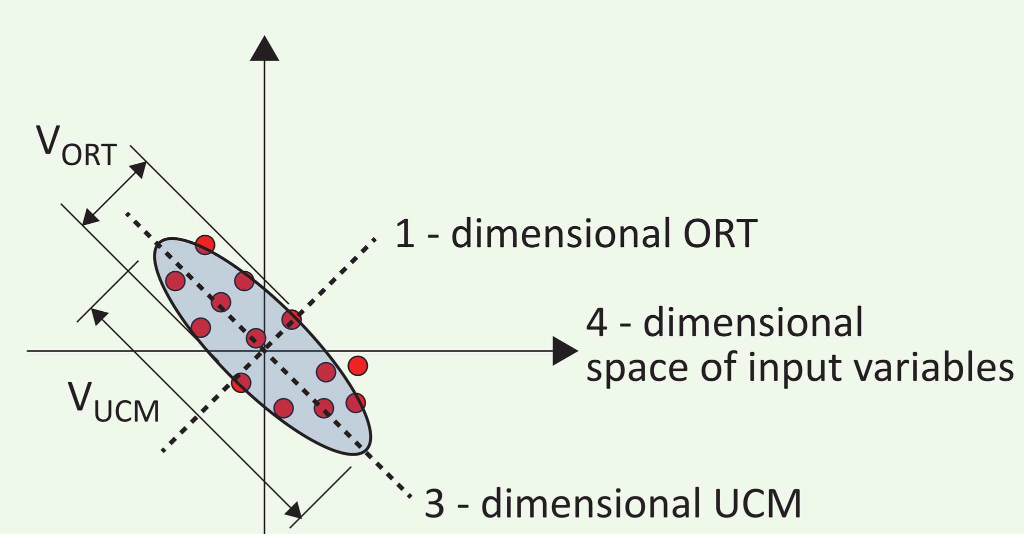
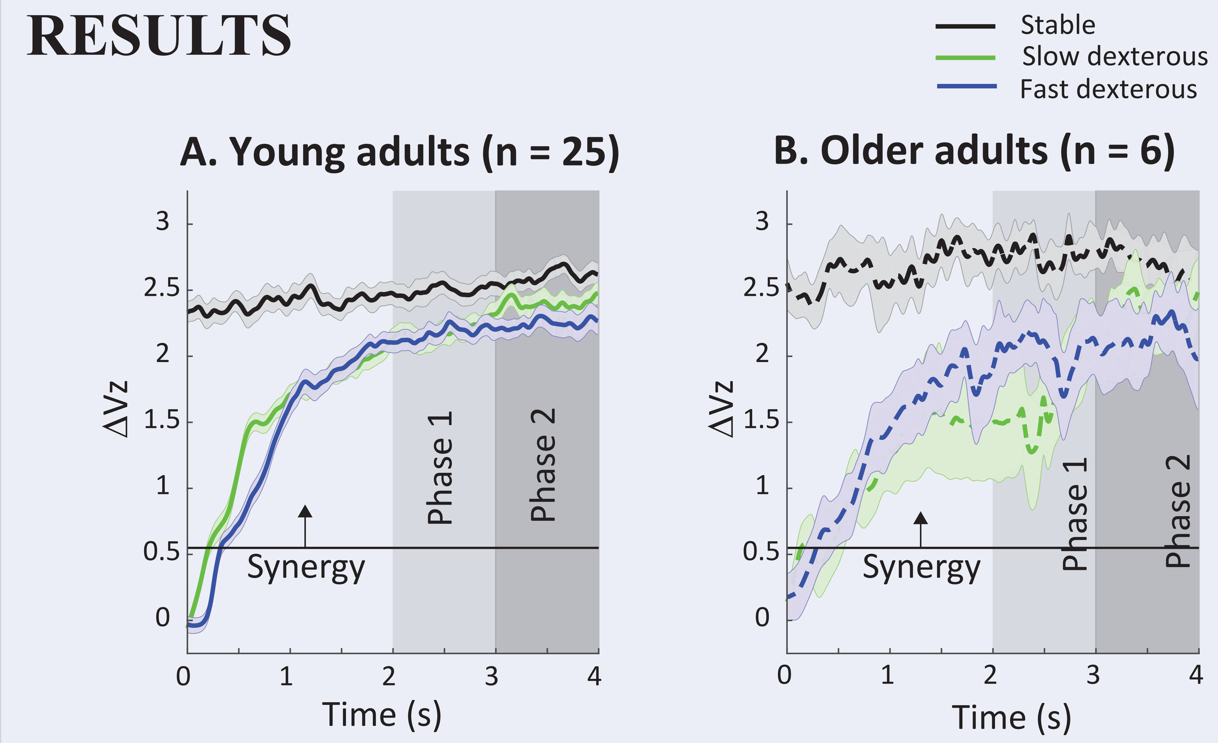


Figure 3. The geometry of the uncontrolled manifold (UCM) analysis. Input variable data is projected onto the 3-dimensional UCM and the 1-dimensional orthogonal manifolds. Variance in the projections are V_{UCM} and V_{ORT}.

RESULTS



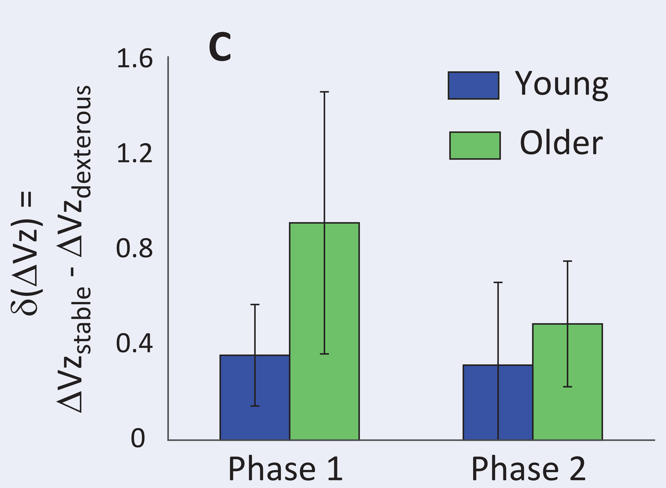


Figure 4. Synergy index time series for young **(A)** *and older adults* **(B)***. Binned values of change in ΔVz relative to the stable task values* **(C)***. These are subjected to statistical analysis.*

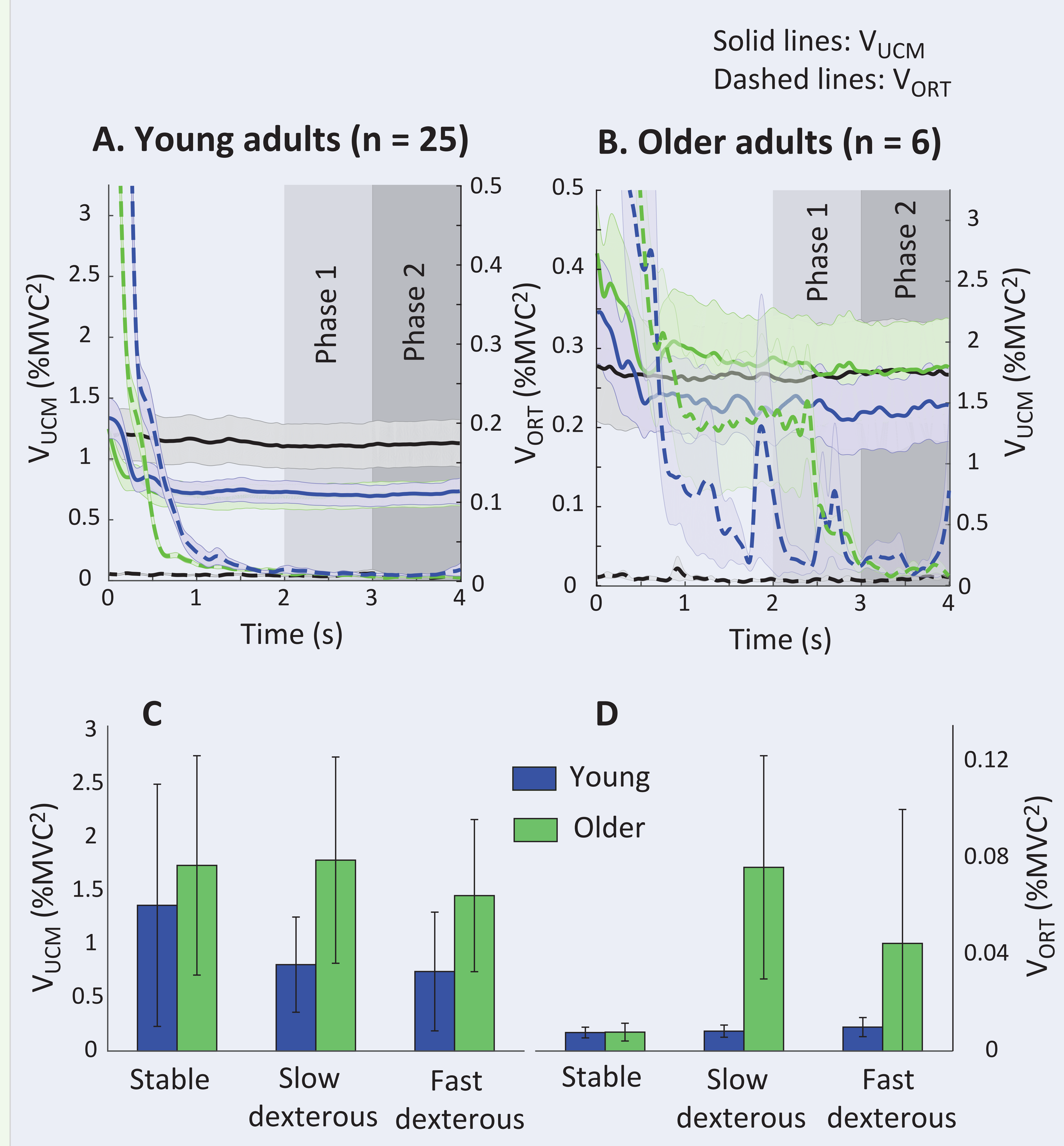


Figure 5. Time series of V_{UCM} and V_{ORT} for young **(A)** *and older adults* **(B)***. Binned values in later part of the trial (Phase 1 and 2) are subjected to statistical analysis. Values for V_{UCM} in plot* **(C)** *and V_{ORT} in plot* **(D)**.

Young Adults (RM ANOVA; Task type x Phase ; n = 25)
1. ΔVz reduces for dexterous tasks by 12%
   [$F_{(2,48)}$ = 13.794; $p < 0.01$], (Supports HYPOTHESIS 1)
2. V_{UCM} reduces by 37% [$F_{(2,48)}$ = 6.225; $p < 0.01$],
3. No change in V_{ORT} [$p = 0.074$].

Older adults (RM ANOVA; Task type x Phase; n = 6)
1. ΔVz reduces for dexterous tasks by 16%
   [$F_{(2,10)}$ = 12.816; $p = 0.002$], (Supports HYPOTHESIS 1)
2. No change in V_{UCM} [$p = 0.709$],
3. V_{ORT} increases by 600% [$F_{(2,10)}$ = 9.78; $p = 0.002$].

Across-age comparison
(Mixed RM ANOVA; repeated measures: Task type and Phase; between-subject factor: Age; n = 6)
Compared to young adults, older adults
1. tend to reduce ΔVz more [$F_{(1,10)}$ = 4.095; $p = 0.07$], (HYPOTHESIS 2 rejected),
2. tend to have greater V_{UCM} [$F_{(1,10)}$ = 3.331; $p = 0.098$],
3. cannot change V_{UCM} across task types,
4. have greater error (V_{ORT}) but much more so for the dexterous tasks [Task type x Age interaction: $F_{(2,20)}$ = 9.442; $p = 0.001$].

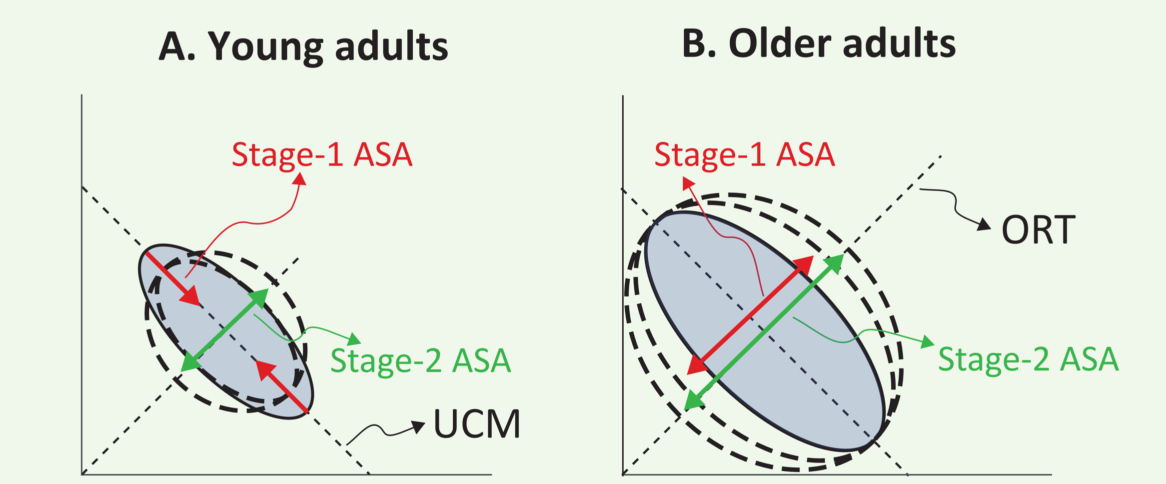


Figure 6. Anticipatory synergy adjustment is a two-stage process. Stage-1 ASA occurs in response to a cue to produce a quick action. Stage-2 ASA occurs prior to execution of cued action. Young **(A)** *and older* **(B)** *adults differ in Stage-1 ASA.*

CONCLUSIONS

* Anticipatory synergy adjustments (ASA) occur in two stages
  1. ***STAGE-1 ASA:*** ΔVz reduces in response to a cue to produce quick movement. The cue can be vague.
  2. ***STAGE-2 ASA:*** ΔVz reduces up to 400 ms prior to change in task variable only when subject knows timing of action [3].
* Stage-1 ASA in young adults: reduction in V_{UCM} (Figure 6A)
  1. System state restricted for efficient state transitions,
  2. Reduced self motion.
* Stage-1 ASA in older adults: increase in V_{ORT} (Figure 6B).
* Older adults respond slower in traditional dexterity tests perhaps due to inappropriate configuration within the UCM.

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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