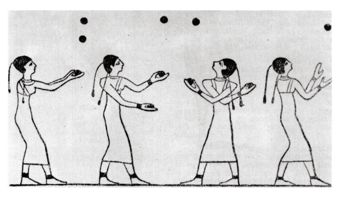

The ancient wall painting from the 15th (1994 to 1781 B.C.) from Wikipedia (https://en.wikipedia.org/wiki/Juggling)

Mobile Brain/Body Imaging of three-ball juggling:

Dynamics of neurobehavioral interactions between motor execution and perception

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Background

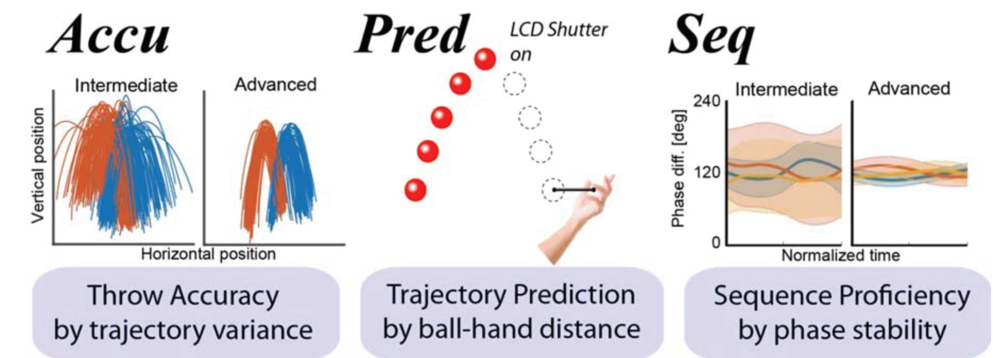
Towards complex skill learning: Juggling

Juggling is a tractable model of a complex motor skill, with a history of behavioral study from the 1970s[a,b] and more recent demonstrations of neurostructural changes during its learning[c]. It extends traditional computational neuroscience approaches to motor skill learning.

Aims

Aim 1: Develop a neurobiological model of juggling skill

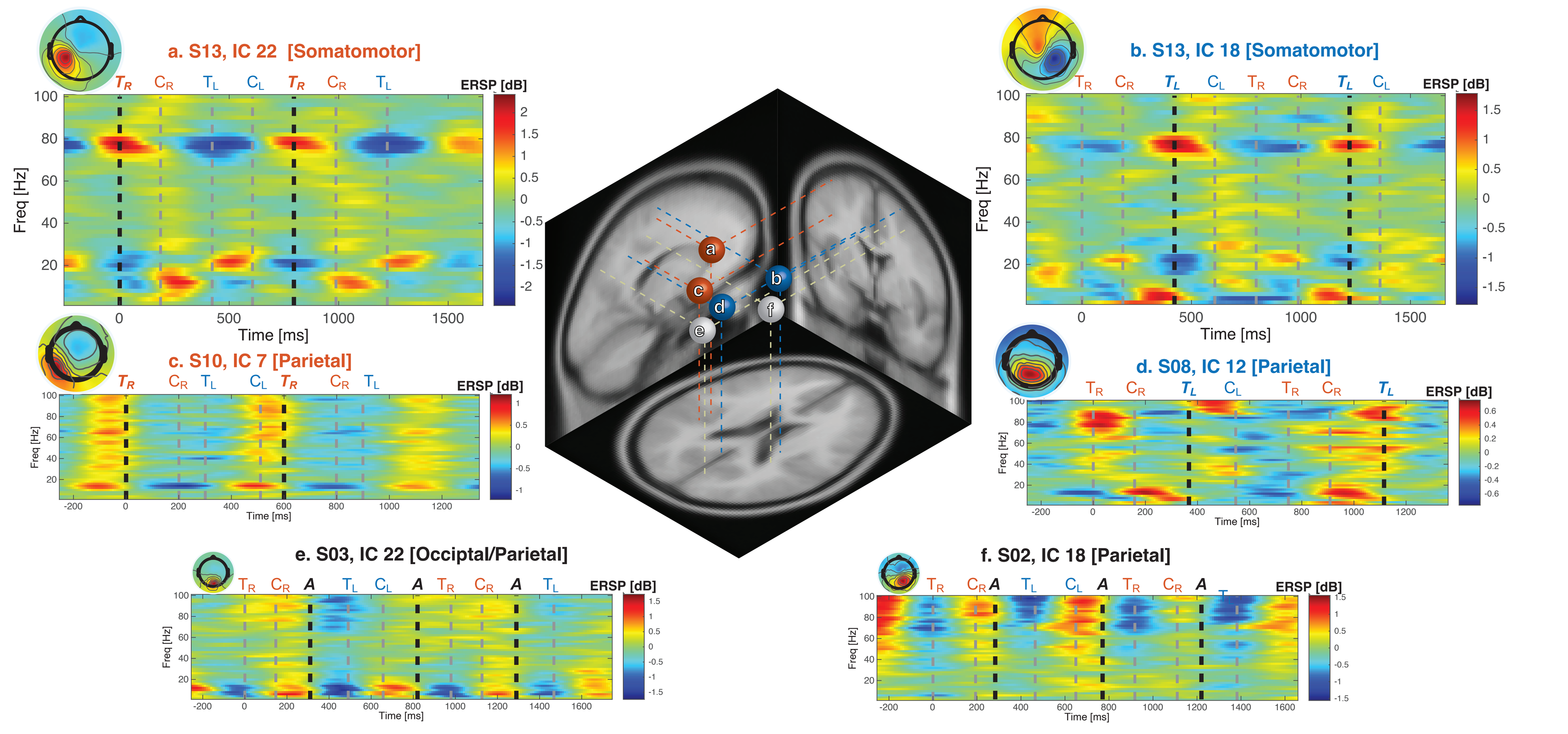
Quantify and discover brain correlates of juggling skill.



Aim 2: Determine the effect of slow-tempo training on performance, offline gain and the brain

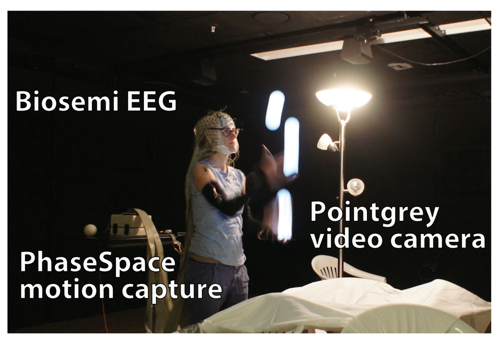
Novel visuo-haptic VR to simulate juggling under reduced gravity.

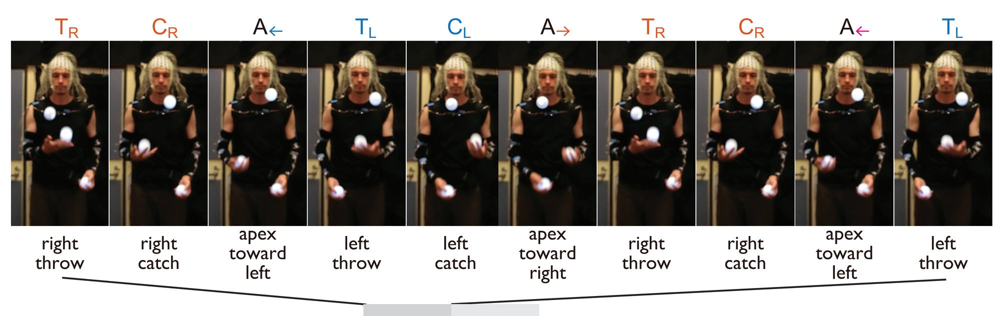
Brain: Motor, Parietal and Occiptal ICs encode juggling events



Somatomotor, Parietal and Occiptal ICs timed to key events of juggling cycle: Catch, Throw, Ball Apex. Prominent 70Hz narrow-band activity previously observed in rhythmic dystonia[h].

Behavior





Task

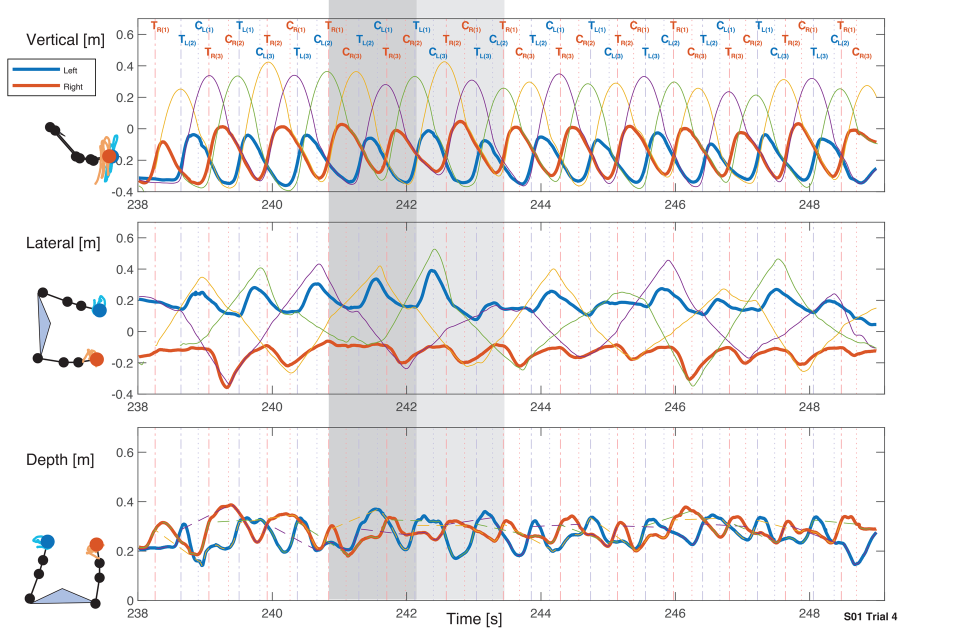
- 3-ball Cascade Juggling
- 5 x 10 minute blocks

Subjects

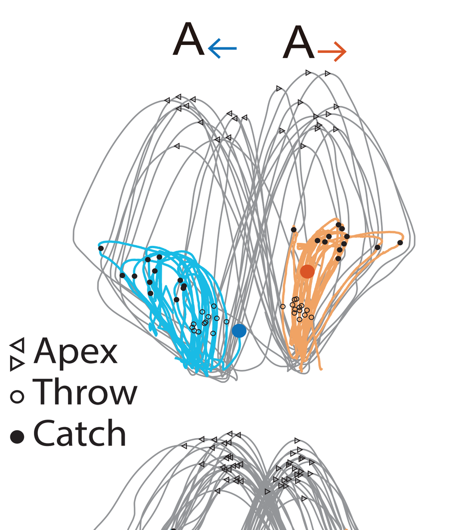
- N=14 amateur jugglers

MoBI Recording

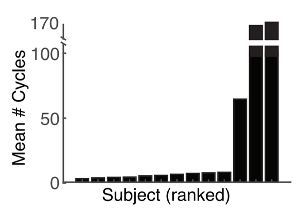
- EEG (205 ch 512 Hz)
- Mocap (9ch, 480 Hz)
- Video (60 Hz)
- Lab Streaming Layer sync
- New ASR algorithm*



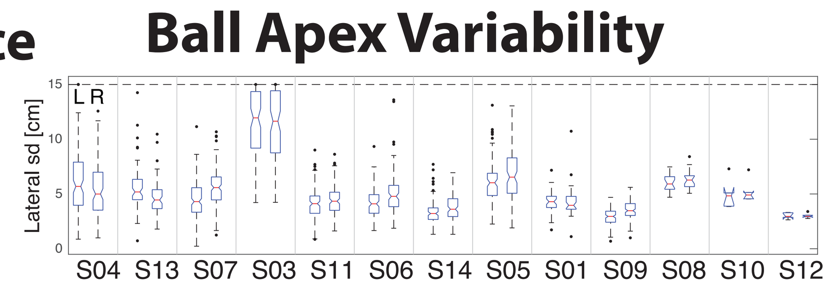
Reconstructed ball and hand trajectories with throw, catch and apex events



Performance

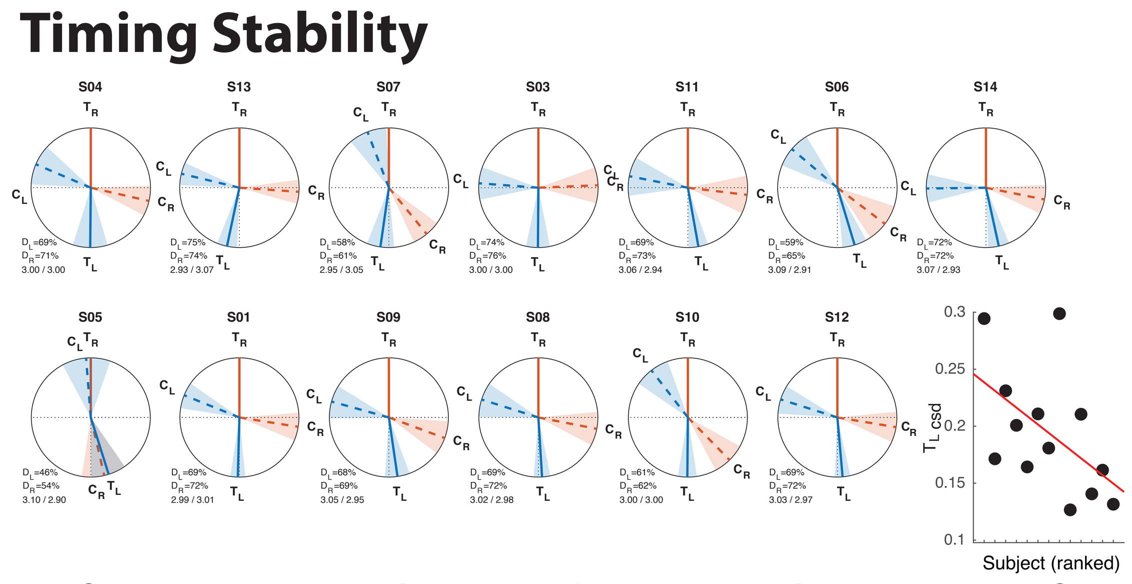


Ball Apex Variability



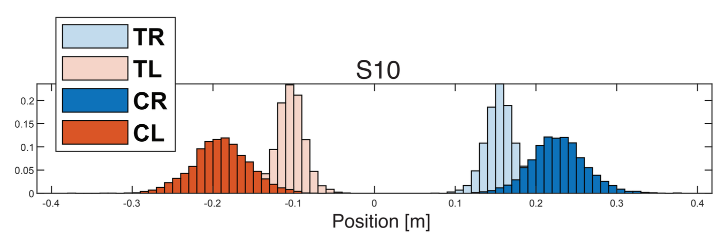
Cross-trial consistency marks highest performers

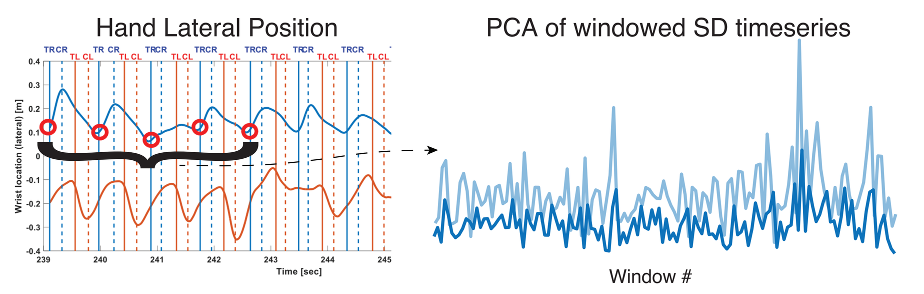
Timing Stability

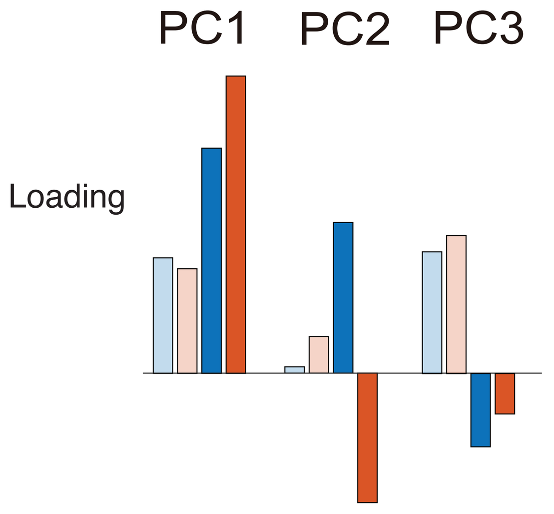


Performance correlates with temporal precision of throw timing. Catch timing absorbs cycle variance.

Hand position and phase temporal structure





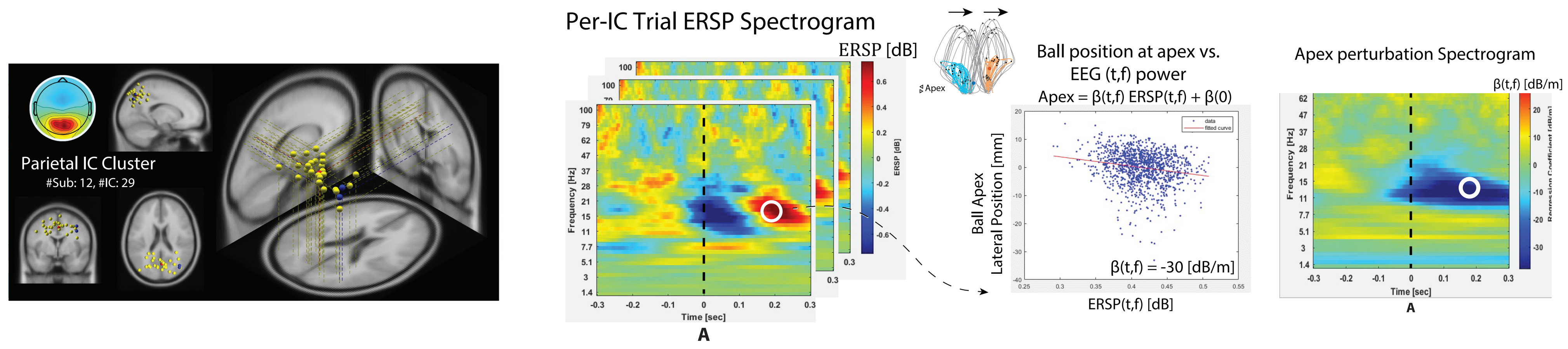


Interpretation:
PC1 (60% variance): Positive, Catch > Throw
PC2 (30% variance): Contrst Left catch vs. Right catch
PC3 (7% variance): Contrasts Throw vs Catch

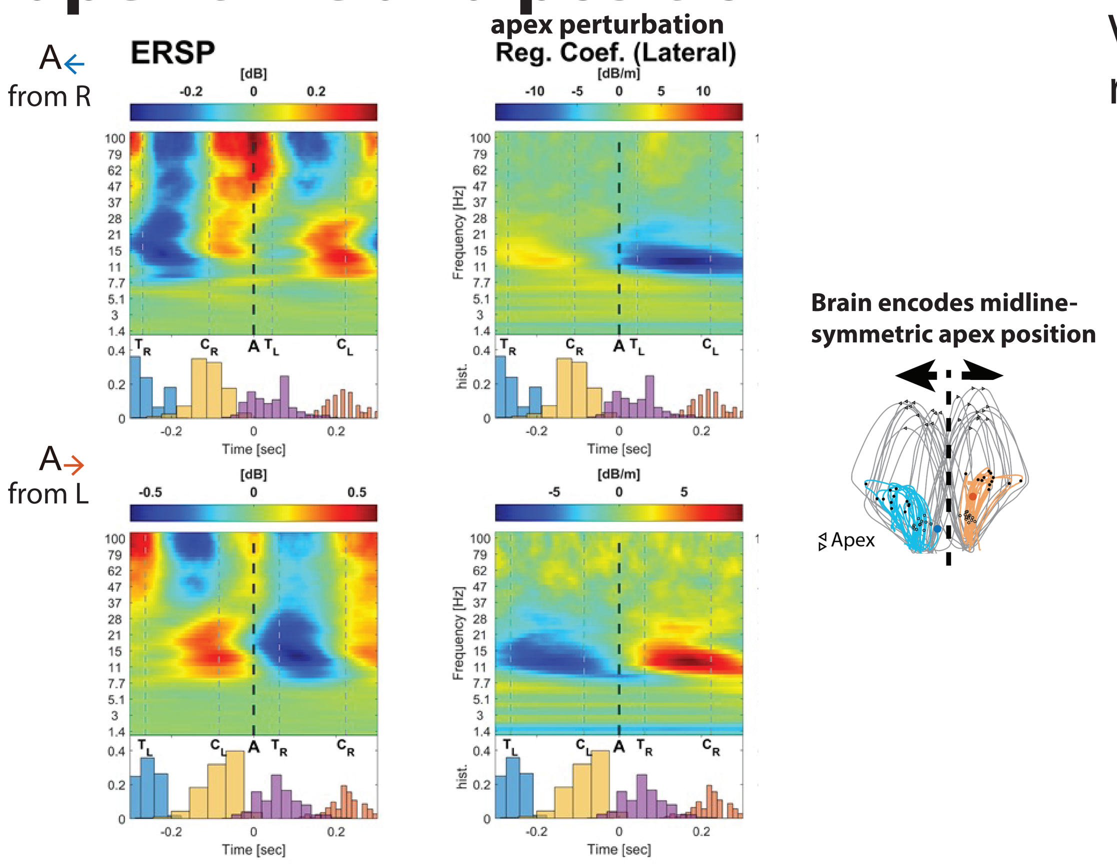
Three distinct modes of motor control?
Note: A similar pattern is seen *across* all skill levels

Brain + Behavior: Ball Apex Perturbations

Ball apex is a critical perceptual event in the control of juggling[i,j]. We examine how the apex position is encoded in parietal components, revealing the natural coordinates of ball position are measured symmetrically about the midline.

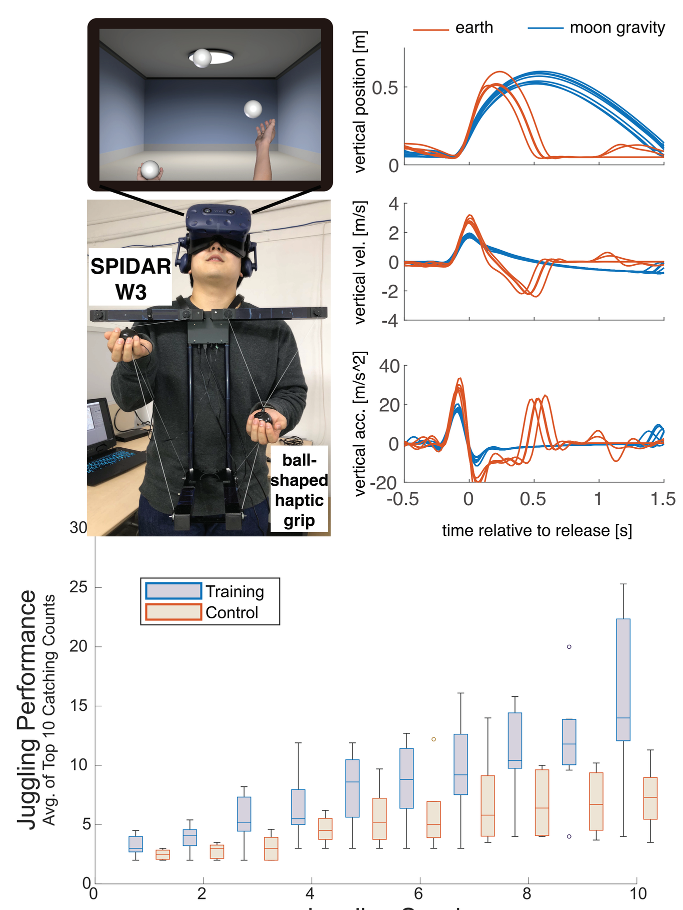


Parietal ICs respond to apex time and position



Aim 2: VR Training

Visuo-haptic VR training at simulated reduced gravity speeds learning



Discussion

Brain + Behavior Dynamics

Interesting aspects of skill may lie not on mean, which is highly constrained by juggling, but on within-trial and between-trial variation. Trial-trial and cycle-cycle analysis has examined in finer grain how brain supports behavioral response.

Motor control Targets

Timing of ball throws becomes increasingly precise with skill. Suggests ball throw is a proactive spatiotempora goal, while catch events are more reactive to ball trajectory.

Behavioral correlation modes

PCA decomposition of fluctuations in hand position at throw and catch suggest three orthogonal processes--next step: search in brain to see if these dissociate.

Encoding of Ball Apex Perturbations

Spatial perturbations of ball apex position were reliably encoded as variations in ERSP power in the 10 – 25 Hz range. The sign of the perturbation indicates that the coordinates for lateral perturbations is represented in the brain with body mid-line symmetry.

Slow-tempo Training

Training in slow-motion improves learning.

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[h] Miocinovic S, Swann NC, de Hemptinne C, Miller A, Ostrem JL, Starr PA (2018) Parkinsonism and Related Disorders. Parkinsonism & Related Disorders 49:104–5.
[i] van Santvoord A (Tony)A. M, Beek PJ. Spatiotemporal variability in cascade juggling (1996). Acta Psychol (Amst). 91(2):131–51.
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* Kim, Iversen, Chang, Kothe & Miyakoshi. (in prep) Juggler's ASR: Artifact subspace reconstruction using order statistics to correct periodical artifacts with short intervals.

Video Presentation