Identifying the Neurobiology of Performance and Training Retention in Pilots via Task-based Functional Magnetic Resonance Imaging

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Disclosures

- This project is supported by funding from:
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- The study protocol was approved by the San Antonio Institutional Review Board in compliance with all applicable Federal regulations governing the protection of human subjects.
- The voluntary, full informed consent of the subjects used in this research was obtained as required by 32 CFR 219 and DoDI 3216.02.
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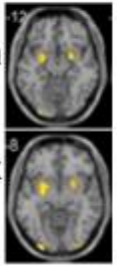
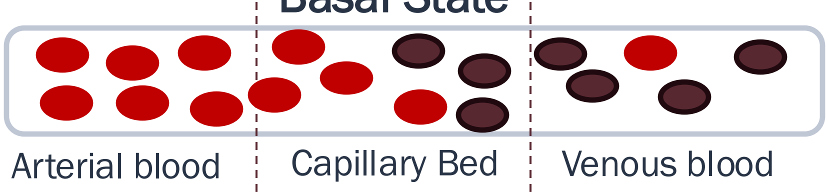
Study Overview

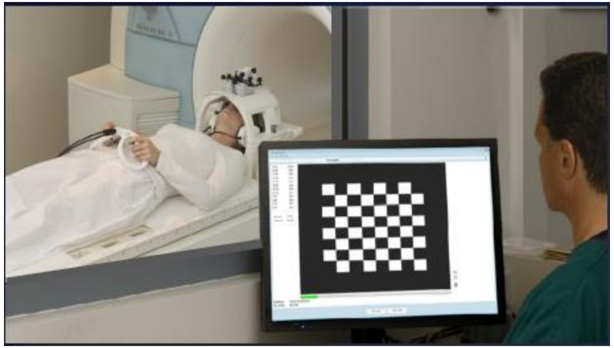
Targeting Brain Circuitry

Overall Task	Sub-Tasks	Anatomy Needed	Strengthen Anatomy
Tolerate G 	Controlled Breathing Isometric contraction		
"Fly Well" 	Aerial Pursuit / Control 	Basal Ganglia Insular Cortex 	Flight Training

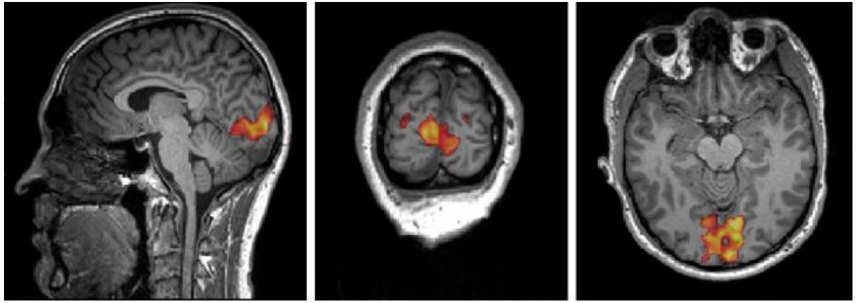
How Does Functional MRI Work?

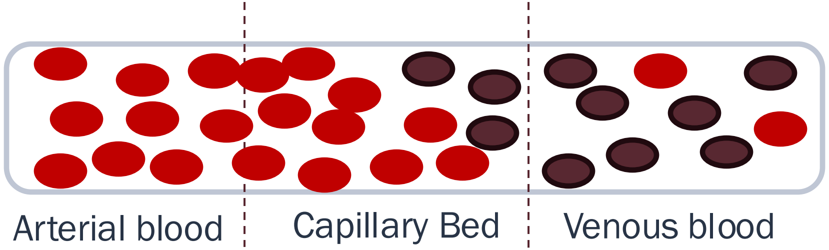
Basal State





Active State





↑ activity = ↑ blood flow = ↑ oxy/deoxy Hb

Methods - Integration of X-plane into MRI

NordicNeuroLab Eye Tracking Goggles

3T Siemens Vida at WHASC w/ Joystick & Throttle

X-Plane

Target parameters:

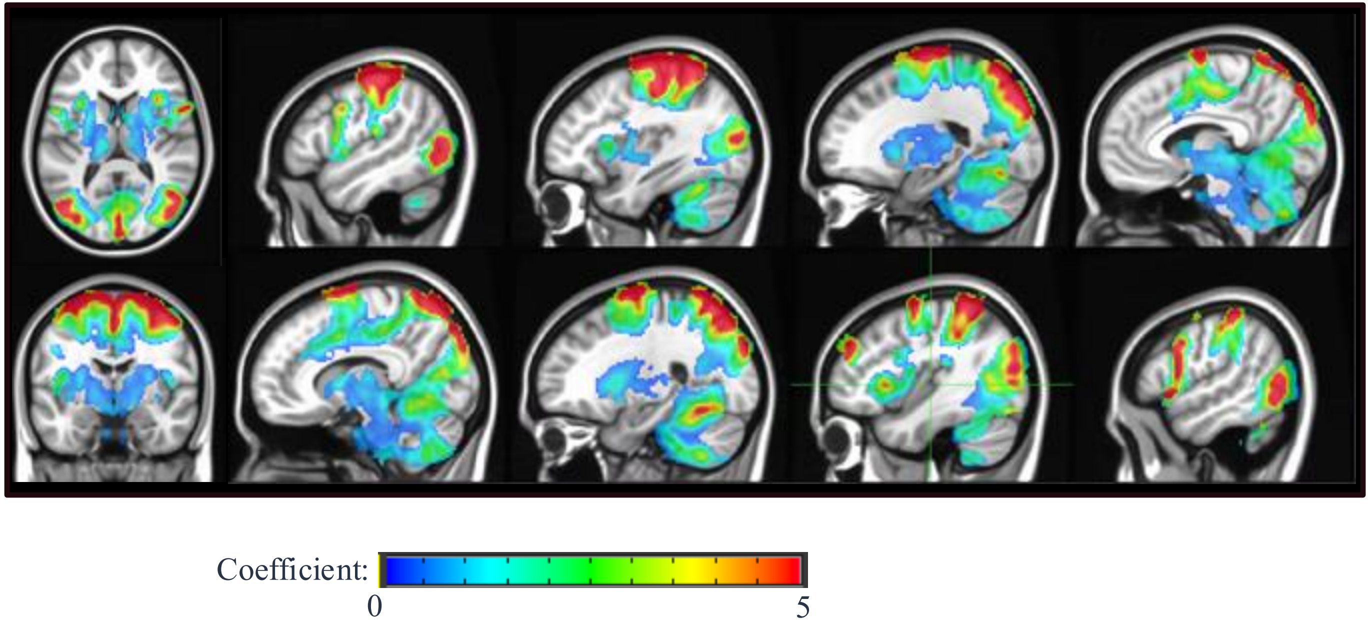
- PICT: 15000 feet Altitude, 090 (E) Heading; 350 (knots Airspeed)
- UAR: recover to straight/level flight from a far-from-level attitude
- Vertical S (USAF Inst.) task: Alternate 14.5'-15.5' altitude smoothly

Beer J, Morse B, Dart T, Adler S, Sherman P. Lingering Altitude Effects During Piloting and Navigation in a Synthetic Cockpit. Aerosp Med Hum Perform. 2023 Mar 1;94(3):135-141.

Results – Unusual Attitude Recovery

In the UAR Task, activations include motor and premotor areas, basal ganglia circuitry, cerebellum, visual networks, and dorsal and ventral attention networks.

(Group average across 42 sessions of data from 24 subjects)



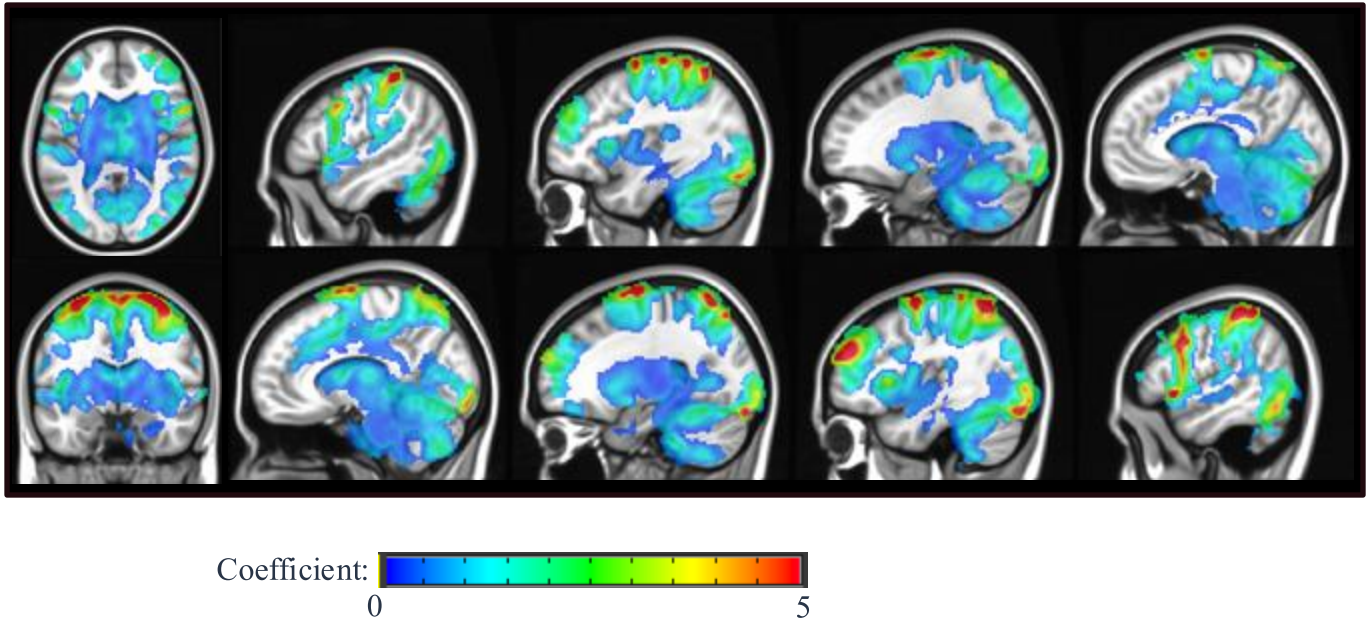
Activation map for UAR task (subtraction of passive viewing and follow the leader from active piloting task). Colored voxels indicate significance at corrected $p < 0.05$, and the voxel color indicates the magnitude of the fit coefficient. Warmer colors indicate voxels with stronger activations to the task. Significant suppression of activity in the Default Mode Network is not shown.

Results – Straight and Level Task

Similar activations were observed for the Straight and Level Task, suggesting that our current fMRI protocol is accurately assessing the neuro-anatomical networks of active flight control.

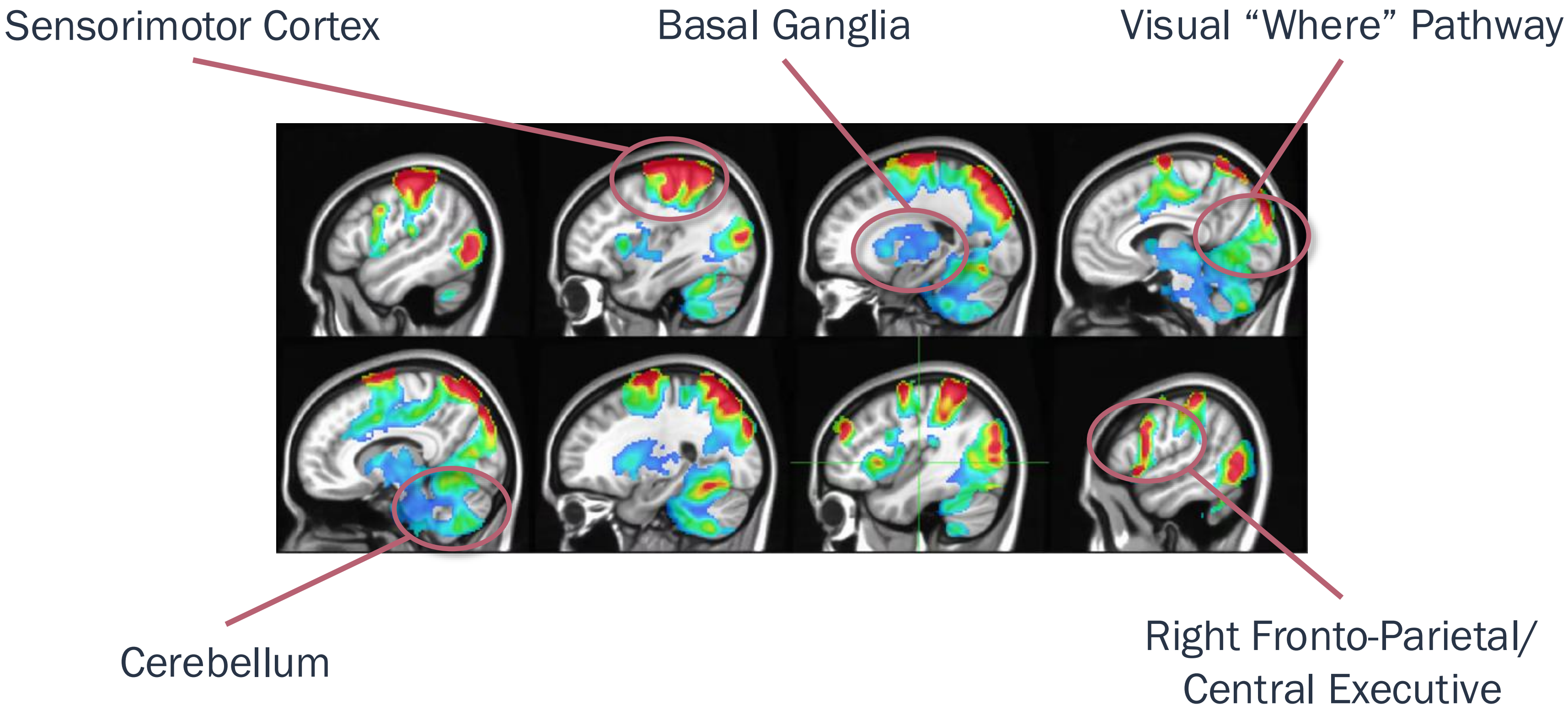
(Group average across 47 sessions of data)

Results are consistent with prior work by Callen, et al studying simulated control of gliders in scanner.

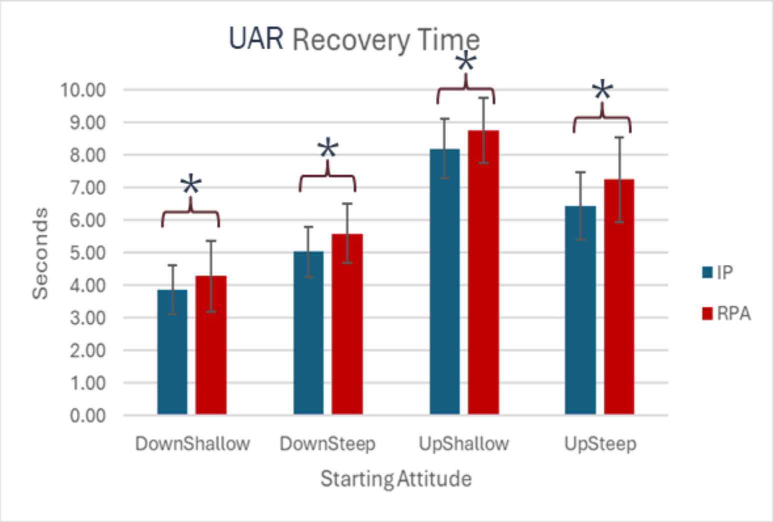


Activation map for the Straight and Level Task (subtraction of passive viewing task from active piloting task). Colored voxels indicate significance at corrected $p < 0.05$, and the voxel color indicates the magnitude of the fit coefficient. Warmer colors indicate voxels with stronger activations to the task. Significant suppression of activity in the Default Mode Network is not shown.

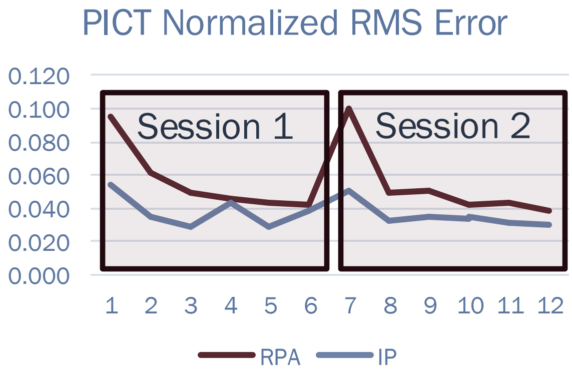
Results – Brain Regions



Behavioral Outcomes

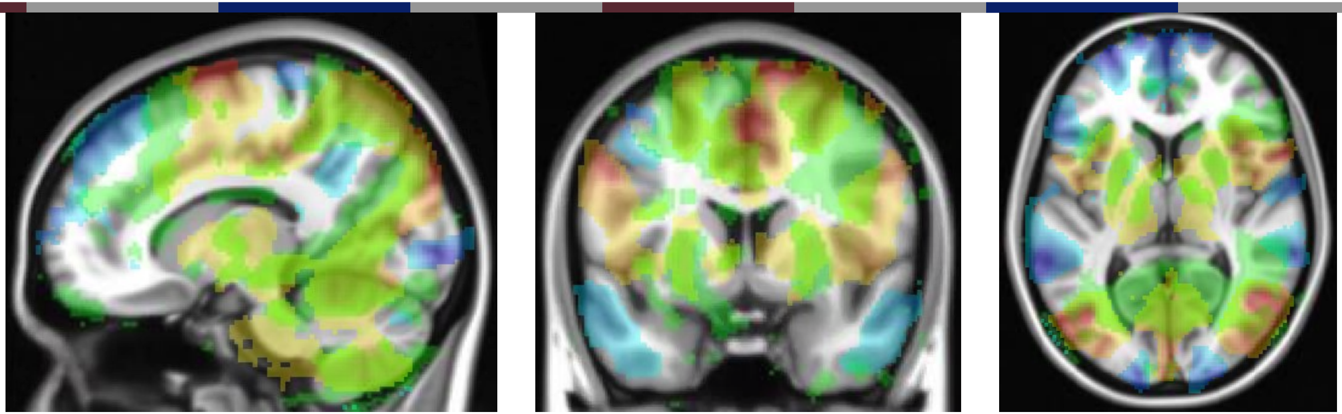


- Analysis of behavioral outcomes and their relationship to brain activity is ongoing.
- Differences in response times based on initial aircraft position, with Pitch Up/Shallow Bank taking longest to reorient.
- IP flew more precisely than RPA, and showed less of a within-session learning effect
- For Vertical S, IP trainees demonstrated more precision in airspeed and vertical velocity



Warrior Medics – Mission Ready – Patient Focused

Neural Correlates of Behavior



Activation maps for significant association between UAR Recovery Score and activation during task overlaid on task activation map. Colored voxels indicate significance at corrected *q* < 0.05.

- No significant associations with SaLT.
- Decreased activity in the cuneus/secondary visual cortex and cerebellum, and increased activity in putamen were associated with better performance on the UAR.

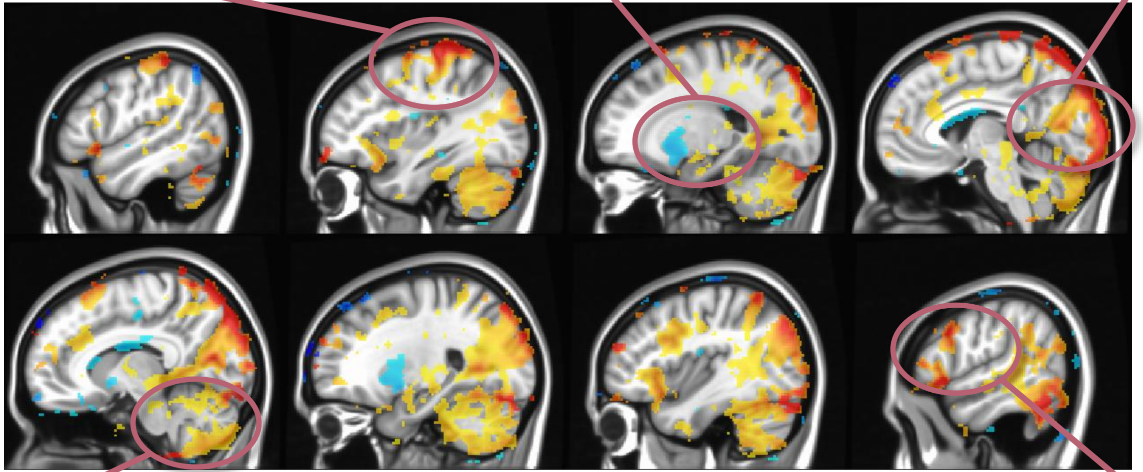
UAR: Data from 39 sessions in 23 pilots.
SaLT: Data from 47 sessions in 25 pilots.

Results – Brain Regions Linked to UAR Performance

Sensorimotor Cortex

Basal Ganglia

Visual “Where” Pathway



Cerebellum

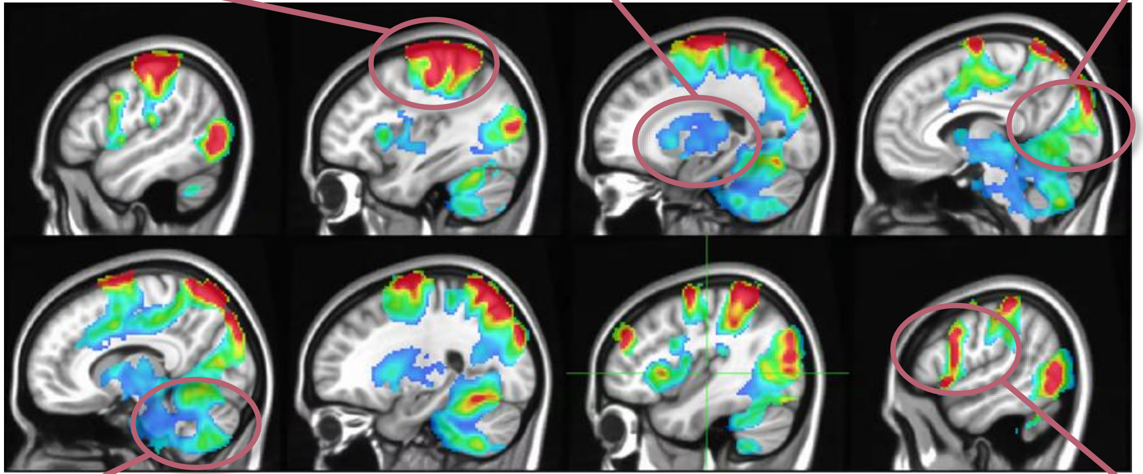
Right Fronto-Parietal/
Central Executive

Results – Reminder, Brain Regions Active During UAR

Sensorimotor Cortex

Basal Ganglia

Visual "Where" Pathway



Cerebellum

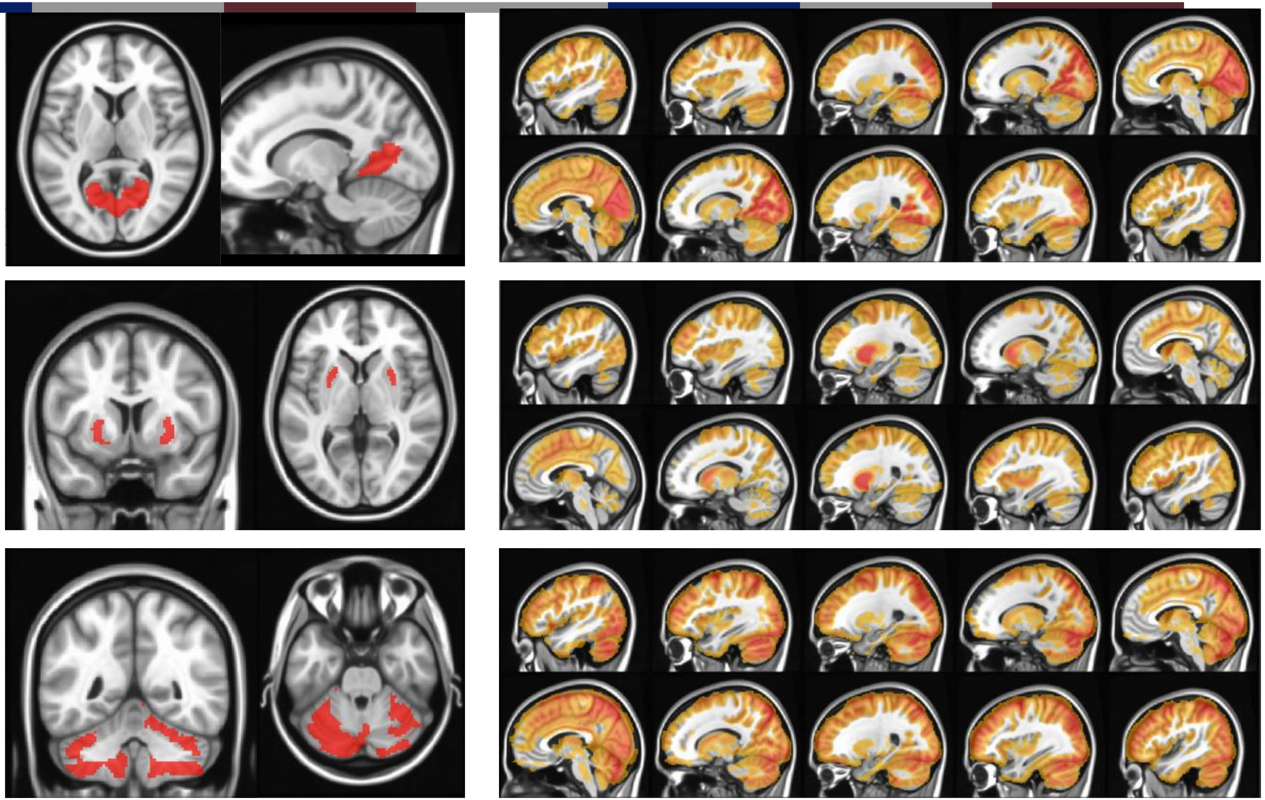
Right Fronto-Parietal/
Central Executive

Functional Connectivity During Vertical S Task

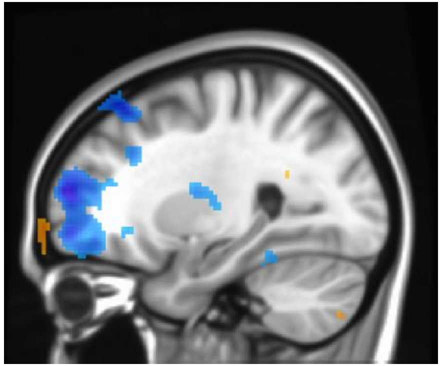
For all three seeds, there is brain-wide connectivity, that extends well beyond the network of the seed region.

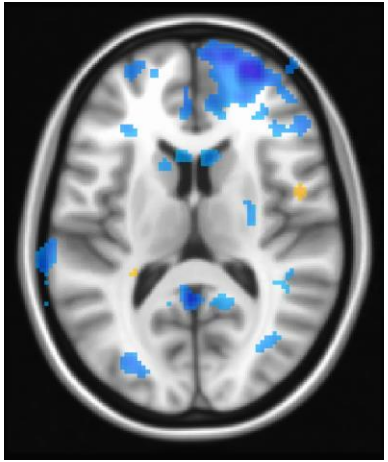
This is indicative of whole-brain recruitment to perform the task.

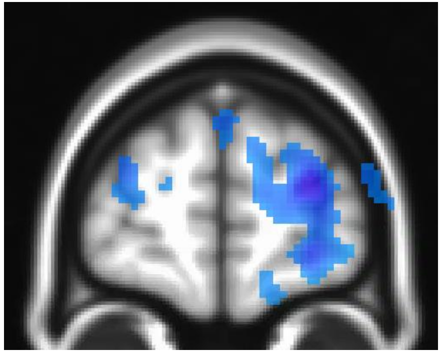
Analysis includes 42 sessions from 23 pilots.

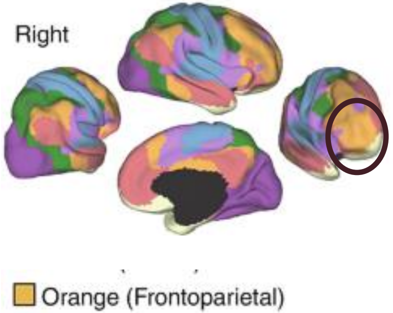


Airspeed-Connectivity Results









- Better performance on the Vertical S (lower error in Airspeed) were associated with higher **connectivity** between the three seed regions and the inferior frontal gyrus, on the right side
- This area is part of the fronto-parietal network
  - This is the same network we identified earlier, but not precisely the same area

Conclusions

- Five main brain regions involved in flight control, and their activity is related to performance
  - More activity in the putamen is advantageous, for the rest, less activity is ‘good’
  - Unclear with these data if this is because of a change in strategy, efficiency in the networks, or a result of finishing the task more quickly.
- Simulated flight control requires coordinated brain-wide activity
  - Pilots who flew well have more coordination between the right frontoparietal/central executive network and the other regions we considered (cerebellum, visual networks, putamen).

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