Developmental Changes in Motor Performance are Mediated by Right Parietal Beta Oscillatory Dynamics

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Background

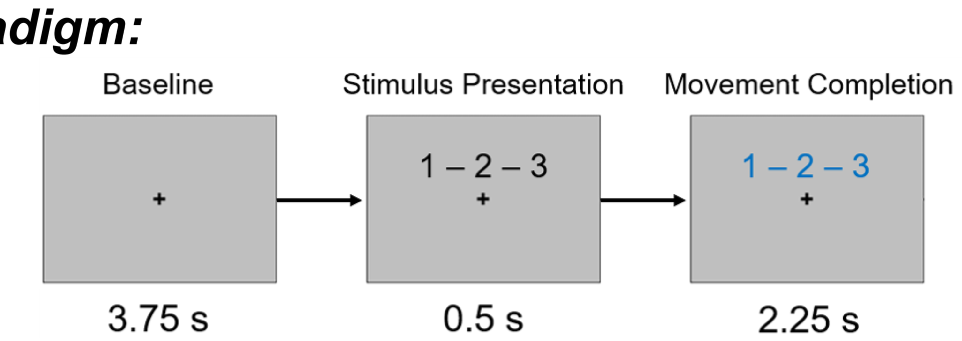
- Throughout development, the ability of children and adolescents to perform complex, coordinated movements significantly improves
- Nonetheless, the neurophysiological dynamics that underlie this improvement in complex motor performance has yet to be established
- There is a well-established pattern of neural oscillatory activity throughout the extended motor that serves motor planning, execution, and termination and is known to follow a specific developmental trajectory
- The current study sought to identify which neural components and motor regions were uniquely responsible for the development of complex motor action

Methods

Participants:

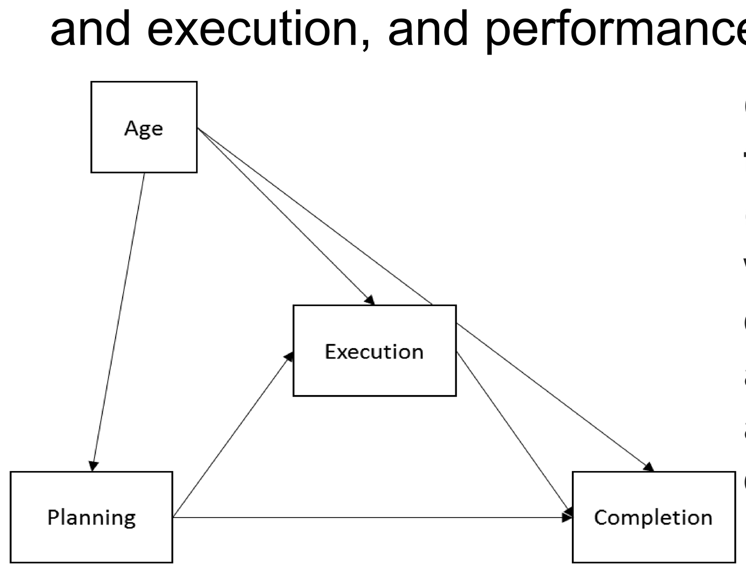
- 107 typically-developing children aged 9-14 years old (avg. age 11.52 years) were recruited

Task Paradigm:



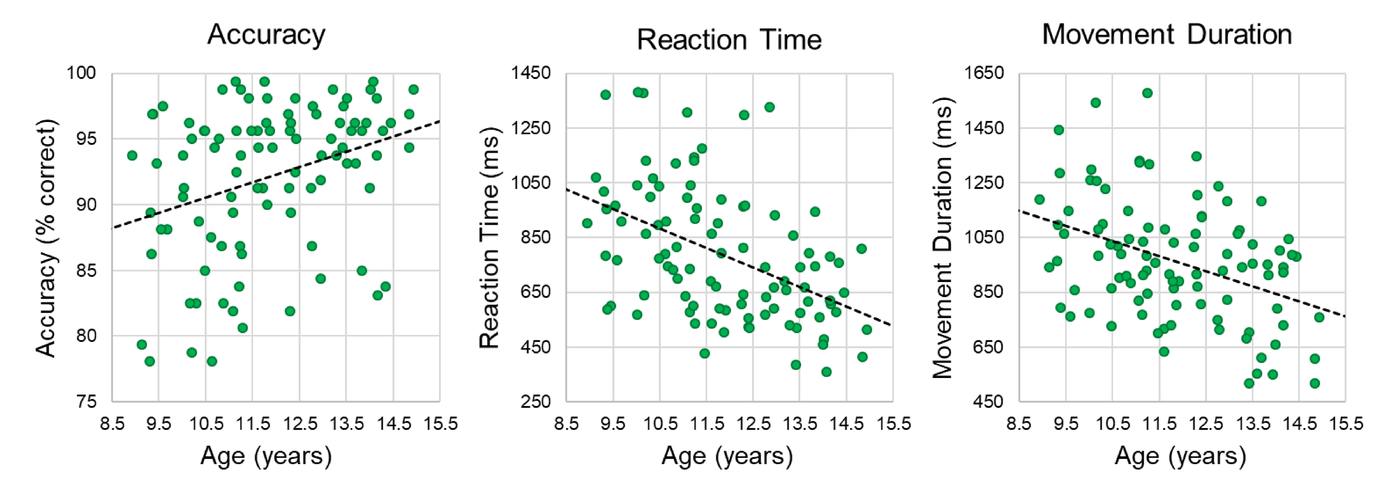
MEG Acquisition and Pre-Processing, and Data Modeling:

- Neuromagnetic responses were sampled continuously at 1kHz using a 306-sensor Elekta Neuromag system.
- Data were corrected for head motion, subjected to noise reduction, and coregistered to a T1-weighted MRI.
- Artifact-free epochs were transformed into the time frequency domain using complex demodulation.
- Time-frequency windows used for beamforming were determined by statistical analysis of the MEG gradiometers.
- Cortical networks were imaged through an extension of the linearly-constrained minimum variance vector beamformer.
- Virtual sensors corresponding to peak activity in the beamformer images were extracted from each region of the motor network.
- Relationships between age, neural activity during planning and execution, and performance were modeled using SEM.

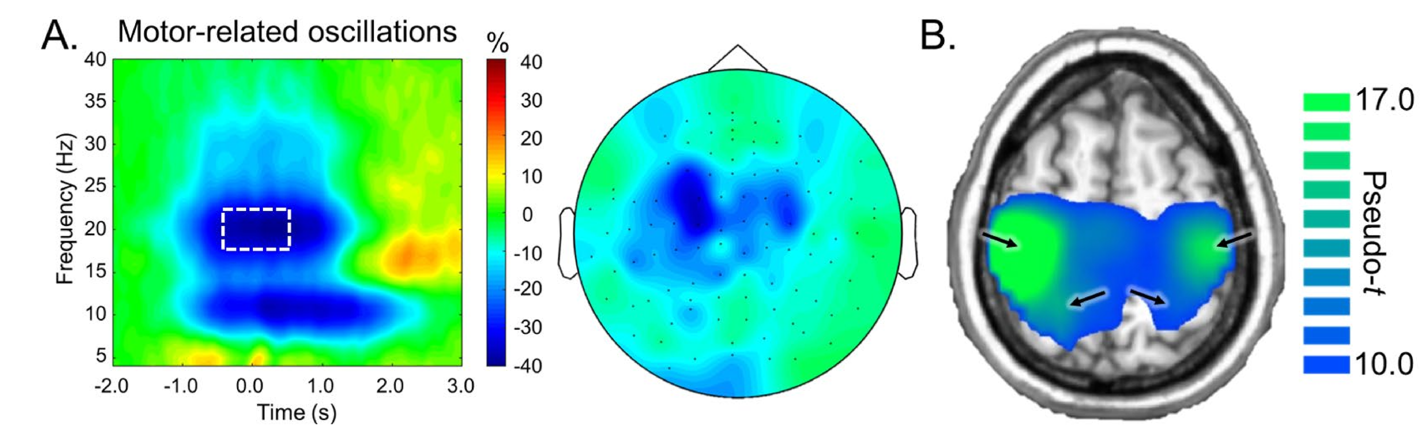


Conceptual mediation model tested. Execution variables (neural activity and reaction time) were tested as potential mediators of the effects of neural planning activity on task performance. We also probed developmental effects on the neural and behavioral measures via chronological age.

Results

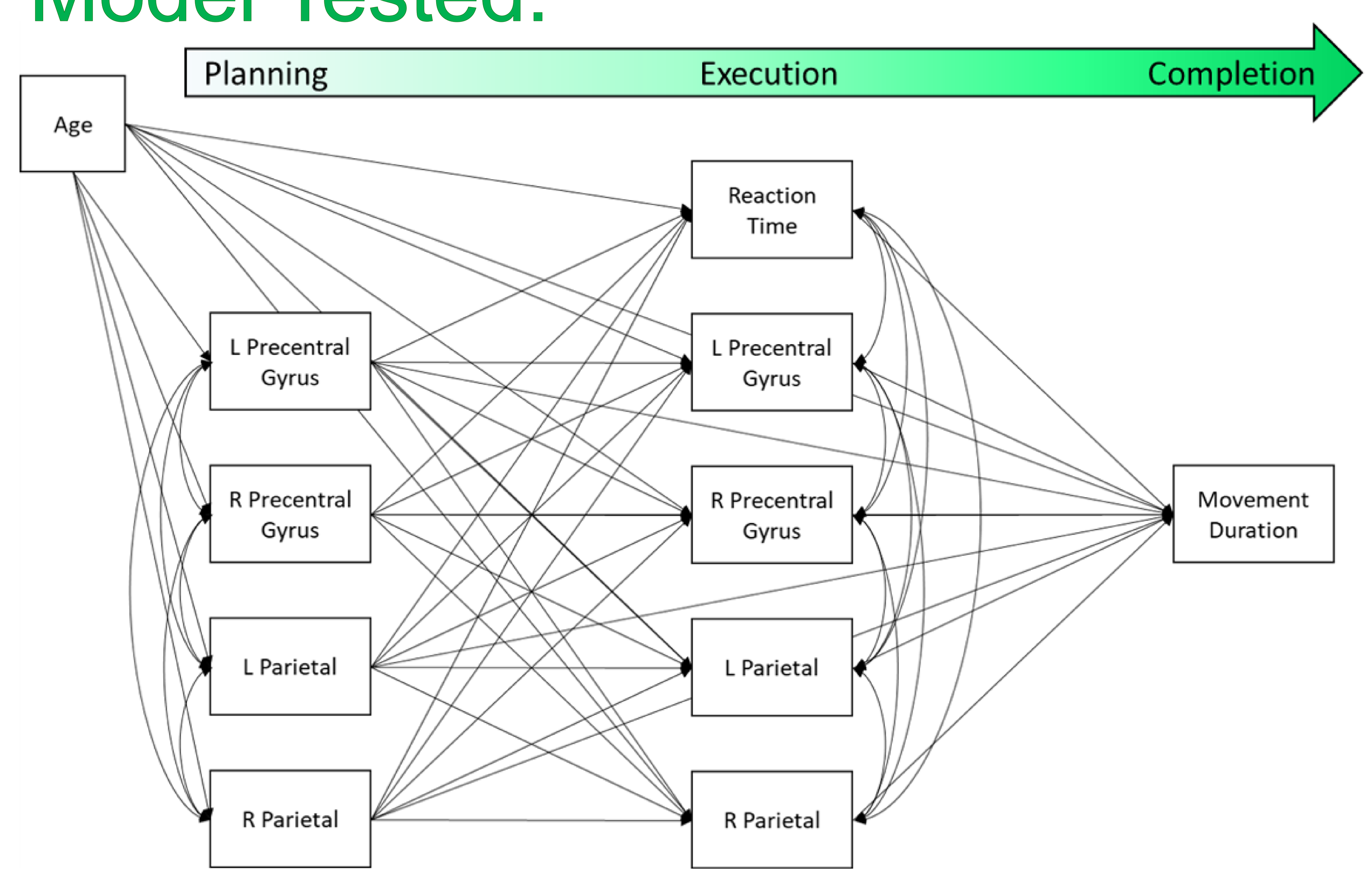


Behavioral Results. There were significant correlations between age and accuracy (left), reaction time (middle) and movement duration (right; all p's < .001).

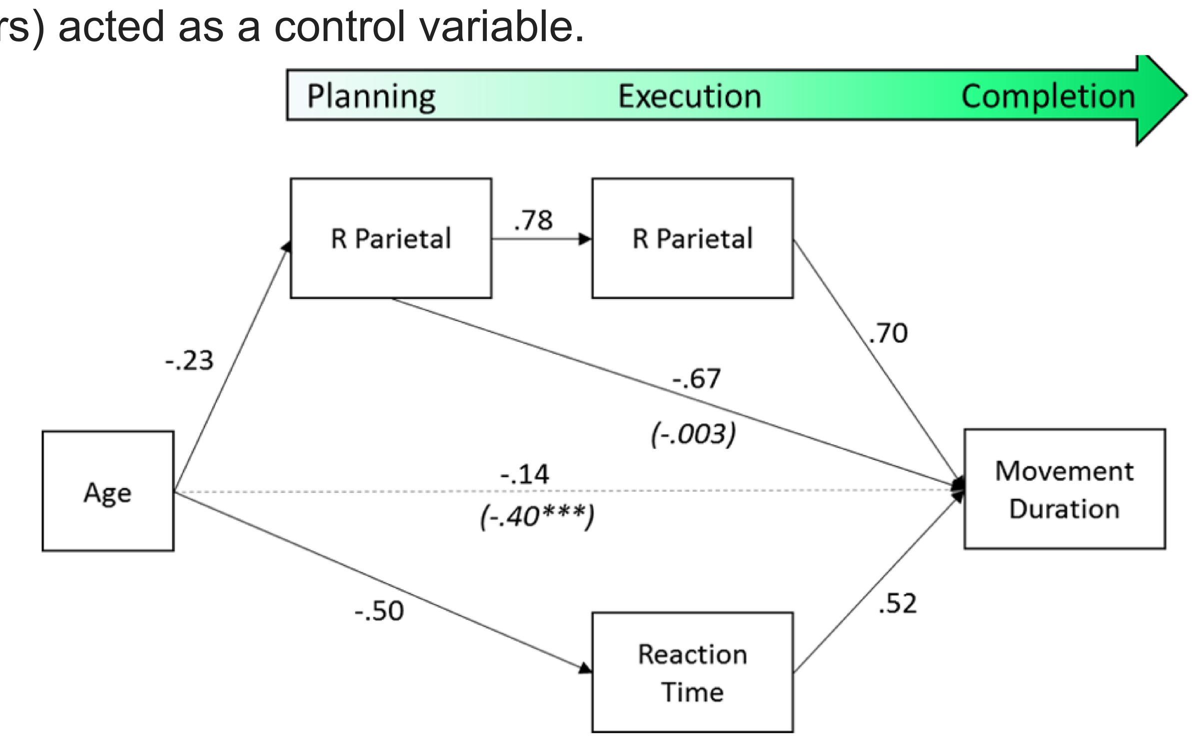


MEG Results. A) Left: Representative grand-averaged time-frequency spectrogram. Right: Sensor-level distribution of 17-23 Hz activity before and during movement across the sensor array. B) Grand-averaged source image of beta activity (17-23 Hz, -0.4 to 0.4 s). Arrows denote peak clusters of motor-related neural activity.

Model Tested:

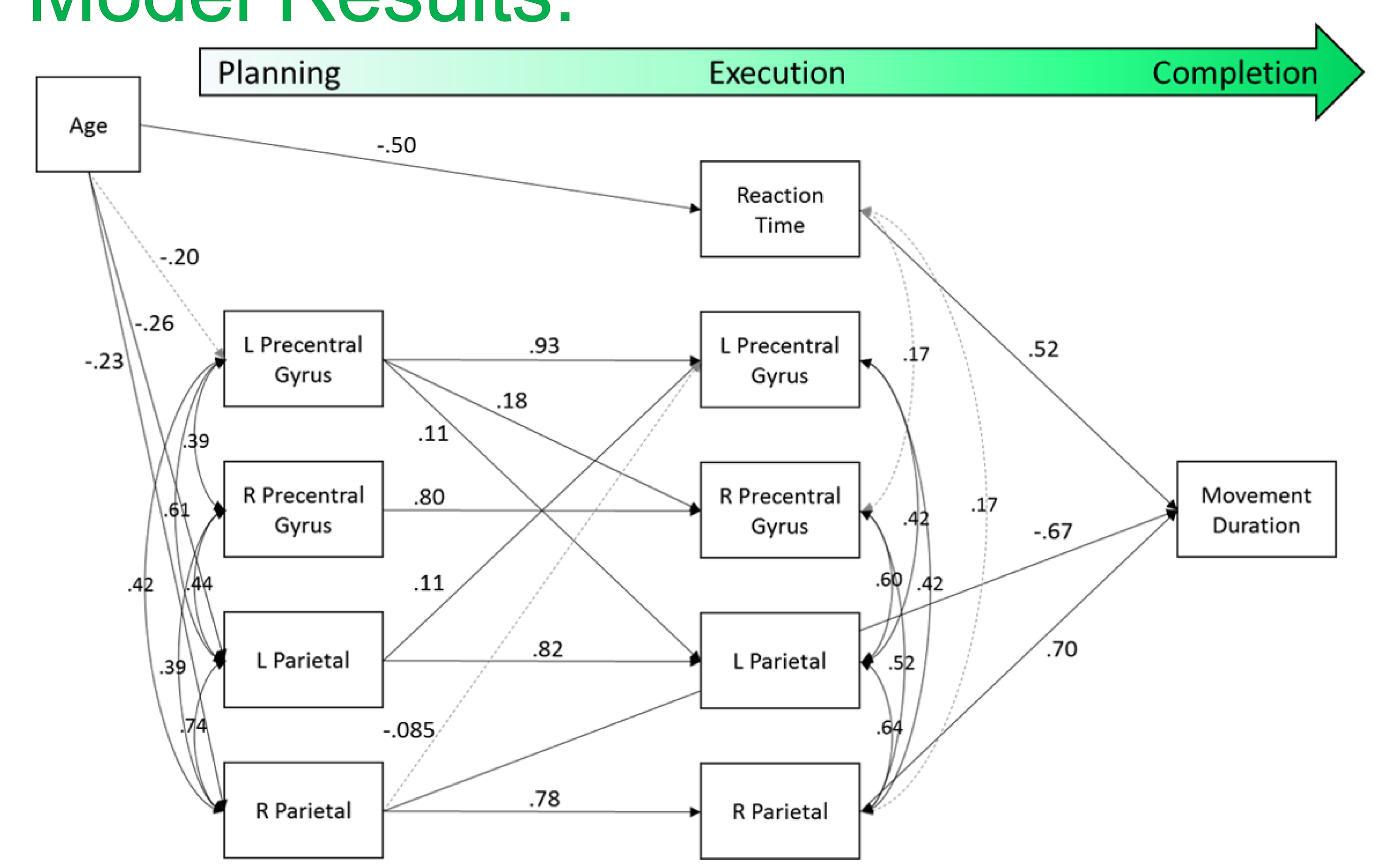


Full mediation model tested. Planning variables included source activity (pseudo-*t*) during the planning period (-0.4 to 0.0 s, 0.0 s = movement onset) for the left and right precentral gyri and parietal cortices. Planning variables predicted execution variables, which included source activity (pseudo-*t*) in the same neural regions during the execution period (0.0 to 0.4 s), as well as reaction time (in ms). Planning and execution variables predicted movement duration (in ms). Age (in years) acted as a control variable.



Statistically significant mediating effects. Significant estimates ($p < .05$) are denoted with a solid black line. Note that the total effect of age on movement duration was significant ($p < .001$; shown in parentheses), but this relationship was fully mediated (dashed gray line denoting non-significance). All listed parameters are standardized coefficients.

Model Results:



Results of the full mediation model. Statistically significant estimates (p < .05) are denoted with a solid black line, while those that were approaching significance ($p < .10$) are shown by a dashed gray lines. Nonsignificant estimates are not shown. All listed parameters are standardized coefficients.

Conclusions

- There were robust age-related effects on behavior and beta neural activity during planning, as well as intuitive links between planning-related beta activity and activity within the same region during motor execution.
- When all factors were tested, only right parietal beta dynamics mediated the relationship between age and task performance.
- These models suggest that strong, sustained neural activity in the right parietal cortex enhances motor performance, and that these sustained responses develop throughout childhood and early adolescence.
- These are the first data to link age-related trajectories in beta neural dynamics with distinct motor performance metrics, and implicate the right parietal cortex as a crucial hub in the motor network.

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