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IMPROVING FUNCTIONAL IMAGING PREDICTIONS THROUGH MULTI-MODAL INTEGRATION OF BRAIN ANATOMY

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1 INTRODUCTION

Several neuroimaging studies have identified patterns of correlated brain activity across distant regions, indicating the existence of underlying mechanisms that impose fundamental constraints on brain function, beyond the complex interactions between neurons. Despite these findings, there is still no clear understanding of how these patterns emerge or why they appear altered in various neurological disorders. Current literature suggests that these patterns could be explained by standing waves resonating within the brain, similar to the vibrational modes observed in musical instruments. Studies have successfully reconstructed brain activity based on the superposition of resonance modes defined by the brain's surface mesh. However, the role of the brain's structural properties, beyond mere geometry, remains largely unexplored. This work aims to fill that gap by investigating whether brain activity is influenced by the physical properties of the brain tissue itself, not just its geometry, to better explain why consistent alterations in these patterns are observed in disorders of consciousness.

2 MATERIALS AND METHODS

The 3D brain model in this study included white matter (WM), gray matter (GM), cerebrospinal fluid (CSF), and a simplified skull. The model was based on a segmented MNI-152 T1-weighted template and surface meshes were created in Geomagic Wrap, then refined into solid meshes in FEMAP. The simplified skull was generated by offsetting the CSF's external surface by 5 mm.

Simulations in Abaqus were used to extract the brain's natural frequencies and mode shapes under three boundary conditions (BC): fixed translational displacements at the skull base (Figure 1a), and simplified neck (Figure 1b) and spine (Figure 1c) models represented as 12 cm and 50 cm cylinders, respectively, with their base surfaces fixed. A frequency linear perturbation approach was applied, using the Lanczos eigensolver to extract 25 eigenvalues. Material properties for brain tissue and CSF were simplified as linear elastic.

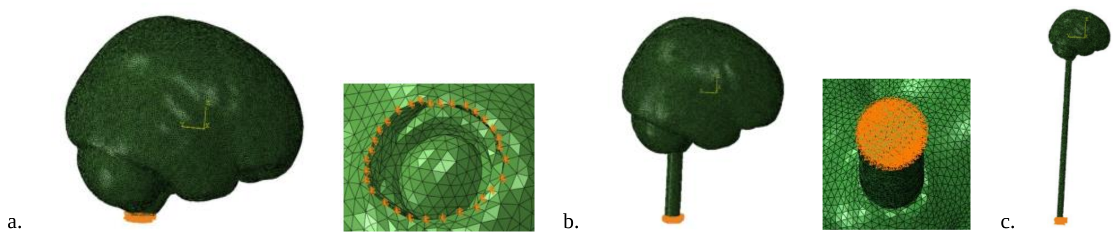


Figure 1 –Illustration of the applied boundary conditions: a. Skull BC; b. Neck BC; and c. Spine BC.

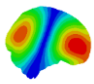
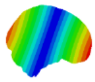
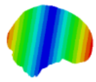
3 Results

The study identified thirty-six distinct mode shapes from the first 25 eigenmodes of the simulations. Of these, sixteen modes were common across all simulations and exhibited similar mode shapes and frequencies, despite different BC.

Two modes were exclusive to the spine and neck BC, which might be attributed to the fixed surfaces being farther from the brain. Six modes were unique to specific BC (skull, neck, or spine).

Comparing the simulation results with literature, the spine BC simulation matched most closely with existing studies (Table 1). However, discrepancies in mode shapes and frequencies were noted, likely due to differences in model details, such as the presence of additional structures in the literature model and the different representation of CSF.

Table 1 - Mid-sagittal representation of the displacement distribution in the brain and eigenfrequencies for the first three mode shapes in the skull, neck and spine boundary conditions.

		Frequency (Hz)	Error (%)		Frequency (Hz)	Error (%)		Frequency (Hz)	Error (%)
Mode number		**1**			**2**			**3**	
Skull BC		24.2			33.3			83.1	
Neck BC		10.6	56.3		11.1	66.6		23.9	71.2
Spine BC		1.8	92.6		1.8	94.6		9.9	88.1

4 Discussion and Conclusions

This study investigated how model complexity and boundary conditions affect the brain's resonance modes. It found that both the model's complexity and the presence of structures like CSF influence the resonance patterns and natural frequencies of the brain. Simulations showed that different boundary conditions affect results, with some differences in frequencies compared to existing literature. However, mode shapes were generally consistent with previous studies.

The study underscores the importance of model complexity in determining brain resonance modes.

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