Resting-State Functional Magnetic Resonance Imaging of Brain Network Integrity in Acute Disordered Consciousness

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Introduction

- Brain injuries are external/internal forces that disrupt normal brain function (Ex. traumatic brain injury [TBI], stroke, metabolic encephalopathy)
- Disorders of Consciousness (DoC): Spectrum of impaired alertness and arousal
- Covert Consciousness, e.g., Cognitive Motor Dissociation (CMD): Conscious but unable to behaviorally respond to commands; hidden brain activity is detectable via functional diagnostic imaging/electrophysiology when subjects are instructed to perform cognitive tasks, though assessment is limited by subjects' cognitive abilities
- Functional magnetic resonance imaging (fMRI) maps brain activity by detecting blood-oxygen-level-dependent (BOLD) signal changes
- Resting-state functional magnetic resonance imaging (rsfMRI): Subject lies still while being scanned, not performing any deliberate cognitive tasks
- Brain networks: Spatially distributed regions of temporally correlated activity
- Default Mode Network (DMN): Brain network most active when at rest/idle

Objective: Set the foundation for measuring relationships between the Default Mode Network activation and emergence of consciousness

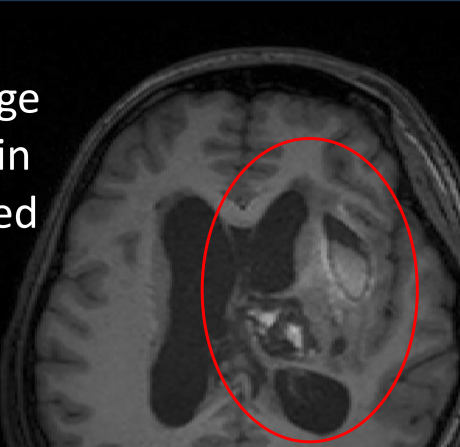


Figure 1. Hemorrhage visualized in T1-weighted MRI of P3

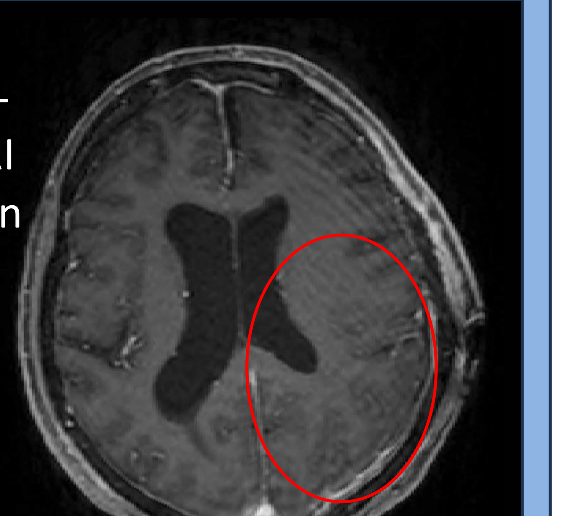


Figure 2. Artifact in T1-weighted MRI due to motion in P5

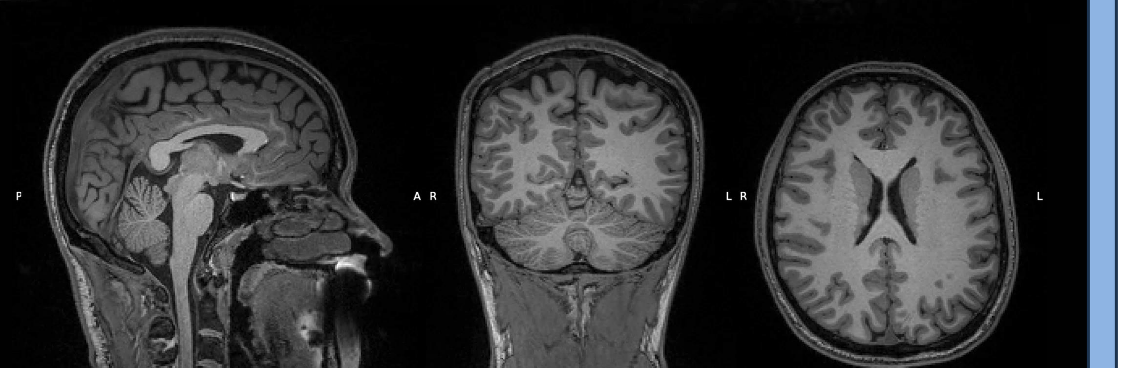
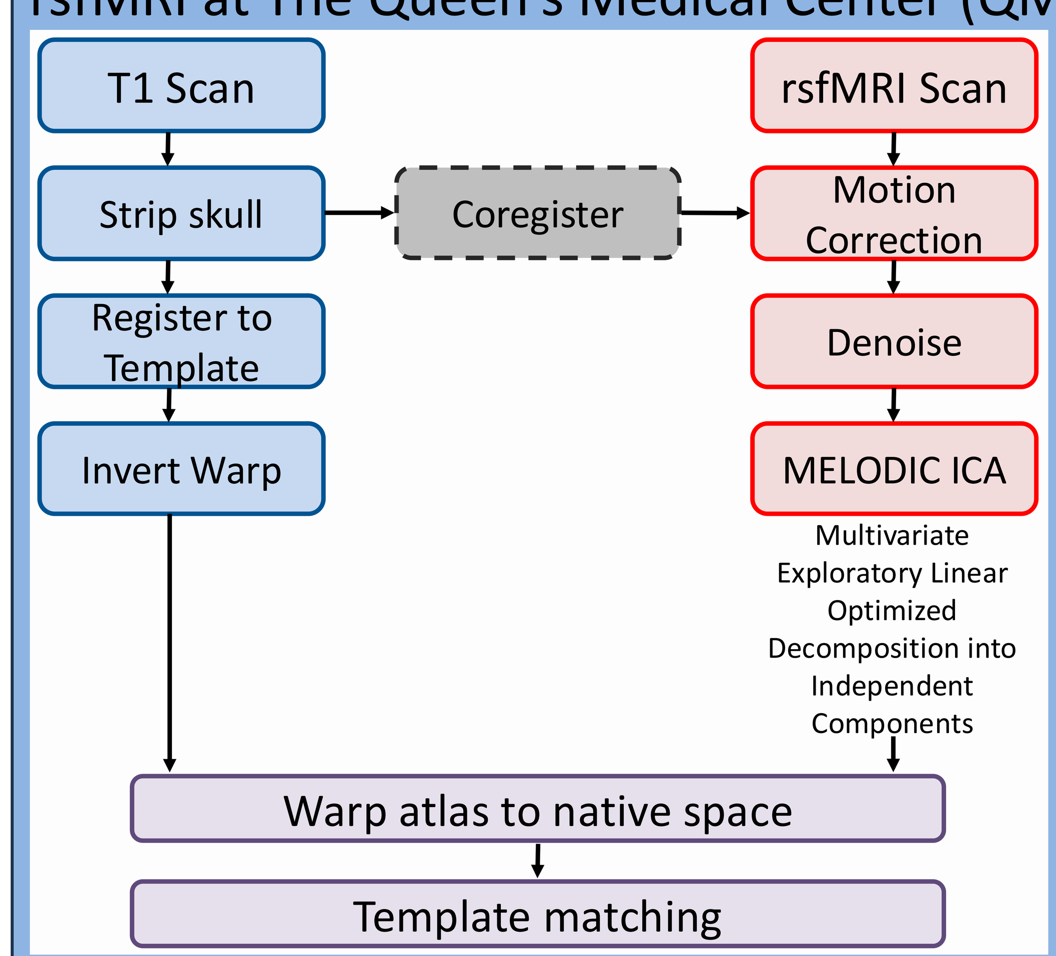


Figure 3. Healthy T1-weighted MRI scan of C2

Methods

Population: 5 adults with predominantly severe Glasgow Coma Scale (GCS) score of 3-8 and 2 healthy controls who underwent rsfMRI at The Queen's Medical Center (QMC)



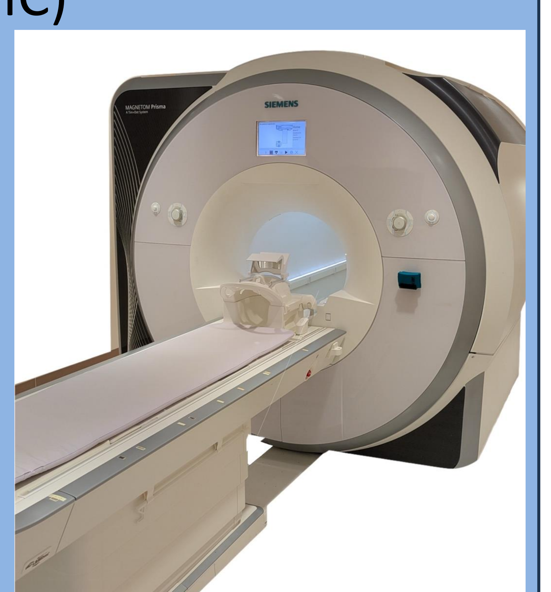


Figure 5. 3.0T Siemens MAGNETOM MRI Scanner; Foam padding used to minimize motion artifacts

Figure 4. Pipeline process of patient scans; ICA = Independent Component Analysis

Results

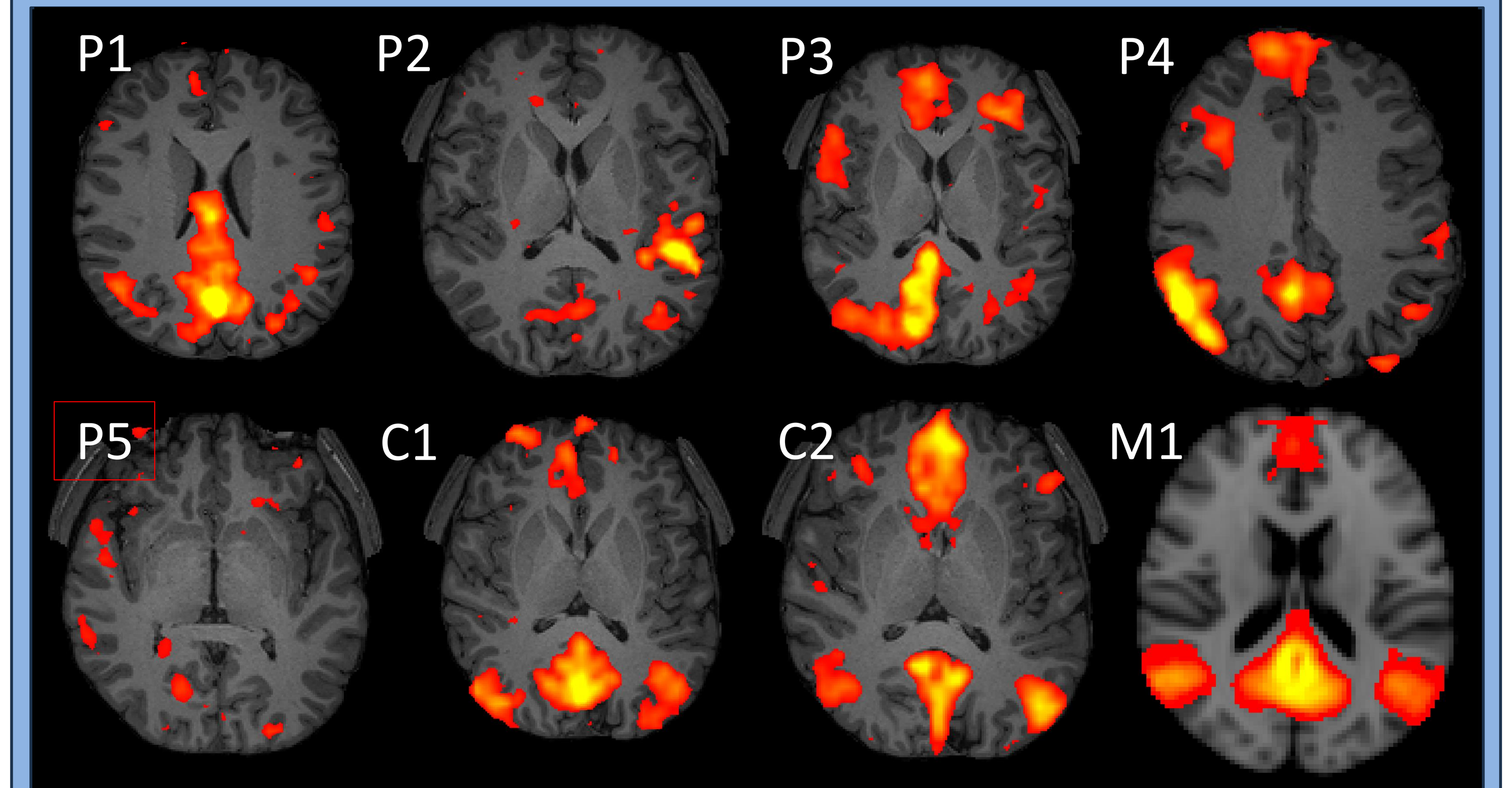


Figure 6. DMN rsfMRI of patients [P1-P5], controls [C1-C2], and model [M1]
Red = Patient noted as having motion artifact. DMN regions include the medial prefrontal cortex, posterior cingulate cortex, precuneus, and angular gyrus

Name	Subject	Brain Injury	GCS		Sedation
			Initial	At MRI	
P1	Patient 1	MVC; blunt TBI; DAI	5	3	Y
P2	Patient 2	Spontaneous hypertensive pontine ICH	3	3	Y
P3	Patient 3	MVC; blunt TBI; deep IPH/IVH; HCP	6	5	Y
P4	Patient 4	Found down in jail cell	3	4	Y
P5	Patient 5	Ground level fall; progressive acute traumatic L SDH	15	10	N
C1	Control 1	Healthy	15	15	N
C2	Control 2	Healthy	15	15	N
M1	Smith Atlas in MNI/Standard Space				

Table 1. Information of subjects (patients + controls)
MVC = Motor vehicle collision; DAI = Diffuse axonal injury; ICH = Intracerebral hemorrhage; IPH = Intraparenchymal hemorrhage; IVH = Intraventricular hemorrhage; HCP = Hemiplegic cerebral palsy; SDH = Subdural hematoma

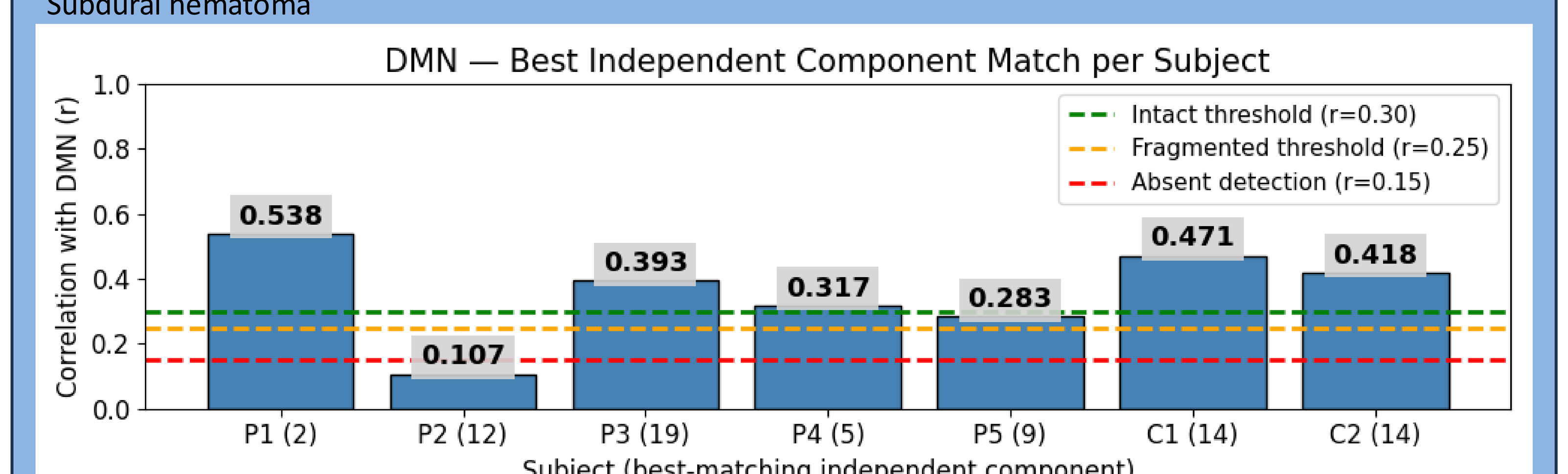


Figure 7. Highest correlating Independent Component (IC) per subject

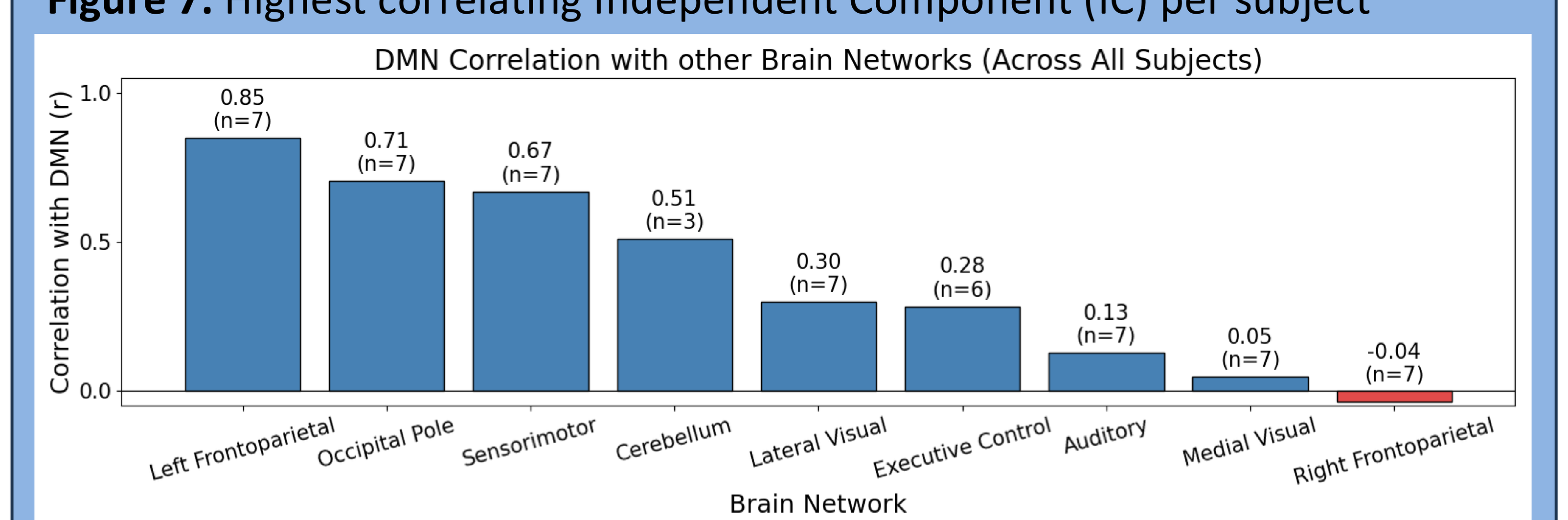


Figure 8. Only includes subjects' present networks.
n = # of subjects contributing to the correlation; Valid IC needed for both brain networks

Discussions & Conclusions

Table 2. Summary of patient results
GCS at discharge and length of stay refer only to the patient's time at QMC, not complete recovery; Data at further facilities was unattainable
Red = Severe/Absent; Orange=Moderate/Fragmented; Green = Mild/Intact

Patient	P1	P2	P3	P4	P5
Brain Injury	TBI; DAI	Spontaneous hypertensive pontine ICH	TBI; Hemorrhage	Cytotoxic edema in corpus callosum splenium	Progressive acute traumatic L SDH
GCS at MRI	3	3	5	4	10
Correlation to DMN	0.538	0.107	0.393	0.317	0.283
GCS at Discharge	9	6	9	14	15
Length of stay at QMC (Days)	15	16	96	>200	16
Discharge Disposition from QMC	ICU	Death	Pediatric skilled nursing facility	Still present at QMC	Acute care hospital

- The processing pipeline successfully isolated DMN activity in P1, P3, and P4. High correlation with the DMN (r = 0.31-0.54) aligned with higher potential for neurological recovery. Severe motion artifact limited interpretation of P5's imaging.
- No recognizable DMN activity was identified in P2 visually or quantitatively. This absence of network integrity, despite structural integrity of DMN brain regions, corresponded with the lowest discharge GCS and eventual mortality.
- C1 and C2 are the most visually comparable to the DMN. However, P1 had the highest quantitative correlation to the DMN, followed by C1 and C2. Visual inspection remained important to image interpretation in this pipeline.
- Low dose sedation did not completely suppress DMN activity and may have improved quality of data acquisition.

Limitations: Small cohort size, variable clinical follow-up periods inherent to retrospective observational study design.

Future research should examine additional brain networks. A larger sample size would yield more conclusive results.

This study sets the foundations for future research on relationships between the Default Mode Network activation, consciousness, and clinical outcomes after acute brain injury.

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