SUPPLEMENTARY MATERIAL: Comparing Structure-Function Relationships in Brain Networks Using EEG and fNIRS

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ABSTRACT

Identifying relationships between structural and functional networks is crucial for understanding the large-scale organization of the human brain. The potential contribution of emerging techniques like functional near-infrared spectroscopy to investigate the structure-functional relationship has yet to be explored. In our study, using simultaneous Electroencephalography (EEG) and Functional near-infrared spectroscopy (fNIRS) recordings from 18 subjects, we characterize global and local structure-function coupling using source-reconstructed EEG and fNIRS signals in both resting state and motor imagery tasks, as this relationship during task periods remains underexplored. Employing the mathematical framework of graph signal processing, we investigate how this relationship varies across electrical and hemodynamic networks and different brain states. Results show that fNIRS structure-function coupling resembles slower-frequency EEG coupling at rest, with variations across brain states and oscillations. Locally, the relationship is heterogeneous, with greater coupling in the sensory cortex and increased decoupling in the association cortex, following the unimodal to transmodal gradient. Discrepancies between EEG and fNIRS are noted, particularly in the frontoparietal network. Cross-band representations of neural activity revealed lower correspondence between electrical and hemodynamic activity in the transmodal cortex, irrespective of brain state while showing specificity for the somatomotor network during a motor imagery task. Overall, these findings initiate a multimodal comprehension of structure-function relationship and brain organization when using affordable functional brain imaging.

Table S1. Global structure-function coupling: Summary of Statistical Tests Comparing EEG and fNIRS Measures Across Different Conditions and Modalities: Overall comparison between EEG and fNIRS for each condition; Comparison of EEG and fNIRS measures within each modality for each condition; Comparison between conditions for each modality; Comparison between band-limited EEG and fNIRS measures for each condition. P-values (FDR-corrected for multiple comparisons) and z-values are reported for each comparison, indicating the significance of observed differences (in red) or similarities between the measures.

Global structure-function coupling																
Overall comparison between modalities					**EEG within modality comparison for each condition**						**Comparison between band-limited EEG and fNIRS for each condition**					
RS					**RS**			**Task**			**RS**			**RS**		
Modality_1	**Modality_2**	**p-val**	**z-val**			**p-val**	**z-val**		**p-val**	**z-val**	***delta vs hbo***	0.001	5.725	***delta vs hbr***	0.312	-1.012
EEG	***NIRS***	0.0004	3.5490		***delta vs theta***	0.001	-6.409	***delta vs theta***	0.001	-9.680	***theta vs hbo***	0.001	7.719	***theta vs hbr***	0.455	0.747
Task							9.594	***delta vs alpha***	0.001	-9.227	***alpha vs hbo***	0.445	0.765	***alpha vs hbr***	0.001	-5.517
Modality_1	***Modality_2***	**p-val**	**z-val**		***delta vs beta***	0.001	-11.789	***delta vs beta***	***0.2378***	-1.181	***beta vs hbo***	0.001	10.864	***beta vs hbr***	0.001	5.466
EEG	***NIRS***	0.0773	1.7663		***delta vs gamma***	0.001	-11.827	***delta vs gamma***	0.0010	-8.472	***gamma vs hbo***	0.001	11.052	***gamma vs hbr***	0.001	5.652
					theta vs alpha	0.001	12.845	***theta vs alpha***	***0.4394***	0.773	**Task**	**p-val**	**z-val**	**Task**	**p-val**	**z-val**
Comparison between conditions for each modality					***theta vs beta***	0.001	-9.701	***theta vs beta***	0.001	9.631	***delta vs hbo***	0.248	1.155	***delta vs hbr***	0.001	-3.990
EEG	**p-val**	**z-val**			***theta vs gamma***	0.001	-9.272	***theta vs gamma***	*0.0167*	2.394	***theta vs hbo***	0.001	7.442	***theta vs hbr***	0.504	0.668
RS vs Task delta	0.001	5.348			***alpha vs beta***	0.001	-15.972	***alpha vs beta***	0.001	11.141	***alpha vs hbo***	0.001	7.196	***alpha vs hbr***	0.699	0.386
RS vs Task theta	0.376	0.886			***alpha vs gamma***	0.001	-15.451	***alpha vs gamma***	***0.0514***	1.948	***beta vs hbo***	0.043	2.028	***beta vs hbr***	0.001	-3.889
RS vs Task alpha	0.001	-7.734			***beta vs gamma***	0.9656	0.043	***beta vs gamma***	0.001	-10.981	***gamma vs hbo***	0.001	6.515	***gamma vs hbr***	0.454	-0.749
RS vs Task beta	0.001	12.286														
RS vs Task gamma	0.001	9.643			**fNIRS within modality comparison for each condition**											
fNIRS	**p-val**	**z-val**			**RS**			***Task***								
RS vs Task hbo	0.769	0.294				**p-val**	**z-val**		**p-val**	**z-val**						
RS vs Task hbr	0.423	0.800			***hbo vs hbr***	0.001	-7.842	***hbo vs hbr***	0.001	-8.054						

Table S2. Mean and std of SDI values across ROIs and subjects for each EEG band and fNIRS chromophore, in RS and task conditions.

	Delta	Theta	Alpha	Beta	Gamma	HbO	HbR
RS	1.11 ± 0.12	1.16 ± 0.08	0.95 ± 0.13	1.30 ± 0.09	1.30 ± 0.1	1.0 ± 0.1	1.19 ± 0.09
Task	0.98 ± 0.07	1.13 ± 0.11	1.11 ± 0.09	0.97 ± 0.08	1.07 ± 0.07	0.96 ± 0.06	1.14 ± 0.08

Table S3. Regions of interest (ROIs) displaying significant disparities between EEG and fNIRS.

Number of different ROIs						
	RS	**Task**			**RS**	**Task**
Delta vs HbO	24	21		***Delta vs HbR***	25	23
Theta vs HbO	28	20		***Theta vs HbR***	22	20
Alpha vs HbO	25	20		***Alpha vs HbR***	27	21
Beta vs HbO	32	22		***Beta vs HbR***	20	24
Gamma vs HbO	32	20		***Gamma vs HbR***	22	22

Table S4. SDI mean and std for each network, band, and hemoglobin type for the two conditions (RS and Task)

	RS						Task				
	DMN	**DAN**	**FPN**	**VIS**	**SMN**		**DMN**	**DAN**	**FPN**	**VIS**	**SMN**
Delta	1.14 ± 0.17	1.51 ± 0.19	0.95 ± 0.21	0.67 ± 0.15	0.48 ± 0.10	***Delta***	1.13 ± 0.13	1.27 ± 0.12	0.90 ± 0.20	0.55 ± 0.09	0.38 ± 0.05
Theta	1.17 ± 0.16	1.54 ± 0.12	1.06 ± 0.22	0.78 ± 0.16	0.49 ± 0.08	***Theta***	1.14 ± 0.18	1.46 ± 0.15	1.25 ± 0.25	0.65 ± 0.12	0.47 ± 0.08
Alpha	1.06 ± 0.16	1.3 ± 0.21	0.77 ± 0.24	0.63 ± 0.18	0.36 ± 0.06	***Alpha***	1.13 ± 0.18	1.45 ± 0.11	1.19 ± 0.23	0.64 ± 0.11	0.51 ± 0.07
Beta	1.27 ± 0.14	1.58 ± 0.12	1.52 ± 0.25	0.85 ± 0.15	0.51 ± 0.09	***Beta***	1.09 ± 0.14	1.28 ± 0.12	0.84 ± 0.12	0.57 ± 0.09	0.37 ± 0.04
Gamma	1.26 ± 0.14	1.6 ± 0.15	1.49 ± 0.23	0.85 ± 0.14	0.52 ± 0.09	***Gamma***	1.12 ± 0.13	1.39 ± 0.09	1.0 ± 0.11	0.64 ± 0.08	0.44 ± 0.05
HbO	0.87 ± 0.11	1.2 ± 0.12	1.02 ± 0.24	0.69 ± 0.19	0.56 ± 0.20	***HbO***	0.93 ± 0.10	1.19 ± 0.14	0.91 ± 0.20	0.68 ± 0.12	0.52 ± 0.12
HbR	0.99 ± 0.16	1.35 ± 0.14	1.54 ± 0.31	0.81 ± 0.19	0.69 ± 0.21	***HbR***	0.99 ± 0.15	1.33 ± 0.12	1.38 ± 0.15	0.78 ± 0.12	0.58 ± 0.13

Table S5. Network structure-function coupling: Summary of Statistical Tests Comparing cross-band EEG and fNIRS Measures Across Different Conditions. P-values and z-values are reported for each comparison, indicating the significance of observed differences (in red) or similarities between the measures.

RS									
Group1	**Group2**	**Network**	**p_value**	**z_value**	**Group1**	**Group2**	**Network**	**p_value**	**z_value**
EEG	*HbO*	*DMN*	0.000	3.724	*EEG*	*HbR*	*DMN*	0.004	2.853
EEG	*HbO*	*AN*	0.000	3.593	*EEG*	*HbR*	*AN*	0.010	2.591
EEG	*HbO*	*FPN*	0.064	1.851	*EEG*	*HbR*	*FPN*	0.001	-3.245
EEG	*HbO*	*VIS*	0.396	0.849	*EEG*	*HbR*	*VIS*	0.500	-0.675
EEG	*HbO*	*SMN*	0.248	-1.154	*EEG*	*HbR*	*SMN*	0.002	-3.114
Task									
Group1	**Group2**	**Network**	**p_value**	**z_value**	**Group1**	**Group2**	**Network**	**p_value**	**z_value**
EEG	*HbO*	*DMN*	0.000	3.593	*EEG*	*HbR*	*DMN*	0.048	1.982
EEG	*HbO*	*AN*	0.001	3.201	*EEG*	*HbR*	*AN*	0.647	0.457
EEG	*HbO*	*FPN*	0.078	1.764	*EEG*	*HbR*	*FPN*	0.000	-3.636
EEG	*HbO*	*VIS*	0.122	-1.546	*EEG*	*HbR*	*VIS*	0.000	-3.593
EEG	*HbO*	*SMN*	0.022	-2.286	*EEG*	*HbR*	*SMN*	0.001	-3.332