

Supplementary Information

Formula 1: Newman's modularity is defined as (from package 'igraph' v.1.3.5 manual):

"The modularity of a graph with respect to some division (or vertex types) measures how good the division is, or how separated are the different vertex types from each other. It defined as:"

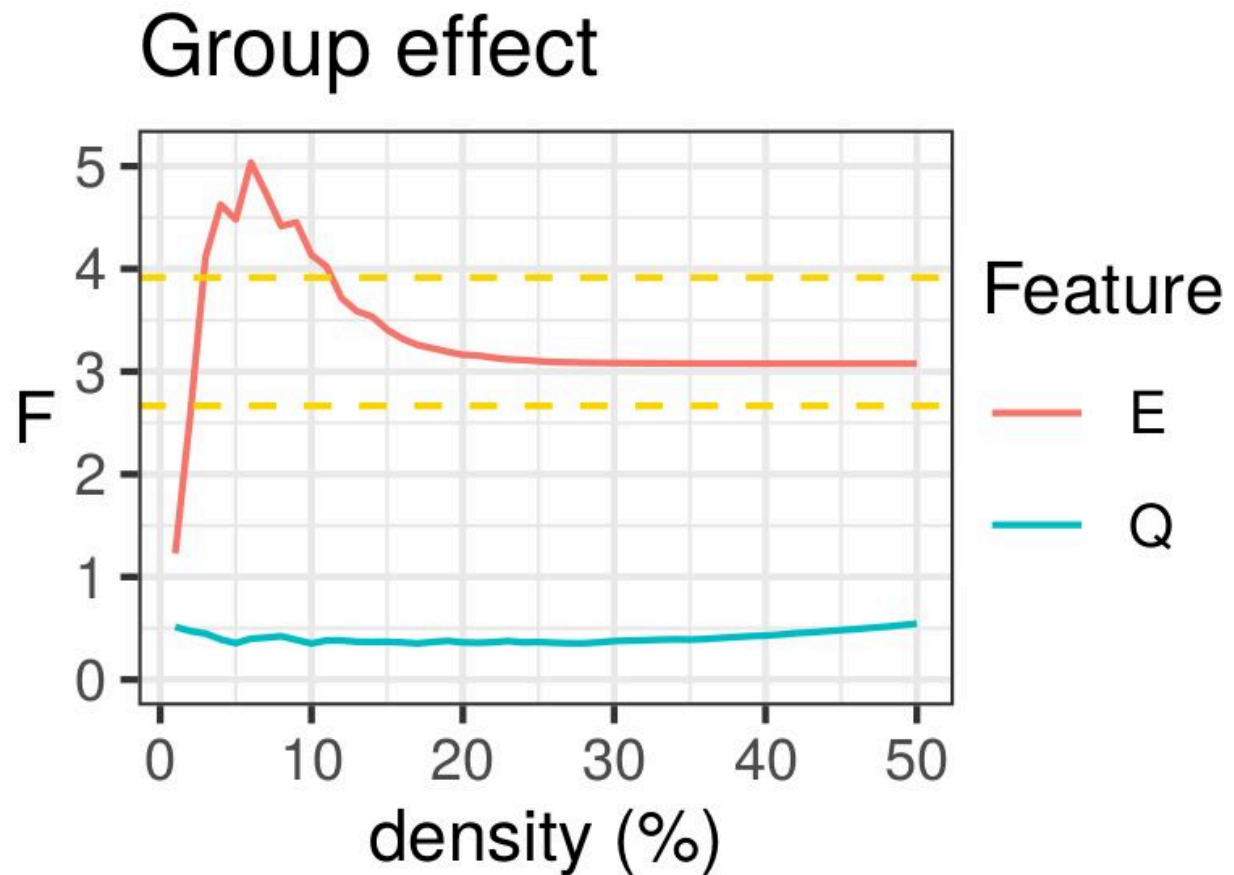
$$Q = \frac{1}{2m} \sum_{i,j} \left(A_{ij} - \frac{k_i k_j}{2m} \right) \delta(c_i, c_j)$$

Where m is the number of edges, A_{ij} is the element of the A adjacency matrix in row i and column j , k_i and k_j is the sum of weights of adjacent edges for nodes (vertex) i and j , respectively. c_i and c_j accounts for the module of i and j , respectively. And, $\delta(c_i, c_j)$ is 1 if $c_i = c_j$ and 0 otherwise.

Formula 2: Global efficiency is defined as the average nodal efficiency, that is, the network average of the inverse of the nodal shortest path distance:

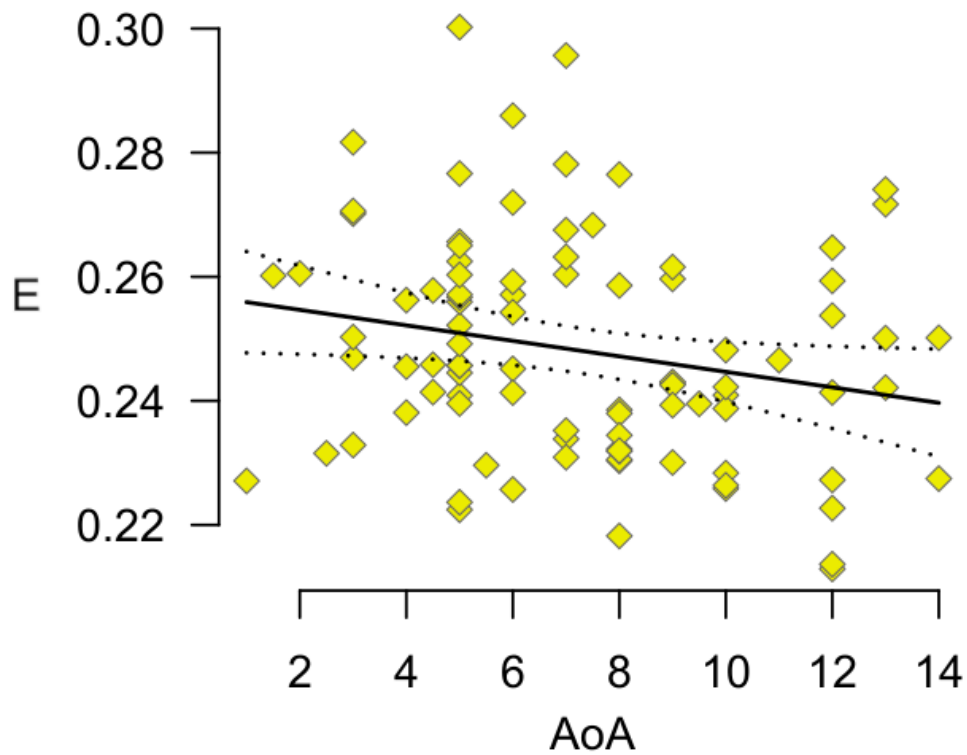
$$E = \frac{1}{n} \sum_i e_i = \frac{1}{n} \sum_i \frac{\sum_{j \neq i} d_{ij}^{-1}}{n-1}$$

Where n accounts for the number of nodes in the network, e_i is the efficiency of node i , and d_{ij} is the distance between nodes i and j based on the weighted Dijkstra's algorithm.



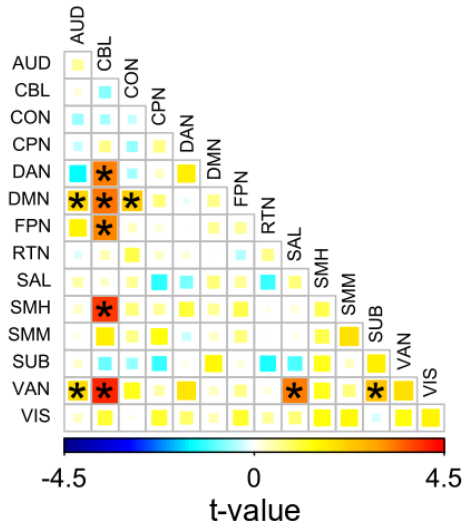
Supplementary Figure 1. Group effect of brain network features by connectivity density. Dashed yellow lines stand for significance of the F-test at $p < 0.05$ and $p < 0.01$. Feature abbreviations: efficiency (E) and modularity (Q).

**Age of acquisition effect
($\rho = -0.22$; $p = 0.037$)**

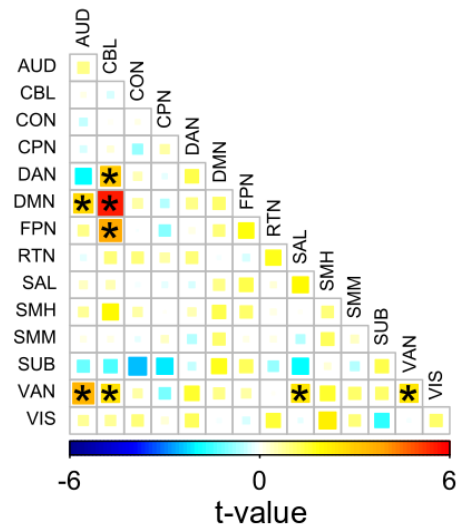


Supplementary Figure 2. Scatterplot with the relationship between whole-brain efficiency (E) and age of acquisition (AoA) in years for early and late bilingual participants.

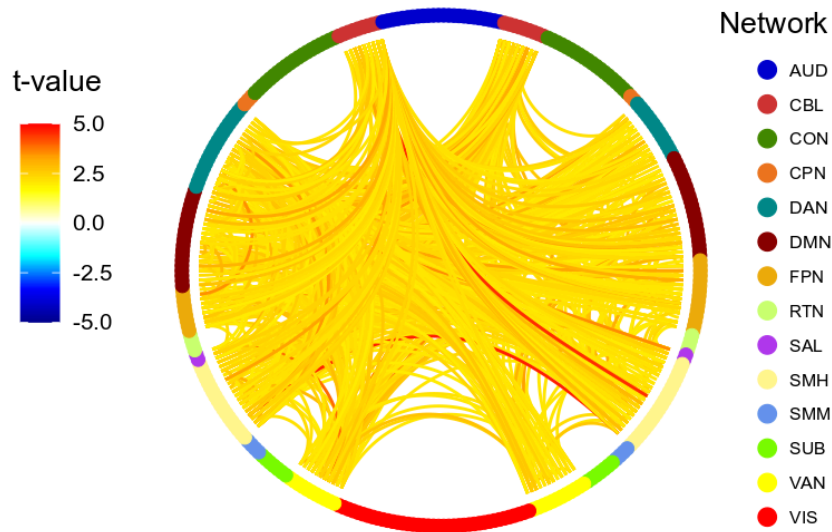
A) Sim.B > Mono (edge $p < 0.05$)



B) Early.B > Mono (edge $p < 0.05$)



C) Sim.B > Mono (edge $p < 0.05$)

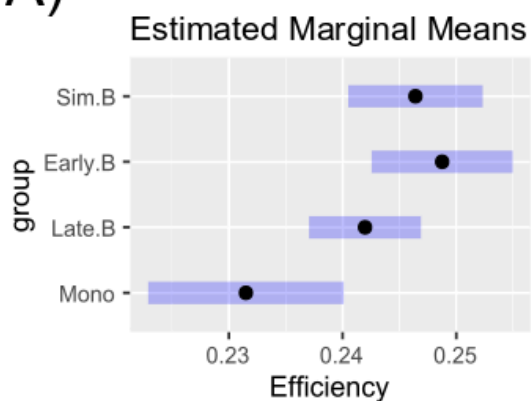


Supplementary Figure 3. NBS results with an edgewise a priori threshold of $p < 0.05$. Pairwise plots of significant (both $p = 0.001$; FWE-corrected) clusters of connections with higher functional connectivity between simultaneous (A) and early (B) bilinguals versus monolinguals at the module level. Chord diagram depicting a significant ($p = 0.001$; FWE-corrected) cluster of edges with higher functional connectivity in the simultaneous compared to the monolingual group at the ROI level (C). Abbreviations:

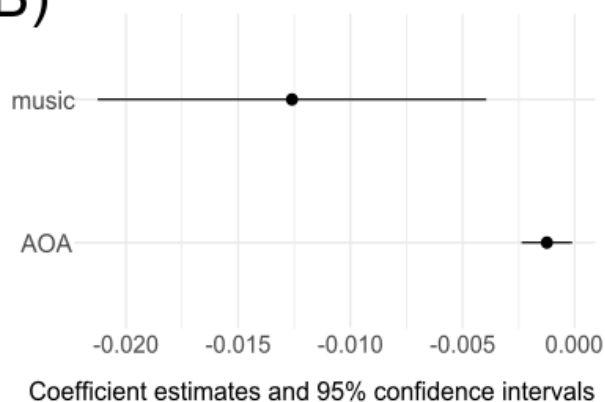
AUD, auditory; CBL, cerebellar; CON, cingulo-opercular; CPN, cingulo-parietal; DMN, default mode; DAN, dorsal attention; FPN, fronto-parietal; RTN, retrosplenial-temporal; SAL, salience; SMH, sensorimotor-hand; SMM, sensorimotor-mouth; SUB, subcortical; VAN, ventral attention; VIS, visual.

Whole-brain

A)



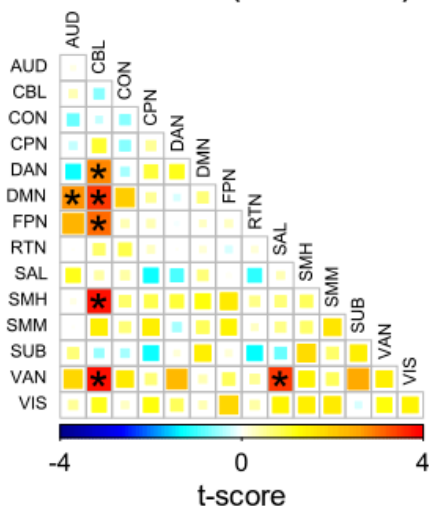
B)



Functional Networks

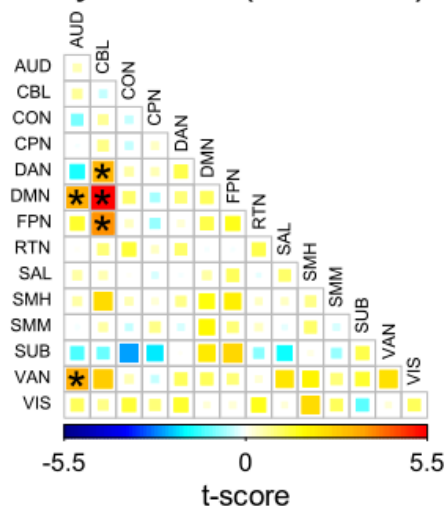
C)

Sim.B > Mono (Music corr.)



D)

Early.B > Mono (Music corr.)



Supplementary Figure 4: Music training as binary covariate as reported in 26 participants. Top: Whole-brain global efficiency (E) Estimated Marginal Means (EMMs) for the mono/bilingual groups with music training as covariate (A). Estimated coefficients

for the Age of Acquisition (AoA) and music covariate linear effects to E (B). Bottom: Pairwise plots of significant (FWE-corrected) clusters of connections with higher functional connectivity between simultaneous (C) and early (D) bilinguals versus monolinguals including binary music training as covariate. Abbreviations: AUD, auditory; CBL, cerebellar; CON, cingulo-opercular; CPN, cingulo-parietal; DMN, default mode; DAN, dorsal attention; FPN, fronto-parietal; RTN, retrosplenial-temporal; SAL, salience; SMH, sensorimotor-hand; SMM, sensorimotor-mouth; SUB, subcortical; VAN, ventral attention; VIS, visual. Corresponding 95% confidence intervals are depicted for A) and B) estimates.

Supplementary Tables

Supplementary table 1.

Post-hoc pairwise Welch's two-sample t-test between mono/bilingual groups for whole-brain global efficiency. Group abbreviations: monolinguals (Mono), and late (Late.B), early (Early.B), and simultaneous (Sim.B) bilinguals. Family-wise Error (FWE) correction was based on the Bonferroni-Holm method.

Contrast	t-score	DOF	p	pFWE
Late.B - Mono	1.88	36.2	0.068	0.222
Early.B - Mono	3.26	40.3	0.002	0.014
Sim.B - Mono	2.77	42.7	0.008	0.042
Early.B - Late.B	1.81	74.3	0.074	0.222
Sim.B - Late.B	1.24	80.8	0.218	0.436
Sim.B - Early.B	-0.49	70.9	0.625	0.625

Supplementary table 2.

List of functional network (modules) connections with higher functional connectivity in the Simultaneous bilingual compared to the monolingual group within the FWE-corrected cluster using Network-Based Statistics. Network abbreviations: CBL, cerebellar; DMN, default mode; DAN, dorsal attention; FPN, fronto-parietal; SAL, salience; SMH, sensorimotor-hand; VAN, ventral attention.

Net 1	Net 2	t-value	DOF	p-value
CBL	DAN	3.25	56	0.002
CBL	DMN	3.38	56	0.0013
CBL	FPN	3.21	56	0.0022
CBL	SMH	3.93	56	0.0002
CBL	VAN	4.09	56	0.0001
SAL	VAN	3.29	56	0.0017

Supplementary table 3.

List of functional network (modules) connections with higher functional connectivity in the Early bilingual compared to the monolingual group within the FWE-corrected cluster using Network-Based Statistics. Network abbreviations: CBL, cerebellar; DMN, default mode; DAN, dorsal attention; FPN, fronto-parietal; SAL, salience; SMH, sensorimotor-hand; VAN, ventral attention.

Net 1	Net 2	t-value	DOF	p-value
AUD	DMN	2.88	51	0.0058
AUD	VAN	3.49	51	0.001
CBL	DAN	3.04	51	0.0037
CBL	DMN	5.58	51	9.28e-7
CBL	FPN	3.79	51	0.0004

Supplementary table 4.

List of ROI-to-ROI connections with higher functional connectivity in the Simultaneous bilingual compared to the monolingual group within the FWE-corrected cluster using Network-Based Statistics. Network abbreviations: AUD, auditory; CBL, cerebellar; CON, cingulo-opercular; CPN, cingulo-parietal; DMN, default mode; DAN, dorsal attention; FPN, fronto-parietal; RTN, retrosplenial-temporal; SAL, salience; SMH, sensorimotor-hand; SMM, sensorimotor-mouth; SUB, subcortical; VAN, ventral attention; VIS, visual.

ROI1	ROI2	net1	net2	t	df	p
Area_8BM_L	Cerebellum Crus1 Left	DMN	CBL	3.23	56	0.0021
Area_8Ad_L	Cerebellum Crus1 Left	DMN	CBL	2.84	56	0.0062
Area_10d_L	Cerebellum Crus1 Left	DMN	CBL	3.03	56	0.0037
Area_2_R	Cerebellum Crus1 Left	SMH	CBL	2.84	56	0.0063
Area_posterior_47r_R	Cerebellum Crus1 Left	FPN	CBL	3.11	56	0.0029
Area_8Ad_R	Cerebellum Crus1 Left	DMN	CBL	2.79	56	0.0072
Area_8B_Lateral_R	Cerebellum Crus1 Left	DMN	CBL	2.74	56	0.0083
Area_PGi_L	Cerebellum Crus1 Right	DMN	CBL	2.75	56	0.0081
Area_8BM_L	Cerebellum Crus1	FPN	CBL	4.36	56	5.7e-05

	Right					
Area_8BM_L	Cerebellum Crus1 Right	DMN	CBL	3.44	56	0.0011
Area_8Ad_L	Cerebellum Crus1 Right	DMN	CBL	3.07	56	0.0033
Area_STSd_posterior_L	Cerebellum Crus1 Right	VAN	CBL	2.72	56	0.0088
Area_PGs_L	Cerebellum Crus1 Right	DMN	CBL	2.8	56	0.007
Area_8C_L	Cerebellum Crus1 Right	DAN	CBL	3	56	0.004
Area_IFSp_R	Cerebellum Crus2 Left	FPN	CBL	3.11	56	0.0029
Area_PGi_L	Cerebellum Crus2 Right	DMN	CBL	2.71	56	0.0088
Area_8BM_L	Cerebellum Crus2 Right	FPN	CBL	3.37	56	0.0014
Area_8C_L	Cerebellum Crus2 Right	DAN	CBL	2.85	56	0.006
Dorsal_area_6_R	Cerebellum 4 5 Left	SMH	CBL	4.53	56	3.1e-05
Area_8BM_L	Cerebellum 4 5 Right	DMN	CBL	3.42	56	0.0012
Dorsal_area_6_R	Cerebellum 4 5 Right	SMH	CBL	3.3	56	0.0017
Anterior_IntraParietal_Area_L	Cerebellum 6 Left	SMH	CBL	2.67	56	0.0098
Area_PH_L	Cerebellum 6 Left	DAN	CBL	2.69	56	0.0095
Dorsal_area_6_R	Cerebellum 6 Left	SMH	CBL	3.4	56	0.0013
Area_6mp_R	Cerebellum 6 Left	SMH	CBL	2.89	56	0.0055
Area_2_R	Cerebellum 6 Left	SMH	CBL	2.69	56	0.0094

Area_STSd_posterior_L	Cerebellum 6 Right	VAN	CBL	3.73	56	0.00045
Area_IFSa_L	Cerebellum 6 Right	DAN	CBL	3.29	56	0.0017
Area_44_L	Cerebellum 6 Right	VAN	CBL	2.72	56	0.0088
Area_45_L	Cerebellum 6 Right	VAN	CBL	2.76	56	0.0078
Area_PH_L	Cerebellum 6 Right	DAN	CBL	3.13	56	0.0028
Rostral_Area_6_L	Cerebellum 6 Right	DAN	CBL	3.7	56	0.00049
Area_IFJa_L	Cerebellum 6 Right	DAN	CBL	4.2	56	9.7e-05
Area_TE1_Middle_L	Cerebellum 6 Right	DMN	CBL	2.73	56	0.0084
Dorsal_area_6_R	Cerebellum 6 Right	SMH	CBL	3.18	56	0.0024
Cerebellum Crus1 Right	Cerebellum 6 Right	CBL	CBL	3.13	56	0.0028
Area_46_L	Cerebellum 7b Left	DAN	CBL	2.68	56	0.0095
Area_2_R	Cerebellum 7b Left	SMH	CBL	2.98	56	0.0042
Area_IFSp_R	Cerebellum 7b Left	FPN	CBL	2.68	56	0.0096
Area_8B_Lateral_R	Cerebellum 7b Left	DMN	CBL	3.23	56	0.0021
Lateral_Area_7A_L	Cerebellum 7b Right	SMH	CBL	2.67	56	0.0098
Area_6_anterior_L	Cerebellum 7b Right	SMH	CBL	2.77	56	0.0077
Medial_IntraParietal_Area_L	Cerebellum 7b Right	DAN	CBL	3.06	56	0.0034
Area_IFJa_L	Cerebellum 7b Right	DAN	CBL	2.86	56	0.006
Dorsal_area_6_R	Cerebellum 7b Right	SMH	CBL	2.81	56	0.0069
Area_2_R	Cerebellum 7b Right	SMH	CBL	2.69	56	0.0095
Area_5m_L	Cerebellum 8 Left	SMH	CBL	3.3	56	0.0017
Area_7PC_R	Cerebellum 8 Left	SMH	CBL	3.21	56	0.0022

Area_2_R	Cerebellum 8 Left	SMH	CBL	3.11	56	0.0029
Lateral_Area_7A_L	Cerebellum 8 Right	SMH	CBL	2.85	56	0.006
Area_5m_L	Cerebellum 8 Right	SMH	CBL	2.79	56	0.0073
Primary_Motor_Cortex_L	Cerebellum 8 Right	SMH	CBL	2.7	56	0.0091
Area_2_L	Cerebellum 8 Right	SMH	CBL	2.95	56	0.0046
Area_IFSa_L	Cerebellum 8 Right	DAN	CBL	3.06	56	0.0034
Medial_IntraParietal_Area_L	Cerebellum 8 Right	DAN	CBL	3.61	56	0.00066
Rostral_Area_6_L	Cerebellum 8 Right	DAN	CBL	3.08	56	0.0032
Area_posterior_9-46v_L	Cerebellum 8 Right	FPN	CBL	3.28	56	0.0018
Area_2_R	Cerebellum 8 Right	SMH	CBL	2.72	56	0.0087
Area_STSd_anterior_R	Cerebellum 8 Right	DMN	CBL	2.9	56	0.0053
Area_PGs_L	Cerebellum 9 Right	DMN	CBL	2.74	56	0.0082
Area_PH_L	Cerebellum 10 Right	DAN	CBL	3.09	56	0.0031
Cerebellum 7b Right	Cerebellum 10 Right	CBL	CBL	2.71	56	0.0089
Area_9_anterior_L	Vermis 1 2	DMN	CBL	3.05	56	0.0035
Area_55b_L	Vermis 3	VAN	CBL	2.79	56	0.0072
Area_STSd_anterior_R	Vermis 3	DMN	CBL	2.99	56	0.0041
Area_23d_L	Vermis 4 5	DMN	CBL	2.7	56	0.0091
Medial_IntraParietal_Area_L	Vermis 4 5	DAN	CBL	2.87	56	0.0057
Area_PH_L	Vermis 4 5	DAN	CBL	3.11	56	0.0029

Dorsal_area_6_R	Vermis 4 5	SMH	CBL	3.58	56	0.00072
Superior_Frontal_Lan guage_Area_L	Vermis 6	DMN	CBL	2.72	56	0.0088
Area_1_R	Vermis 6	SMH	CBL	2.83	56	0.0064
Area_8BM_R	Vermis 6	DMN	CBL	2.95	56	0.0046
Primary_Motor_Cortex _L	Vermis 7	SMH	CBL	2.81	56	0.0068
Rostral_Area_6_L	Vermis 7	DAN	CBL	2.94	56	0.0047
Area_3a_R	Vermis 7	SMH	CBL	2.8	56	0.007
Area_posterior_9-46v_ L	Vermis 8	FPN	CBL	2.68	56	0.0097
Area_3a_R	Vermis 8	SMH	CBL	2.7	56	0.0091
Area_2_R	Vermis 8	SMH	CBL	2.94	56	0.0048
Area_TemporoParieto Occipital_Junction_1_ R	Vermis 8	VAN	CBL	2.75	56	0.0079
Area_5m_L	Area_6_anterior_L	SMH	SMH	2.78	56	0.0074
Area_2_L	Area_PFt_L	SMH	DAN	3.43	56	0.0011
Area_5m_L	Area_2_L	SMH	SMH	3.07	56	0.0033
Area_Lateral_IntraPari etal_ventral_L	Area_2_L	DAN	SMH	2.71	56	0.0089
Area_8BM_L	Area_posterior_47r_L	FPN	VAN	2.85	56	0.006
Superior_Frontal_Lan guage_Area_L	Area_47s_L	VAN	VAN	2.84	56	0.0063
Area_44_L	Area_47s_L	VAN	VAN	2.74	56	0.0082
Area_8BM_L	Area_47l_(47_lateral) _L	FPN	VAN	2.84	56	0.0062

Anterior_Agranular_In sula_Complex_L	Area_47l_(47_lateral) _L	SAL	VAN	3.92	56	0.00025
Area_2_L	Medial_IntraParietal_ Area_L	SMH	DAN	2.71	56	0.0089
Area_2_L	Area_PH_L	SMH	DAN	2.72	56	0.0086
Area_2_L	Area_PH_L	SMH	DAN	2.97	56	0.0043
Area_TE1_posterior_L	Area_8C_L	FPN	DAN	3.49	56	0.00096
Area_45_L	Area_8C_L	VAN	DAN	2.77	56	0.0076
Anterior_Agranular_In sula_Complex_L	Area_IFJa_L	SAL	DAN	2.97	56	0.0044
Area_PH_L	Area_IFJa_L	DAN	DAN	2.78	56	0.0073
Area_posterior_9-46v_ L	Area_IFJa_L	FPN	DAN	2.67	56	0.01
Area_8BM_L	Area_TE1_Middle_L	FPN	DMN	2.91	56	0.0052
Area_TE1_Middle_L	Area_9_anterior_L	DMN	DMN	2.82	56	0.0066
Area_8BM_L	Superior_6-8_Transiti onal_Area_R	FPN	DMN	2.73	56	0.0084
Area_8C_L	Area_TE1_posterior_ R	DAN	FPN	3.31	56	0.0016
Area_47l_(47_lateral)_ L	Area_8BM_R	VAN	FPN	3.54	56	0.00082
Superior_Frontal_Lan guage_Area_L	Area_anterior_32_pri me_R	DMN	SAL	3.54	56	0.00082
Area_9_Posterior_L	Area_anterior_32_pri me_R	DMN	SAL	2.81	56	0.0069
Area_PH_L	Area_6_anterior_R	DAN	DAN	3.29	56	0.0017
Area_5m_L	Area_6mp_R	SMH	SMH	2.87	56	0.0057

Area_7PC_R	Area_posterior_47r_R	SMH	FPN	3.12	56	0.0029
Superior_Frontal_Lan guage_Area_L	Anterior_Agranular_In sula_Complex_R	DMN	VAN	2.67	56	0.0099
Area_47s_L	Anterior_Agranular_In sula_Complex_R	VAN	VAN	2.72	56	0.0088
Area_47l_(47_lateral)_ L	Anterior_Ventral_Insul ar_Area_R	VAN	SAL	2.86	56	0.006
Area_5m_L	Medial_IntraParietal_ Area_R	SMH	DAN	2.81	56	0.0068
Medial_IntraParietal_A rea_L	Area_IntraParietal_0_ R	DAN	DAN	2.91	56	0.0051
Area_PH_L	Area_IntraParietal_0_ R	DAN	DAN	2.92	56	0.005
Area_2_R	Area_IntraParietal_0_ R	SMH	DAN	3.08	56	0.0032
Area_PH_L	Area_PHT_R	DAN	DAN	2.84	56	0.0062
Area_2_L	Area_PFt_R	SMH	SMH	4.65	56	2.1e-05
Area_2_L	Rostral_Area_6_R	SMH	DAN	2.81	56	0.0068
Dorsal_area_6_L	Area_8BM_R	SMH	DMN	2.91	56	0.0052
Area_STSd_anterior_ R	Auditory_5_Complex_ R	DMN	VAN	2.98	56	0.0042