Supplementary materials for manuscript:

Using structural connectivity to augment community structure in EEG functional connectivity

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Table S1: (related to Figure 2A) Detailed GLM results with outputs of Matlab's stepwiseglm() and explained variances. *Estimate* is the coefficient value, *SE* is the standard error. Only significant effects are listed. For explained variances, the variables are listed in the order in which they were entered into the model; r2 full (cum.) and r2 single corresponds to the explained variance of the predictor variable in the full model, cumulatively, and the GLM in which the variable was the only predictor (additionally to the intercept). SCSI: search information of the structural connectivity, ED: Euclidean distance, RRV: relative regional variance.

alpha band without filtering

coefficients

	Estimate	SE	tStat	pValue
(Intercept)	1.24E+00	2.02E-02	6.14E+01	0.00E+00
SCSI	-9.43E-02	3.63E-03	-2.60E+01	1.09E-130
ED	-1.19E-02	3.09E-04	-3.84E+01	4.49E-249
RRV	5.05E-01	4.32E-02	1.17E+01	1.11E-30
SC:ED	1.19E-03	4.99E-05	2.38E+01	5.04E-112
ED:RRV	-4.00E-03	6.04E-04	-6.63E+00	4.18E-11

explained variances

		r2 full (cum.)	r2 single
1.	ED	0.55	0.55
2.	RRV	0.57	0.02
3.	SCSI	0.59	0.14
4.	SC:ED	0.67	0.36
5.	ED:RRV	0.67	0.01

beta band without filtering

coefficients

	Estimate	SE	tStat	pValue
(Intercept)	1.56E+00	3.04E-02	5.14E+01	0.00E+00
SCSI	-9.78E-02	4.67E-03	-2.09E+01	3.41E-89
ED	-1.34E-02	4.41E-04	-3.04E+01	3.37E-170
ROIsize	-2.42E-05	4.23E-06	-5.73E+00	1.13E-08
RRV	2.21E-01	1.60E-02	1.38E+01	7.92E-42
SC:ED	1.07E-03	5.51E-05	1.95E+01	4.63E-78
SC:ROIsize	3.25E-06	6.97E-07	4.66E+00	3.34E-06
ED:ROIsize	1.66E-07	5.66E-08	2.93E+00	3.41E-03

explained variances

		r2 full (cum.)	r2 single
1.	ED	0.58	0.58
2.	RRV	0.59	0.01
3.	SCSI	0.61	0.15
4.	SC:ED	0.66	0.39
5.	ROIsize	0.66	0.00
6.	SC:ROIsize	0.67	0.05
7.	ED:ROIsize	0.67	0.17

gamma band without filtering

coefficients

	Estimate	SE	tStat	pValue
(Intercept)	1.17E+00	1.94E-02	6.01E+01	0.00E+00
SCSI	-8.63E-02	3.49E-03	-2.47E+01	1.56E-119
ED	-1.12E-02	2.98E-04	-3.76E+01	8.06E-241
RRV	3.30E-01	4.16E-02	7.94E+00	3.27E-15
SC:ED	1.06E-03	4.80E-05	2.22E+01	1.28E-98
ED:RRV	-2.11E-03	5.81E-04	-3.63E+00	2.87E-04

explained variances

		r2 full (cum.)	r2 single
1.	ED	0.56	0.56
2.	RRV	0.57	0.01
3.	SCSI	0.59	0.16
4.	SC:ED	0.66	0.38
5.	ED:RRV	0.66	0.01

alpha band with filtering (SC, G=100, best fit to fMRI-FC)
coefficients

	Estimate	SE	tStat	pValue
(Intercept)	1.78E+00	4.14E-02	4.30E+01	2.30E-296
SCSI	-1.43E-01	6.58E-03	-2.17E+01	3.28E-95
ED	-1.48E-02	5.24E-04	-2.83E+01	1.53E-151
ROIsize	1.29E-05	5.46E-06	2.37E+00	1.81E-02
RRV	-2.13E-01	7.07E-02	-3.01E+00	2.63E-03
SC:ED	1.38E-03	6.52E-05	2.11E+01	1.49E-90
SC:ROIsize	-3.42E-06	9.44E-07	-3.62E+00	2.97E-04
SC:RRV	4.75E-02	8.69E-03	5.47E+00	5.03E-08
ED:ROIsize	4.45E-07	6.73E-08	6.62E+00	4.51E-11
ROIsize:RRV	2.93E-05	9.28E-06	3.16E+00	1.61E-03

explained variances

		r2 full (cum.)	r2 single
1.	ED	0.41	0.41
2.	SCSI	0.57	0.39
3.	SCSI:ED	0.62	0.47
4.	ROIsize	0.65	0.09
5.	RRV	0.67	0.00
6.	SCSI:RRV	0.68	0.03
7.	ED:ROIsize	0.68	0.02
8.	SCSI:ROIsize	0.68	0.02
9.	ROIsize:RRV	0.68	8.00E-04

beta band with filtering (SC, G=100, best fit to fMRI-FC)

coefficients

	Estimate	SE	tStat	pValue
(Intercept)	1.91E+00	4.34E-02	4.40E+01	1.79E-306
SCSI	-1.33E-01	6.90E-03	-1.93E+01	4.72E-77
ED	-1.43E-02	5.49E-04	-2.60E+01	1.03E-130
ROIsize	1.92E-05	5.73E-06	3.36E+00	7.93E-04
RRV	-2.28E-01	7.41E-02	-3.07E+00	2.15E-03
SC:ED	1.21E-03	6.83E-05	1.78E+01	3.04E-66
SC:ROIsize	-2.57E-06	9.90E-07	-2.60E+00	9.48E-03
SC:RRV	4.86E-02	9.12E-03	5.33E+00	1.07E-07
ED:ROIsize	3.78E-07	7.06E-08	5.35E+00	9.45E-08
ROIsize:RRV	2.11E-05	9.73E-06	2.17E+00	3.04E-02

explained variances

		r2 full (cum.)	r2 single
1.	ED	0.43	0.43
2.	SCSI	0.58	0.38
3.	ROIsize	0.62	0.10
4.	SCSI:ED	0.66	0.49
5.	RRV	0.67	0.01
6.	SCSI:RRV	0.68	0.04
7.	ED:ROIsize	0.68	0.01
8.	SCSI:ROIsize	0.68	0.01
9.	ROIsize:RRV	0.68	2.55E-05

gamma band with filtering (SC, G=100, best fit to fMRI-FC)

coefficients

	Estimate	SE	tStat	pValue
(Intercept)	1.65E+00	3.99E-02	4.13E+01	7.91E-279
SCSI	-1.35E-01	6.34E-03	-2.13E+01	2.96E-92
ED	-1.39E-02	5.05E-04	-2.75E+01	2.50E-144
ROIsize	1.53E-05	5.26E-06	2.91E+00	3.60E-03
RRV	-2.08E-01	6.81E-02	-3.06E+00	2.24E-03
SC:ED	1.28E-03	6.28E-05	2.03E+01	1.19E-84
SC:ROIsize	-2.64E-06	9.10E-07	-2.90E+00	3.80E-03
SC:RRV	4.56E-02	8.38E-03	5.44E+00	5.77E-08
ED:ROIsize	3.19E-07	6.49E-08	4.92E+00	9.11E-07
ROIsize:RRV	2.58E-05	8.94E-06	2.89E+00	3.89E-03

explained variances

		r2 full (cum.)	r2 single
1.	ED	0.43	0.43
2.	SCSI	0.58	0.39
3.	SCSI:ED	0.63	0.48
4.	ROIsize	0.66	0.08
5.	RRV	0.68	0.00
6.	SCSI:RRV	0.68	0.04
7.	ED:ROIsize	0.69	0.02
8.	SCSI:ROIsize	0.69	0.03
9.	ROIsize:RRV	0.69	3.00E-04

fMRI

coefficients

	Estimate	SE	tStat	pValue
(Intercept)	6.78E-01	2.50E-02	2.72E+01	5.02E-141
SCSI	-5.58E-02	4.26E-03	-1.31E+01	7.69E-38
ED	-4.76E-03	3.31E-04	-1.44E+01	5.19E-45
ROIsize	2.91E-06	1.74E-06	1.67E+00	9.42E-02
RRV	-1.65E-01	6.05E-02	-2.73E+00	6.43E-03
SC:ED	5.35E-04	5.27E-05	1.02E+01	1.03E-23
SC:RRV	3.02E-02	7.26E-03	4.15E+00	3.41E-05
ED:RRV	-2.37E-03	7.26E-04	-3.27E+00	1.11E-03
ROIsize:RRV	1.58E-05	7.67E-06	2.06E+00	3.94E-02

explained variances

		r2 full (cum.)	r2 single
1.	ED	0.19	0.19
2.	SCSI	0.23	0.14
3.	SC:ED	0.27	0.18
4.	RRV	0.28	0.03
5.	ROIsize	0.28	0.03
6.	SC:RRV	0.28	0.05
7.	ED:RRV	0.29	0.08
8.	ROIsize:RRV	0.29	0.01

search information [a.u.]
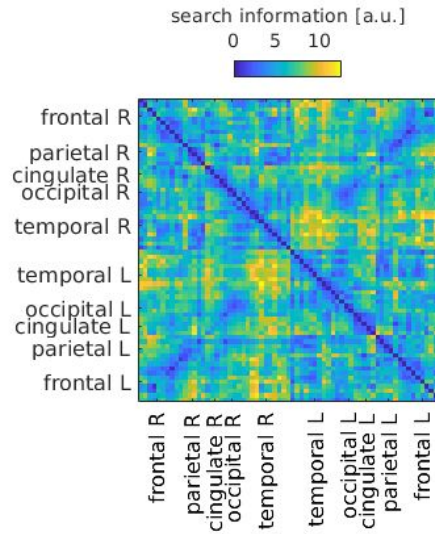
Figure S1: (related to Results - "SC provides additional predictive power for EEG-FC" and Methods- "Search Information") Search information matrix used in the GLM and FC-correlation analyses.

A - Relationship between SC, FC, and Euclidean distance
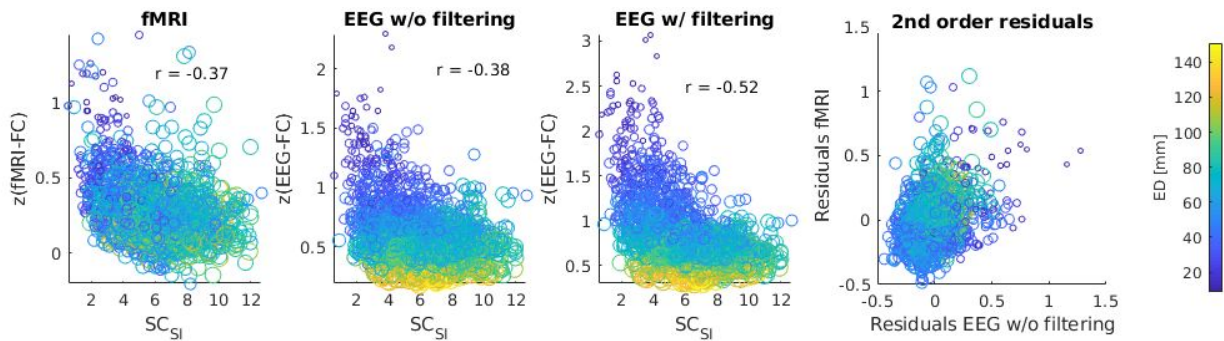
B - Distribution of 1st order residuals
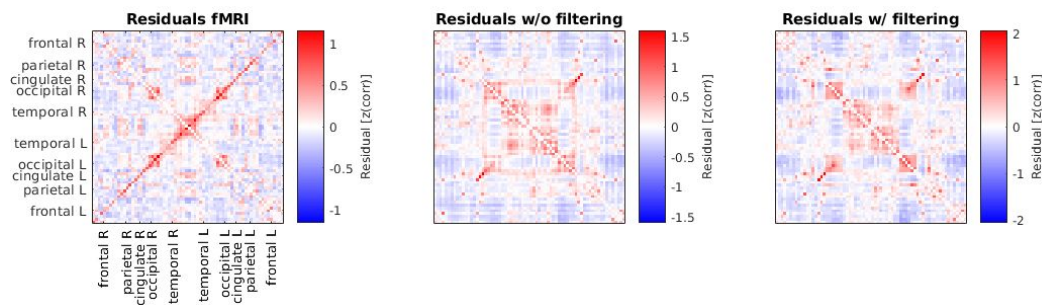
Figure S2: (related to GLM analysis) **A**: In the first three panels, z-transformed FC-values are plotted against SC_{SI} for fMRI, EEG before and EEG after filtering (G=100, ED match). In the forth panel, the FC values that remain unexplained after regressing out Euclidean distance as well as SC_{SI} (2nd order residuals) are plotted for EEG and fMRI in order to highlight the differences between the modalities. A positive residual means that the FC was underestimated, a negative one, overestimated. Sizes and colors of the circles code for the Euclidean distance. **B**: Residuals of single-variable GLM which predicts FC solely from SC_{SI}.
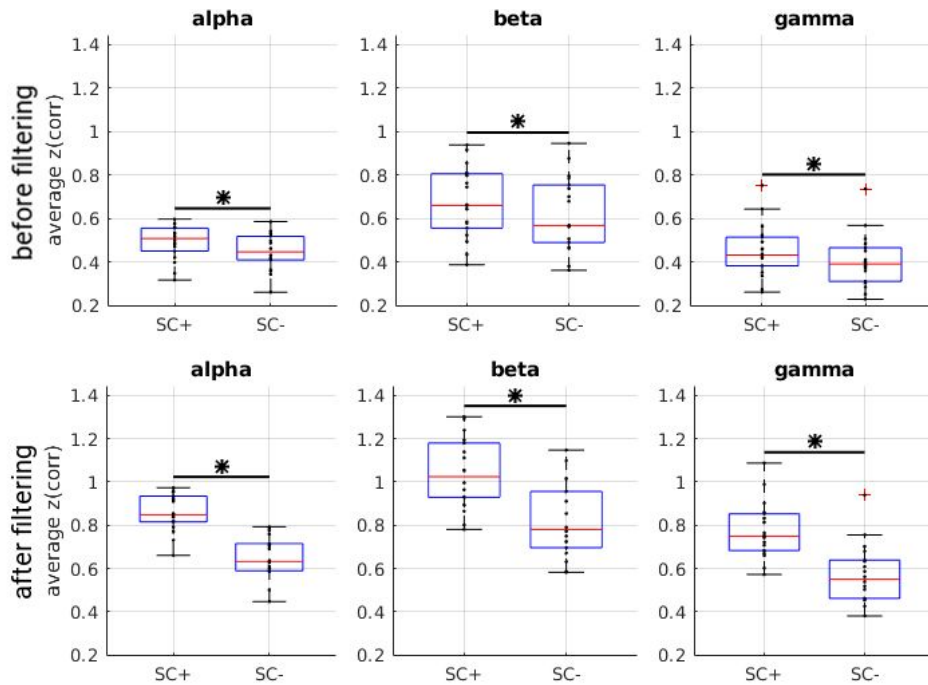
Figure S3: (related to Figure 2B) Comparison between average EEG-FC values for pairs that are connected by SC ("SC+") and those that are not ("SC-"), before (top row; identical to main manuscript) and after (bottom row) filtering. The samples that are compared are matched in their ED distribution to control for the fact that pairs that are connected tend to be closer together than those that are not. Stars mark significant results according to the Wilcoxon signed-rank test at alpha=0.05 (Bonferroni-corrected for multiple comparisons).
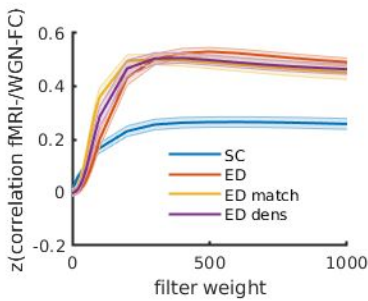
Figure S4: (related to Results) Results of graph filtering applied to white Gaussian noise (WGN). **A**: Correlation of FCs derived from filtered WGN with fMRI-FC (similar to Figure 4A). **B**: Similarity between filtered EEG-FCs and WGN-FCs. For each value of G, the best-fitting WGN-FC (out of all values of G) was selected and the correlation is shown.
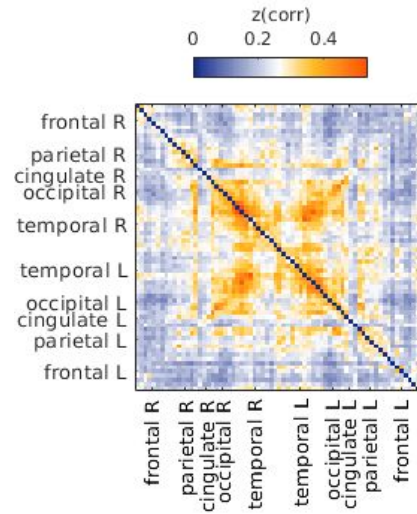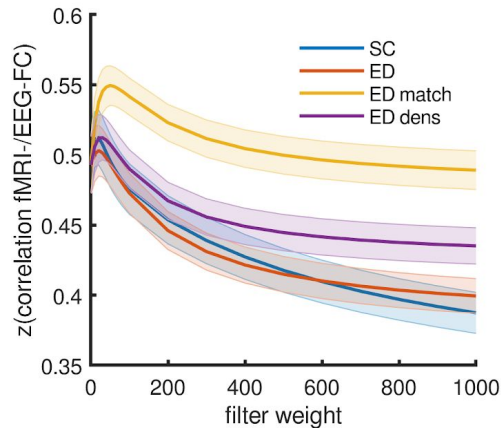
Figure S5: (Related to Results: "Graph filtering increases resemblance between EEG-FC and fMRI-FC", and Discussion: "Comparison to other methods that attenuate volume conduction") Average EEG-FC (without filtering) after each individual's EEG signals were orthogonalized.
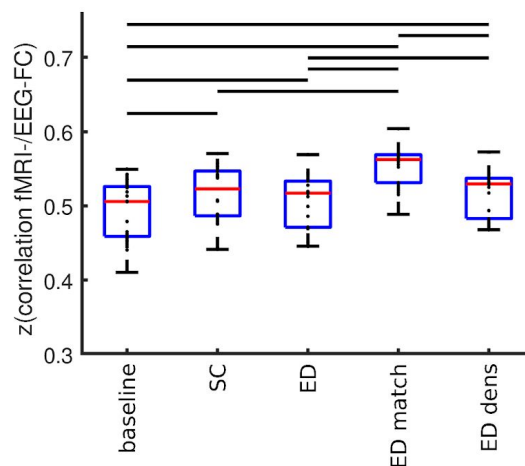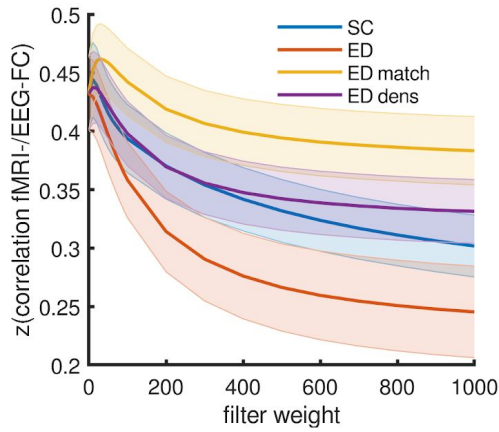

Figure S6: (related to Discussion) **A**:Fit (z-transformed correlation) between the EEG-FC (beta band, *coherence*) computed from time courses with different filter weights (G) and the fMRI-FC. The shaded regions mark the 95% confidence interval. **B**: Boxplots showing results of the Wilcoxon signed rank test comparing the maximum fits (shown in panel A) across versions of the SC as well as to the baseline correlation between unfiltered EEG-FC and fMRI-FC. Black bars mark significant differences. Red lines mark the median, each black dot marks the value for one subject.

A - Correlations between fMRI-
& EEG-FCs (imaginary part of coherence)

B - Boxplots of correlations
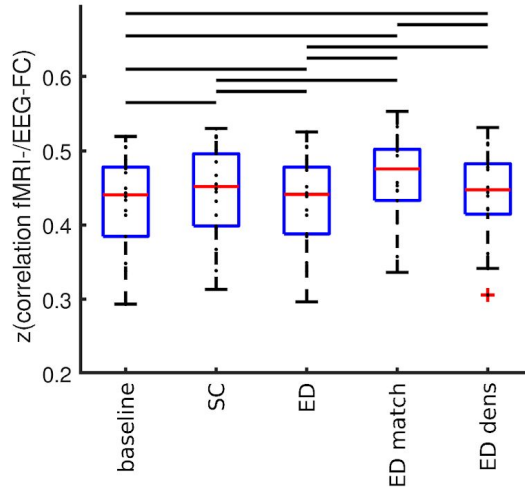

Figure S7: (related to Discussion) **A**:Fit (z-transformed correlation) between the EEG-FC (beta band, *imaginary part of coherence*) computed from time courses with different filter weights (G) and the fMRI-FC. The shaded regions mark the 95% confidence interval. **B**: Boxplots showing results of the Wilcoxon signed rank test comparing the maximum fits (shown in panel A) across versions of the SC as well as to the baseline correlation between unfiltered EEG-FC and fMRI-FC. Black bars mark significant differences. Red lines mark the median, each black dot marks the value for one subject.
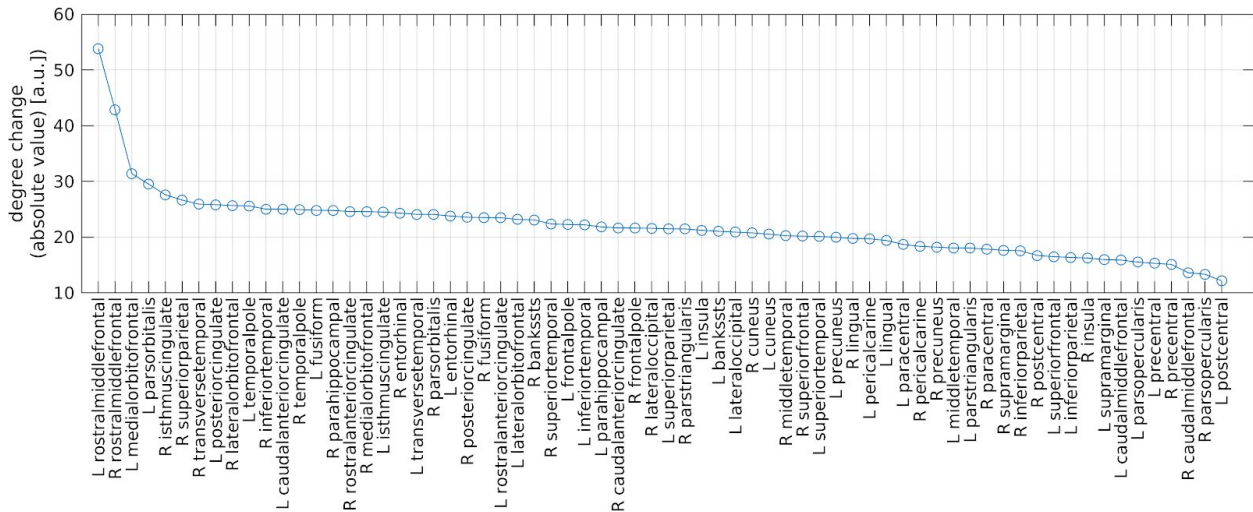

Figure S8: (related to Figure 6) Degree changes of all 68 ROIs induced by filtering. Average EEG-FCs of the beta band before and after filtering (G=100, "ED match", best fit to fMRI-FC) were resampled and the absolute values of the difference was taken. The values plotted here are the sums over the rows/columns.
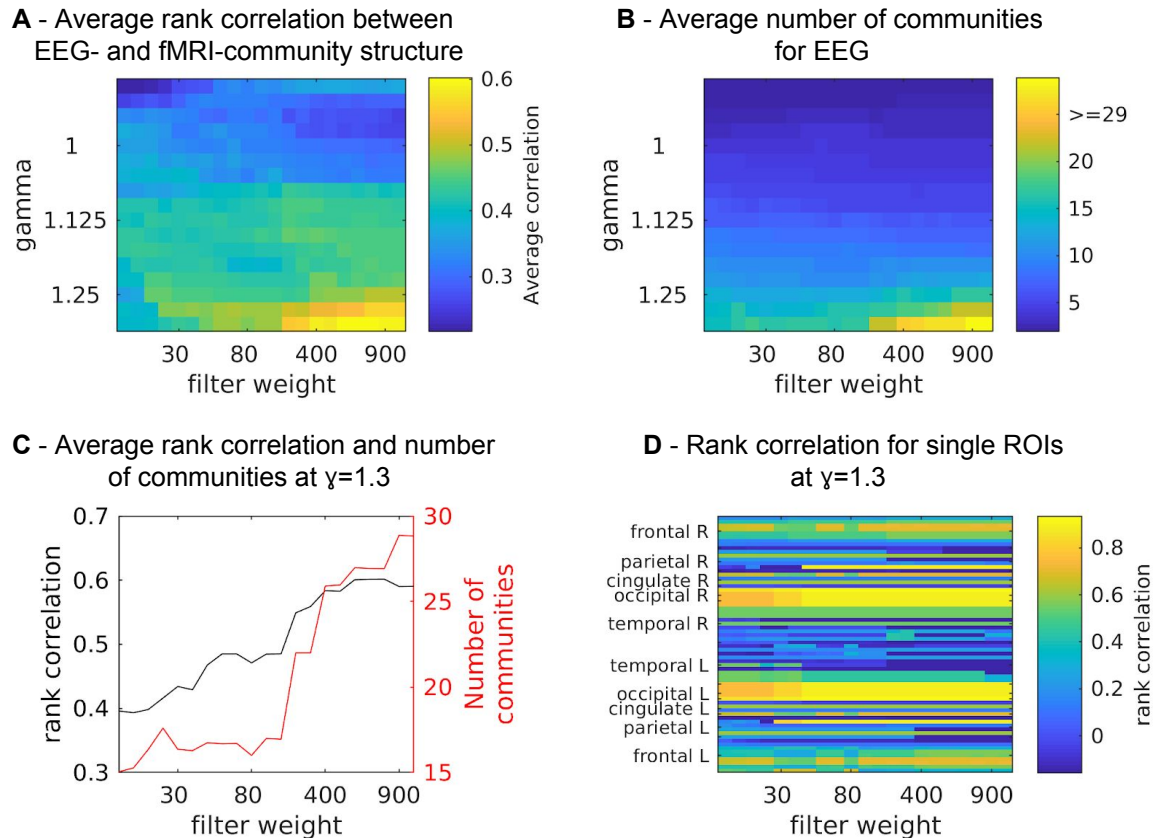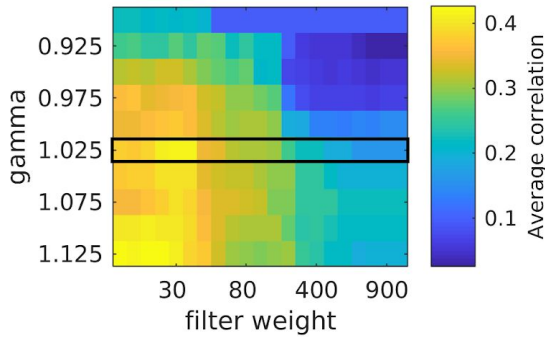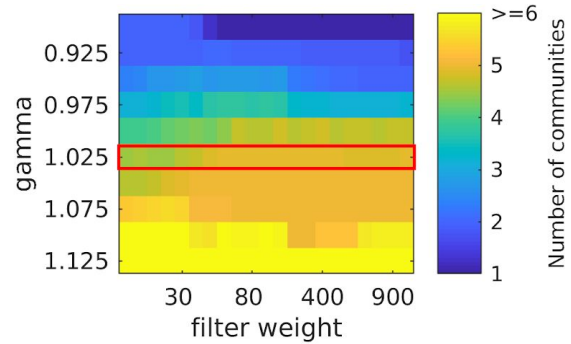
A - Average rank correlation between EEG- and fMRI-community structure

B - Average number of communities for EEG

C - Average rank correlation and number of communities at ɣ=1.3

D - Rank correlation for single ROIs at ɣ=1.3

Figure S9: (related to Figure 9) Results of the community analysis when the number of communities is not limited to be no greater than 7. **A**: Agreement between community structure of EEG- and fMRI-FC as measured by average rank correlations between "community matrices" (not shown). In this case, the overall maximum of 0.60 in community agreement as measured by rank correlation between community matrices is found at G=700 and ɣ=1.3. **B**: Average number of communities found by the Louvain clustering algorithm. At G=700 and ɣ=1.3, the number of communities is 27. **C:** Rank correlations and number of communities for ɣ=1.3. **D**: Rank correlations between rows/columns of "community matrices" of EEG- and fMRI-FC, for ɣ=1.3.
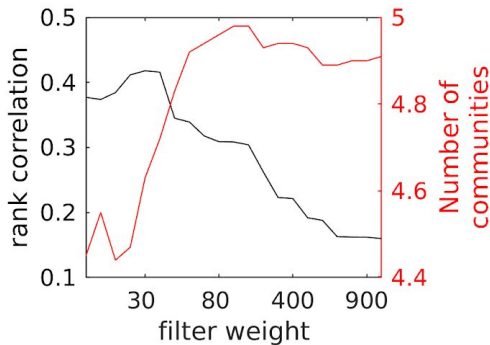
A - Average rank correlation between EEG- and fMRI-community structure

B - Average number of communities for EEG

C - Average rank correlation and number of communities at γ=1.025

D - Rank correlation for single ROIs at γ=1.025
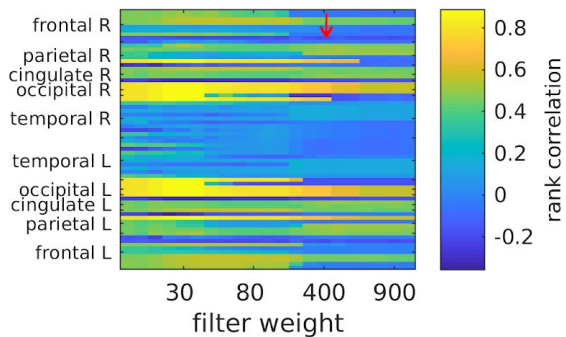
Figure S10: (related to Discussion; similar to Figure 9) Results of the community analysis when using the SC graph as a filter. **A**: Agreement between community structure of EEG- and fMRI-FC as measured by average rank correlations between "community matrices" (not shown). The black box marks the γ which is shown in panel C. **B**: Average number of communities found by the Louvain clustering algorithm. The red box marks the γ which is shown in panel C. **C**: Rank correlations and number of communities for γ=1.025 (marked in the same colors in panels A and B). **D**: Rank correlations between rows/columns of "community matrices" of EEG- and fMRI-FC, for γ=1.025 (marked with colored boxes in panels A and B). The red arrow marks the area for which rank correlations of parietal areas are increased - see Figure S5.

A - Community co-assignments of right paracentral lobule before filtering
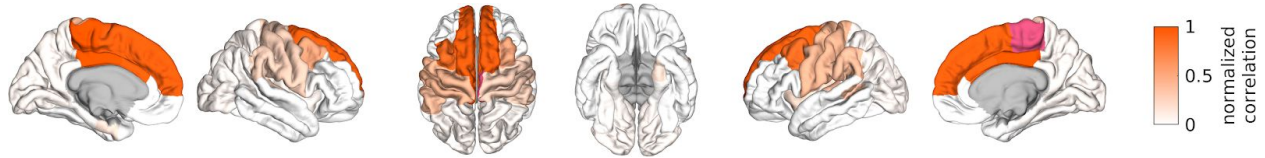
B - Community co-assignments of right paracentral lobule after filtering with the SC graph, G=400
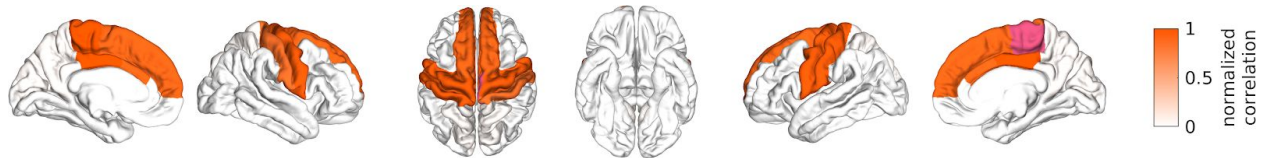
C - Community co-assignments of right paracentral lobule in fMRI
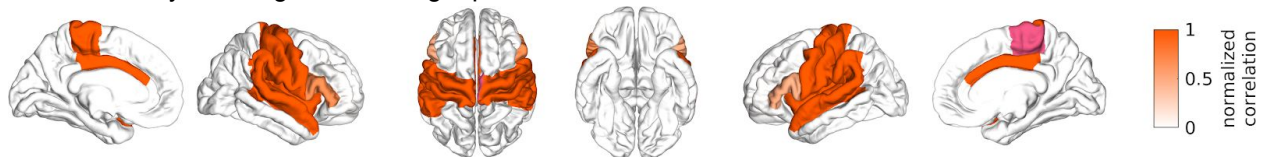
Figure S11: (related to Discussion) Community co-assignments of right paracentral lobule. **A**: Before filtering, this region is mostly grouped with some frontal regions. This figure looks different from what is shown for the same region in Figure 11A because the values of ɣ are different. **B**: After filtering *with the SC graph*, the region is robustly grouped with bilateral pre- and postcentral gyri, however, the grouping with the frontal regions is not removed. Most importantly, the overall fit to the fMRI community structure for these parameter settings ($\gamma=1.025$, G=400) is only 0.22. **C**: In fMRI, this network includes the insula as well as some temporal regions and is symmetrical.

Table S2: (related to Results: "Graph filtering increases resemblance between EEG-FC and fMRI-FC", and Discussion: "Comparison to other methods that attenuate volume conduction") Subject-wise correlations between EEG-FC and fMRI-FC with and without filtering as well as with orthogonalization (without filtering).

S	1	2	3	4	5	7	8	9	12	13	14	15	16	17	18	19	20	21
unfiltered	0.36	0.41	0.41	0.46	0.44	0.48	0.46	0.49	0.42	0.42	0.51	0.49	0.51	0.44	0.29	0.27	0.41	0.36
filtered (best)	0.50	0.52	0.51	0.54	0.50	0.56	0.54	0.54	0.48	0.51	0.55	0.56	0.53	0.54	0.41	0.40	0.50	0.51
orthogonalized	0.05	0.08	0.31	0.27	0.16	0.19	0.20	0.22	0.30	0.23	0.12	0.32	0.31	0.19	0.01	0.14	0.17	0.26

Table S3: (related to Methods-Data section) Number and lengths of artifact-free intervals that were included in the envelope correlation-based FC analysis, as well as the number of 3s-segments used for computing coherence and imaginary part of coherence, for each subject.

subject ID	# intervals	lengths intervals (seconds, Fs=1000Hz)													# segments ([i]coh)
s01	9	52	36	42	37	27	26	26	29	20					64
s02	6	90	20	22	20	31	39								64
s03	7	260	63	37	27	20	164	21							167
s04	9	37	51	45	57	20	24	73	213	153					111
s05	2	383	35												97
s07	5	96	38	80	39	29									63
s08	5	60	39	92	329	48									155
s09	7	33	47	46	54	38	38	70							77
s12	6	77	72	92	79	162	253								227
s13	9	41	89	20	26	25	21	26	24	23					61
s14	9	47	30	26	93	60	59	87	39	42					61
s15	9	26	37	32	22	33	179	38	114	26					85
s16	13	38	24	25	21	44	28	24	40	41	31	45	53	26	120
s17	12	26	109	62	38	69	40	40	33	85	31	35	81		160
s18	2	25	20												5
s19	4	54	254	22	83										96
s20	7	68	24	23	27	39	44	19							19
s21	8	64	93	117	48	23	19	26	40						104