

# Graph Var

## Quick Guide

# GraphVar: A user-friendly toolbox for comprehensive graph analyses of functional brain connectivity.

- *features:*

- I. Pipeline construction of graph networks
- II. Calculation of network topological measures
- III. Generation of subject specific random networks
- IV. (Partial) correlation analyses of network measures with user defined variables
- V. Perform group comparisons (t-test, ANOVA) on network measures
- VI. Calculations on raw connectivity matrices (Network based statistics)
- VII. Parametric and non-parametric testing
- VIII. Interactive and visual results exploration

- Kruschwitz, J.D<sup>1,2\*</sup>, List, D. <sup>1,2\*</sup>, Waller, L. <sup>2</sup>, Rubinov, M. <sup>3</sup>, Walter, H<sup>1</sup>.

\*equal contribution

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<sup>2</sup> Technische Universität Dresden, Dresden, Germany

<sup>3</sup> University of Cambridge, Cambridge, United Kingdom

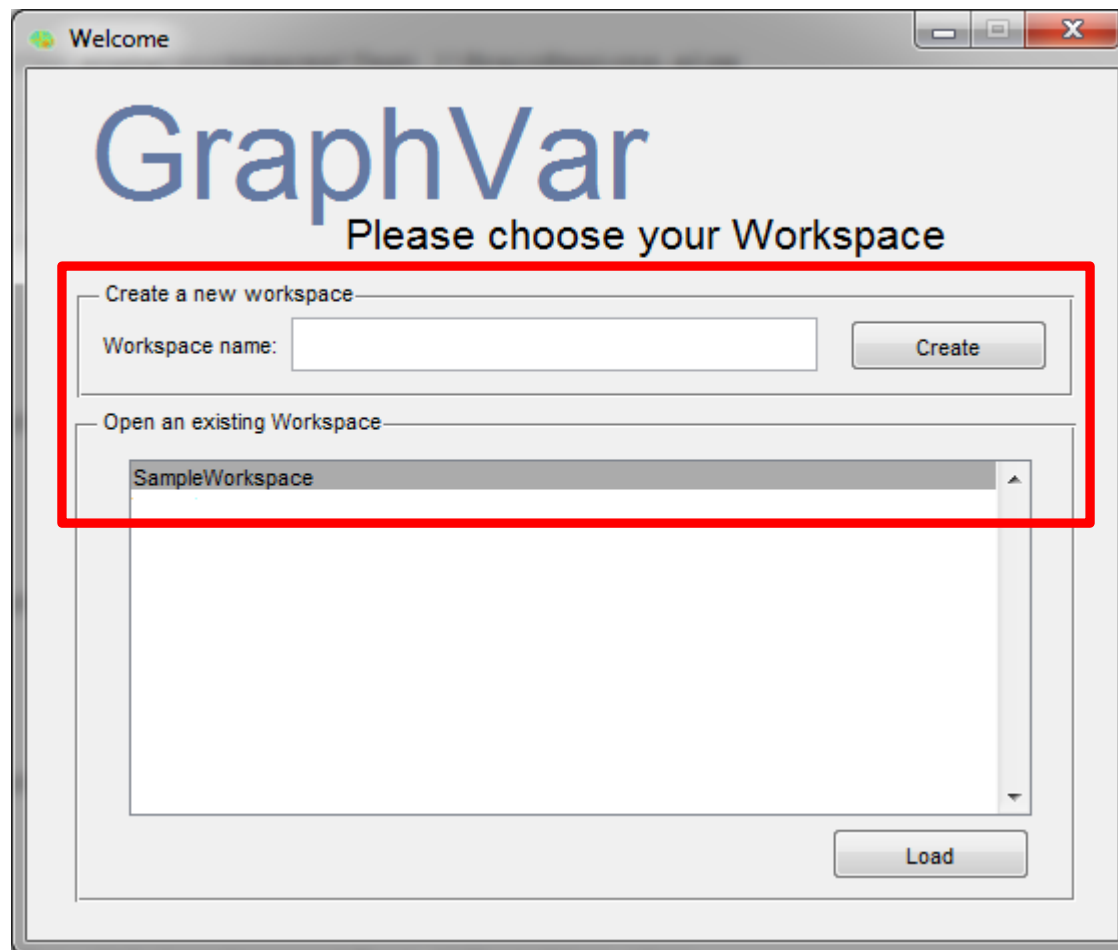
# Getting Started

- I. Unzip in your preferred directory
- II. Add to your Matlab path (Add Folder ...)
- III. Start with the command „start\_GraphVar“
- IV. Create a new workspace or try the „SampleWorkspace“ with the sample data

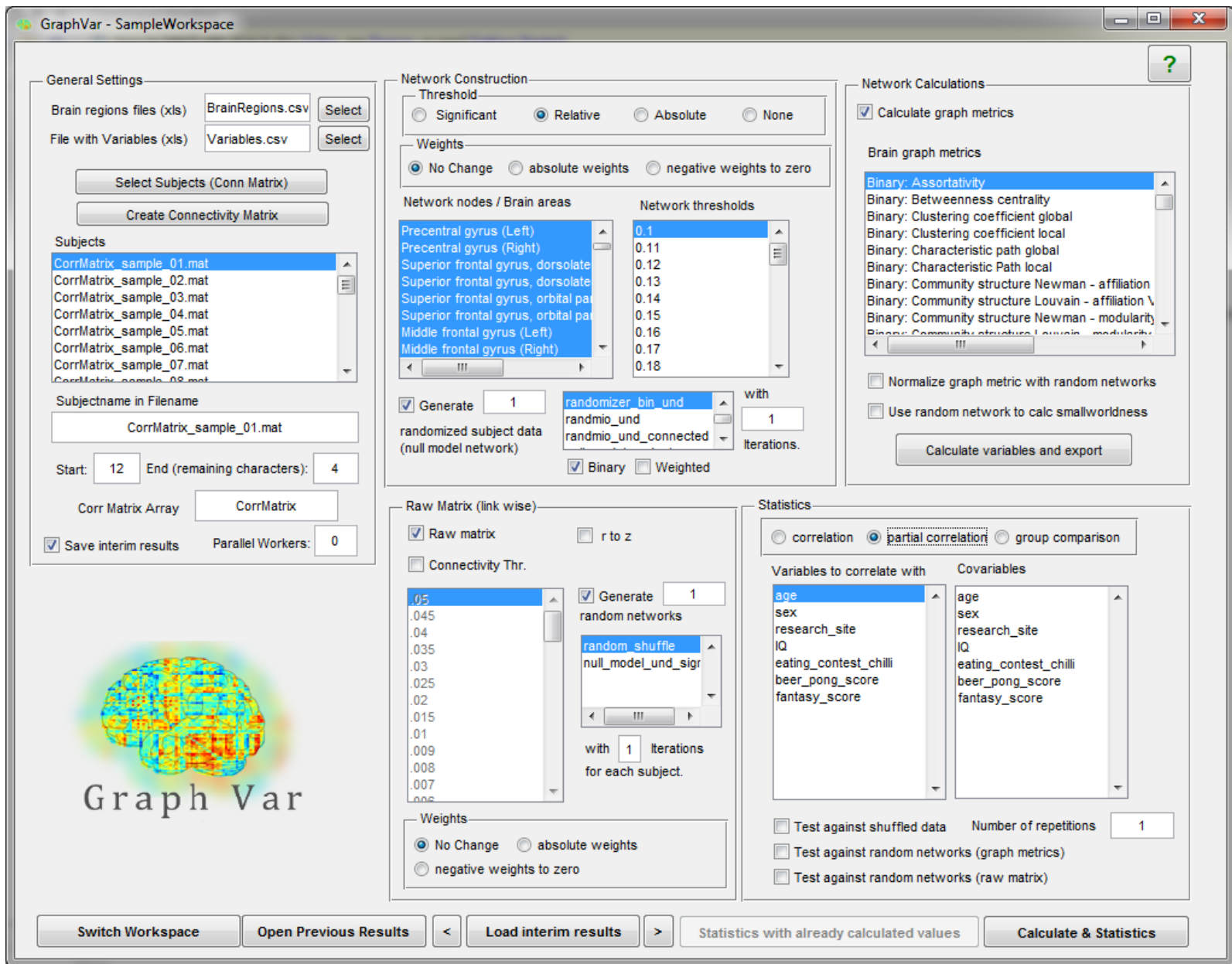
## Requirements:

- I. This current version runs under Windows and Linux
- II. Matlab Statistics toolbox for statistical analyses (calculation and export of graph measures will work without)
- III. If SPM is installed you may have to move the statistics toolbox to the top to prevent conflicts

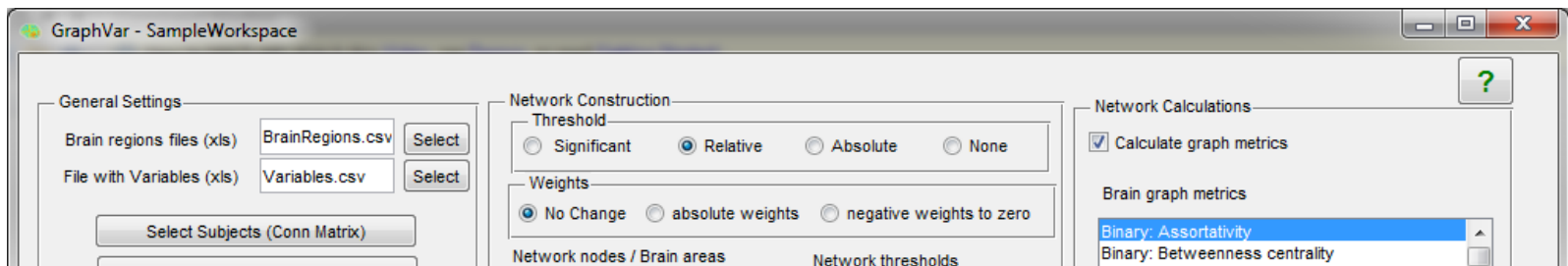
# The Analysis Setup GUI



Welcome



# Setup panel



Input:

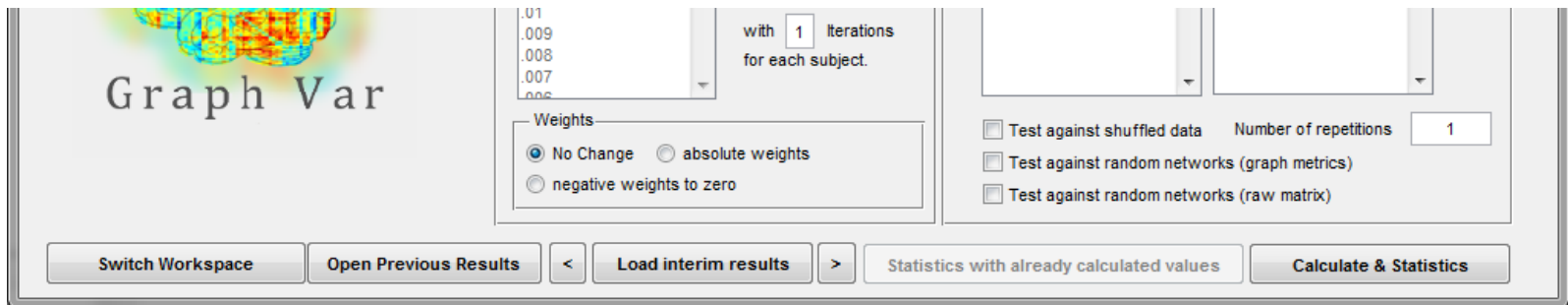
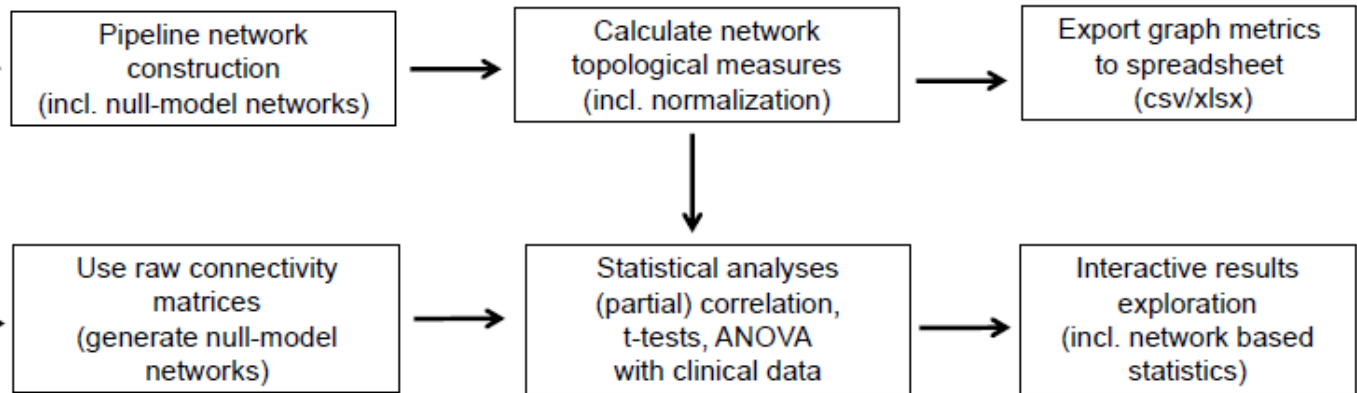


or

	Node 1	Node 2	Node 3	Node n
Time course...				
Time course...				
Time course...				
Time course...				

and

Subject data  
(e.g. clinical data)



# Workflows

GraphVar - SampleWorkspace

General Settings  
 Brain regions files (xls) BrainRegions.csv Select  
 File with Variables (xls) Variables.csv Select  
 Select Subjects (Conn Matrix)  
 Create Connectivity Matrix

Network Construction  
 Threshold  
 Significant  Relative  Absolute  None  
 Weights  
 No Change  absolute weights  negative weights to zero  
 Network nodes / Brain areas Network thresholds  
 Precentral gyrus (Left) 0.1  
 Superior frontal gyrus, orbital part 0.15  
 Middle frontal gyrus (Left) 0.16  
 Middle frontal gyrus (Right) 0.17  
 0.18

Network Calculations  
 Calculate graph metrics  
 Brain graph metrics  
 Binary: Assortativity  
 Binary: Betweenness centrality  
 Binary: Clustering coefficient g  
 Binary: Clustering coefficient l  
 Characteristic path glo  
 Characteristic Path loc  
 Community structure M  
 Community structure L  
 Community structure N  
 Community structure I  
 Community structure V  
 Community structure  
 Normalize graph metric with  
 Use random network to calculate  
 Calculate variables

CorrMatrix\_sample\_04.mat  
 CorrMatrix\_sample\_05.mat  
 CorrMatrix\_sample\_06.mat  
 CorrMatrix\_sample\_07.mat  
 CorrMatrix\_sample\_08.mat  
 Subjectname in Filename  
 CorrMatrix\_sample\_01.mat  
 Start: 12 End (remaining characters): 4  
 Corr Matrix Array CorrMatrix  
 Save interim results Parallel Workers: 0

Generate 1 with 1 iterations.  
 randomized subject data (null model network)  
 Binary  Weighted  
 randomizer\_bin und  
 randmio\_und  
 randmio\_und\_connected

Raw Matrix (link wise)  
 Raw matrix  r to z  
 Connectivity Thr.  
 .05  
 .045  
 .04  
 Generate 1  
 random networks  
 with 1 iterations for each subject.  
 Weights  
 No Change  absolute weights  
 negative weights to zero

Statistics  
 correlation  partial correlation  group  
 Variables to correlate with  
 age  
 sex  
 research\_site  
 Covariables  
 age  
 sex  
 research\_site  
 IQ  
 eating\_contest  
 beer\_pong\_sc  
 fantasy\_s  
 Test against shuffled data Number of repetitions 1  
 Test against random networks (graph metrics)  
 Test against random networks (raw matrix)

Calculate and export graph metrics

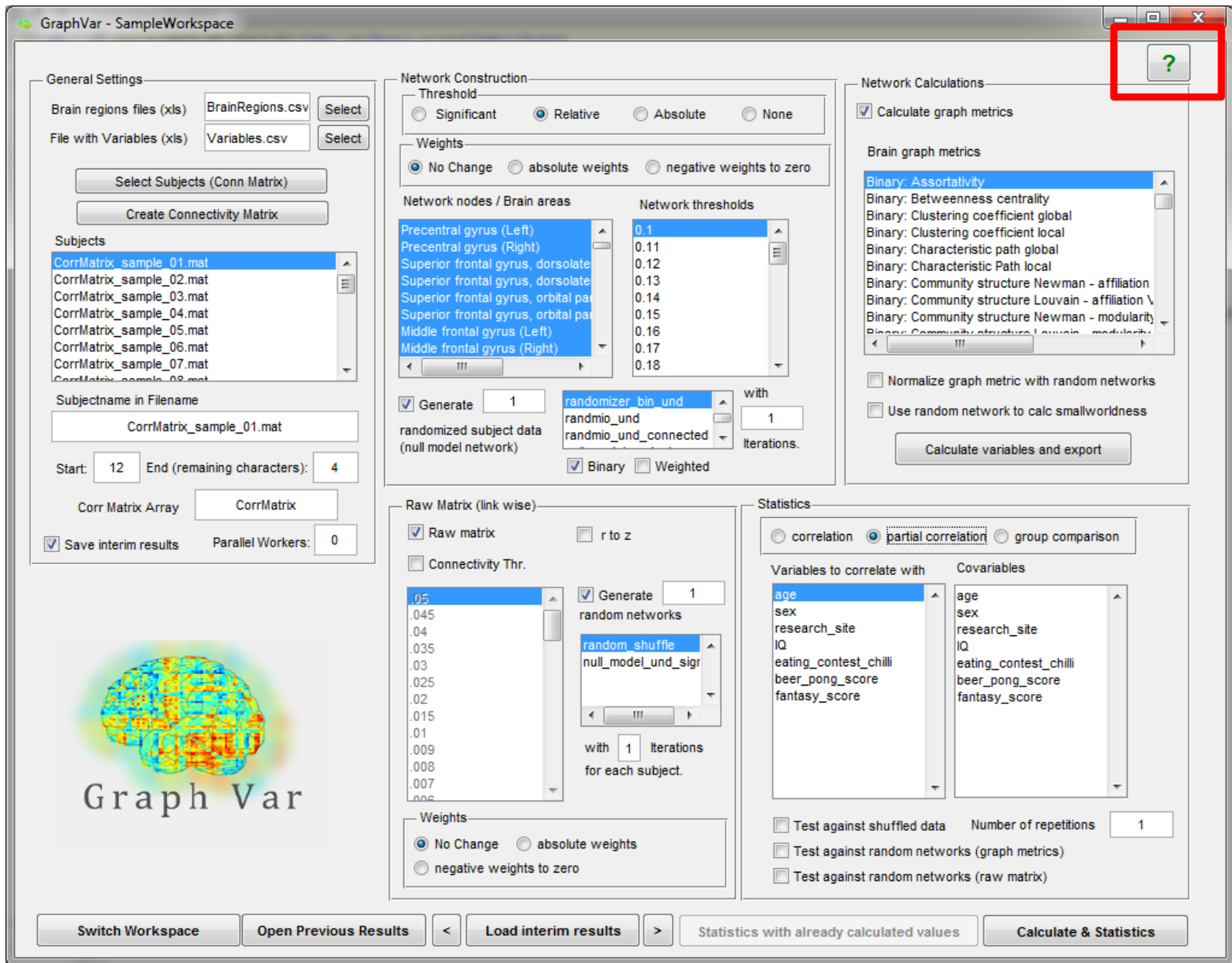
Statistics with graph metrics

Statistics on raw matrix

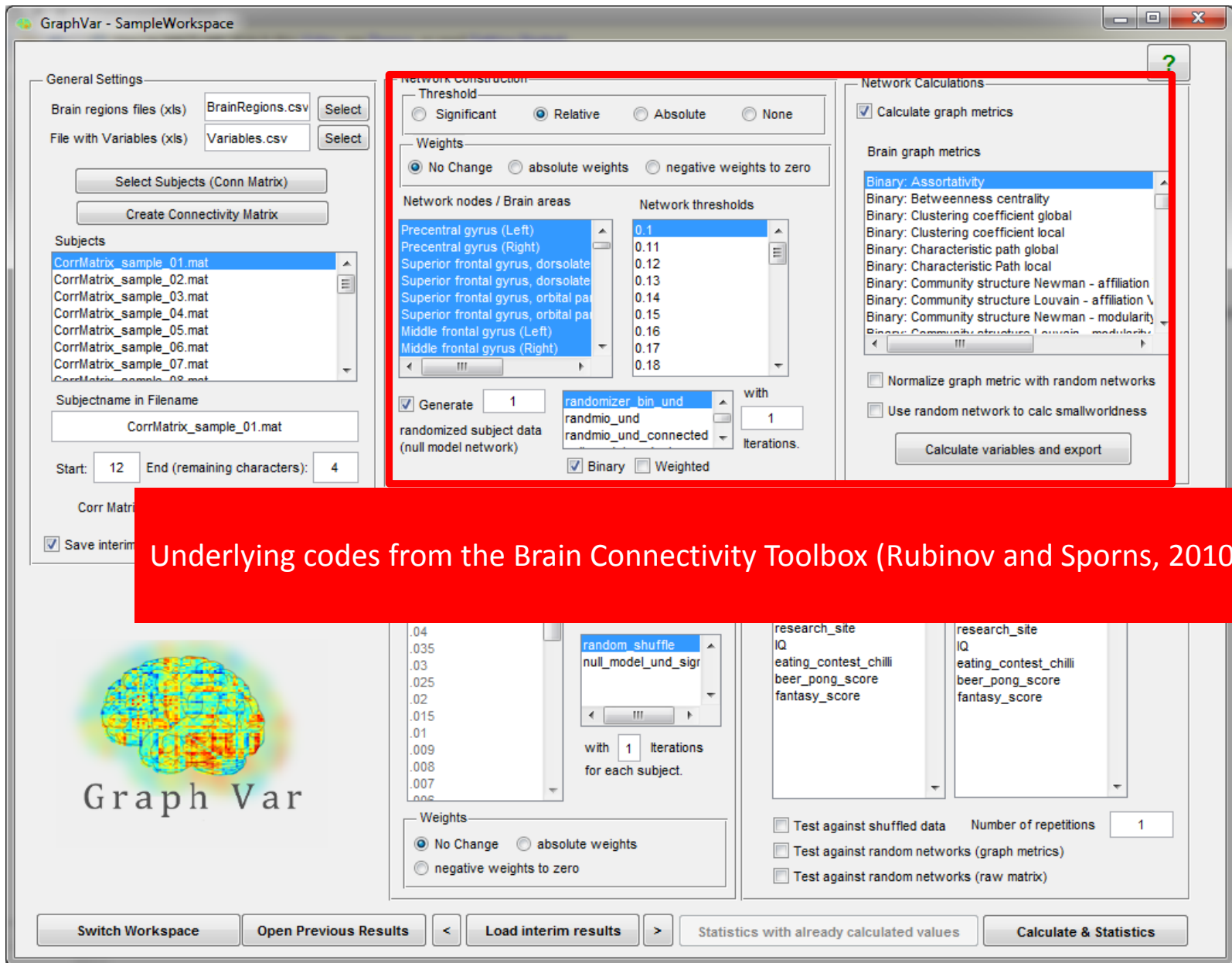
Graph Var

Switch Workspace Open Previous Results Load interim results Statistics with already calculated values Calculate & Statistics

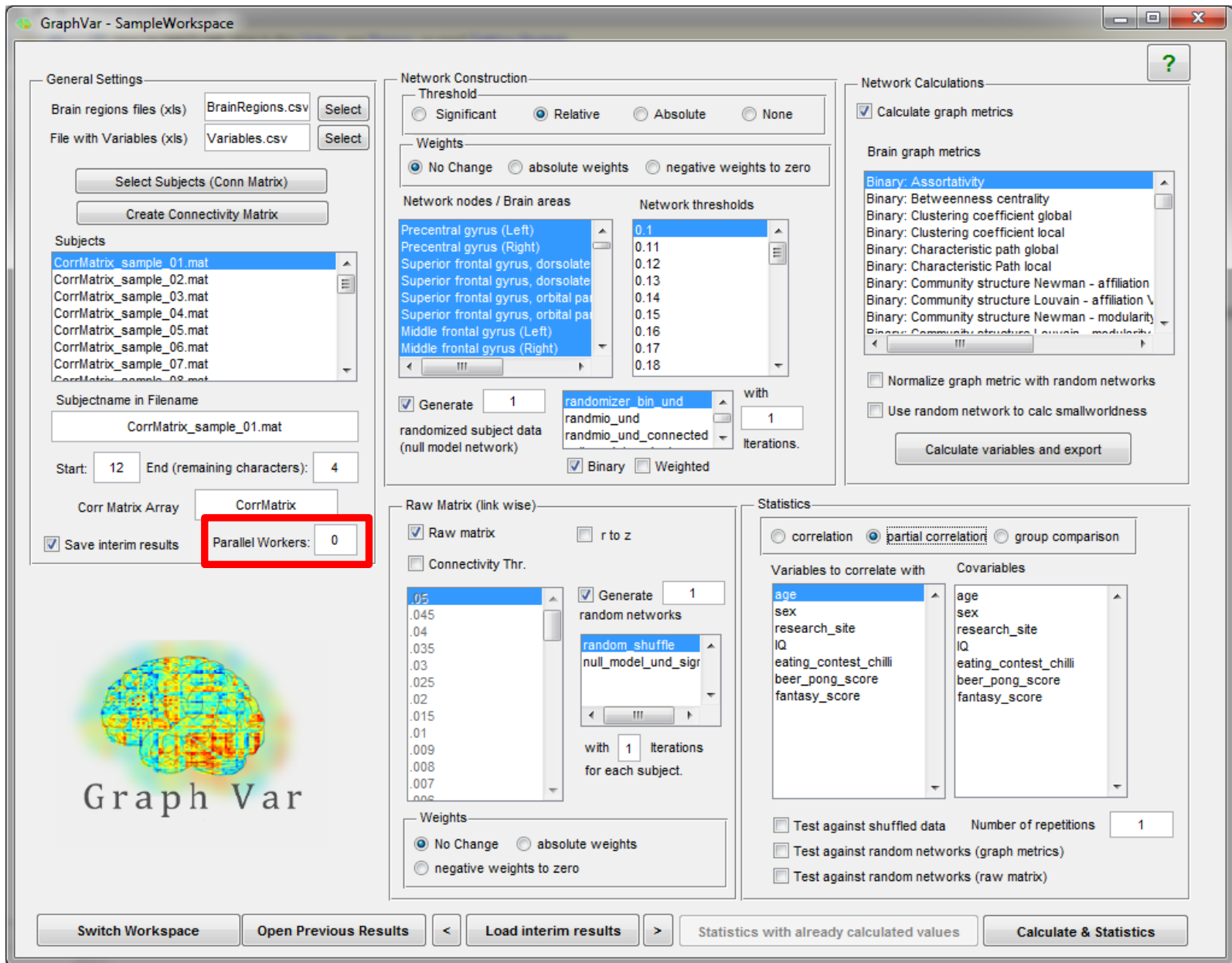
# Workflows



Setup panel (mouse over help)



Setup panel



# Parallel Computing (with toolbox)

GraphVar - SampleWorkspace

**General Settings**

Brain regions files (xls)

File with Variables (xls)

Subjects

- CorrMatrix\_sample\_01.mat
- CorrMatrix\_sample\_02.mat
- CorrMatrix\_sample\_03.mat
- CorrMatrix\_sample\_04.mat
- CorrMatrix\_sample\_05.mat
- CorrMatrix\_sample\_06.mat
- CorrMatrix\_sample\_07.mat
- CorrMatrix\_sample\_08.mat

Subjectname in Filename

Start:  End (remaining characters):

Corr Matrix Array

Save interim results    Parallel Workers:

**Network Construction**

Threshold

Significant     Relative     Absolute     None

Weights

No Change     absolute weights     negative weights to zero

Network nodes / Brain areas

- Precentral gyrus (Left)
- Precentral gyrus (Right)
- Superior frontal gyrus, dorsolate
- Superior frontal gyrus, dorsolate
- Superior frontal gyrus, orbital pa
- Superior frontal gyrus, orbital pa
- Middle frontal gyrus (Left)
- Middle frontal gyrus (Right)

Network thresholds

- 0.1
- 0.11
- 0.12
- 0.13
- 0.14
- 0.15
- 0.16
- 0.17
- 0.18

Generate   with  iterations.

randomized subject data (null model network)

Binary     Weighted

**Network Calculations**

Calculate graph metrics

Brain graph metrics

- Binary: Assortativity
- Binary: Betweenness centrality
- Binary: Clustering coefficient global
- Binary: Clustering coefficient local
- Binary: Characteristic path global
- Binary: Characteristic Path local
- Binary: Community structure Newman - affiliation
- Binary: Community structure Louvain - affiliation \
- Binary: Community structure Newman - modularity
- Binary: Community structure Louvain - modularity

Normalize graph metric with random networks

Use random network to calc smallworldness

**Raw Matrix (link wise)**

Raw matrix     r to z

Connectivity Thr.

Generate  iterations

with  iterations for each subject.

Weights

No Change     absolute weights     negative weights to zero

**Statistics**

correlation     partial correlation     group comparison

Variables to correlate with

- age
- sex
- research\_site
- IQ
- eating\_contest\_chilli
- beer\_pong\_score
- fantasy\_score

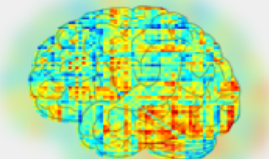
Covariables

- age
- sex
- research\_site
- IQ
- eating\_contest\_chilli
- beer\_pong\_score
- fantasy\_score

Test against shuffled data    Number of repetitions

Test against random networks (graph metrics)

Test against random networks (raw matrix)



Graph Var

# General settings

GraphVar - SampleWorkspace

General Settings

Brain regions files (xls) BrainRegions.csv Select

File with Variables (xls) Variables.csv Select

Select Subjects (Conn Matrix)

Create Connectivity Matrix

Subjects

- CorrMatrix\_sample\_01.mat
- CorrMatrix\_sample\_02.mat
- CorrMatrix\_sample\_03.mat
- CorrMatrix\_sample\_04.mat
- CorrMatrix\_sample\_05.mat
- CorrMatrix\_sample\_06.mat
- CorrMatrix\_sample\_07.mat
- CorrMatrix\_sample\_08.mat

Subjectname in Filename

CorrMatrix\_sample\_01.mat

Start: 12 End (remaining characters): 4

Corr Matrix Array CorrMatrix

Save interim results Parallel Workers: 0

Network

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Weights

No Change  absolute weights

negative weights to zero

Test against shuffled data Number of repetitions 1

Test against random networks (graph metrics)

Test against random networks (raw matrix)

Switch Workspace Open Previous Results < Load interim results > Statistics with already calculated values Calculate & Statistics

Load (existing) Connectivity Matrices

GraphVar - SampleWorkspace

General Settings

Brain regions files (xls)

File with Variables (xls)

Subjects

- CorrMatrix\_sample\_01.mat
- CorrMatrix\_sample\_02.mat
- CorrMatrix\_sample\_03.mat
- CorrMatrix\_sample\_04.mat
- CorrMatrix\_sample\_05.mat
- CorrMatrix\_sample\_06.mat
- CorrMatrix\_sample\_07.mat
- CorrMatrix\_sample\_08.mat

Subjectname in Filename

Start:  End (remaining characters):

Corr Matrix Array

Save interim results Parallel Workers:

Partial correlation (control for nodes)

Spearman correlation

Percentage bend correlation

Mutual information

Create random time series

Randomize  Shuffle

Number of random series

Network Threshold

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Weights

No Change  absolute weights

negative weights to zero

Test against random data Number of repetitions

Test against random networks (graph metrics)

Test against random networks (raw matrix)

## Individual nodal time courses

Node 1	Node 2	Node 3	Node n
Time course...	Time course...	Time course...	Time course...

# Generate Connectivity Matrices

GraphVar - SampleWorkspace

General Settings

Brain regions files (xls) **BrainRegions.csv** **Select**

File with Variables (xls) Variables.csv Select

Select Subjects (Conn Matrix)

Create Connectivity Matrix

Subjects

- CorrMatrix\_sample\_01.mat
- CorrMatrix\_sample\_02.mat
- CorrMatrix\_sample\_03.mat
- CorrMatrix\_sample\_04.mat
- CorrMatrix\_sample\_05.mat
- CorrMatrix\_sample\_06.mat
- CorrMatrix\_sample\_07.mat
- CorrMatrix\_sample\_08.mat

Subjectname in Filename

CorrMatrix\_sample\_01.mat

Start: 12 End (remaining characters): 4

Corr Matrix Array CorrMatrix

Save interim results Parallel Workers: 0

Network Thresh

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Brain.xlsx - Microsoft Excel

Datei Start Einfügen Seitenlayout Formeln Daten Überprüfen Ansicht

Einfügen Einfügen Einfügen

Zwischenabl... Schriftart

Ausrichtung Zahl Formatvorlagen Zellen Bearbeiten

E22

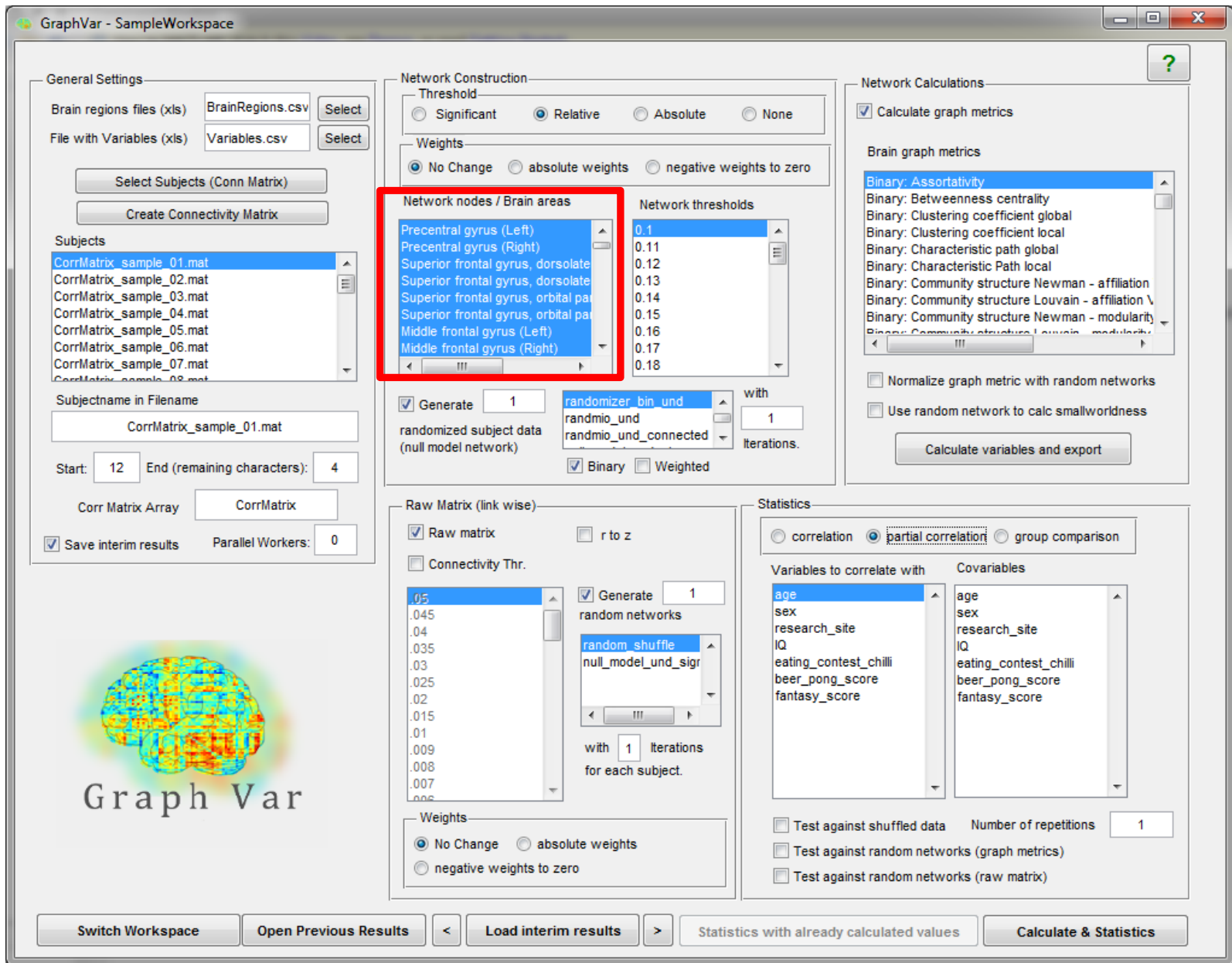
	A	B	C
1	1	Precentral_L	Precentral gyrus (Left)
2	1	Precentral_R	Precentral gyrus (Right)
3	1	Frontal_Sup_L	Superior frontal gyrus, dorsolateral (Left)
4	1	Frontal_Sup_R	Superior frontal gyrus, dorsolateral (Right)
5	1	Frontal_Sup_Orb_L	Superior frontal gyrus, orbital part (Left)
6	1	Frontal_Sup_Orb_R	Superior frontal gyrus, orbital part (Right)
7	1	Frontal_Mid_L	Middle frontal gyrus (Left)
8	1	Frontal_Mid_R	Middle frontal gyrus (Right)
9	1	Frontal_Mid_Orb_L	Middle frontal gyrus orbital part (Left)
10	1	Frontal_Mid_Orb_R	Middle frontal gyrus orbital part (Right)
11	1	Frontal_Inf_Oper_L	Inferior frontal gyrus, opercular part (Left)
12	1	Frontal_Inf_Oper_R	Inferior frontal gyrus, opercular part (Right)
13	1	Frontal_Inf_Tri_L	Inferior frontal gyrus, triangular part (Left)
14	1	Frontal_Inf_Tri_R	Inferior frontal gyrus, triangular part (Right)
15	1	Frontal_Inf_Orb_L	Inferior frontal gyrus, orbital part (Left)
16	1	Frontal_Inf_Orb_R	Inferior frontal gyrus, orbital part (Right)
17	1	Rolandic_Oper_L	Rolandic operculum (Left)
18	1	Rolandic_Oper_R	Rolandic operculum (Right)

Graph Var

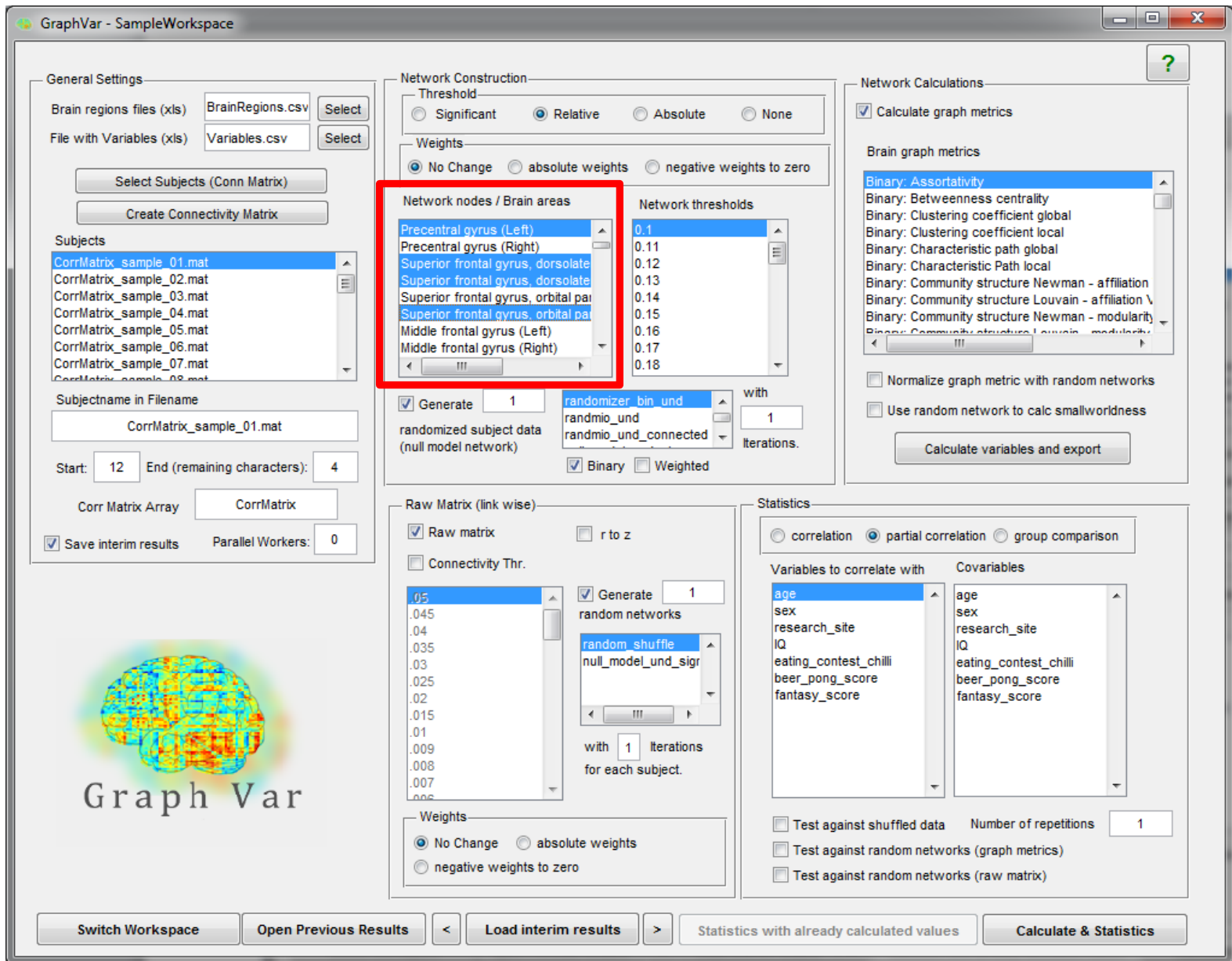
Switch Workspace Open Previous Results

Bereit aalCOG 100 %

Label nodes



Label nodes



# Redefine Network (Subnetwork analyses)

The image shows the GraphVar software interface with a 'Select rows' dialog box open. The dialog box contains the following text and options:

Please select Variables: First selection(Radio button)= Variable with name; Second selection = Variables should be useable for

- Subj\_ID
- age
- sex
- research\_site
- IQ
- eating\_contest\_chilli
- beer\_pong\_score
- fantasy\_score

The background window shows the 'General Settings' section with 'Brain regions files (xls)' set to 'BrainRegions.csv' and 'File with Variables (xls)' set to 'Variables.csv'. The 'Subjects' list includes 'CorrMatrix\_sample\_01.mat' through 'CorrMatrix\_sample\_08.mat'. The 'Network Calculations' section is partially visible, showing a list of graph metrics.

# Variable Selection

GraphVar - SampleWorkspace

General Settings

Brain regions files (xls) BrainRegions.csv Select

**File with Variables (xls) Variables.csv Select**

Select Subjects (Conn Matrix)

Create Connectivity Matrix

Subjects

- CorrMatrix\_sample\_01.mat
- CorrMatrix\_sample\_02.mat
- CorrMatrix\_sample\_03.mat
- CorrMatrix\_sample\_04.mat
- CorrMatrix\_sample\_05.mat
- CorrMatrix\_sample\_06.mat
- CorrMatrix\_sample\_07.mat
- CorrMatrix\_sample\_08.mat

Subjectname in Filename

CorrMatrix\_sample\_01.mat

Start: 12 End (remaining characters): 4

Corr Matrix Array CorrMatrix

Save interim results Parallel Workers: 0

Network Construction

Threshold

Significant  Relative  Absolute  None

Network Calculations

Calculate graph metrics

Variables - Microsoft Excel

	A	B	C	D	E	F	G	H	I	J	K
1	Subj_ID	age	sex	research_site	IQ	eating_co	beer_pon	fantasy_score			
2	sample_01	21	male	New York	100	48	13	68,1			
3	sample_02	43	male	New York	130	47	15	23,9			
4	sample_03	26	male	New York	115	53	21	28,8			
5	sample_04	25	male	Paris	98	56	10	40,2			
6	sample_05	22	male	Paris	55	62	20	48,4			
7	sample_06	33	male	Paris	120	66	17	43,5			
8	sample_07	36	male	Paris	80	68	16	32,1			
9	sample_08	33	male	Paris	99	73	15	37			
10	sample_09	39	male	Paris	65	63	25	46,8			
11	sample_10	46	male	Paris	140	48	23	43,5			
12	sample_11	33	male	London	122	64	18	48,4			
13	sample_12	46	male	London	130	58	23	46,8			
14	sample_13	42	male	London	111	51	19	46,8			
15	sample_14	47	male	London	82	46	14	41,9			
16	sample_15	35	male	New York	79	71	16	40,2			
17	sample_16	43	female	New York	83	54	9	41,9			
18	sample_17	32	female	New York	69	58	16	48,4			
19	sample_18	22	female	New York	68	59	18	30,4			
20	sample_19	22	female	New York	110	64	18	51,7			
21	sample_20	38	female	New York	109	44	17	46,8			
22	sample_21	38	female	New York	55	56	22	32,1			

Graph Var

Switch Workspace Open Previous Results Load interim results Statistics with already calculated values Calculate & Statistics

# Variable Selection

GraphVar - SampleWorkspace

General Settings

Brain regions files (xls)

File with Variables (xls)

Subjects

- CorrMatrix\_sample\_01.mat
- CorrMatrix\_sample\_02.mat
- CorrMatrix\_sample\_03.mat
- CorrMatrix\_sample\_04.mat
- CorrMatrix\_sample\_05.mat
- CorrMatrix\_sample\_06.mat
- CorrMatrix\_sample\_07.mat
- CorrMatrix\_sample\_08.mat

Subjectname in Filename

Start:  End (remaining characters):

Corr Matrix Array

Save interim results Parallel Workers:

Network Construction

Threshold

Significant  Relative  Absolute  None

Weights

No Change  absolute weights  negative weights to zero

Network nodes / Brain areas

- Precentral gyrus (Left)
- Precentral gyrus (Right)
- Superior frontal gyrus, dorsolate
- Superior frontal gyrus, orbital pa
- Superior frontal gyrus, orbital pa
- Middle frontal gyrus (Left)
- Middle frontal gyrus (Right)

Network thresholds

- 0.1
- 0.11
- 0.12
- 0.13
- 0.14
- 0.15
- 0.16
- 0.17
- 0.18

Generate   with  iterations.

randomized subject data (null model network)

Binary  Weighted

Network Calculations

Calculate graph metrics

Brain graph metrics

- Binary: Assortativity
- Binary: Betweenness centrality
- Binary: Clustering coefficient global
- Binary: Clustering coefficient local
- Binary: Characteristic path global
- Binary: Characteristic Path local
- Binary: Community structure Newman - affiliation
- Binary: Community structure Louvain - affiliation \
- Binary: Community structure Newman - modularity
- Binary: Community structure Louvain - modularity

Normalize graph metric with random networks

Use random network to calc smallworldness

Raw Matrix (link wise)

Raw matrix  r to z

Connectivity Thr.

Generate  iterations

random networks

with  iterations for each subject.

Weights

No Change  absolute weights  negative weights to zero

Statistics

correlation  partial correlation  group comparison

Variables to correlate with

- age
- sex
- research\_site
- IQ
- eating\_contest\_chilli
- beer\_pong\_score
- fantasy\_score

Covariables

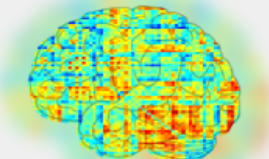
- age
- sex
- research\_site
- IQ
- eating\_contest\_chilli
- beer\_pong\_score
- fantasy\_score

Test against shuffled data Number of repetitions

Test against random networks (graph metrics)

Test against random networks (raw matrix)

Switch Workspace Open Previous Results < Load interim results > Statistics with already calculated values Calculate & Statistics



Graph Var

# Variable Selection

GraphVar - SampleWorkspace

General Settings

Brain regions files (xls) BrainRegions.csv Select

File with Variables (xls) Variables.csv Select

Select Subjects (Conn Matrix)

Create Connectivity Matrix

Subjects

CorrMatrix\_sample\_01.mat  
CorrMatrix\_sample\_02.mat  
CorrMatrix\_sample\_03.mat  
CorrMatrix\_sample\_04.mat  
CorrMatrix\_sample\_05.mat  
CorrMatrix\_sample\_06.mat  
CorrMatrix\_sample\_07.mat  
CorrMatrix\_sample\_08.mat

Subjectname in Filename

CorrMatrix\_sample\_01.mat

Start: 12 End (remaining characters): 4

Corr Matrix Array CorrMatrix

Save interim results Parallel Workers: 0

Network Construction

Threshold

Significant  Relative  Absolute  None

Weights

No Change  absolute weights  negative weights to zero

Network nodes / Brain areas

Precentral gyrus (Left)  
Precentral gyrus (Right)  
Superior frontal gyrus, dorsolate  
Superior frontal gyrus, orbital pa  
Superior frontal gyrus, orbital pa  
Middle frontal gyrus (Left)  
Middle frontal gyrus (Right)

Network thresholds

0.1  
0.11  
0.12  
0.13  
0.14  
0.15  
0.16  
0.17  
0.18

Generate 1 randomized subject data (null model network) with 1 iterations.

randomizer\_bin und  
randmio\_und  
randmio\_und\_connected

Binary  Weighted

Network Calculations

Calculate graph metrics

Brain graph metrics

Binary: Assortativity  
Binary: Betweenness centrality  
Binary: Clustering coefficient global  
Binary: Clustering coefficient local  
Binary: Characteristic path global  
Binary: Characteristic Path local  
Binary: Community structure Newman - affiliation  
Binary: Community structure Louvain - affiliation \n  
Binary: Community structure Newman - modularity  
Binary: Community structure Louvain - modularity

Normalize graph metric with random networks

Use random network to calc smallworldness

Calculate variables and export

Raw Matrix (link wise)

Raw matrix  r to z

Connectivity Thr.

0.05  
.045  
.04  
.035  
.03  
.025  
.02  
.015  
.01  
.009  
.008  
.007  
.006

Generate 1 random networks

random\_shuffle  
null\_model\_und\_sigr

with 1 iterations for each subject.

Weights

No Change  absolute weights  
 negative weights to zero

Statistics

correlation  partial correlation  group comparison

Variables to correlate with

age  
sex  
research\_site  
IQ  
eating\_contest\_chilli  
beer\_pong\_score  
fantasy\_score

Covariables

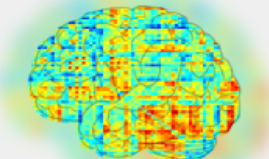
age  
sex  
research\_site  
IQ  
eating\_contest\_chilli  
beer\_pong\_score  
fantasy\_score

Test against shuffled data Number of repetitions 1

Test against random networks (graph metrics)

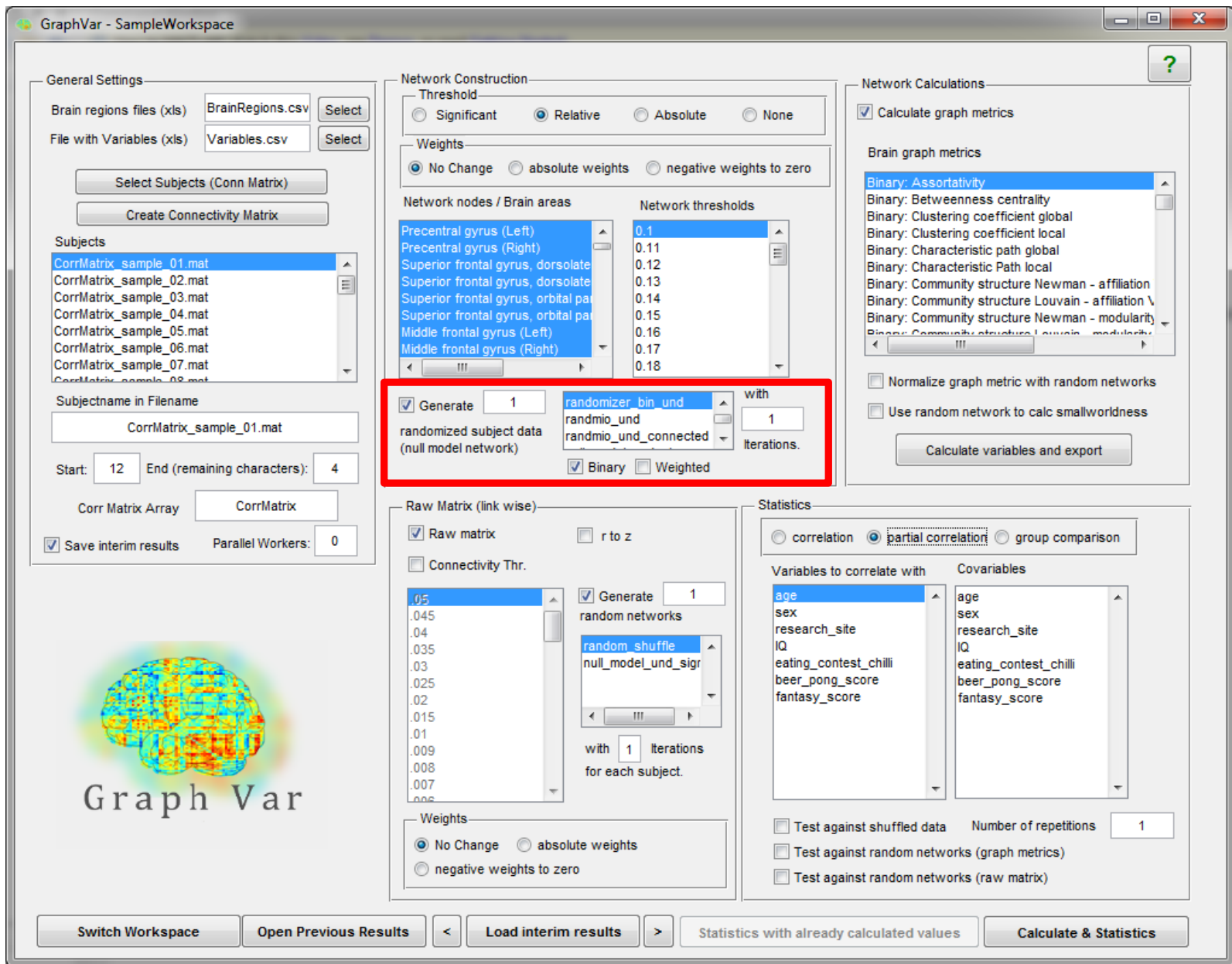
Test against random networks (raw matrix)

Switch Workspace Open Previous Results < Load interim results > Statistics with already calculated values Calculate & Statistics



Graph Var

# Network construction



# Null model Networks

GraphVar - SampleWorkspace

General Settings

Brain regions files (xls)

File with Variables (xls)

Subjects

- CorrMatrix\_sample\_01.mat
- CorrMatrix\_sample\_02.mat
- CorrMatrix\_sample\_03.mat
- CorrMatrix\_sample\_04.mat
- CorrMatrix\_sample\_05.mat
- CorrMatrix\_sample\_06.mat
- CorrMatrix\_sample\_07.mat
- CorrMatrix\_sample\_08.mat

Subjectname in Filename

Start:  End (remaining characters):

Corr Matrix Array

Save interim results Parallel Workers:

Network Construction

Threshold

Significant  Relative  Absolute  None

Weights

No Change  absolute weights  negative weights to zero

Network nodes / Brain areas

- Precentral gyrus (Left)
- Precentral gyrus (Right)
- Superior frontal gyrus, dorsolateral
- Superior frontal gyrus, orbital part
- Middle frontal gyrus (Left)
- Middle frontal gyrus (Right)

Network thresholds

- 0.1
- 0.11
- 0.12
- 0.13
- 0.14
- 0.15
- 0.16
- 0.17
- 0.18

Generate  with  iterations.

randomized subject data (null model network)

- randomizer\_bin und
- randmio\_und
- randmio\_und\_connected

Binary  Weighted

Raw Matrix (link wise)

Raw matrix  r to z

Connectivity Thr.

Generate  iterations

random networks

- random\_shuffle
- null\_model\_und\_sigr

with  iterations for each subject.

Weights

No Change  absolute weights  negative weights to zero

Statistics

correlation  partial correlation  group comparison

Variables to correlate with

- age
- sex
- research\_site
- IQ
- eating\_contest\_chilli
- beer\_pong\_score
- fantasy\_score

Covariables

- age
- sex
- research\_site
- IQ
- eating\_contest\_chilli
- beer\_pong\_score
- fantasy\_score

Test against shuffled data Number of repetitions

Test against random networks (graph metrics)

Test against random networks (raw matrix)

Network Calculations

Calculate graph metrics

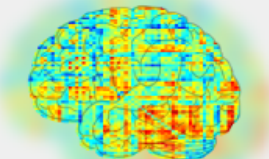
Brain graph metrics

- Binary: Assortativity
- Binary: Betweenness centrality
- Binary: Clustering coefficient global
- Binary: Clustering coefficient local
- Binary: Characteristic path global
- Binary: Characteristic Path local
- Binary: Community structure Newman - affiliation
- Binary: Community structure Louvain - affiliation
- Binary: Community structure Newman - modularity
- Binary: Community structure Louvain - modularity

Normalize graph metric with random networks

Use random network to calc smallworldness

Switch Workspace Open Previous Results < Load interim results > Statistics with already calculated values



Graph Var

# Network topological measures

GraphVar - SampleWorkspace

General Settings | Network Construction Threshold

ExportData.xlsx - Microsoft Excel

Calibri | 11 | A A A | Standard | Einfügen | Σ | ↕ | Sortieren | Suchen und Auswählen | Bearbeiten

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	clustering	Corrected AI	0,05													
2	0,1	-0,07237061	0,09357033	-0,04627269	-0,00182195	-0,01050473	0,01379858	0,08164257	-0,03847343	-0,0544339	-0,02977521	0,07549174	0,00852406	0,00846319	0,11717267	0,0722
3	0,11	-0,07502656	0,09658773	-0,04119779	0,01382449	-0,01258913	0,01688709	0,09898348	-0,05137778	-0,06825057	-0,04164273	0,06610055	0,03442335	-0,01435543	0,09281828	0,0894
4	0,12	0,0120058	0,10466911	-0,00895391	0,05711628	0,01955126	-0,01148392	0,10050013	0,01365077	-0,04494219	-0,03273493	0,06353858	0,03103569	0,0087535	0,10324542	0,0827
5	0,13	0,04582824	0,13772624	-0,02306489	0,00408741	0,02521199	-0,05174935	0,09786645	0,02258706	-0,02283654	-0,04284299	0,04495615	0,02025344	0,00380567	0,13499298	0,1110
6	0,14	0,0511311	0,14548641	-0,01061045	0,02692522	0,02569613	-0,07578842	0,08611047	0,07279156	-0,00061421	-0,03408272	0,0344073	0,03682116	-0,00855096	0,13497625	0,0966
7	0,15	0,03443045	0,15909194	-0,02614552	0,01287442	0,03147307	-0,0258052	0,11819733	0,01573078	-0,01061199	0,022515	0,03183292	-0,01734021	0,14352523	0,106	
8	0,16	0,0218163	0,14646699	-0,00873069	-0,00431096	0,04221829	-0,00731211	0,10055191	0,00010491	0,033381	-0,00616201	0,02677757	0,03036297	-0,01787866	0,14972208	0,1063
9	0,17	0,03632444	0,00718125	-0,00913568	0,07146096	0,00725661	0,08765865	0,01369501	0,02569157	-0,00414277	0,03320073	0,02824449	0,00330053	0,14970207	0,0884	
10	0,18	0,02603423	0,09428395	0,00556482	-0,00146251	0,0687442	0,01148425	0,06401952	0,01504792	0,02779036	-0,00971193	0,0384917	0,0363997	0,02119241	0,14140577	0,0841
11	0,19	0,02785595	0,06774574	0,01046093	-0,0019819	0,09621474	0,01773432	0,0489363	0,03839059	0,04745267	-0,01980946	0,04508741	0,03606135	0,01092866	0,1287091	0,0685
12	0,2	0,04587938	0,06213632	0,02744064	0,02045259	0,08726685	0,00666983	0,03770598	0,06392727	0,05961167	-0,03766387	0,06344042	0,02195677	0,0353122	0,11020771	0,0577
13	0,21	0,06486796	0,05679674	0,03897945	0,02358691	0,09757207	0,01422356	0,02319688	0,06564341	0,05814384	-0,04080787	0,09320703	-0,00321626	0,02166131	0,09508227	0,0351
14	0,22	0,058714	0,06224944	0,02695073	0,03135441	0,08862638	-0,000302	0,02549718	0,0543516	0,06134	-0,0428498	0,08729143	0,00418408	0,05731638	0,08314445	0,033
15	0,23	0,06397301	0,06654521	0,03523234	0,03290413	0,09133735	-0,02562673	0,03423818	0,06629271	0,0523437	-0,01926428	0,08666938	0,00315677	0,0456275	0,08901868	0,0302
16	0,24	0,03414516	0,06251224	0,03274688	0,04781523	0,09005042	-0,03851445	0,03342348	0,06758784	0,06171202	-0,00469014	0,0823768	0,00389042	0,03907998	0,1073557	0,0191
17	0,25	0,03672875	0,05469933	0,04586182	0,04821612	0,10420865	-0,03477186	0,198198	0,03721033	0,0740143	-0,00227927	0,08060812	0,00425395	0,0400754	0,0997519	0,0233
18	0,26	0,01747424	0,05420209	0,03590311	0,05848589	0,11140885	-0,03168225	0,04042244	0,05653371	0,07195734	-0,01114387	0,07356878	0,00915254	0,05270245	0,10546793	0,0260
19	0,27	0,01580328	0,04428071	0,02435566	0,0591568	0,11038857	-0,0237288	0,05063582	0,05978296	0,05091287	-0,00782718	0,06159207	0,01121745	0,04329407	0,1127613	0,0323
20	0,28	0,02351684	0,0356175	0,03276314	0,0494245	0,10747968	-0,00769363	0,04713653	0,04672004	0,04336767	-0,01603001	0,04059843	0,03825618	0,05411508	0,12770844	0,0419
21	0,29	0,02501842	0,0541967	0,05575911	0,06100097	0,1129511	-0,00507062	0,04674411	0,06639136	-0,00657019	0,03380182	0,02901097	0,05217609	0,14174836	0,0460	
22	0,3	0,02430434	0,0494022	0,06852582	0,0776597	0,12693814	-0,02032829	0,04167152	0,0657082	0,08286791	-0,01113351	0,03437705	0,03653748	0,06064945	0,12811081	0,0256
23	0,31	0,00693066	0,02564519	0,08129845	0,09324079	0,14914071	-0,02309732	0,03303592	0,07074533	0,10005378	-0,01823477	0,02453839	0,03148339	0,06669698	0,12782989	0,0177
24	0,32	0,00700219	0,02400809	0,07047841	0,09937963	0,13675138	-0,02462539	0,03000154	0,05665468	0,09490111	-0,01605606	0,01217858	0,0564574	0,08390448	0,1354271	0,0214
25	0,33	0,01336929	0,01539236	0,06928921	0,07508637	0,13250768	-0,02808616	0,02756673	0,05730859	0,0926012	-0,01710199	0,01388242	0,05297749	0,09024623	0,14352187	0,0234
26	0,34	0,00758848	0,02620812	0,0677071	0,06722012	0,11887481	-0,02634262	0,02178227	0,0570474	0,08692257	-0,01313068	0,02254991	0,05385351	0,08473614	0,13690305	0,0253
27	0,35	0,00403113	0,0156379	0,06408451	0,08246356	0,10638639	-0,03190663	0,02185981	0,04931325	0,09016646	-0,00524305	0,01547352	0,05881251	0,07707454	0,13851337	0,034
28	0,36	0,0093267	0,00792909	0,07722194	0,06850733	0,11061845	-0,0300424	0,01639147	0,05207328	0,0853444	-0,01508398	0,01029145	0,04980996	0,07668634	0,14426683	0,0341
29	0,37	0,01949276	0,00897587	0,08104787	0,05788151	0,10418969	-0,02780511	0,00976737	0,04727594	0,09857292	-0,0138434	0,04876302	0,07859713	0,13771213	0,0414	
30	0,38	0,02512363	0,00565759	0,08665301	0,05990157	0,11002747	-0,02254784	0,00577295	0,0711287	0,11100946	-0,00464431	0,01052914	0,05035265	0,07995829	0,14693308	0,0370
31	0,39	0,03258273	-0,01398505	0,12322896	0,05839135	0,11256864	-0,00146909	-0,00772905	0,0711287	0,11100946	-0,00464431	0,01052914	0,05035265	0,07995829	0,14693308	0,0370
32	0,4	0,03844288	-0,03084499	0,13936289	0,05984102	0,12575501	-0,00394272	-0,02011598	0,06892946	0,10571306	0,0071975	-0,01069931	0,05261179	0,08216537	0,1596968	0,0433
33	0,41	0,03232405	-0,03001284	0,14826075	0,05671577	0,11100961	-0,00768901	-0,02075938	0,06779407	0,10862153	0,00900181	-0,0123612	0,05957104	0,08808113	0,15288403	0,0472
34	0,42	0,03442605	-0,03124535	0,14955826	0,05777968	0,11737508	-0,00861044	-0,01660732	0,06027197	0,11223547	0,02656532	-0,01393756	0,05839311	0,08426504	0,15594679	0,0463
35	0,43	0,0383731	-0,01160574	0,14320655	0,05820829	0,10247971	-0,00534149	-0,00457463	0,05434887	0,10226185	0,01270905	0,00883996	0,04419414	0,07440936	0,14708955	0,0352
36	0,44	0,03909043	-0,00949087	0,1524302	0,04309986	0,09268341	-0,01198801	-0,01211325	0,05707691	0,101916385	0,01370553	0,05000744	0,06583277	0,14473706	0,0513	
37	0,45	0,04282723	-0,01193977	0,16573786	0,04274644	0,08926346	-0,01339523	-0,0141605	0,05151339	0,11079359	0,02471677	0,00942234	0,06619623	0,06094685	0,1517514	0,057

Network Calculations

- Calculate graph metrics

Brain graph metrics

- Binary: Assortativity
- Binary: Betweenness centrality
- Binary: Clustering coefficient global
- Binary: Clustering coefficient local
- Binary: Characteristic path global
- Binary: Characteristic path local
- Binary: Community structure Newman - affiliation
- Binary: Community structure Louvain - affiliation
- Binary: Community structure Newman - modularity
- Binary: Community structure Louvain - modularity

Normalize graph metric with random networks

Use random network to calc smallworldness

Calculate variables and export

to correlate with:  partial correlation  group comparison

Covariables

- age
- sex
- research\_site
- IQ
- eating\_contest\_chilli
- beer\_pong\_score
- fantasy\_score

Test against shuffled data: Number of repetitions: 1

- Test against random networks (graph metrics)
- Test against random networks (raw matrix)

Switch Workspace | Open Previous Results | Load interim results | Statistics with already calculated values | Calculate & Statistics

# Export Network topological measures

GraphVar - SampleWorkspace

General Settings

Brain regions files (xls) BrainRegions.csv Select

File with Variables (xls) Variables.csv Select

Select Subjects (Conn Matrix)

Create Connectivity Matrix

Subjects

CorrMatrix\_sample\_01.mat  
CorrMatrix\_sample\_02.mat  
CorrMatrix\_sample\_03.mat  
CorrMatrix\_sample\_04.mat  
CorrMatrix\_sample\_05.mat  
CorrMatrix\_sample\_06.mat  
CorrMatrix\_sample\_07.mat  
CorrMatrix\_sample\_08.mat

Subjectname in Filename

CorrMatrix\_sample\_01.mat

Start: 12 End (remaining characters): 4

Corr Matrix Array CorrMatrix

Save interim results Parallel Workers: 0

Network Construction

Threshold

Significant  Relative  Absolute  None

Weights

No Change  absolute weights  negative weights to zero

Network nodes / Brain areas

Precentral gyrus (Left)  
Precentral gyrus (Right)  
Superior frontal gyrus, dorsolateral  
Superior frontal gyrus, orbital part  
Superior frontal gyrus, orbital part  
Middle frontal gyrus (Left)  
Middle frontal gyrus (Right)

Network thresholds

0.1  
0.11  
0.12  
0.13  
0.14  
0.15  
0.16  
0.17  
0.18

Generate 1 with 1 iterations.  
randomizer bin und  
randomio\_und  
randomio\_und\_connected  
randomized subject data (null model network)  Binary  Weighted

Raw Matrix (link wise)

Raw matrix  r to z

Connectivity Thr.

0.05  
.045  
.04  
.035  
.03  
.025  
.02  
.015  
.01  
.009  
.008  
.007  
.006

Generate 1 with 1 iterations for each subject.  
random networks  
random\_shuffle  
null\_model\_und\_sigr

Weights

No Change  absolute weights  
 negative weights to zero

Network Calculations

Calculate graph metrics

Brain graph metrics

Binary: Assortativity  
Binary: Betweenness centrality  
Binary: Clustering coefficient global  
Binary: Clustering coefficient local  
Binary: Characteristic path global  
Binary: Characteristic Path local  
Binary: Community structure Newman - affiliation  
Binary: Community structure Louvain - affiliation  
Binary: Community structure Newman - modularity  
Binary: Community structure Louvain - modularity

Normalize graph metric with random networks  
 Use random network to calc smallworldness

Calculate variables and export

Statistics

correlation  partial correlation  group comparison

Correlate your variables with the network topological measures

Perform group comparison (t-test, ANOVA) with the network topological measures

Switch Workspace Open Previous Results Load interim results Statistics with already calculated values Calculate & Statistics

# Statistics panel

## Non-parametric testing on the metric level

The screenshot shows the 'Statistics' dialog box with the 'partial correlation' radio button selected. The 'Variables to correlate with' list contains 'age', 'sex', 'research\_site', 'IQ', 'eating\_contest\_chilli', 'beer\_pong\_score', and 'fantasy\_score'. The 'Covariables' list contains the same variables. At the bottom, the 'Test against shuffled data' checkbox is checked, and the 'Number of repetitions' is set to 1. This section is highlighted with a red box.

Non-parametric testing (correlation)

The screenshot shows the 'Statistics' dialog box with the 'group comparison' radio button selected. The 'Variables Define Groups' list contains 'age', 'sex', 'research\_site', 'IQ', 'eating\_contest\_chilli', 'beer\_pong\_score', and 'fantasy\_score'. At the bottom, the 'Test against random groups' checkbox is checked, and the 'Number of repetitions' is set to 1. This section is highlighted with a red box.

Non-parametric permutation testing (group)

# Non-parametric testing

## Non-parametric testing on the network level

The screenshot shows a dialog box titled "Statistics" with three radio buttons: "correlation", "partial correlation" (selected), and "group comparison". Below are two lists: "Variables to correlate with" and "Covariables", both containing "age", "sex", "research\_site", "IQ", "eating\_contest\_chilli", "beer\_pong\_score", and "fantasy\_score". At the bottom, there are three checkboxes: "Test against shuffled data" (unchecked), "Test against random networks (graph metrics)" (checked and highlighted with a red box), and "Test against random networks (raw matrix)" (unchecked). A "Number of repetitions" field is set to "1".

Non-parametric testing (correlation)

# Non-parametric testing

GraphVar - SampleWorkspace

General Settings

Brain regions files (xls) BrainRegions.csv Select

File with Variables (xls) Variables.csv Select

Select Subjects (Conn Matrix)

Create Connectivity Matrix

Subjects

CorrMatrix\_sample\_01.mat  
CorrMatrix\_sample\_02.mat  
CorrMatrix\_sample\_03.mat  
CorrMatrix\_sample\_04.mat  
CorrMatrix\_sample\_05.mat  
CorrMatrix\_sample\_06.mat  
CorrMatrix\_sample\_07.mat  
CorrMatrix\_sample\_08.mat

Subjectname in Filename

CorrMatrix\_sample\_01.mat

Start: 12 End (remaining characters):

Corr Matrix Array CorrMatrix

Save interim results Parallel Workers: 0

Network Construction

Threshold

Significant  Relative  Absolute  None

Weights

No Change  absolute weights  negative weights to zero

Network nodes / Brain areas

Precentral gyrus (Left) 0.1  
Precentral gyrus (Right) 0.11  
Superior frontal gyrus, dorsolate 0.12  
Superior frontal gyrus, dorsolate 0.13  
Superior frontal gyrus, orbital pa 0.14  
Superior frontal gyrus, orbital pa 0.15  
Middle frontal gyrus (Left) 0.16

Network thresholds

0.1

Network Calculations

Calculate graph metrics

Brain graph metrics

Binary: Assortativity  
Binary: Betweenness centrality  
Binary: Clustering coefficient global  
Binary: Clustering coefficient local  
Binary: Characteristic path global  
Binary: Characteristic Path local  
Binary: Community structure Newman - affiliation  
Binary: Community structure Louvain - affiliation \\\  
Binary: Community structure Newman - modularity  
Binary: Community structure Louvain - modularity

Normalize graph metric with random networks

Use random network to calc smallworldness

Calculate variables and export

Statistics

correlation  partial correlation  group comparison

Variables to correlate with

age  
sex  
research\_site  
IQ  
eating\_contest\_chilli  
beer\_pong\_score  
fantasy\_score

Covariables

age  
sex  
research\_site  
IQ  
eating\_contest\_chilli  
beer\_pong\_score  
fantasy\_score

Test against shuffled data Number of repetitions 1

Test against random networks (graph metrics)

Test against random networks (raw matrix)

Raw Matrix (link wise)

Raw matrix  r to z

Connectivity Thr.

Generate 1  
random networks  
random\_shuffle  
null\_model\_und\_sigr

with 1 iterations  
for each subject.

Weights

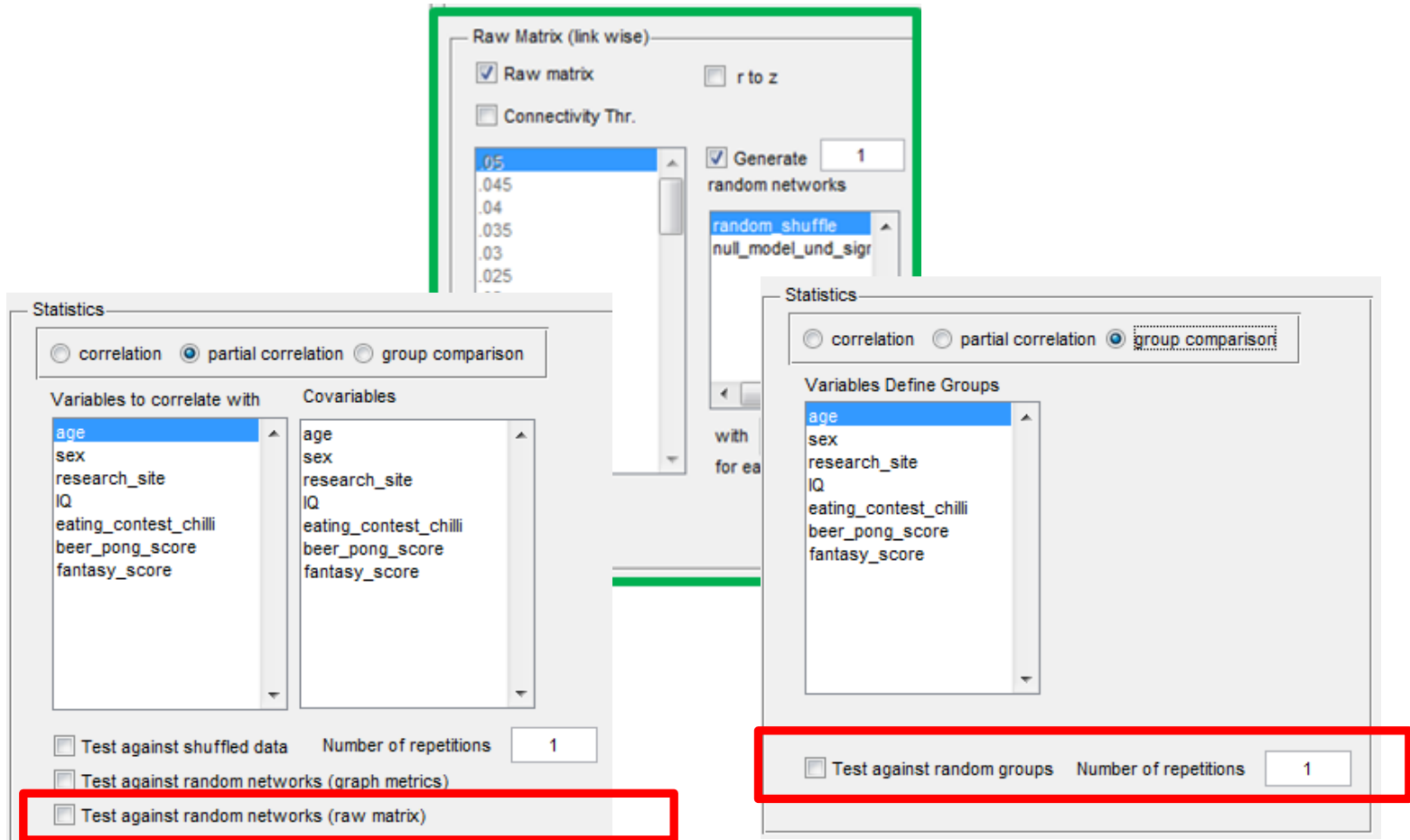
No Change  absolute weights  
 negative weights to zero

Calculate on raw matrix using correlational analysis, or group comparisons (t-test, ANOVA)

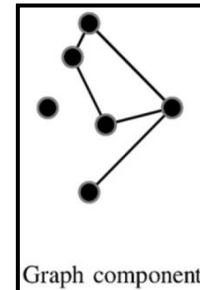
Graph Var

Switch Workspace Open Previous Results Load interim results Statistics with already calculated values Calculate & Statistics

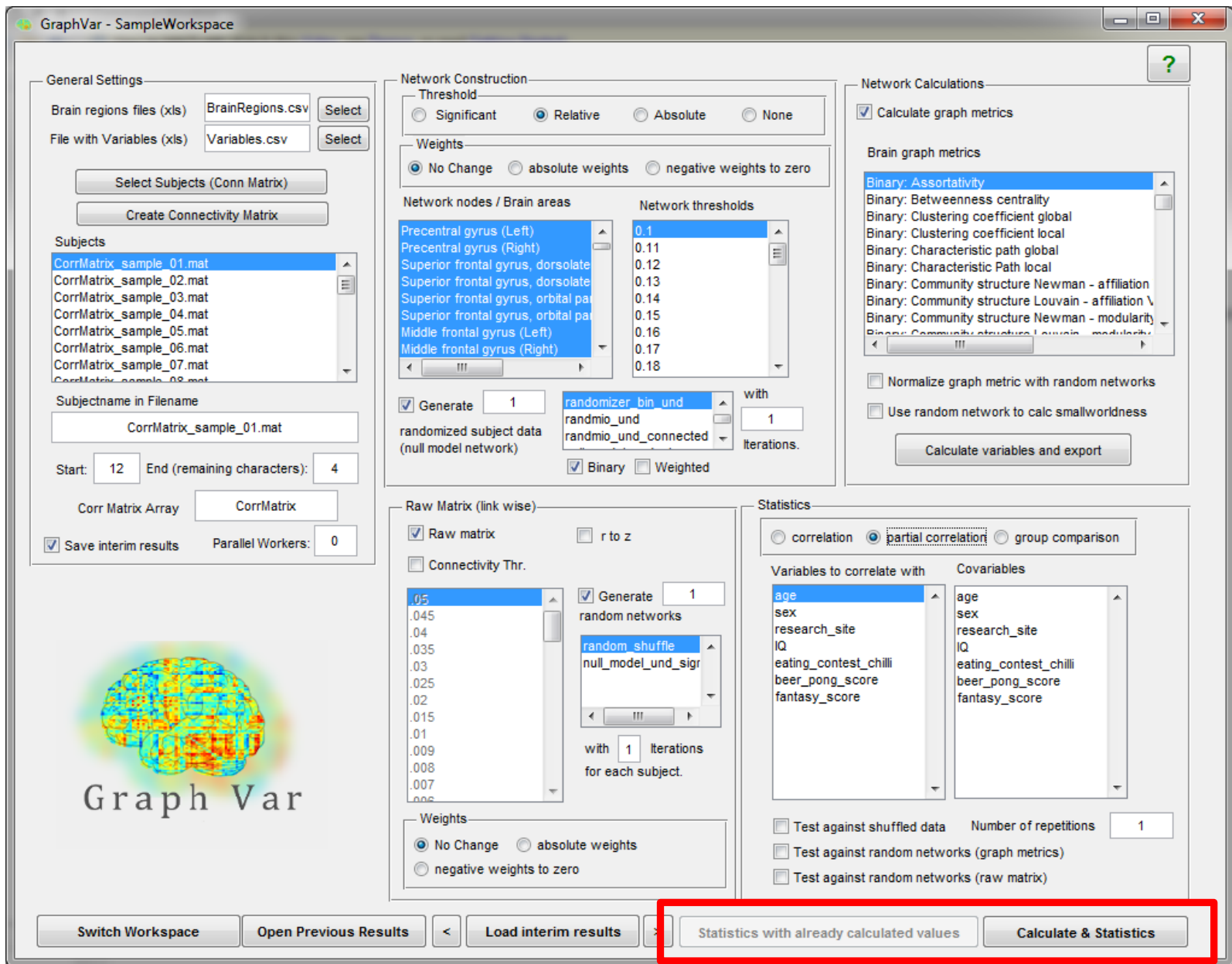
# Network-based statistics



Similar as in the NBS toolbox, GrapVar uses graph components to test for significant associations (comparing against random data)



# Network-based statistics



Ready to go!

GraphVar - SampleWorkspace

General Settings  
 Brain regions files (xls) BrainRegions.csv Select  
 File with Variables (xls) Variables.csv Select  
 Select Subjects (Conn Matrix)  
 Create Connectivity Matrix

Subjects  
 CorrMatrix\_sample\_01.mat  
 CorrMatrix\_sample\_02.mat  
 CorrMatrix\_sample\_03.mat  
 CorrMatrix\_sample\_04.mat  
 CorrMatrix\_sample\_05.mat  
 CorrMatrix\_sample\_06.mat  
 CorrMatrix\_sample\_07.mat  
 CorrMatrix\_sample\_08.mat

Subjectname in Filename  
 CorrMatrix\_sample\_01.mat  
 Start: 12 End (remaining characters):  
 Corr Matrix Array CorrMatrix  
 Save interim results Parallel Workers:

Network Construction  
 Threshold  
 Significant  Relative  Absolute  None  
 Weights  
 No Change  absolute weights  negative weights to zero  
 Network nodes / Brain areas Network thresholds  
 Precentral gyrus (Left) 0.1

Network Calculations  
 Calculate graph metrics  
 Brain graph metrics  
 Binary: Assortativity  
 Binary: Betweenness centrality  
 Binary: Clustering coefficient global  
 Binary: Clustering coefficient local  
 Binary: Characteristic path global  
 Binary: Characteristic Path local  
 Binary: Community structure Newman - affiliation  
 Binary: Community structure Louvain - affiliation  
 Binary: Community structure Newman - modularity  
 Binary: Community structure Louvain - modularity  
 Normalize graph metric with random networks  
 Use random network to calc smallworldness  
 Calculate variables and export

partial correlation  group comparison  
 e with Covariables  
 age  
 sex  
 research\_site  
 IQ  
 eating\_contest\_chilli  
 beer\_pong\_score  
 fantasy\_score  
 Test against shuffled data Number of repetitions 1  
 Test against random networks (graph metrics)  
 Test against random networks (raw matrix)

Graph Var

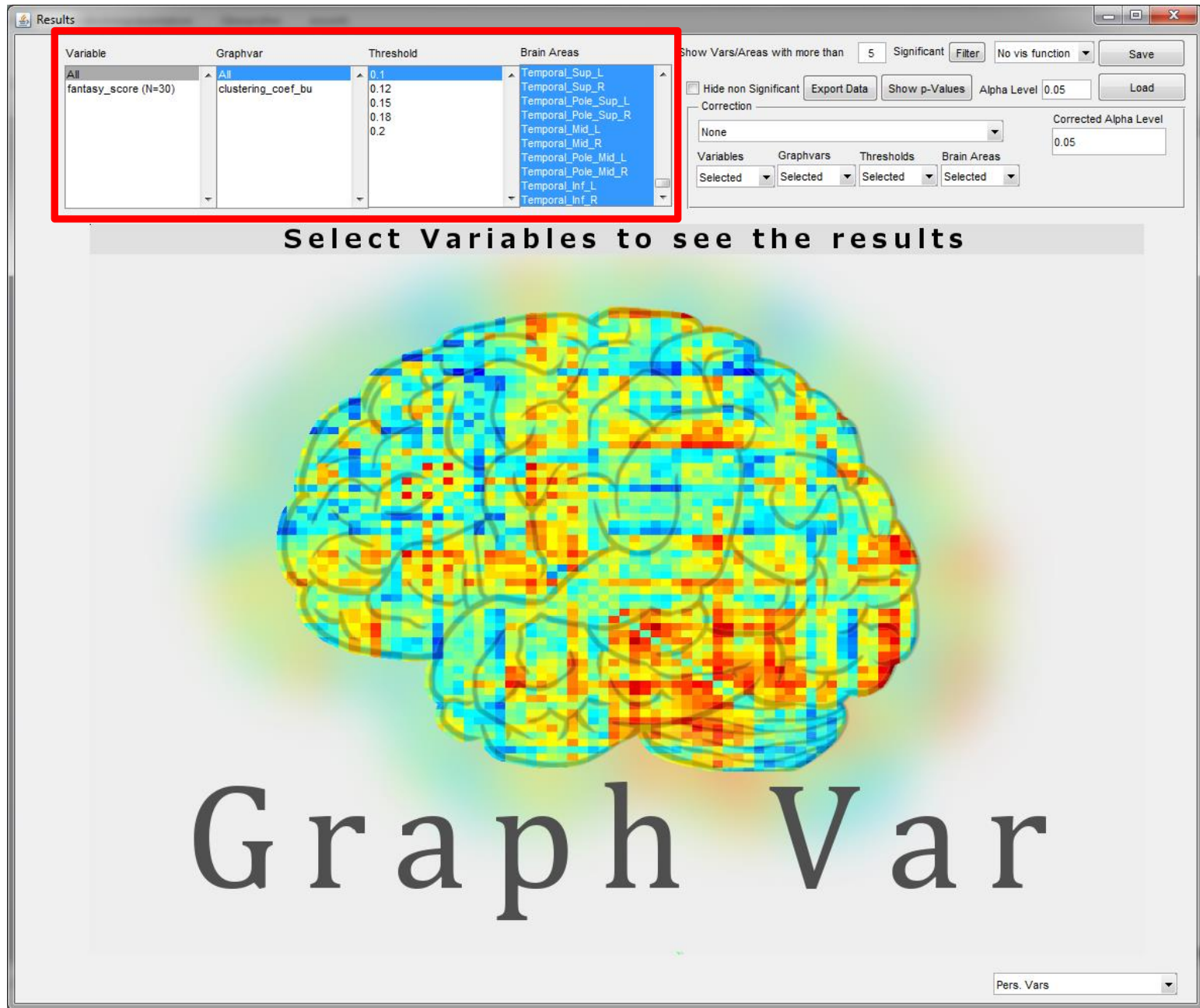
Switch Workspace Open Previous Results < Load interim results > Statistics with already calculated values Calculate & Statistics

**Progress**  
 All Tasks 1192 of 1449 Operations (82%) 2 secs  
 Thresholds 9 of 9  
 Thresholding Subject 30 of 30  
 Graph Function 1 of 1  
 Subject 30 of 30  
 Correlating 652 of 909  
 Cancel all operations

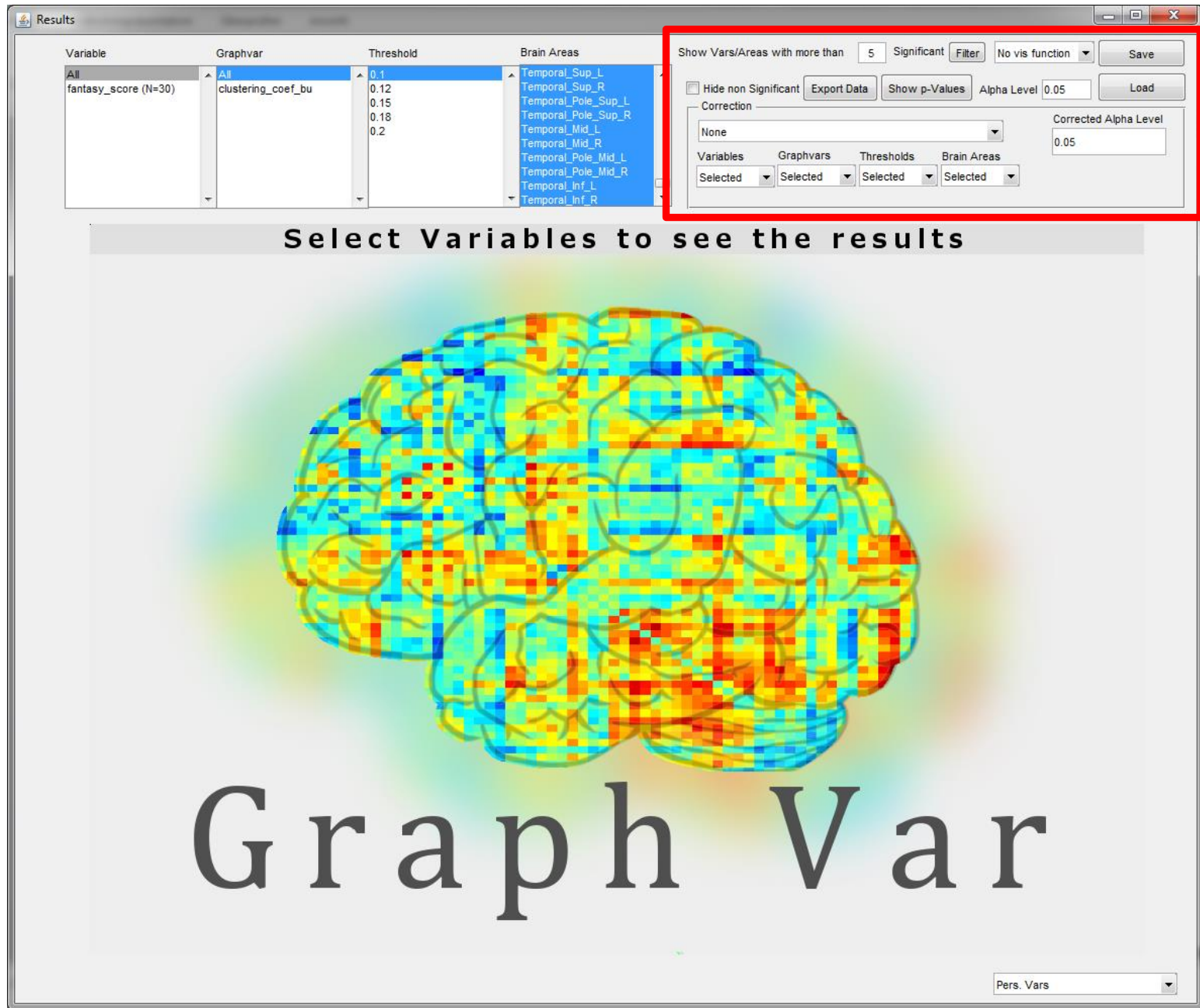
Weights  
 No Change  absolute weights  
 negative weights to zero

Status bar

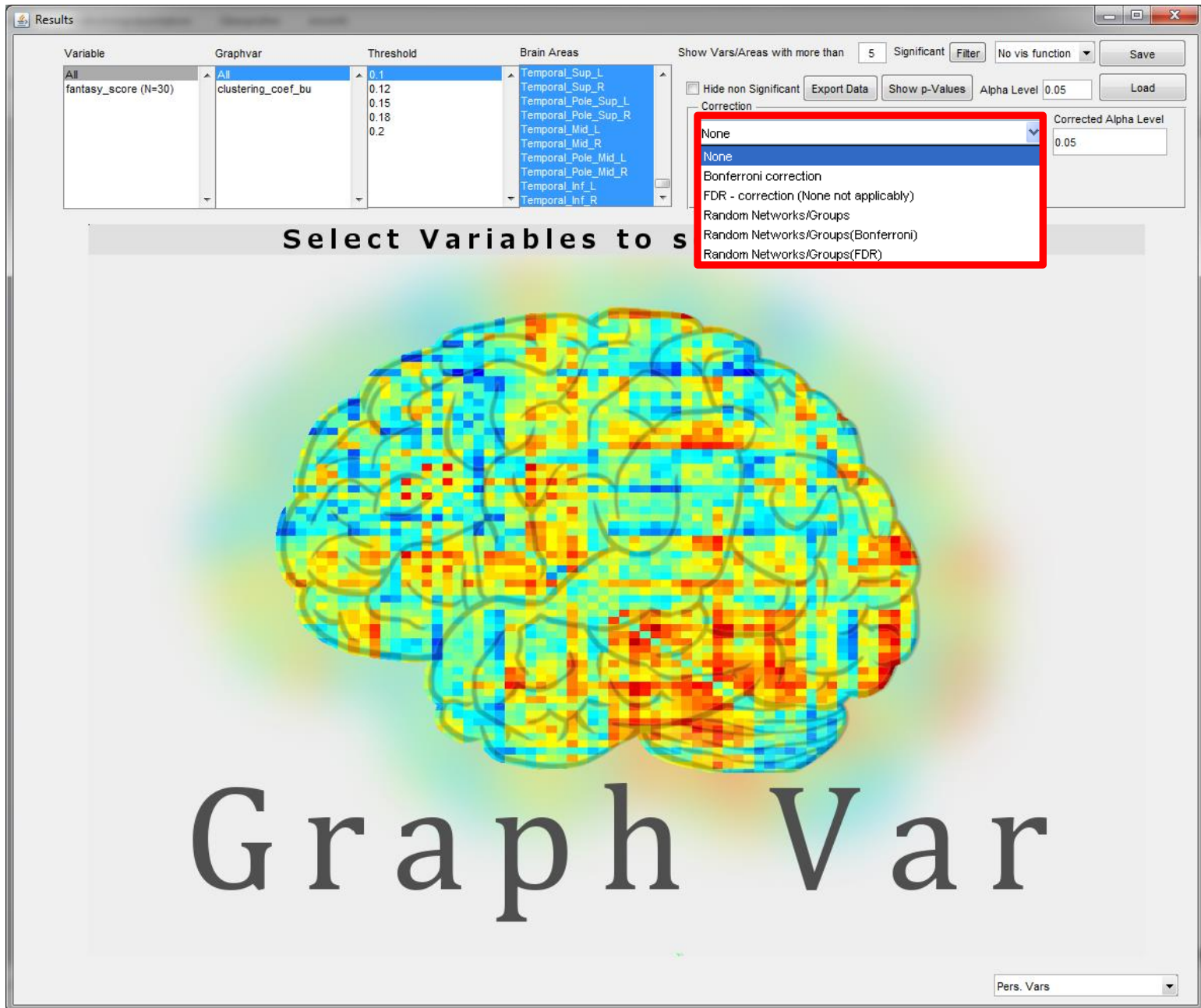
# The Results Viewer GUI



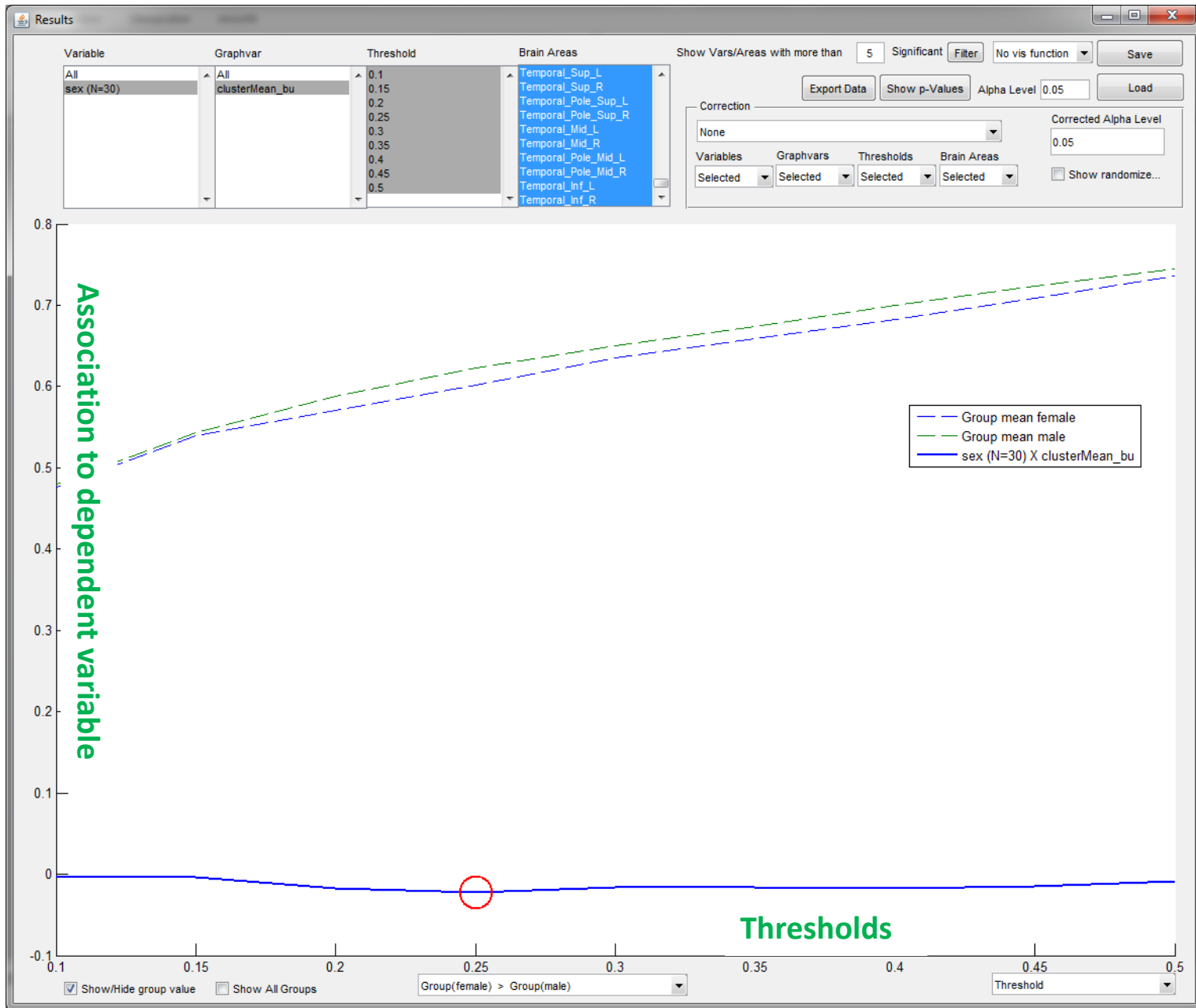
Results selection box



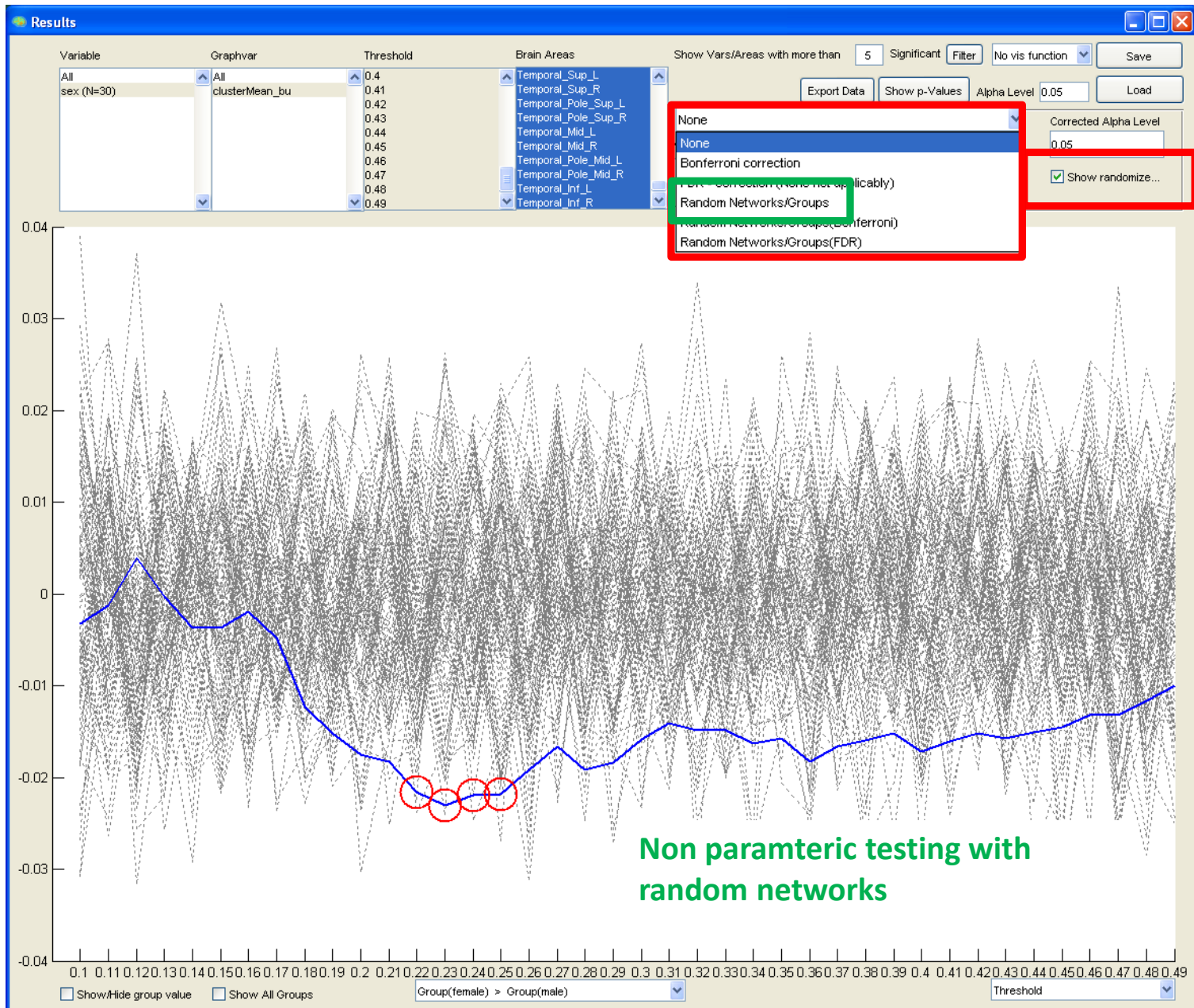
General functions panel



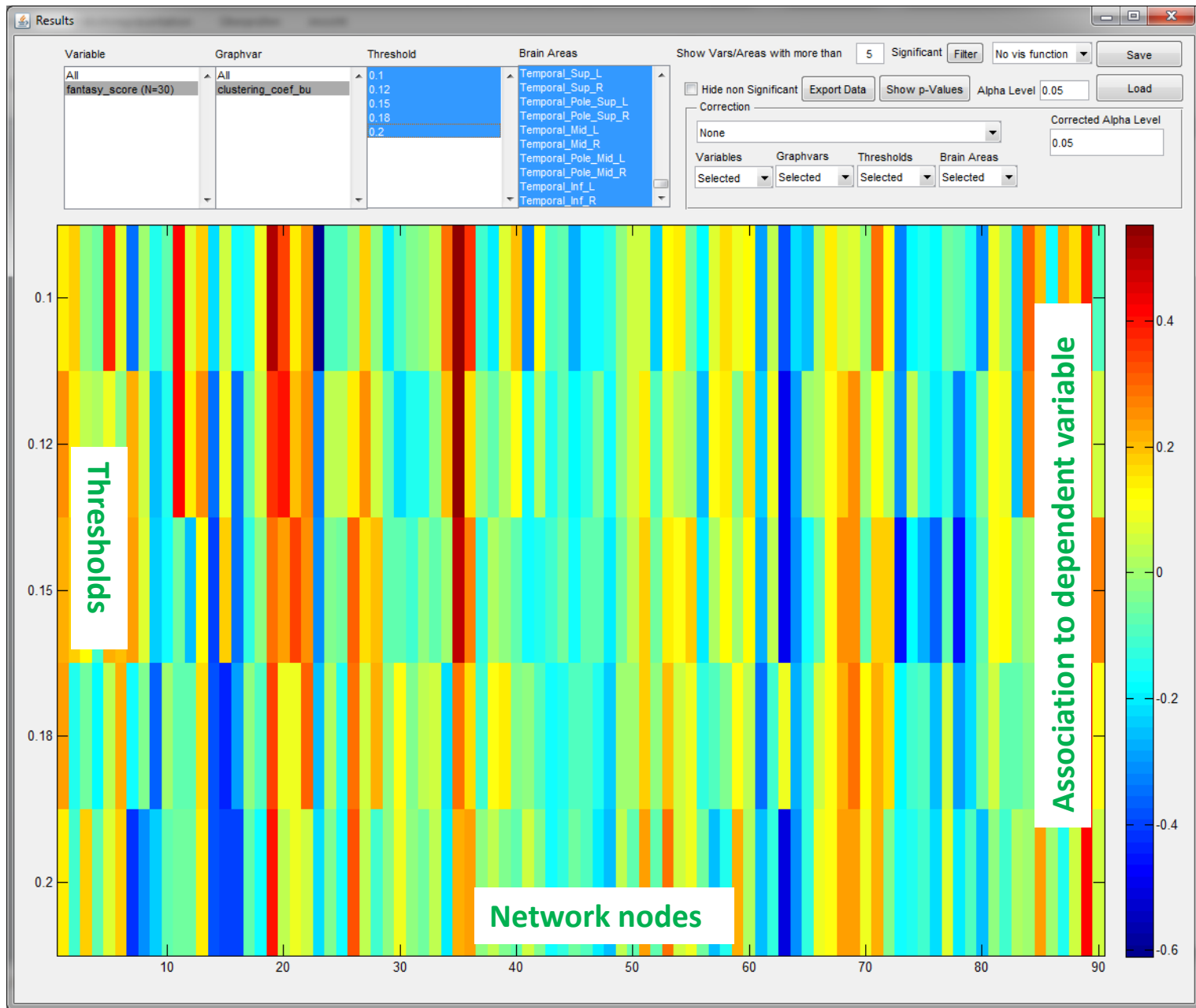
Correction for multiple comparisons



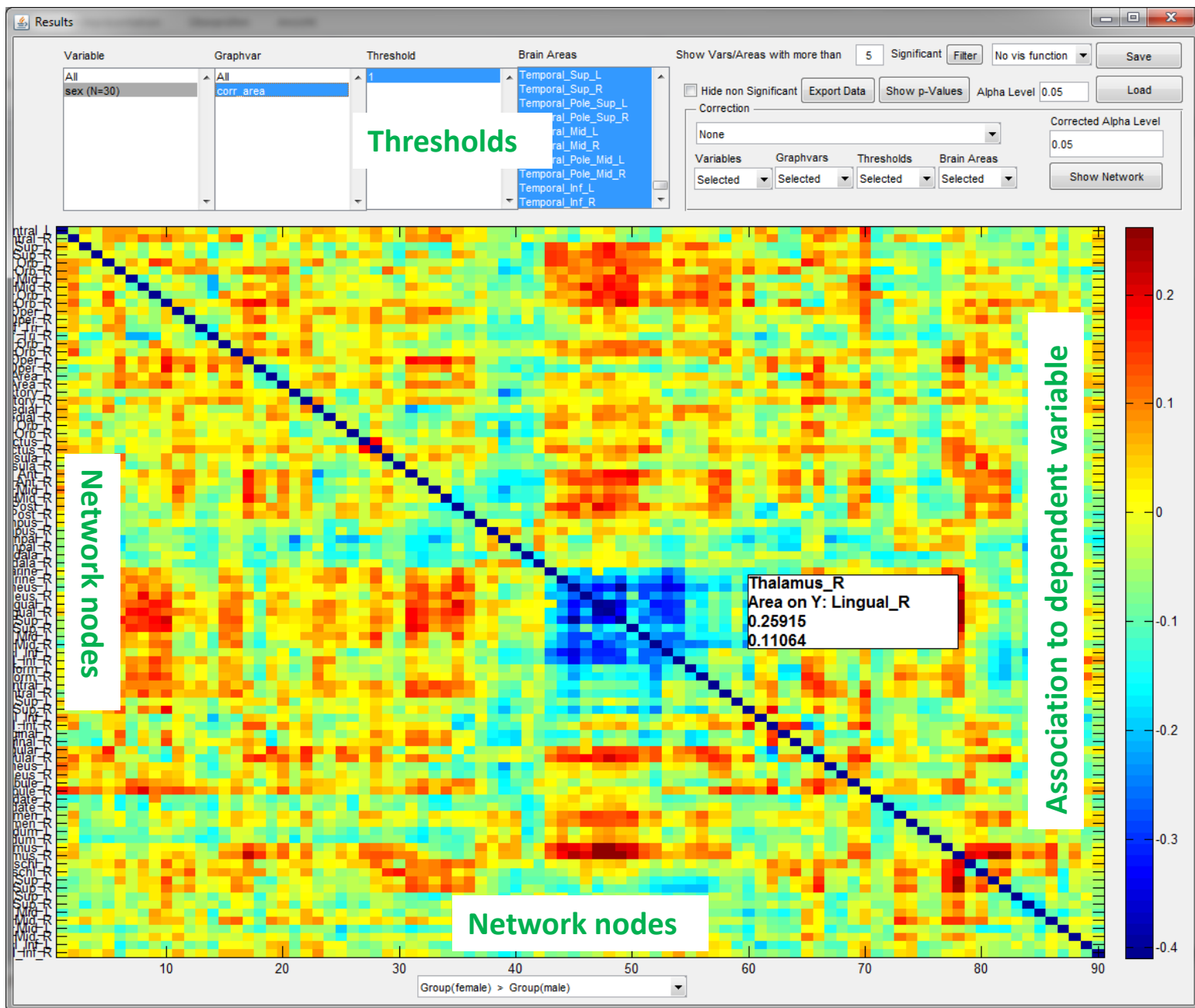
One dimensional graph metrics



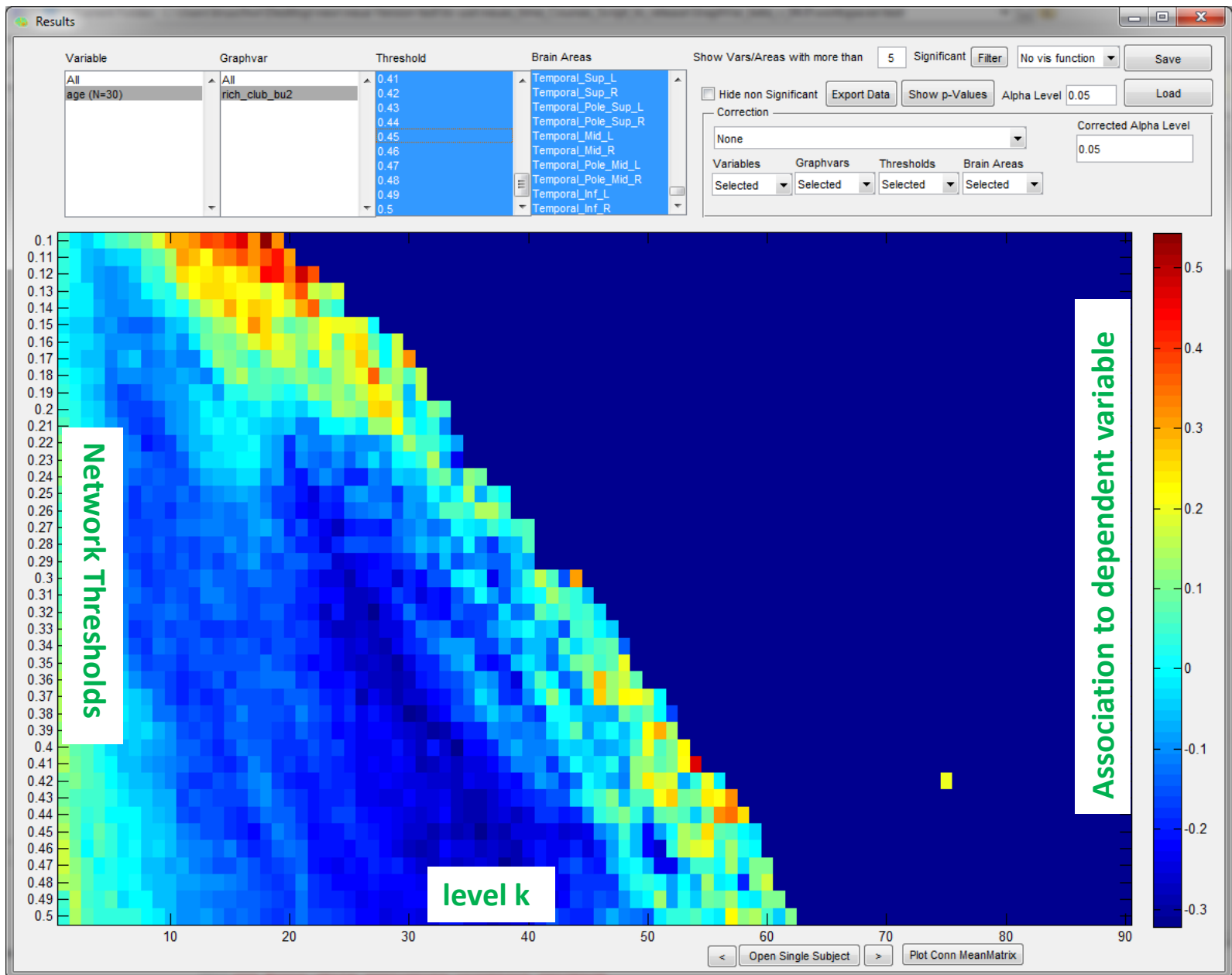
# One dimensional graph metrics



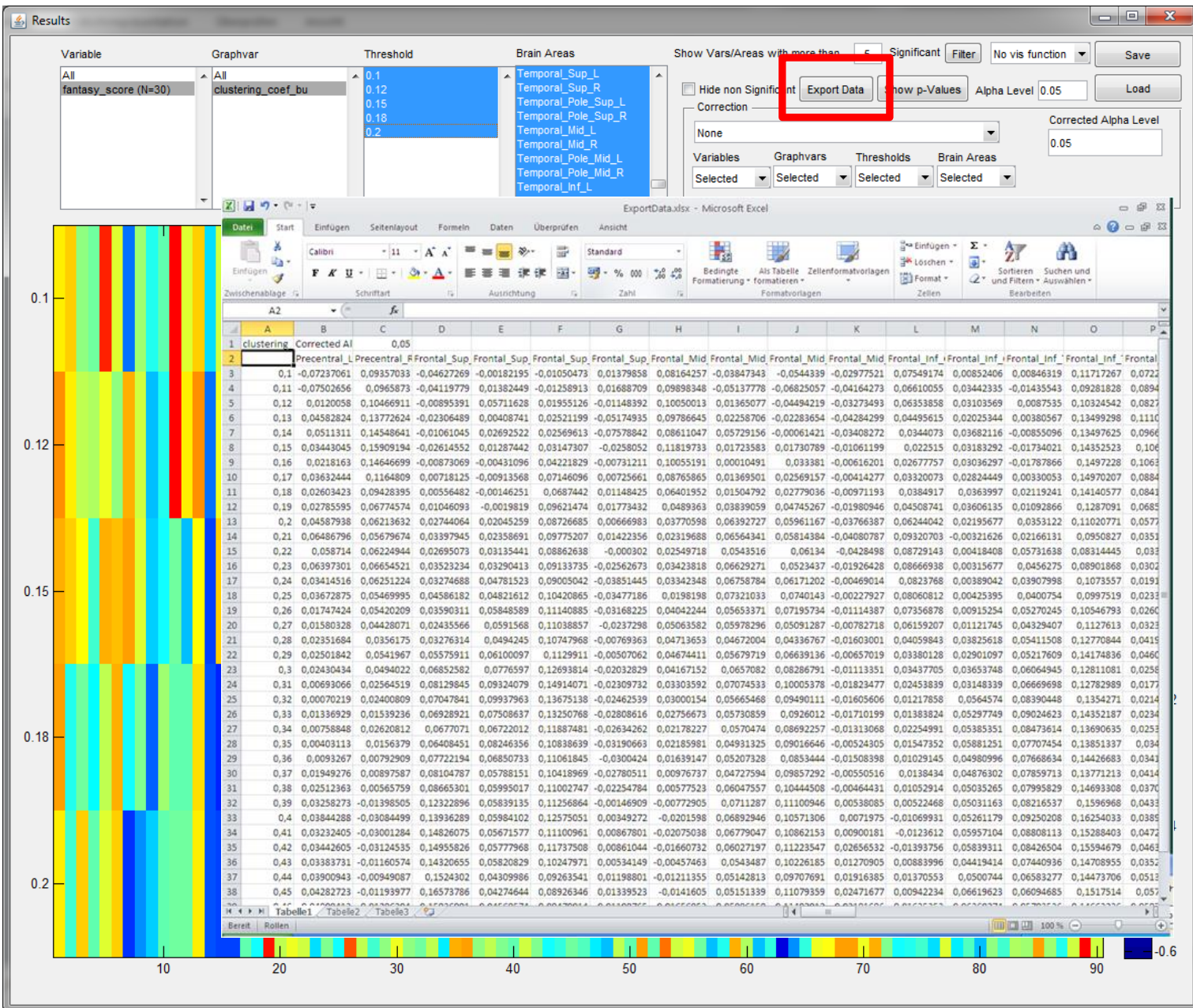
Two dimensional graph metrics



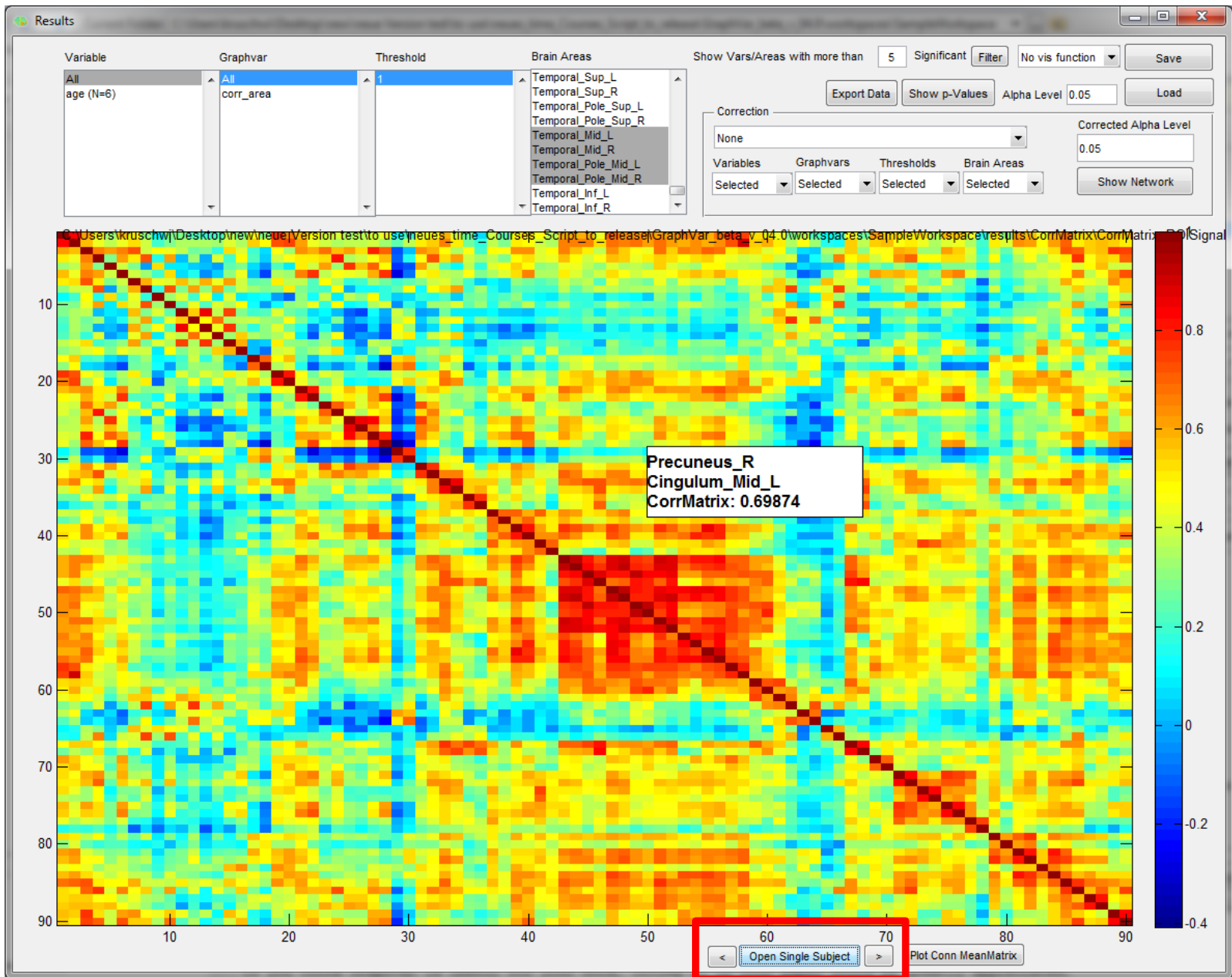
Three dimensional graph metrics



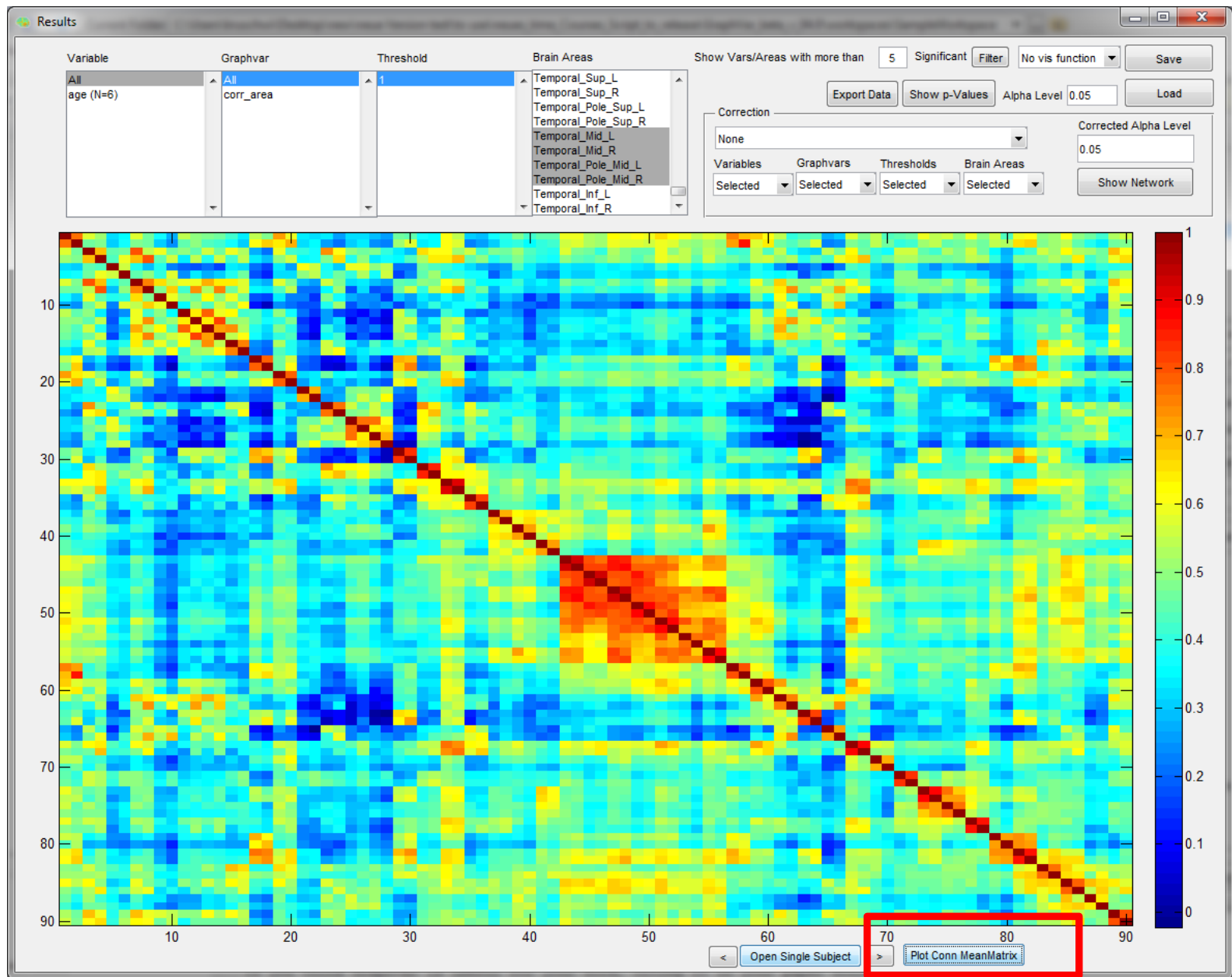
Associations to Rich club coefficients



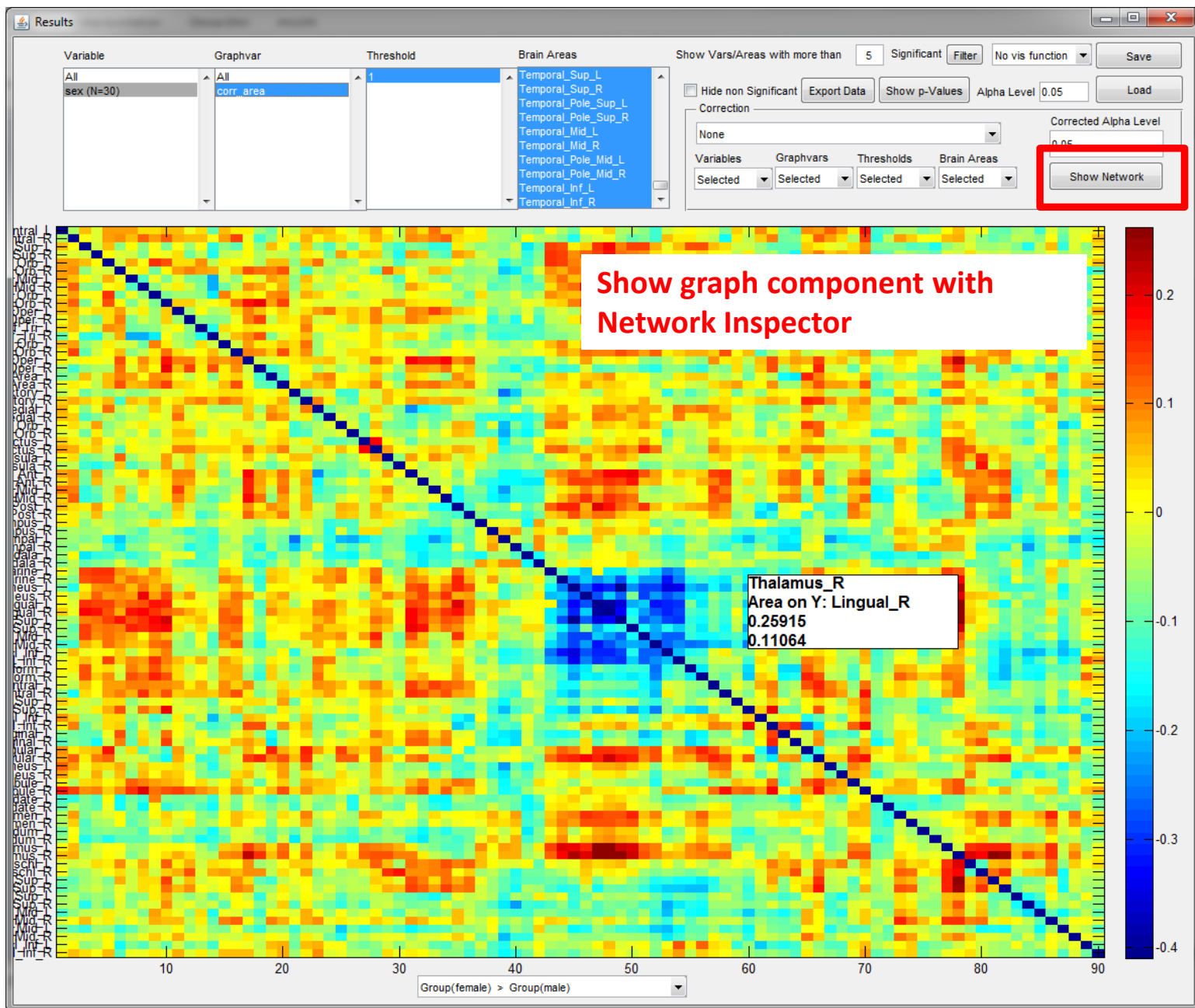
Export Results



Plot single subject association matrices



Plot mean connectivity matrix across subjects

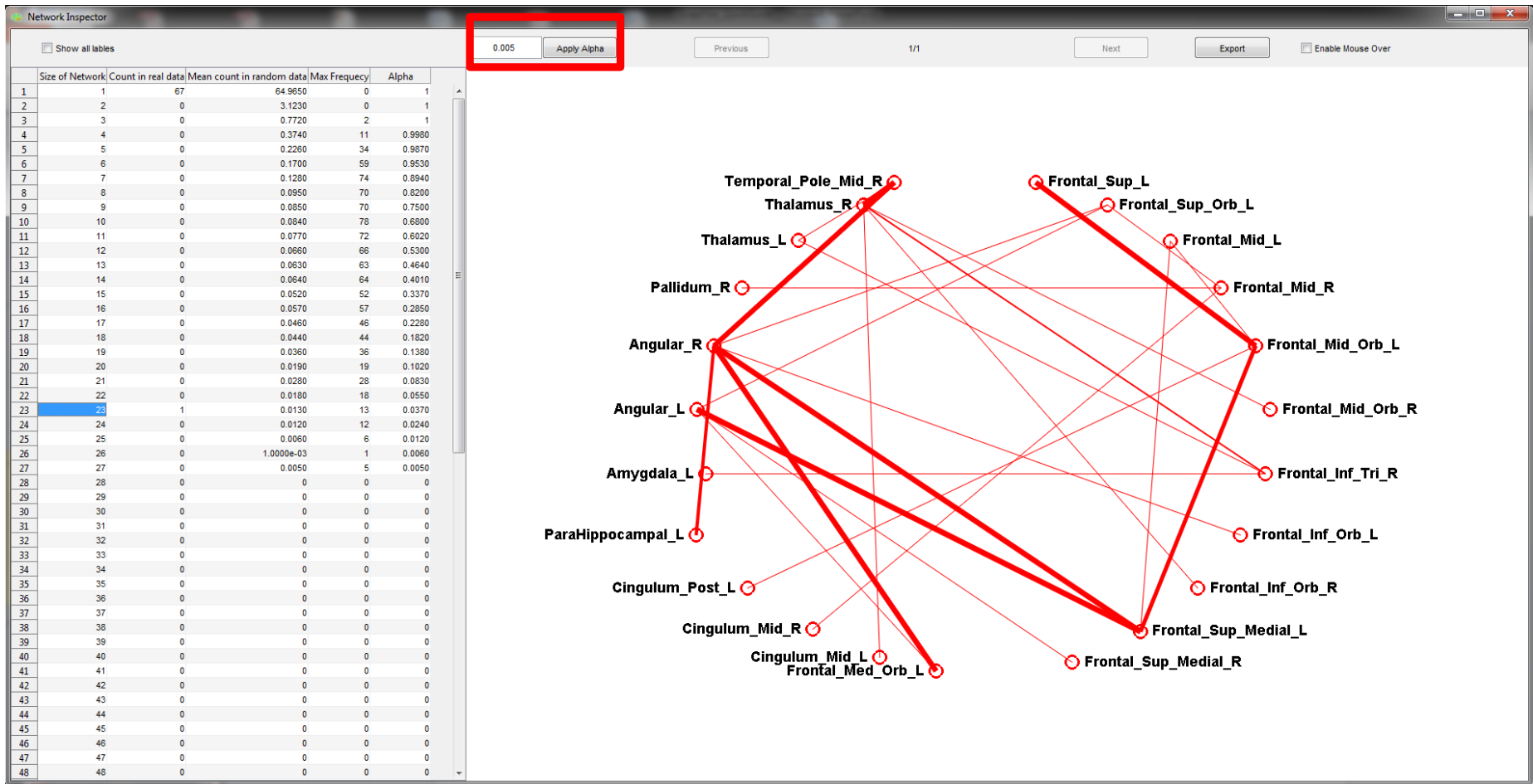


Show graph component with Network Inspector

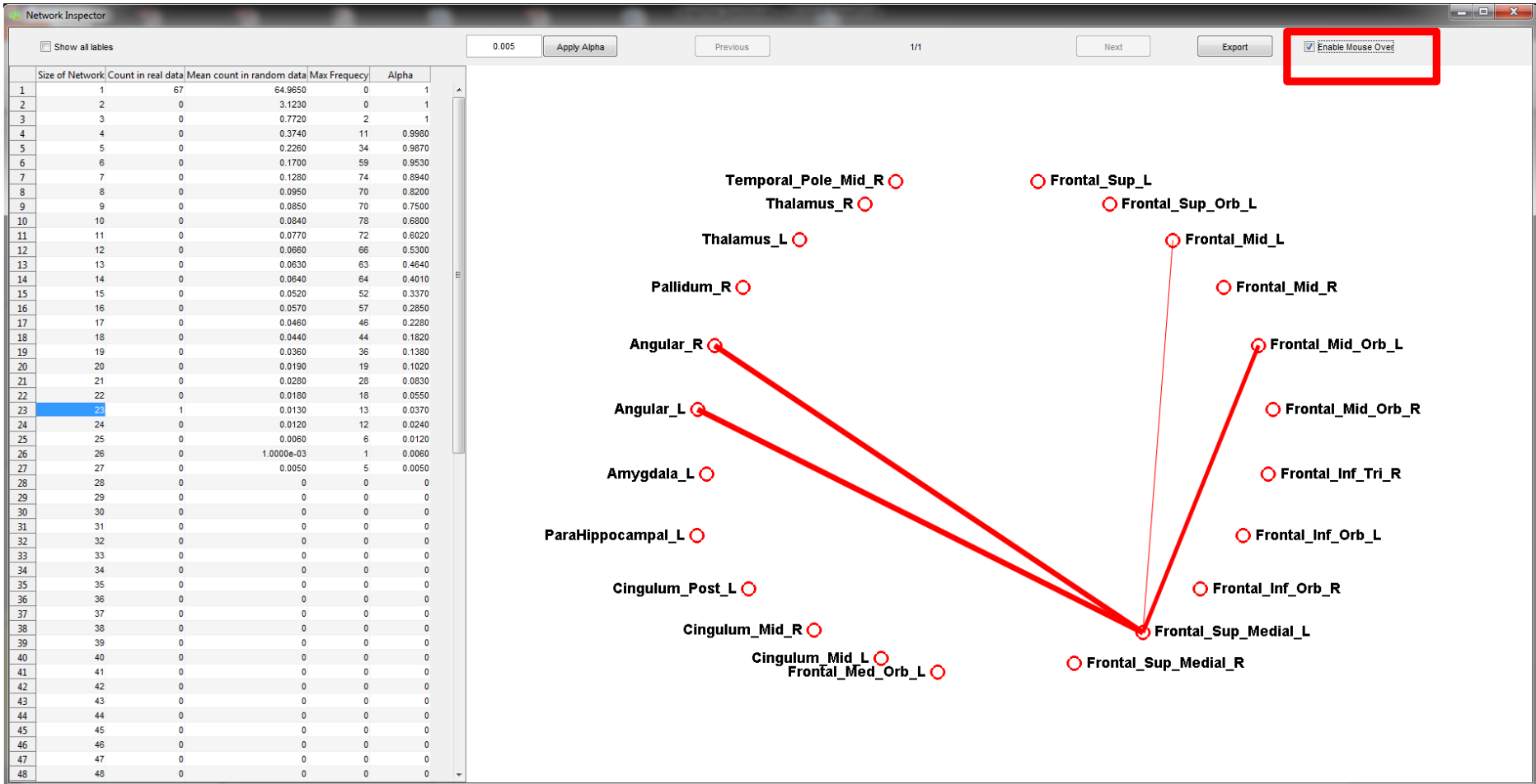
Thalamus\_R  
Area on Y: Lingual\_R  
0.25915  
0.11064

# Identify Graph Components

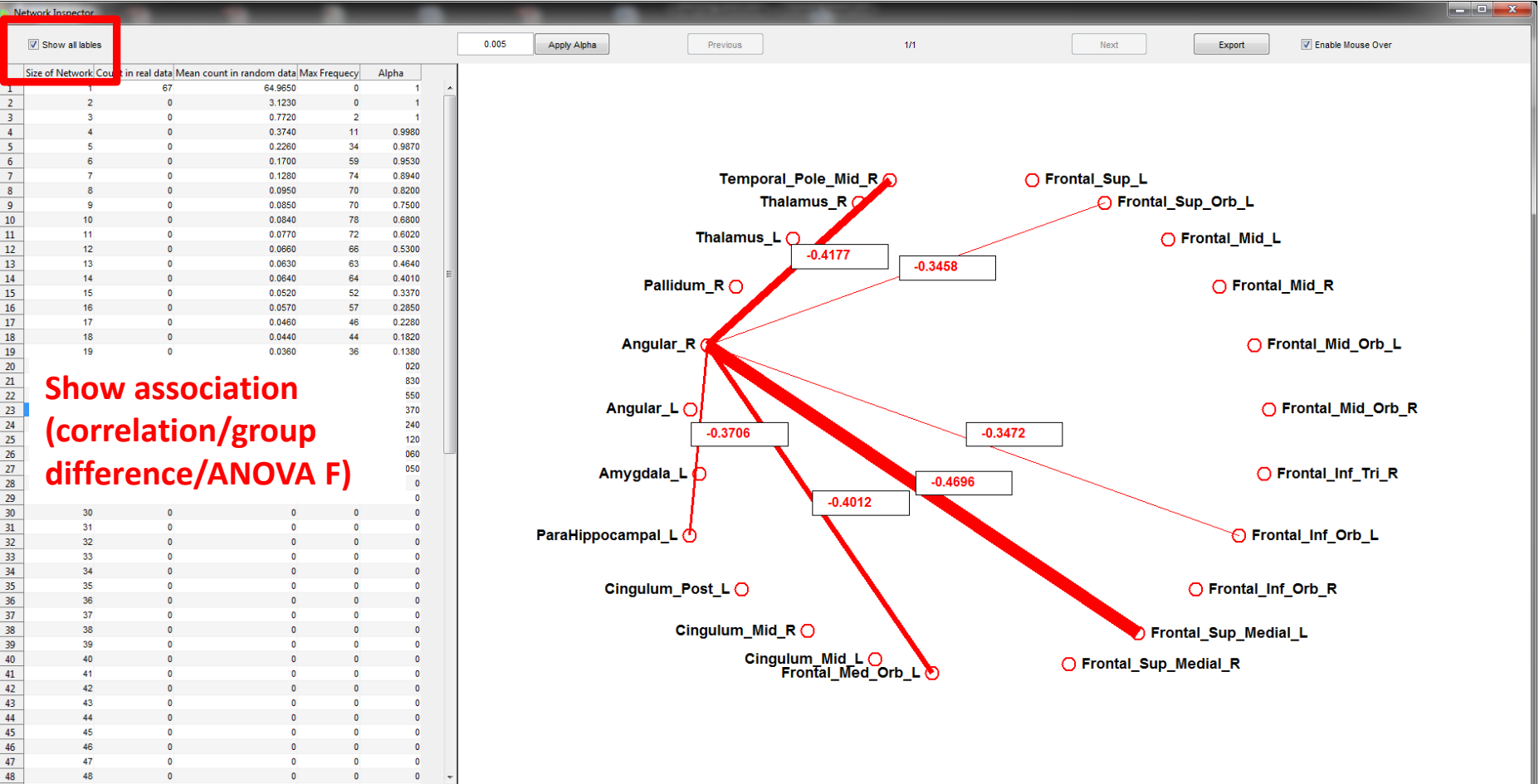
# Network Inspector GUI



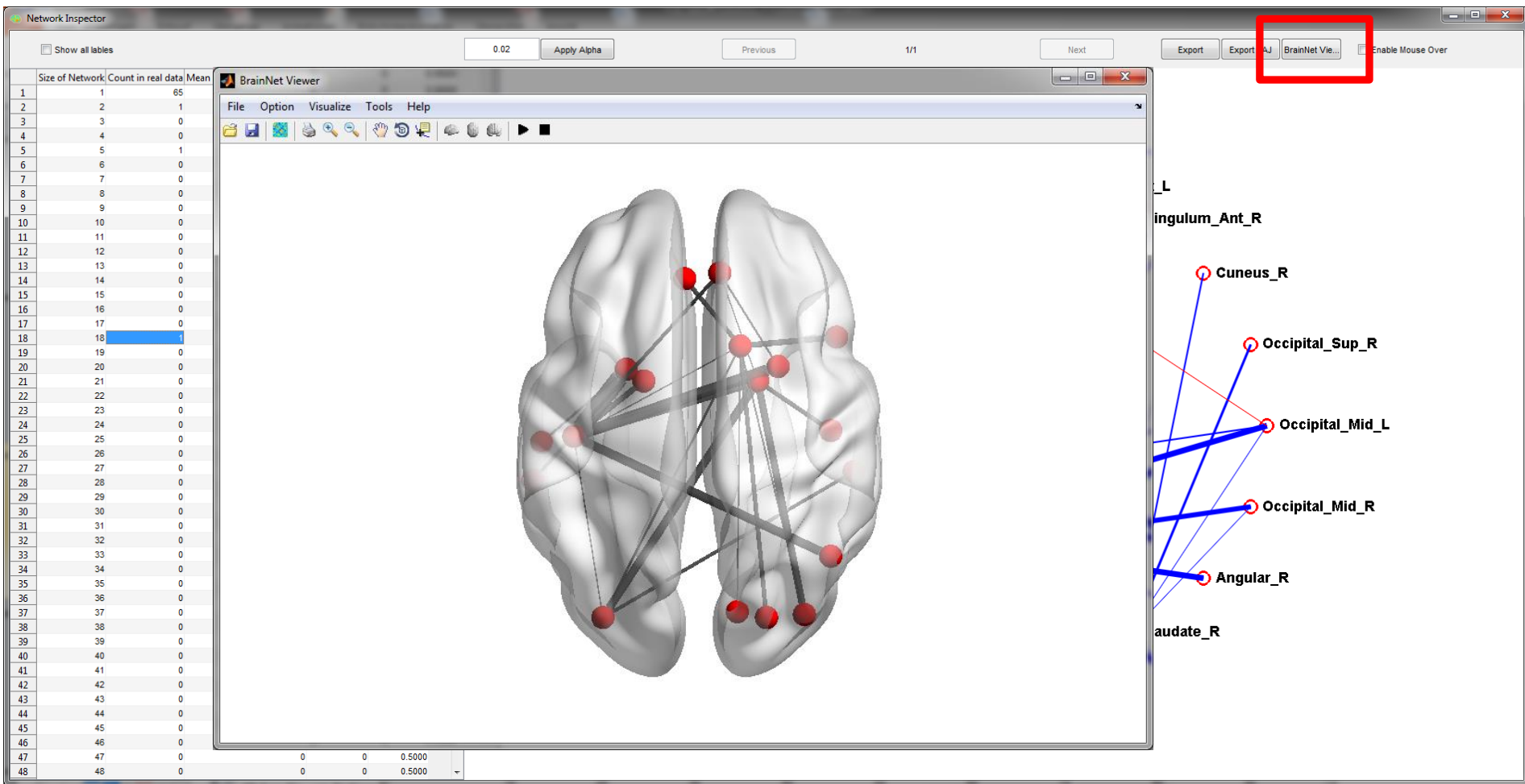
Identify Graph Components



Mouse over



Show association strenght



Open directly in BrainNetViewer  
(Xia et al., 2013; PlosONE)