Sleep deprivation alters the effective connectivity of central executive and salience network with the right intraparietal sulcus

eSLEEP EUROPE
October 4-6, 2023 | Virtual Congress

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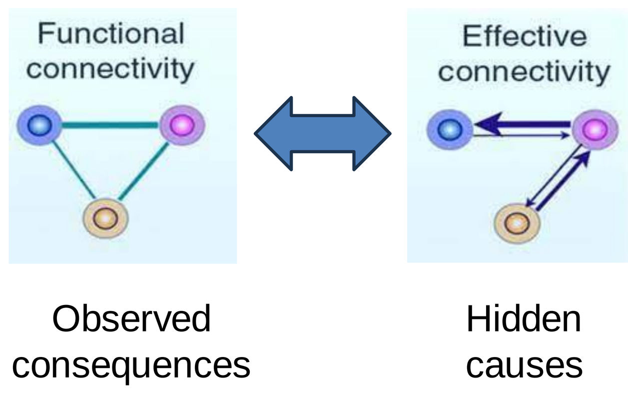
BACKGROUND

Cognitive impairments observed after sleep deprivation (SD) mostly affect attention maintenance and emotional salience[1]. Impairments, such as attention lapses, can be associated to the disrupted activity of the central executive network (CEN), while the impaired saliency discrimination is associated to the altered activity of the salience network (SN)[1]. The intraparietal sulcus is a parietal region densely connected to the frontoparietal networks (as CEN), which has been referred to as a "connectivity hub" with roles in orientation, attention and salience-detection[2]. Results from an ALE meta-analysis on 31 studies found the right intraparietal sulcus (rIPS) to be consistently hypoactive in total sleep deprivation[3], but it is not clear how this region interacts with the above networks.

How do these brain areas influence each other?



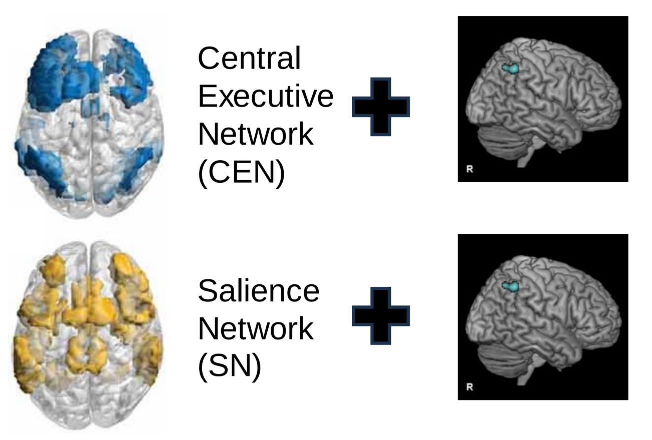
To answer that, the effective connectivity can be investigated. An effective connectivity analysis provides information on how regions influence each other.

Positive/negative connectivity value (Hz) region A to region B → **Increased/decreased** influence of region A on region B

METHODS

ENIGMA SLEEP resting-state datasets	Sleep deprivation protocol
Sleepy Brain study[4] dataset (Karolinska Institute) 41 subjects age 20-30 years TR 2.5	**Acute partial** sleep deprivation (3 hours)
PETcoffee dataset[5] (INM2, Forschungzentrum Juelich) 36 subjects age 22-37 years TR 2.29	**Chronic partial** sleep deprivation (5 hours, 5 days)
Somnosafe dataset[5] (INM2, Forschungzentrum Juelich) 35 subjects age 20-39 years TR 2.29	**Total** sleep deprivation (0 hours)

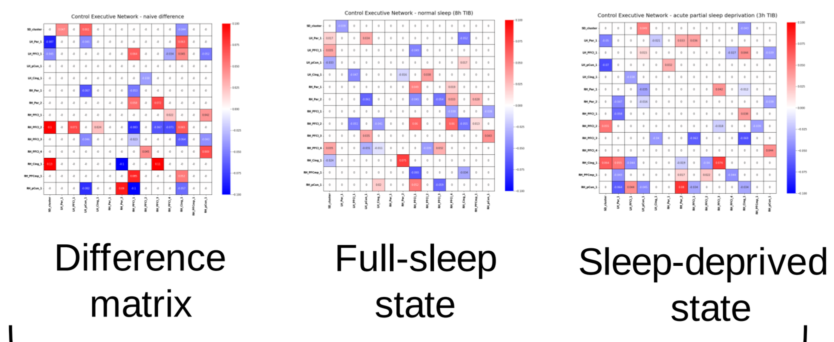
Preprocessing details:
fMRIPrep preprocessing w/ **ICA-AROMA**
Confounds removal (mean WM and CSF, non-aggressive ICA-AROMA)
Signal extraction as first eigenvariate



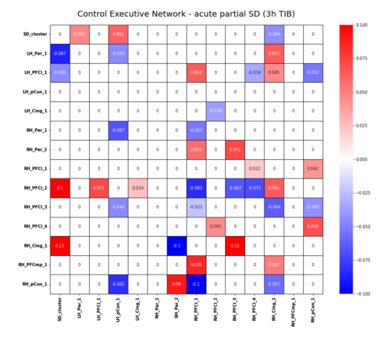
Brain atlas: Schaefer 100 ROI, Yeo 7 Networks[6]

Cluster from Javaheripour et al., 2019

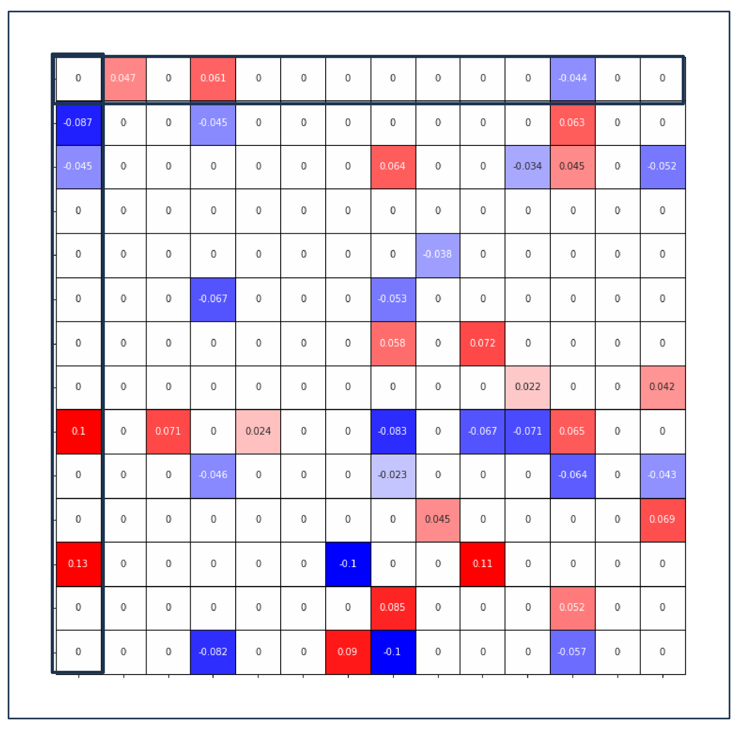
Effective connectivity analysis with spectral Dynamic causal modeling (spDCM)[7] within SPM12 library in MATLAB.



Masking the difference matrix by exclusion of connections absent before (full-sleep state) and after (sleep-deprived state) the treatment, to obtain a **state-informed difference matrix**



Compute **Pairwise Pearson correlation** between state-informed difference matrices related to SD conditions



Compute network-level metrics:
- **Overall impact of treatment:** Absolute sum over connections strengths
- **Network balance after treatment:** Sum over connections strengths

For each difference matrix:
- **Whole network connectivity changes** (whole matrix)
- **rIPS connectivity changes:** rIPS to CEN/SN (first row) CEN/SN to rIPS (first column)

RESULTS

Pairwise correlation between difference matrices related to SD conditions

Central Executive Network (CEN)

Acute Partial SD	1		
Chronic Partial SD	0	1	
Total SD	0.03	-0.02	1

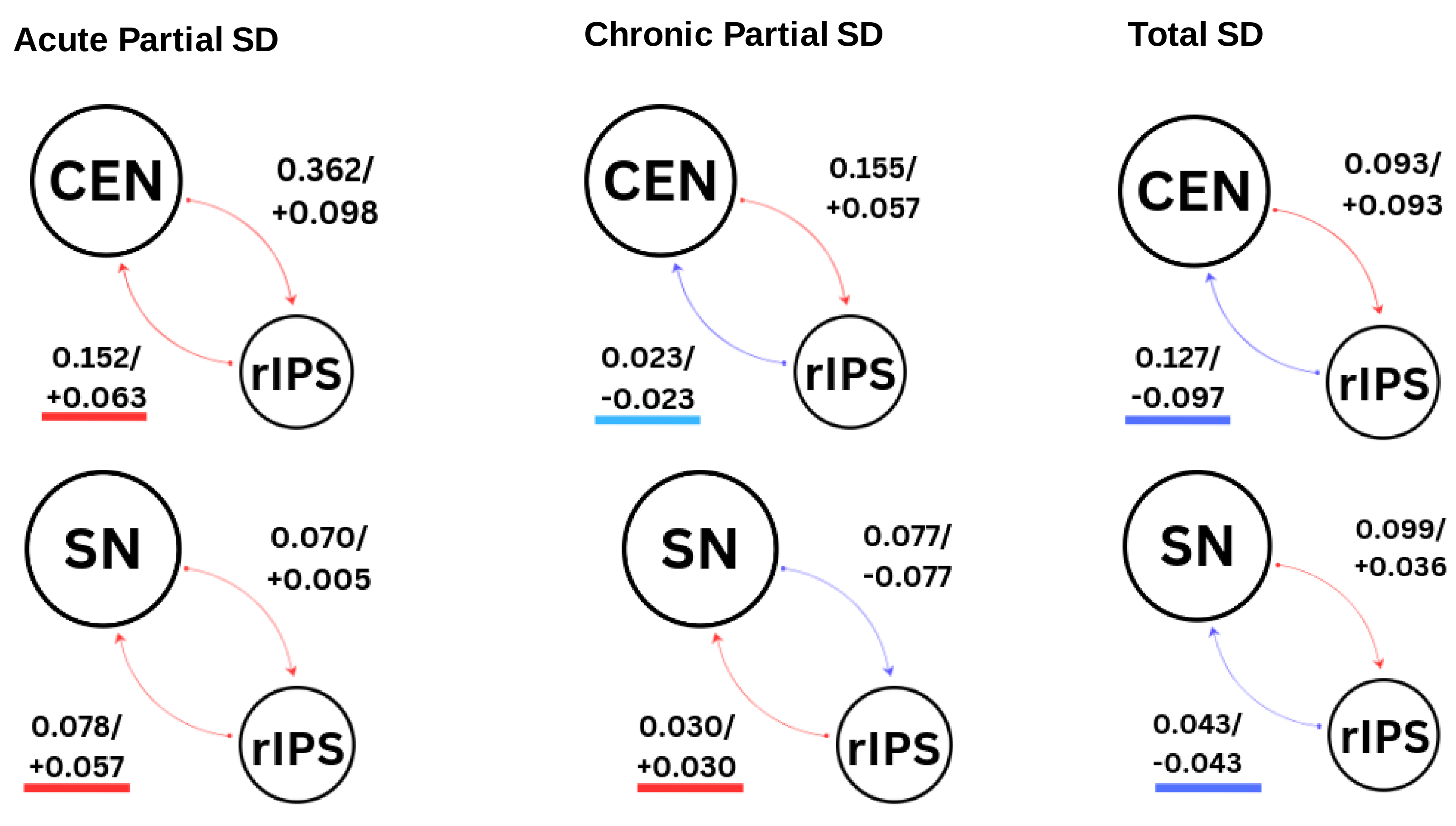
Salience Network (SN)

Acute Partial SD	1		
Chronic Partial SD	0.17	1	
Total SD	-0.06	0.07	1

Whole-network connectivity changes across SD conditions

Network	Metric	Acute Partial SD	Chronic Partial SD	Total SD
CEN + rIPS	Impact	**2.52**	**0.91**	**1.35**
	Balance	**+0.11**	**+0.04**	**-0.22**
SN + rIPS	Impact	**0.84**	**0.24**	**0.89**
	Balance	**+0.23**	**+0.09**	**+0.26**

rIPS connectivity changes across SD conditions



CONCLUSIONS

- Sleep deprivation impacts the resting-state effective connectivity differently depending on the amount sleep debt.

For both salience and central executive networks**:**
- rIPS connectivity altered in all three sleep deprivation conditions.
- rIPS influence on the network decreases at increasing sleep pressure.

- The hypoactivity of the rIPS is reflected in its decreased influence on the resting-state networks, salience and central executive networks. Such reduction in connectivity seems to be dose-dependent on the amount of sleep debt.
- We suggest that sleep deprivation disrupts the role of rIPS as a connectivity hub for resting-state networks, possibly resulting in cognitive dysfunctions as attentional lapses and emotional hyperarousal.

REFERENCES

[1] Krause et al., *Nat Rev Neurosci*, 2017. [2] Brown et al., *IJCHP*, 2023. [3] Javaheripour et al., *Sleep Med Rev*, 2019. [4] Nilsonne et al., *Sci Rep*, 2017. [5] Chu et al., *Journal of Neuroscience*, 2023. [6] Schaefer et al., *Cerebral Cortex*, 2018. [7] Razi et al., *Netw Neurosci*, 2017.

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