CONNECTING AND NETWORKING
(SUMMARY VERSION)

Proposed Brain Networks and Regions (Cerebral Topology & Hodology)

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   - Functional

2. Is there a topological "Central" core?

3. Individual Functional Networks

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   - Executive Control Network (ECN) [aka Fronto-parietal Network (FPN)]
   - Dorsal Attention Network (DAN)
   - Ventral Attention Network (VAN)

   B. Sensorimotor Networks
   - Auditory Network (AUDN)
   - Visual Network (VISN)
   - Motor-Tactile Network (MTN)

   C. Other Functional
   - Salience Network (SALN)
   - Cingulate-Opercular Network (CON)

## CONNECTING: BRAIN NETWORKS AND REGIONS (CEREBRAL TOPOLOGY & HODOLOGY)

**Topology & Hodology**.

- The older and more traditional efforts of neuroscience were directed to learn where things were in the brain. This is known as cerebral **topology**. *Topology* is the scientific (or mathematical) study of **specific places**.
- Over the last twenty to thirty years more and more research has studied how those different places in the brain are connected and how these connected places work together as active networks. There is a new term that labels these efforts: cerebral **hodology**. *Hodology* is the study of **pathways** and, in neuroscience more specifically, the **interconnection of cells** in the brain.

## 1. Types of Connectivity Networks

- **Structural**: "Structural connectivity describes anatomical connections linking a set of neural elements. At the scale of the human brain, these connections generally refer to white matter projections linking cortical and subcortical regions.

- **Functional**: "Functional connectivity is generally derived from time series and ... data may be derived with a variety of techniques, including electroencephalography (EEG), magnetoencephalography (MEG), and functional magnetic resonance imaging (fMRI)...Functional connectivity is highly time-dependent, often changing in a matter of tens or hundreds of milliseconds as functional connections are continually modulated by sensory stimuli and task context.

Forms of functional connectivity networks

### "Task Negative" • Resting State • Intrinsic

There are differing names given to functional connectivity networks in the absence of external stimulation. These include "task negative," "resting state," and "intrinsic" connectivity networks.

"*Task Negative*" networks are described by Raichle as "brain areas frequently seen to decrease its activity during attention demanding tasks" (Raichle, 2015a, p. 1444). This term is used in contrast to "Task Positive" networks as described further below.

"*Resting State*" networks is a term with multiple meanings (Northoff, 2015, p. 1). These include the notion that "Roughly, the brain's resting state activity describes the brain's neural activity in the absence of any specific tasks or stimuli" (p. 1). Note, though, that a decrease in activity may not signal "resting" as much as "inhibition" so that the lack of activity in some conditions like major depressive disorder is an inhibitory phenomenon rather than a kind of idling or going into neutral.

"*Intrinsic" networks*: To avoid confusion suggested by the term "resting-state" networks, ICN is used to denote those "finite set of distributed spatial maps" [i.e., networks] that demonstrate "coherent brain activity...in the absence of an externally cued task" (Seeley, et al, 2007, p. 2349)

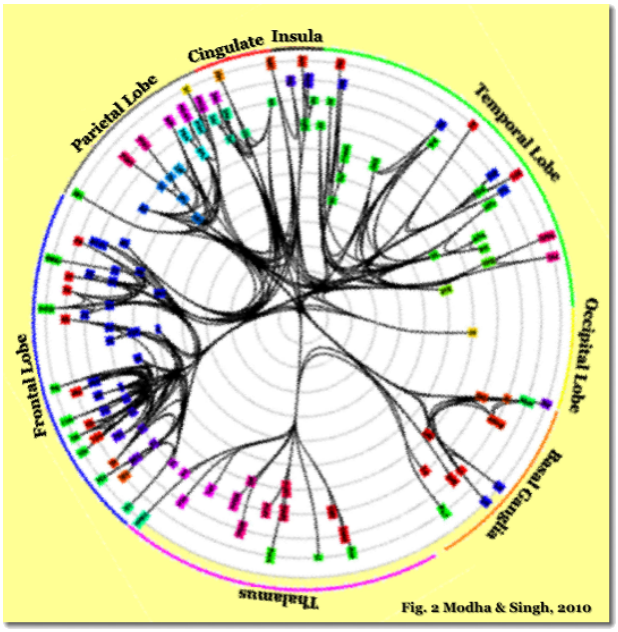
### "Task Positive"

Task Positive networks = "commonly increase activity as a result of cognitive task engagement independent of the specific task...The general task activation pattern suggests an involvement of these regions in foundational capacities such as

attentional control common to cognitive performance in general." (Sadaghiani et al, 2014)

## 2. Is there a topological "Central" core?

Note: "In the context of biology, **homology** is the existence of shared ancestry between a pair of structures, or genes, in different species. A common example of homologous structures in evolutionary biology are the wings of bats and the arms of primates." {Wikipedia}




"We have found a deeply nested and tightly integrated core circuit spanning the entire brain that contains both the task-positive and task-negative networks. ***Assuming homology***, it is indeed reassuring that the core circuit computed using structural data from a half century of anatomical tracing data in nonhuman primates corresponds so well with 3 decades of behavioral imaging research in humans. This hints at ***an evolutionarily preserved core circuit of the brain*** that may be a key to the age-old question of how the mind arises from the brain" (Modha & Singh, 2010, p. 13490, emphasis added)

## 3. Individual Functional Networks

### (A) Intrinsic & "Resting State" Networks

#### 1. Default Mode Network (DMN)

**Involved in internal tasks like daydreaming, self-reflection, and thinking about others. It is most active when a person is not focused on the outside world.** (Claude.ai)

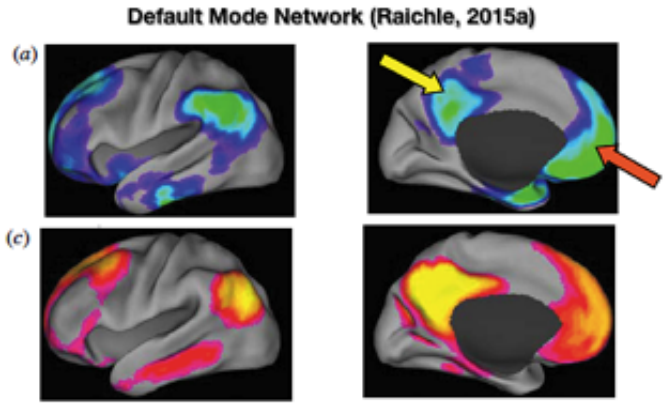



Fig. 2. (a) decreased activity during task performance; (c) resting-state functional connectivity

"the default mode network is hypothesized to perform functions such as self- referential activities, future planning, self-inspection, and emotion regulation, the role of which diminishes during traditional cognitive tasks" (Sylvester et al, 2012, p. 531)

The DMN shows greater activity during resting state ("task negative") conditions compared to performing cognitive tasks.

**Functions**. Various theories have been proposed for the functions of the DMN. In reverse chronological order these include the following:

Buckner & DiNicola (2019) indicate that "detailed high-resolution analyses of single individuals suggest that the default network is not a single network , as historically described, but instead comprises multiple interwoven networks." (Abstract)

- "Evidence emerging from … studies suggests that the default network comprises at least two separate networks with clear spatial distinctions along the posterior and anterior midline, which have often been described as hubs of convergence."(p. 5)
- "A clue to the origins of specialization in the two principal networks linked to the default network (termed default network DN-A and DN-B) is that DN-A is strongly coupled to posterior parahippocampal memory structures, whereas DN-B is not" (p. 6). In this scheme, DN-A may be related to episodic and autobiographical memory functions while DN-B may be related to mentalizing social tasks such as trying to understand what another individual is thinking (theory-of-mind tasks) (See Braga & Buckner, 2017)

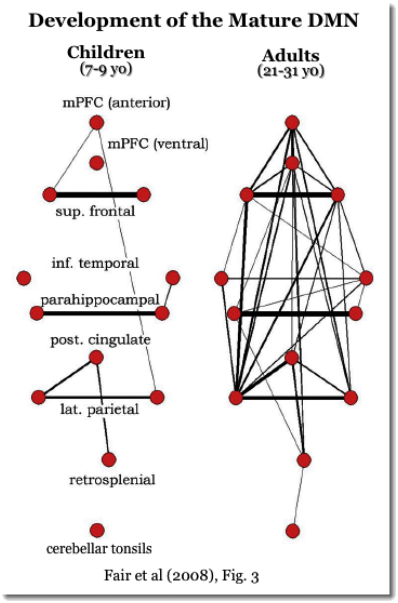
Raichle (2015a) offers multiple comments about functioning in the DMN. These include

- vMPFC - processes that support emotional processing
- dMPFC - self-referential mental activity
- Posterior elements - recollection of prior experiences
- DMN ≠ spontaneous cognition alone, i.e., "unconstrained, conscious cognition [i.e., mind wandering or daydreaming"]

Fair et al. (2008) examined DMN development in children vs. adults and emphasize the adult DMN as involved in

- "self-referential" or "introspective" mental activity, and
- "internal narrative," the "autobiographical self," "stimulus independent thought," "mentalizing," and "self-projection" particularly in respect to the medial prefrontal cortex.

However, they also found clear evidence that "the default regions are only sparsely functionally connected at early school age (7–9 years old); over development, these regions integrate into a cohesive, interconnected network" (p. 4028).



Fair et al (2008), Fig. 3

## 2. Executive Control Network (ECN)

[aka Central Executive Network (CEN) or Fronto-parietal Control Network (FPCN)]

**Involved in cognitive control and flexibility. It helps adjust control based**

**on feedback** (Claude.ai).

**Functions** (Seeley et al., 2007)

"**[O]perate[s] on identified salience**. Such operations require **directing attention to pertinent stimuli as behavioral choices are weighed against shifting conditions, background homeostatic demands, and context.** ...appears to include known sites for **sustained attention** and **working memory** (DLPFC, lateral parietal cortex), **response selection** (dorsomedial frontal/ pre-SMA), and **response sup-pression** (ventrolateral prefrontal cortex)" (Seeley, et al, 2007)

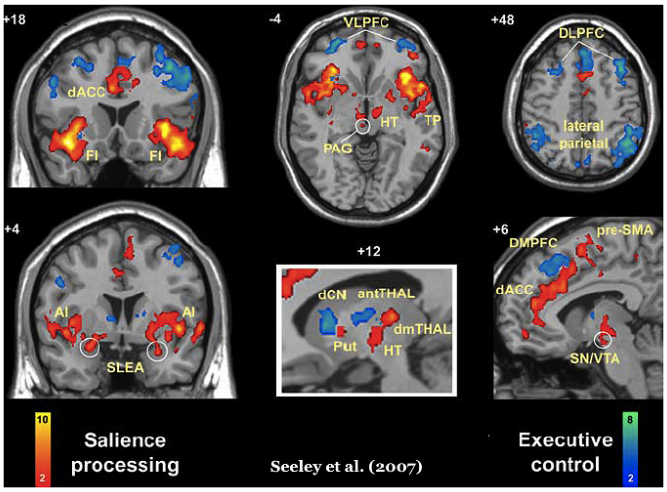



Figure 2. ***Salience Network*** (red-orange colorbar) is anchored by paralimbic anterior cingulate and frontoinsular cortices with extensive connectivity with subcortical & limbic structure. ***Exective-Control Network*** (blue-green colorbar) includes the dorsolateral frontal & parietal cortices linked with more selective subcortical coupling.

AI Anterior insula; antTHAL anterior thalamus; dCN dorsal caudate nucleus, dmTHAL dorsomedial thalamus; DEMPFC dorsomedial prefrontal cortex; HT hypothalamus; PAG periaqueductal gray; Put putamen; SLEA sublenticular extended amygdala; SN/VTA substantia nigra/ventral tegemental area; TP temporal pole; VLPFC ventrolateral prefrontal cortex . Also, dACC dorsal anterior cingulate cortex; FI orbitofrontal insula; preSMA presupplementary motor area

- **Dysfunctions to the ECN "results in the classic dysexecutive syndrome marked by impairments in externally oriented tasks that engage, for example, general intelligence, fluid intelligence, cognitive flexibility, working memory, and problem solving"** (Barbey et al., 2015, p. 95)
- Damage may lead to impaired self-awareness (Ham et al, 2014)

## 3. Dorsal Attention Network (DAN)

**Involved in voluntary, goal-directed tasks that require external attention like working memory and cognitive control. It activates when attention is focused externally.** (Claude.ai)

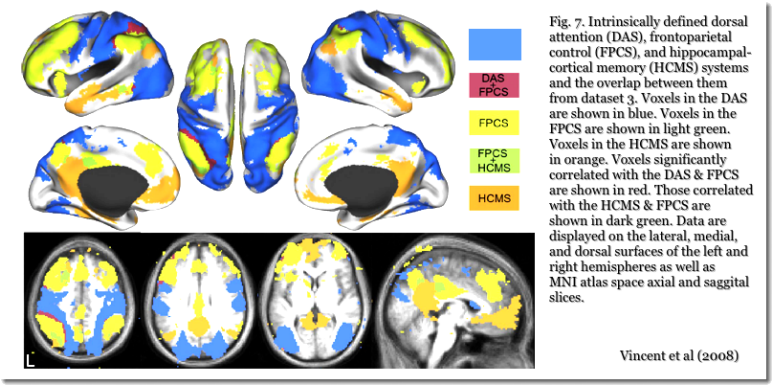



Fig. 7. Intrinsically defined dorsal attention (DAS), frontoparietal control (FPCS), and hippocampal-cortical memory (HCMS) systems and the overlap between them from dataset 3. Voxels in the DAS are shown in blue. Voxels in the FPCS are shown in light green. Voxels in the HCMS are shown in orange. Voxels significantly correlated with the DAS & FPCS are shown in red. Those correlated with the HCMS & FPCS are shown in dark green. Data are displayed on the lateral, medial, and dorsal surfaces of the left and right hemispheres as well as MNI atlas space axial and saggital slices.

**Functions**

- The DAN "plays an important role in selecting visual information based on internal expectations or the sensory salience of visual objects." (Corbetta Lab @ Washington U.)
- Externally directed cognition including covert and overt shifts of spatial

attention, eye movements, and hand-eye coordination" (Vincent et al, 2008).

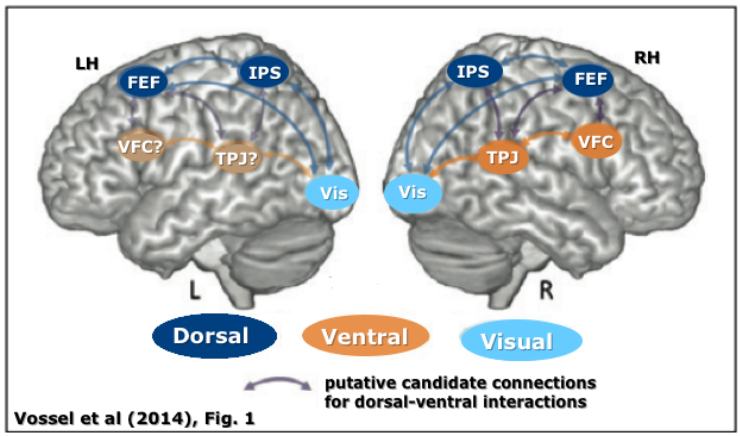
- "DAT network is proposed to underlie selective attention especially in visual and spatial domains (Corbetta and Shulman 2002; Fox et al. 2006
- "detector of novel environmental features" (Raichle, 2015a)

## 4. Ventral Attention Network (VAN)

**Involved in detecting salient stimuli in the environment and reorienting attention based on sensory input. It helps shift attention.** (Claude.ai)

### Location

- "The ventral attention network includes parts of the **ventrolateral PFC** and the **temporal–parietal junction** and is involved in directing attention to newly appearing stimuli.




**FEF Frontal Eye Field; IPS Intraparietal Sulcus; TPJ Temporal-parietal junction; VFC Ventromedial prefrontal cortex; VIS Visual cortex**
**? Suggested additional areas**

### Functions

- "typically responds when behaviorally relevant stimuli occur unexpectedly (e.g., when they appear outside the cued focus of spatial attention)" (Vossel et al., 2014, p. 151)
- Stimulus-driven attention (Sylvester et al, 2012, Table 1)
- "is associated with the orientation of stimulus-driven attention – the automatic orienting to a particular location when a stimulus appears at that location" (Sylvester et al, 2012, p. 530)

"it becomes obvious that flexible attentional control can only be implemented by dynamic interactions of both systems. "

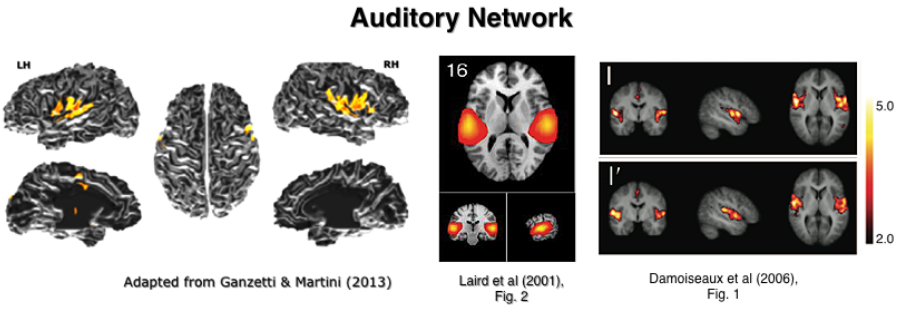
## B. Sensorimotor Networks

### 1. Auditory Network (AUDN)

**Involved in processing auditory information even at rest. It covers auditory cortices.** (Claude.ai)

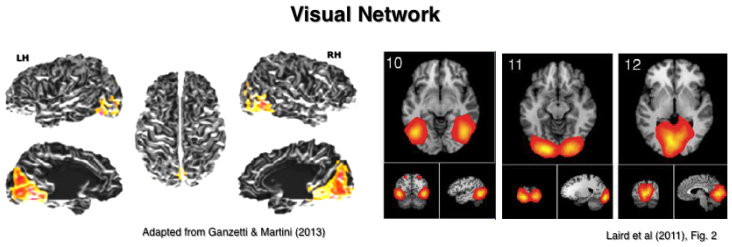
**Function**

- Tone, pitch discrimination
- Speech, music

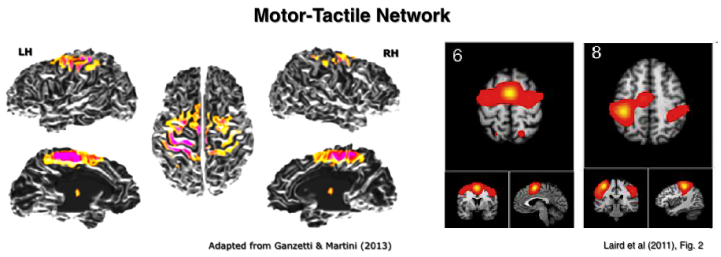



### 2. Visual Network (VISN)

**Involved in processing visual information even at rest. It covers the visual cortices.** (Claude.ai)




### 3. Motor-Tactile Network (MTN) (aka Sensory-Motor Network)




**Involved in sensory-motor processing. It covers sensorimotor cortices.** (Claude.ai)

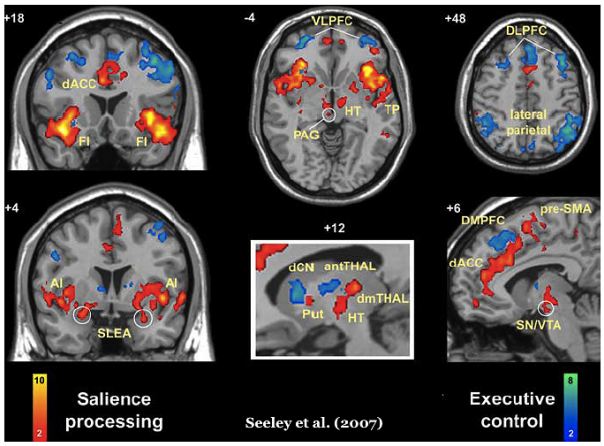
## C. Other Functional

### 1. Salience Network (SALN)

**Involved in detecting and filtering relevant internal and extrapersonal stimuli to guide behavior. It helps determine what is most relevant to pay attention to.** (Claude.ai)

#### Location

- Anterior cingulate cortex (ACC)
- Presupplementary motor areas (preSMA)
- Anterior insula (AI)

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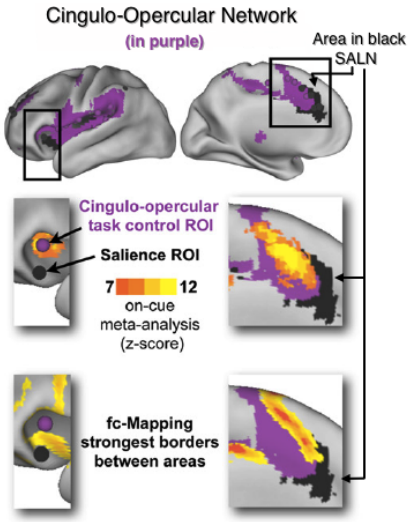
#### Function

- Signals the need for behavioral change" (Bonnelle et al., 2012, p. 4690)
- The nervous system is continuously bombarded by internal and extra-personal stimuli. A leading priority is to identify the most homeostatically relevant among these myriad inputs. This capacity requires a system that can integrate highly processed sensory data with visceral, autonomic, and hedonic "markers," so that the organism can decide what to do (or not to do) next.
- "At least part of the salience network's role seems to be linked to something very basic: the fight or flight response. That response — an accelerated heart rate, dilated pupils and rising blood pressure, readying the body for action — may be orchestrated by the salience network" (Singer, 2013)
- "Too much activity in the salience network can also be problematic. Seeley and Greicius's original [2007] study found that the people who reported the most anxiety before they entered the brain scanner also showed the strongest network connections" (Singer, 2013)
- The SALN is closely coordinated in normal individuals with the DMN. However, in the presence of TBI which affects the SALN, the Default Mode Network may not deactivate and the individual may not be able to respond to environmental cues (Bonnelle et al, 2012, summarizing p. 4693)

## 2. Cingulo-Opercular Network (CON)

After the initial identification of the SALN network (Seeley et al, 2007), later research suggests that it may be part of a larger network termed the *Cingulo-Opercular Network* (CON) involving a "domain-general" role to promote *cognitive control*. Sadagihiani & Esposito (2014) argue that there are two subdivisions to the CON: a partial CON ($CO^P$) and the SALN described above. The characteristics of the CON, particularly the $CO^P$ are described below.



Adapted from Power et al (2011), Fig. 4

### Function

"The sustained involvement of the CON over the extended course of a trial adds support to the idea that the network is involved **in maintaining a task set** (Dosenbach et al., 2006), **coordinating or sequencing task processes**, or **maintaining sustained effort** (Sterzer & Kleinschmidt, 2010), perhaps coupled with transient processes related to error and salience detection" (Sesteiri et al, 2014, p. 12, emphasis added).

*Tonic Alertness*: "**a sustained and endogenously maintained type of top-down control process** distinct from attentional control processes that are phasic in nature. This sustained function is referred to as "vigilance" (Mackworth 1948; Parasuraman 1998), "vigilant attention" (Robertson and Garavan 2004), "sustained attention" (Warm 1984), or "tonic alertness" (Posner 2008). In these accounts, this sustained function—henceforth called tonic alertness—is described as the mentally effortful, self-initiated (rather than externally driven) preparedness to process and to respond." (Sadaghiani et al, 2014, emphasis added)

"The concept of alertness extends beyond situations in which a known task-set is maintained and includes alert states of high vigilance in which information about the environment, the potential sensory input and the need for action is lacking or sparse (such as in a dark unfamiliar environment with potential threats). While task-set maintenance involves the maintenance of specific information about the task, tonic alertness emphasizes the general mechanism of keeping cognitive faculties available for current processing demands and holding unwanted activity at bay" (Sadaghiani et al, 2014).