

White Matter Tracts

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CORTICOSPINAL TRACT

The **corticospinal tract** is a white matter motor pathway starting at the cortex that terminates on motor neurons in the spinal cord, controlling movements of the limbs and trunk.^[1] There are more than 1 million neurons in the corticospinal tract, and they become **myelinated** usually in the first two years of life.

The term **pyramidal tracts** refers to **upper motor neurons** that originate in the **cerebral cortex** and terminate in the **spinal cord** (*corticospinal*) or **brainstem** (*corticobulbar*). Nerves emerge in the **cerebral cortex**, pass down and may cross sides in the **medulla**, and travel as part of the **spinal cord** until they **synapse** with **interneurons** in the middle part of the spinal cord, known as **grey matter**.^[2]

There is some variation in terminology. The *pyramidal tracts* definitively encompass the **corticospinal tracts**. Many, but not all authors also consider the tracts to include the **corticobulbar tracts**

ANATOMY

The corticospinal tract originates in several parts of the brain, including not just the motor areas, but also the primary **somatosensory cortex** and premotor areas.^[1] Most of the neurons originate in the primary motor cortex (precentral gyrus, Brodmann area 4) or the premotor frontal areas.^{[2][3]} About 30% of corticospinal neurons originate in the primary motor cortex, 30% more in premotor cortex and supplementary motor areas, with the remaining 40% distributed between the somatosensory cortex, the parietal lobe, and **cingulate gyrus**.^[4] These upper motor neurons originate in layer V pyramidal cells of the neocortex,^[1] and travel through the posterior limb of the internal capsule in the forebrain, to enter the **cerebral peduncle** at the base of the midbrain. Then both tracts pass through the brain stem, from the **pons** and then to the **medulla**.^[2] The corticospinal tract, along with the corticobulbar tract, form two pyramidal bumps on either side of the medulla of the brain stem - these bumps are the reason they're called the pyramidal tracts.^[1] Corticospinal neurons synapse directly onto alpha motor neurons for direct muscle control.

Betz cells are very large cells that are very visible under a microscope, and while they account for only about 5% of cells projecting to the spinal cord, they are often considered most crucial for communication of motor signals.^[2] These cells are notable because of their rapid conduction rate, over 70m/sec, the fastest conduction of any signals from the brain to the spinal cord.^[4]

There are two divisions of the corticospinal tract, the lateral corticospinal tract and the ventral corticospinal tract. The lateral corticospinal tract neurons cross the midline in the spinal cord, and controls the limbs and digits.^{[1][3]} The lateral tract forms about 90% of connections in the corticospinal tract;^[2] most of these (about 80% of the total neurons) cross over in the medulla, while the rest (about 10% of the total) cross over at their corresponding place in the spinal cord. The ventral corticospinal tract neurons, the remaining 10%, stay on the same side of the body, and control the trunk muscles.

FUNCTION

The primary purpose of the corticospinal tract is for voluntary motor control of the body and limbs. However, connections to the somatosensory cortex suggest that the pyramidal tracts are also responsible for modulating sensory information from the body.^[1]

Because some of the connections cross the midline, each side of the brain is responsible for controlling muscles for the limbs on opposite sides of the body, while controlling trunk muscles on the same side of the body.^[1]

After patients are lesioned in some part of the pyramidal tracts, they are paralyzed on the corresponding side of the body. However, they can re-learn some crude, basic motions, just no fine movements.^[2] This implies that the connections to these tracts are crucial for fine movement, and only partial recovery is possible if they are damaged.

UNCINATE FASCICULUS

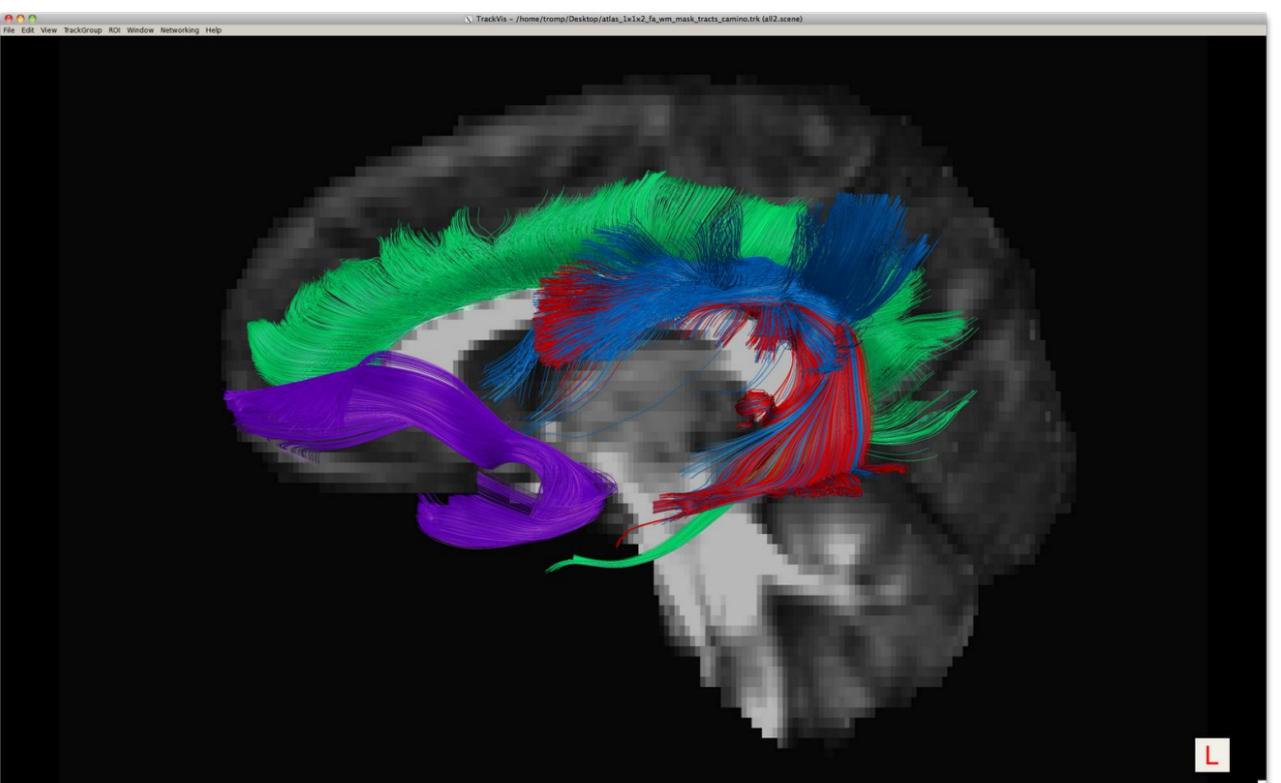
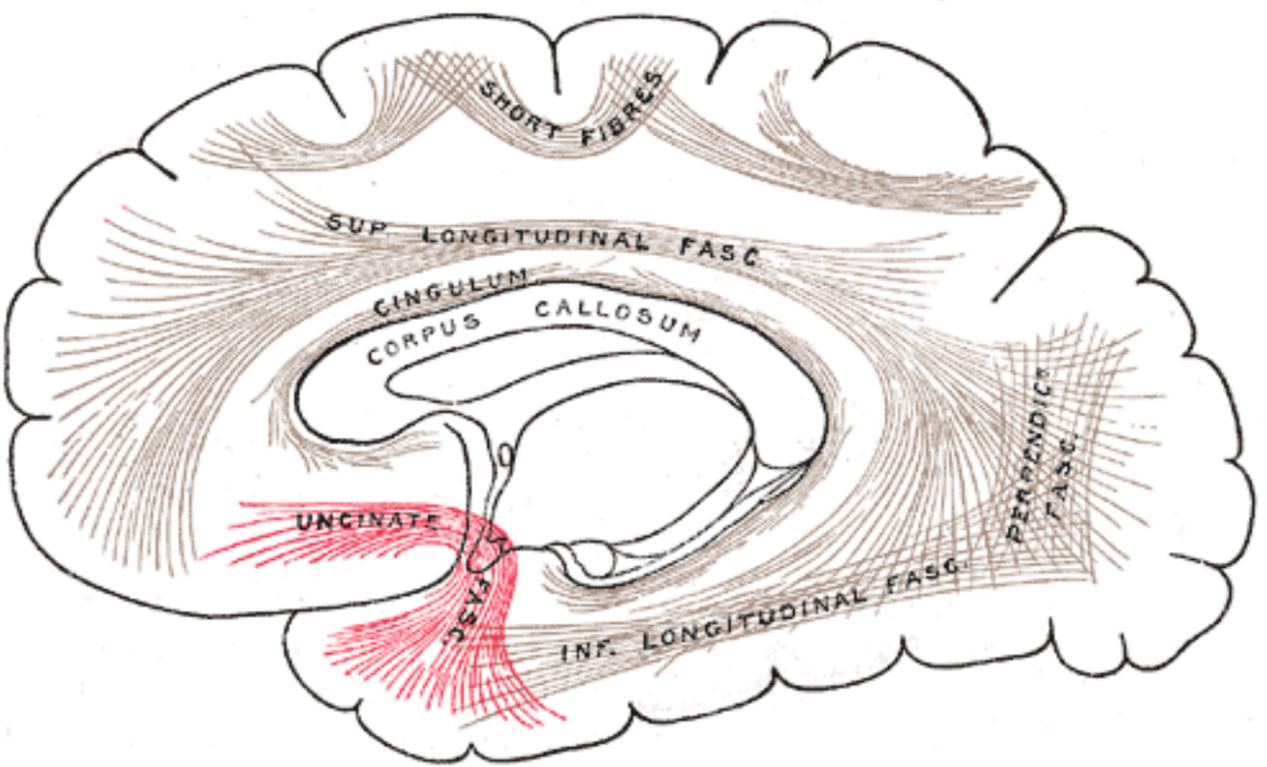
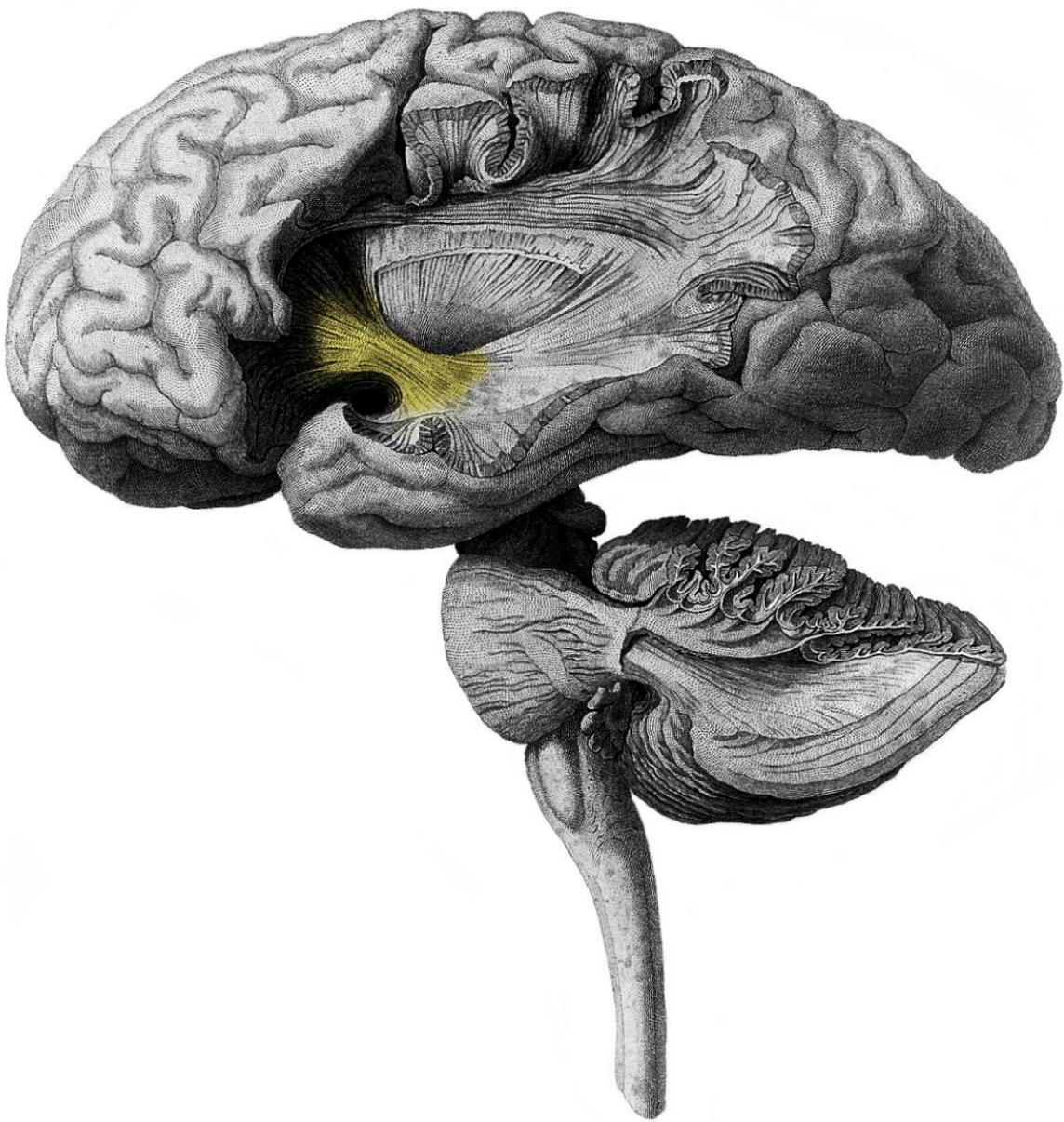
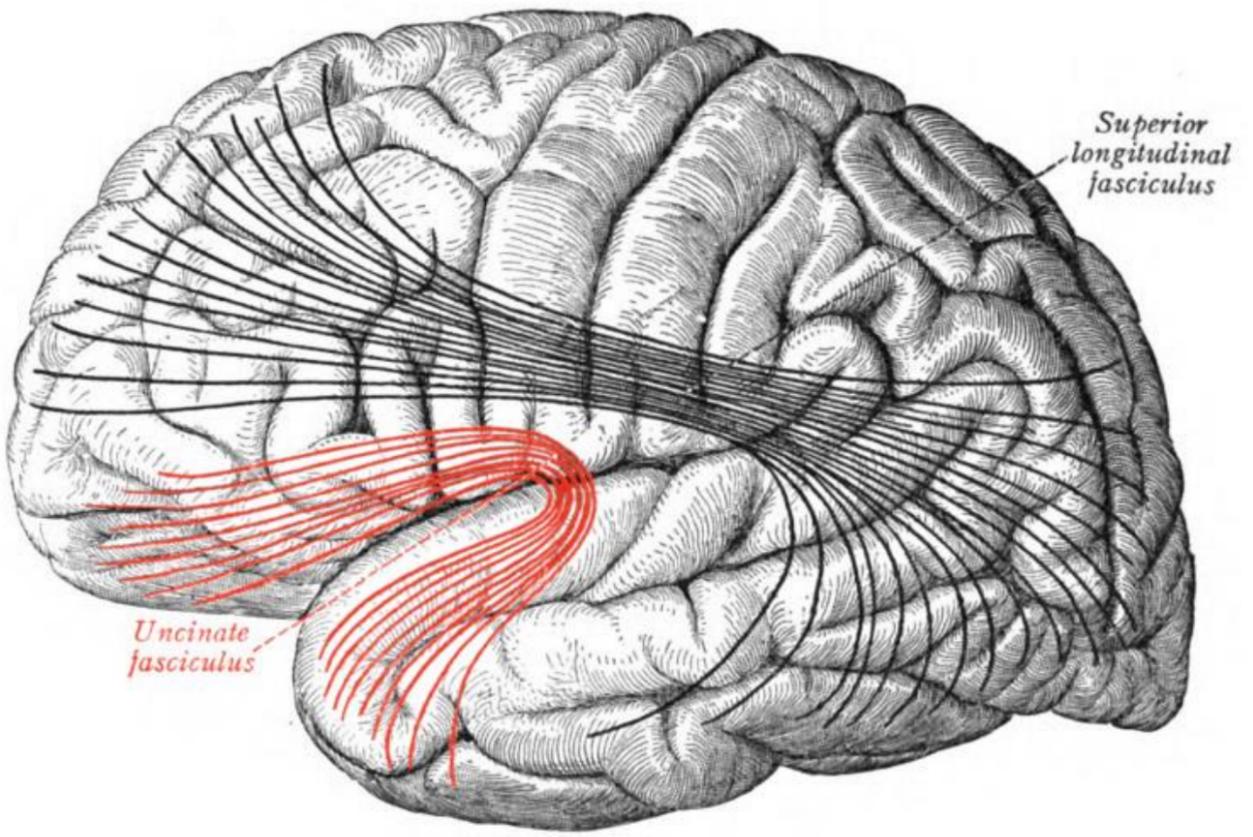
Latin: *Fasciculus uncinatus*

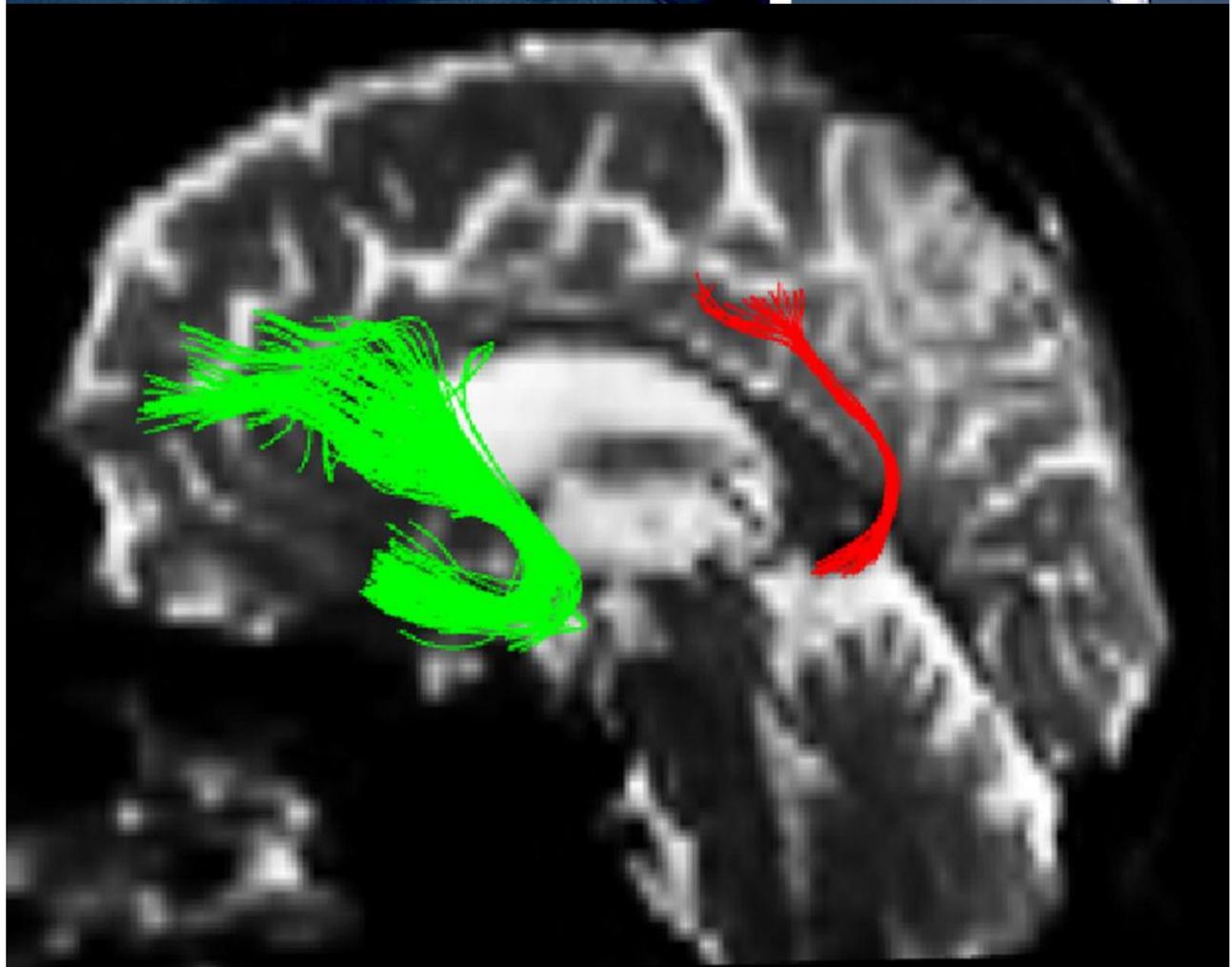
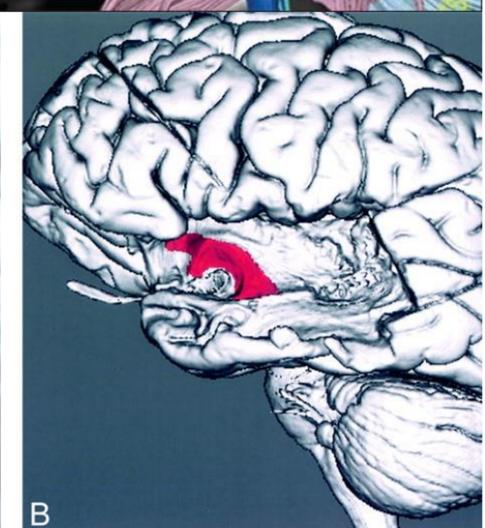
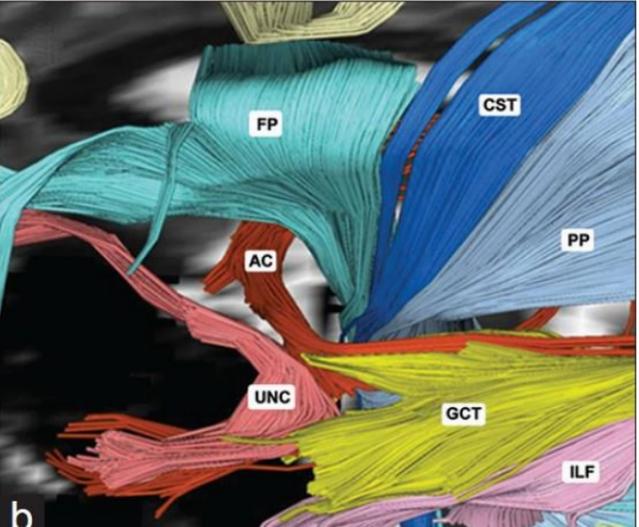
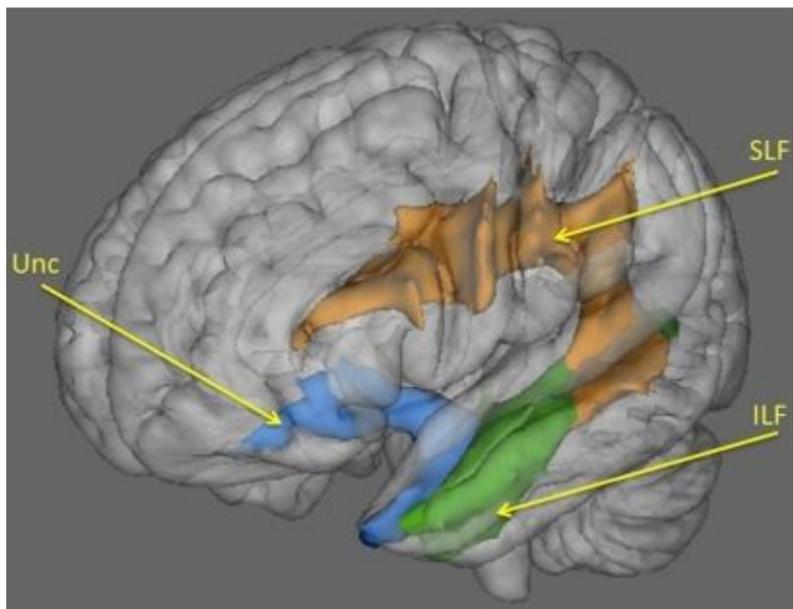
ANATOMY

Hook-shaped bundle that links parts of the limbic system:

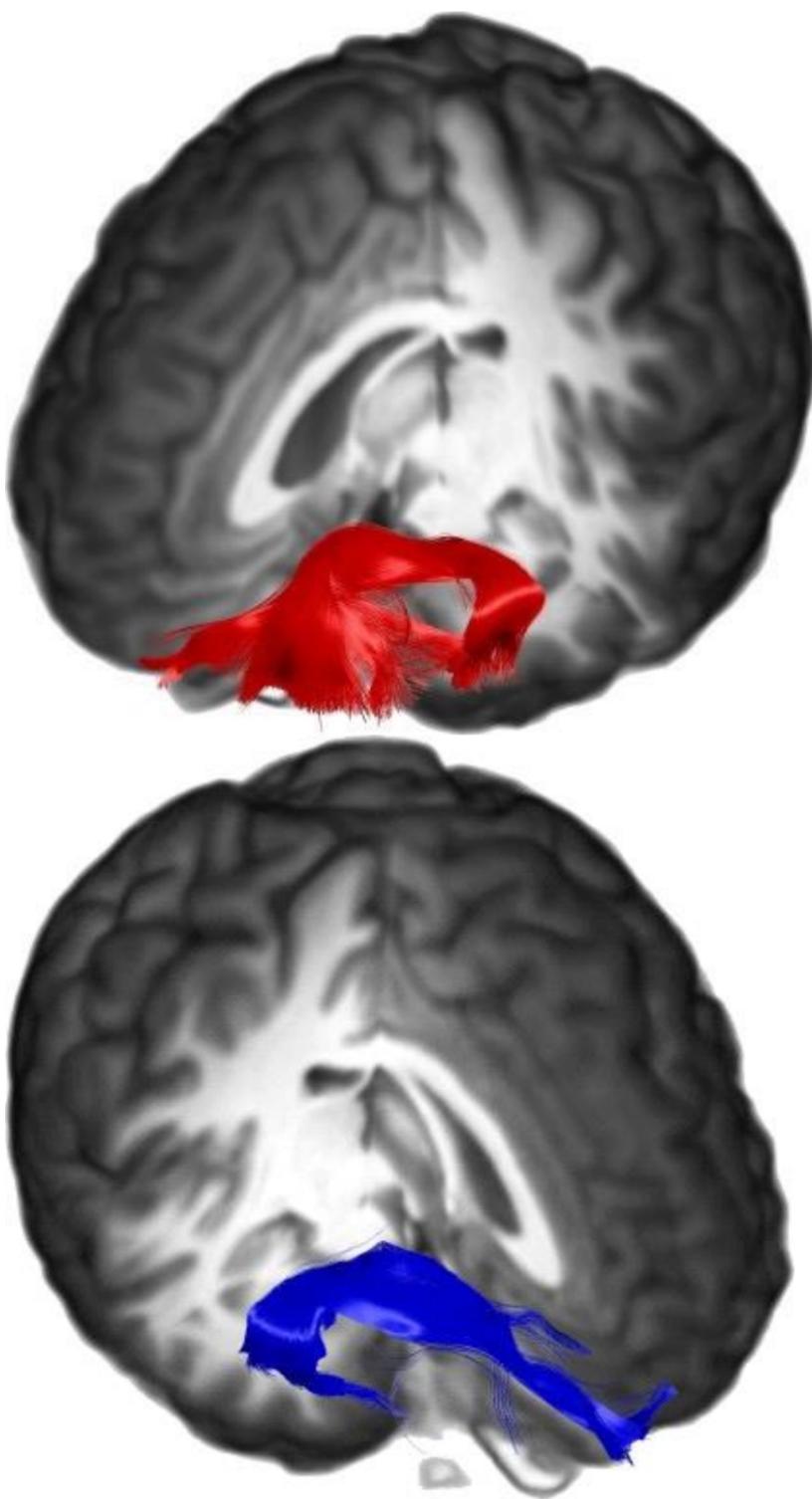
- starts lateral to the amygdala and hippocampus → curving upward behind the external capsule inward of the insular cortex → continuing up into the posterior part of the orbital gyrus.[1]
- average length of the uncinatus fasciculus is 45 mm with a range 40–49 mm.
- volume in adults is 1425.9±138.6 mm³, being slightly larger in men, at 1504.3±150.4, than women 1378.5±107.4.[2]
- three parts:
 - 1) ventral or frontal extension

- 2) intermediary segment (the isthmus) or insular segment
- 3) temporal or dorsal segment





Left-sided uncinate fasciculus (green) and posterior cingulate fasciculus (red)

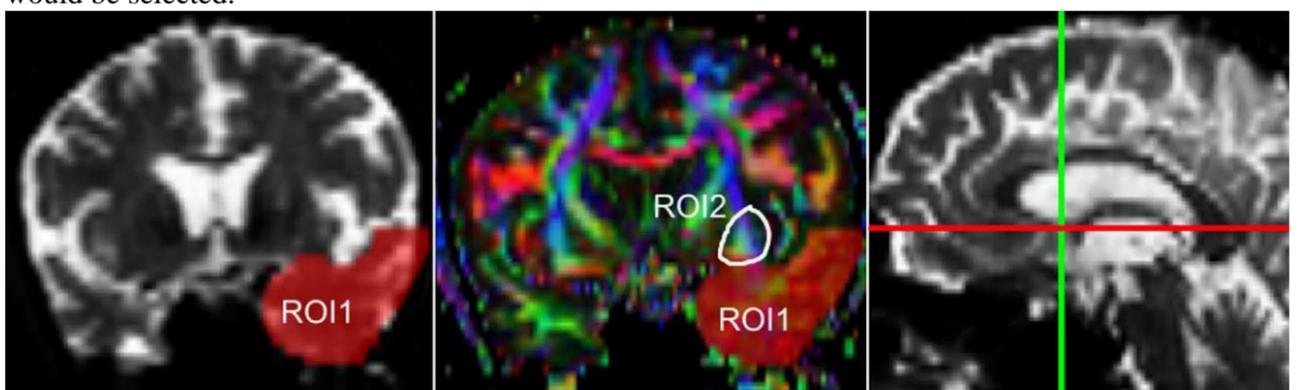


DTI PROTOCOL

described by Wakana et al.

Wakana S, Caprihan A, Panzenboeck MM, Perry JM, Gollub RL, Hua K, et al. Reproducibility of quantitative tractography methods applied to cerebral white matter. Neuroimage. 2007;36:630–44

The ROI location and the location of the coronal slice over a sagittal slice to select the left UNC. Two ROIs were drawn over a coronal slice along the most posterior plane marking the separation of the temporal and frontal lobes, using an image without diffusion-weighting (b0) to provide a better view of anatomical structures. The first ROI (in red) was plotted such that it covered the entire temporal lobe; the second (white) covered the projections over the frontal lobe. A colour FA image provided a better view of the second ROI, shown as the small green zone in the image and labelled 'ROI2'. We then used the 'AND' option so that only those fibres passing through both marked ROIs would be selected.



FUNCTION

The function of the uncinate fasciculus is not known, though it is traditionally considered to be part of the **limbic system**. [2]

- DTI shows a greater fractional anisotropy on the left side than on the right - linked to the left hemispheric specialization for language (however, the electrical brain stimulation upon it fails to disrupt language), suggesting it might not be involved in language, though it is possible that this disruption failed to happen because it was functionally compensated by alternative pathways.[5]
- capacity for auto-nostalgic self-awareness that is re-experiencing previous events as part of one's past as a continuous entity across time has been linked to the right uncinate fasciculus[6] as has proficiency in auditory-verbal memory and declarative memory to the integrity of the left uncinate fasciculus

DEVELOPMENT

- **last white matter tract to mature** in terms of DTI fractional anisotropy - it is alone amongst the major white fibre tracts that **continues to develop beyond the age of 30**. [8]
- **developmentally vulnerable**:
 - in 12-year-old males that were preterm, fractional anisotropy abnormalities in the left anterior uncinate correlated with verbal IQ, full-scale IQ, and Peabody Picture Vocabulary Test-Revised scores.[9]
 - in 10-year-old children who have suffered socioemotional deprivation, the left uncinate fasciculus shows reduced fractional anisotropy, and this might underlie their cognitive, socioemotional, and behavioral difficulties.

CLINICAL SIGNIFICANCE

- though it is affected in several **psychiatric conditions**:

- Abnormalities within the fiber bundles of the uncinate fasciculus associate with social anxiety,[11] Alzheimer's disease,[12] bipolar disorder,[13] and depression in the elderly that had previously been present in adolescence or early adulthood.[14]
- Such abnormalities also link to schizophrenia.[13][15][16] In those with schizotypal personality disorder, reduced fractional anisotropy in the right uncinate fasciculus associates personality traits and clinical symptoms of ideas of reference, suspiciousness, restricted affect, reduced extraversion and social anxiety, while those on the left side associate with general intelligence, verbal and visual memory, and executive performance.[17][18]The greater left than right fractional anisotropy of the uncinate fasciculus is missing in those with schizophrenia.[19]

- In 2009 it was implicated in psychopathy—individuals with a high score in the Psychopathy Checklist and an associated history of violent behavior appeared to have abnormalities in it.[20]
- Phineas Gage (a railroad worker who had an iron bar go through his left frontal lobe)[21] had damage done to his uncinate fasciculus. After the accident, his intellect was untouched, but his personality transformed. He lost all sense of morality and concern for others.

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SUPERIOR LONGITUDINAL FASCICULUS

The **superior longitudinal fasciculus (SLF)** is an **association fiber tract** that is composed of four separate components.^[1] It is present in both **hemispheres** and can be found **lateral** to the **centrum ovale** and connects the **frontal**, **occipital**, **parietal**, and **temporal lobes**. These bundles of axon tracts pass from the frontal lobe through the **operculum** to the posterior end of the **lateral sulcus** where they either radiate to and synapse on neurons in the occipital lobe or turn downward and forward around the **putamen** and then radiate to and synapse on neurons in anterior portions of the temporal lobe.

The SLF is composed of four distinct components SLF I, SLF II, SLF III, and the **arcuate fasciculus (AF)**.^[2] In humans, these four components are bundled together although they are functionally separate. In non-human primates, the SLF and AF are anatomically separate and have separate trajectories

SLF I

SLF I is the dorsal component and originates in the superior and medial **parietal cortex**, passes around the **cingulate sulcus** and in the superior parietal and frontal white matter, and terminates in the dorsal and medial cortex of the frontal lobe (**Brodmann 6, 8, and 9**) and in the **supplementary motor cortex (M II)**.^{[3][4]}

SLF I connects to the superior parietal cortex which encodes locations of body parts in a body-centric coordinate system and with M II and dorsal **premotor cortex**.^[5] This suggests the SLF I is involved with regulating motor behavior, especially conditional associative tasks which select among competing motor tasks based on conditional rules.

SLF II

SLF II is the major component of SLF and originates in the caudal-inferior parietal cortex and terminates in the **dorsolateral prefrontal cortex** (Brodmann 6, 8 and 46).

SLF II connects to the caudal inferior parietal cortex which controls spatial attention and visual and **oculomotor** functions. This suggests the SLF II provides the prefrontal cortex with parietal cortex information regarding perception of **visual space**. Since these bundles are bi-directional, **working memory** (Brodmann 46) in the prefrontal cortex may provide the parietal cortex with information to focus spatial attention and regulate selection and retrieval of spatial information.

SLF III

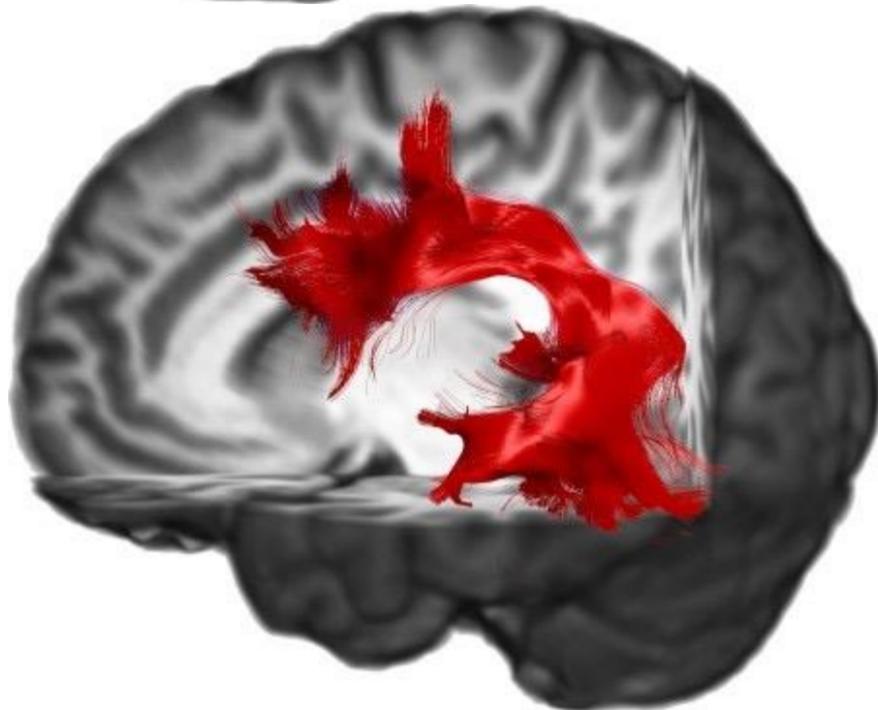
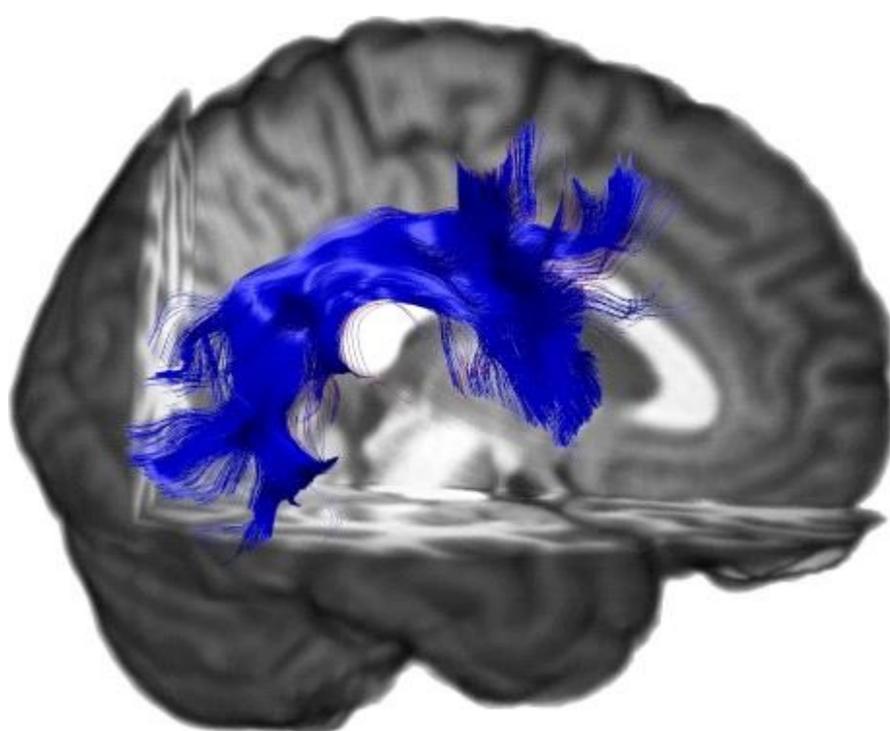
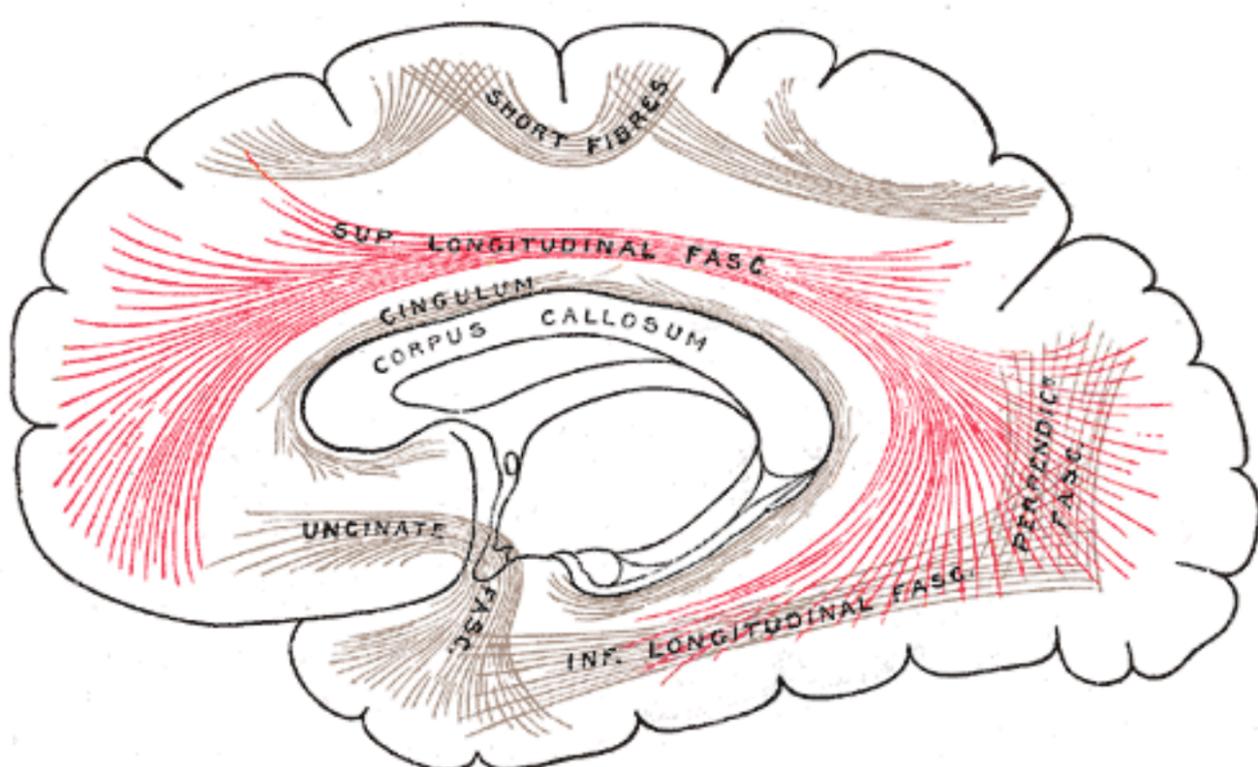
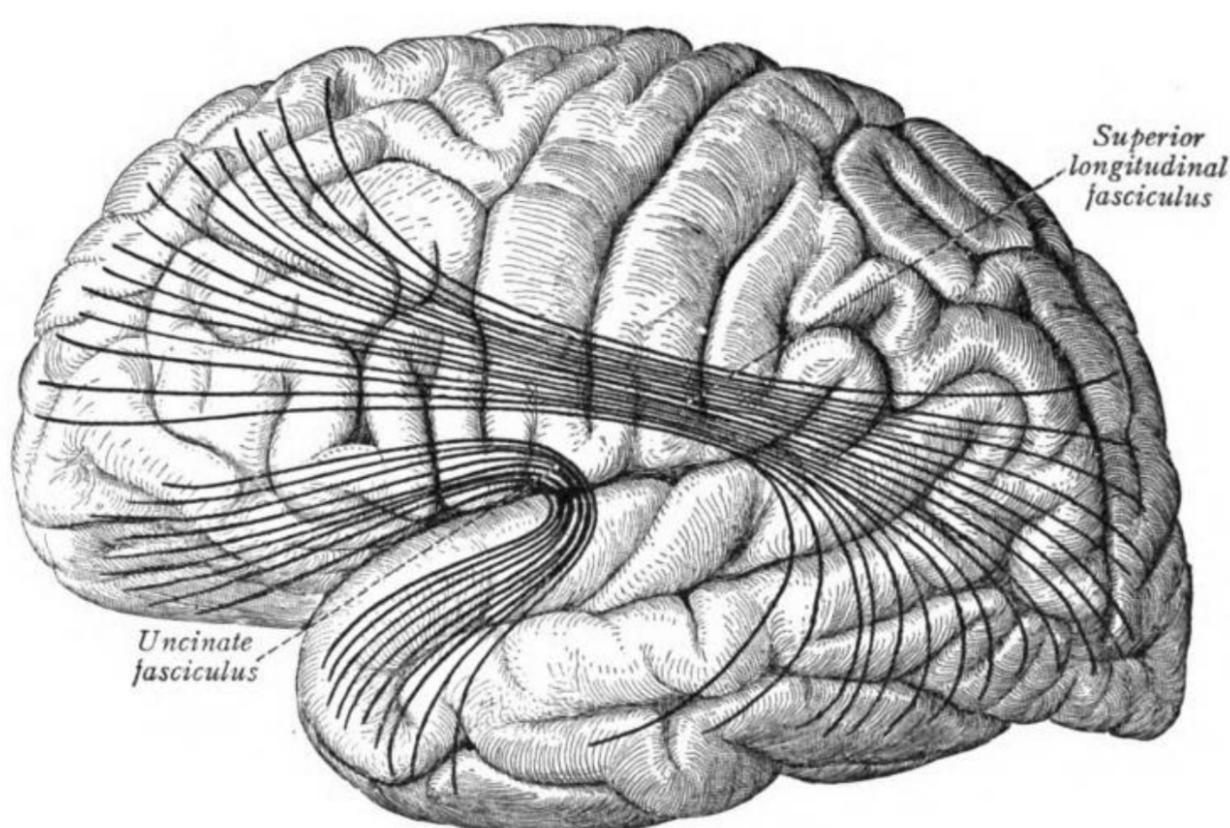
SLF III is the ventral component and originates in the **supramarginal gyrus** (rostral portion of the inferior parietal lobe) and terminates in the ventral premotor and **prefrontal cortex** (Brodmann 6, 44, and 46).

SLF III connects the rostral inferior parietal cortex which receives information from the ventral **precentral gyrus**. This suggests that the SLF III transfers somatosensory information, such as language articulation, between the ventral **premotor cortex**, Brodmann 44 (pars opercularis), the **supramarginal gyrus** (Brodmann 40), and the lateral inferior prefrontal cortex working memory (Brodmann 46).

Arcuate fasciculus

The arcuate fasciculus originates in the caudal area of the superior temporal gyrus and passes next to the neurons of SLF II above the Sylvian fissure and insula in non-human primates. In humans, neurons that originate from the caudal superior temporal gyrus and the superior temporal sulcus pass around the caudal Sylvian fissure and along with the SLF bundle and terminate in the dorsal prefrontal cortex (Brodmann areas 8 and 46).

The arcuate fasciculus connects the superior temporal gyrus (Tpt) with the dorsal prefrontal cortex which suggests auditory information is transmitted between those two areas of cortex.^[6]



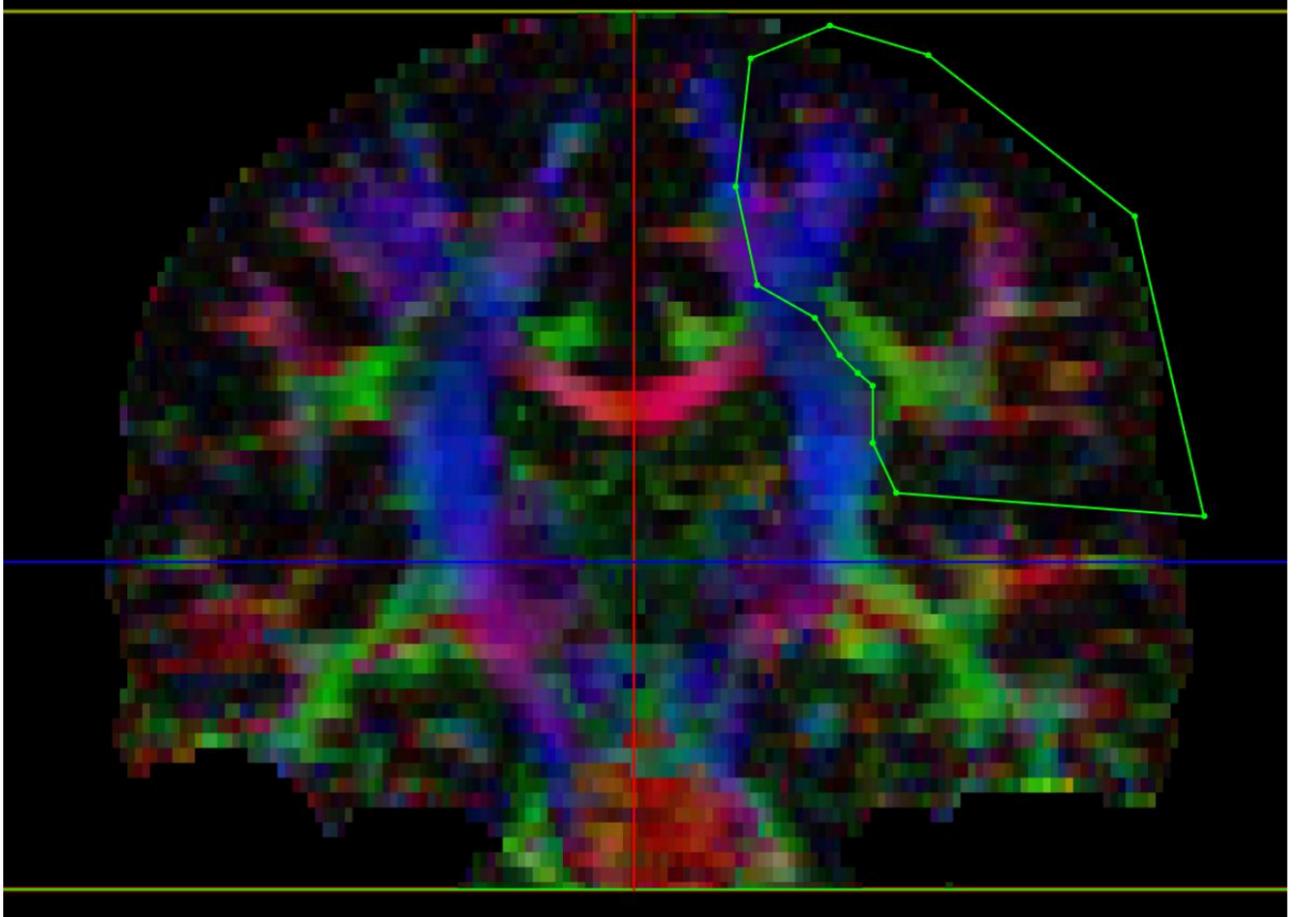
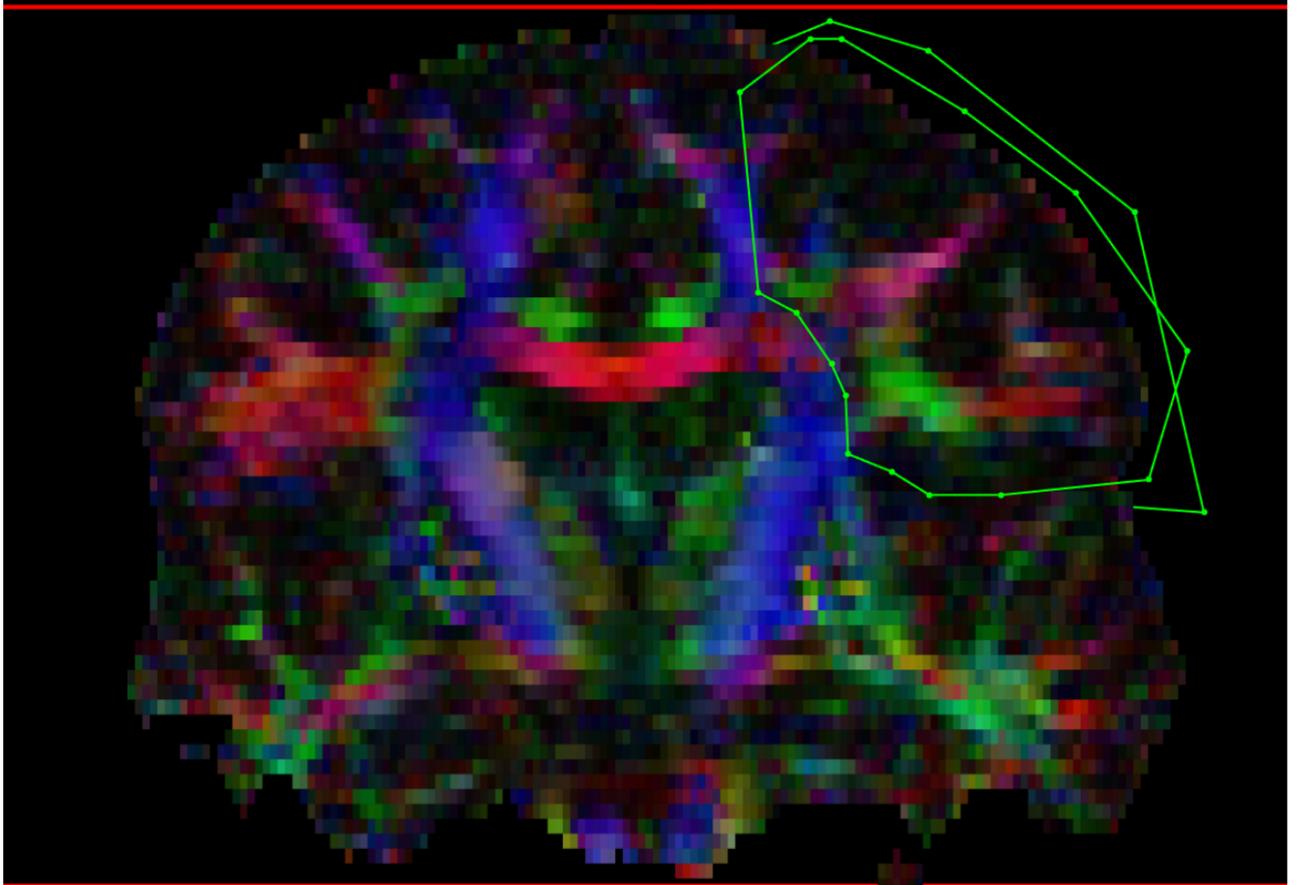
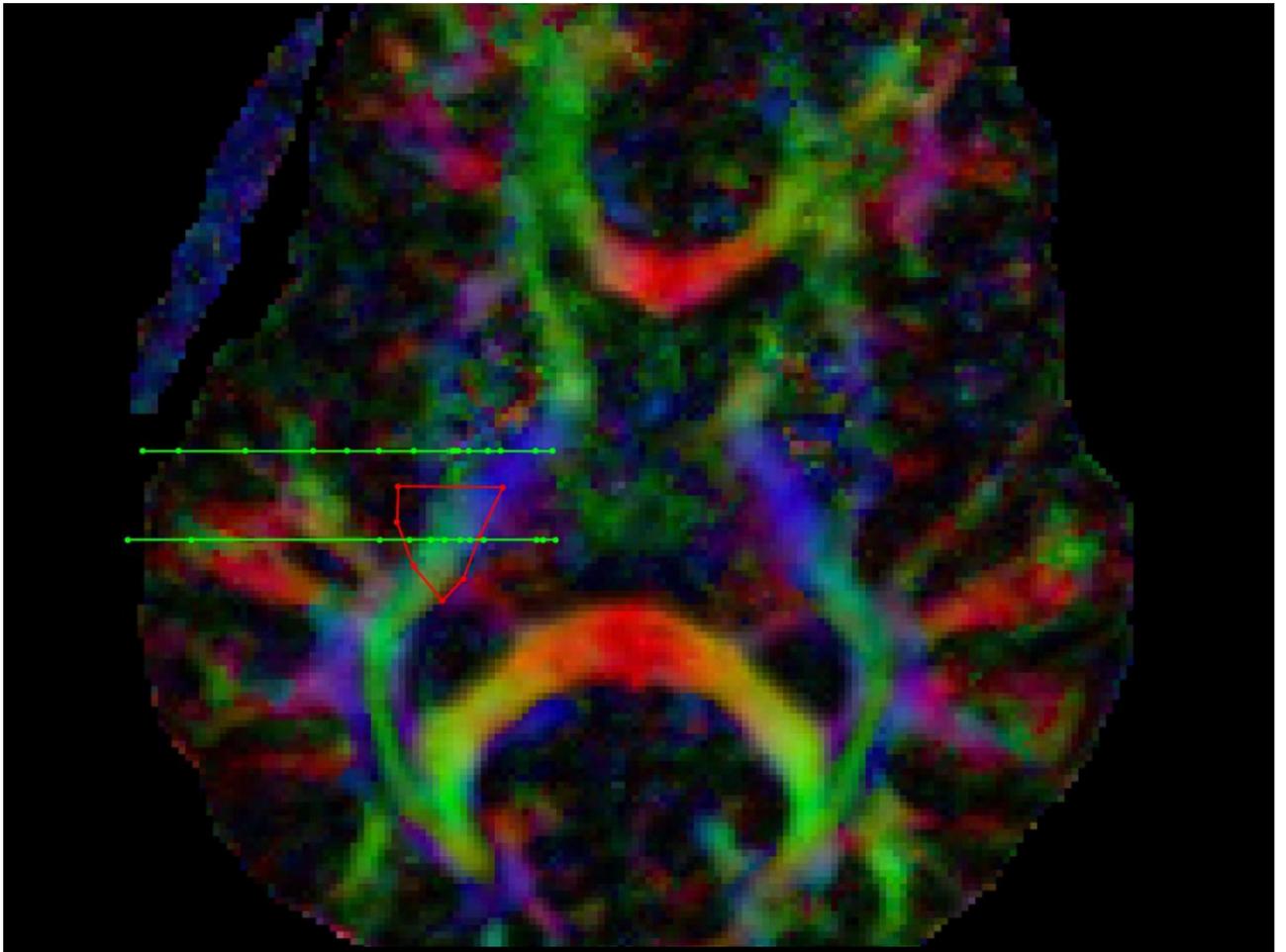
DTI PROTOCOL

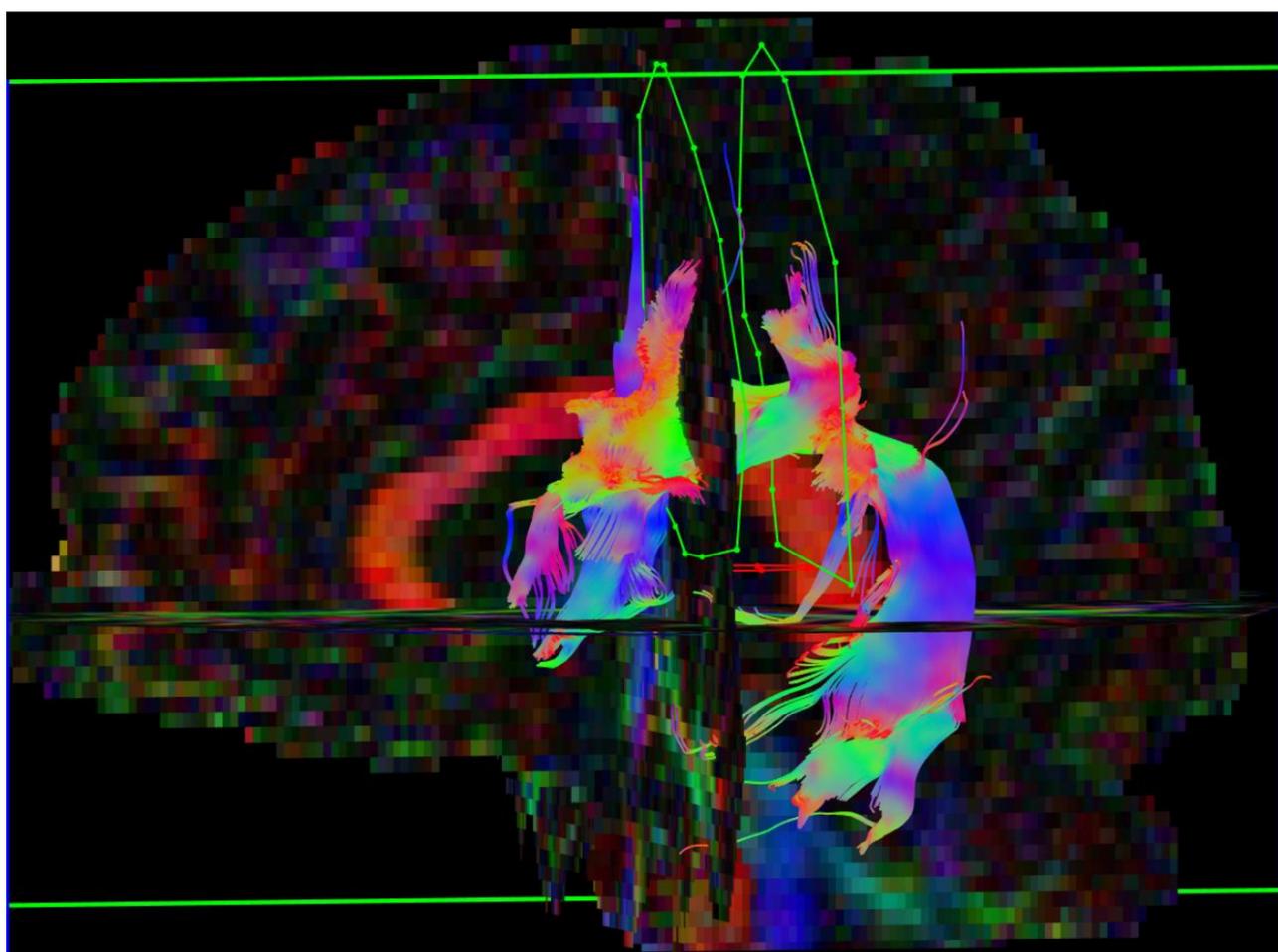
described by Wakana et al.

Wakana S, Caprihan A, Panzenboeck MM, Perry JM, Gollub RL, Hua K, et al. Reproducibility of quantitative tractography methods applied to cerebral white matter. *Neuroimage*. 2007;36:630–44

1. First coronal AND ROI
 - o placed so that it intersects the mid-point of the posterior limb of internal capsule
 - o select the anterior-posterior (green) fibres of the SLF, located lateral to the CC and CST

2. Second coronal AND ROI
 - placed on a coronal image at the posterior margin of the sCC on midline
 - select the anterior-posterior (green) fibres of the SLF
3. Note that the locations for the coronal slices above should serve only as a guide... it's best to roll back-and-forth 5-10 slices from each landmark location, and then choose a slice on which the SLF appears as a tight, coherent, green triangle.
4. axial NOT ROIs may be needed to exclude the descending CST tracts





ARCUATE FASCICLE

Latin: *fasciculus arcuatus*

ANATOMY

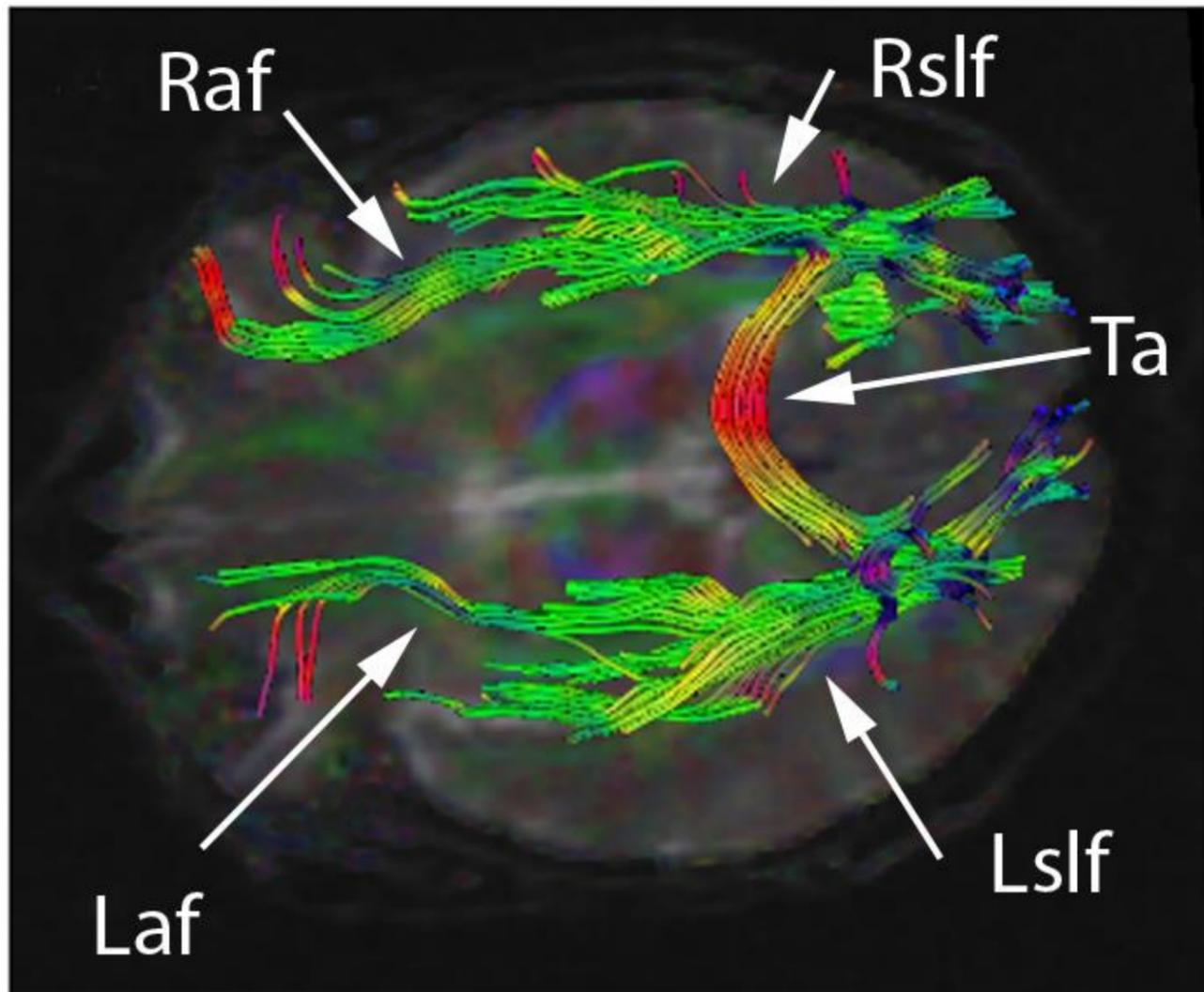
Bidirectionally connects:

posterior superior temporal cortex (Wernicke's area) - inferior parietal cortex - inferior frontal gyrus (Broca's area, premotor cortex [part of Brodmann area 6])

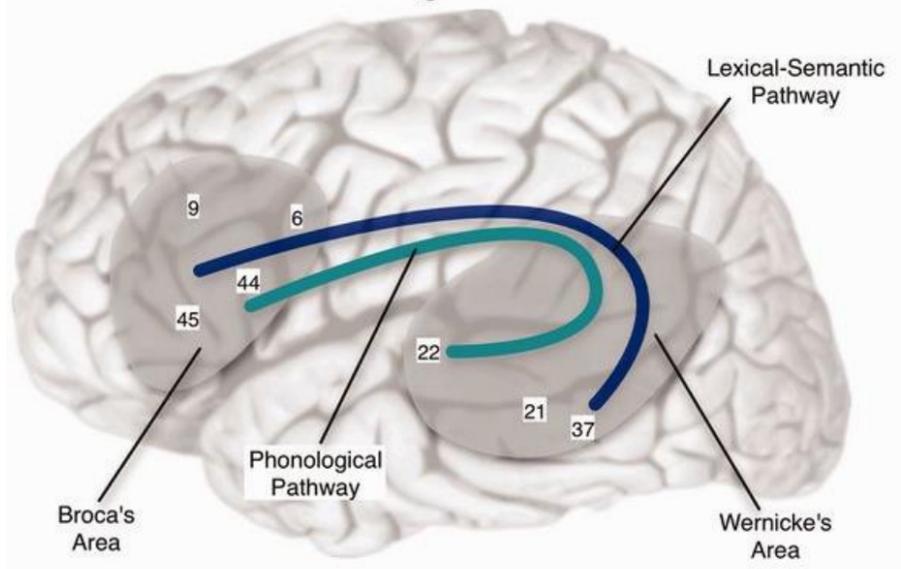
The **arcuate fasciculus** (Latin, *curved bundle*) is a bundle of axons that forms part of the **superior longitudinal fasciculus**.

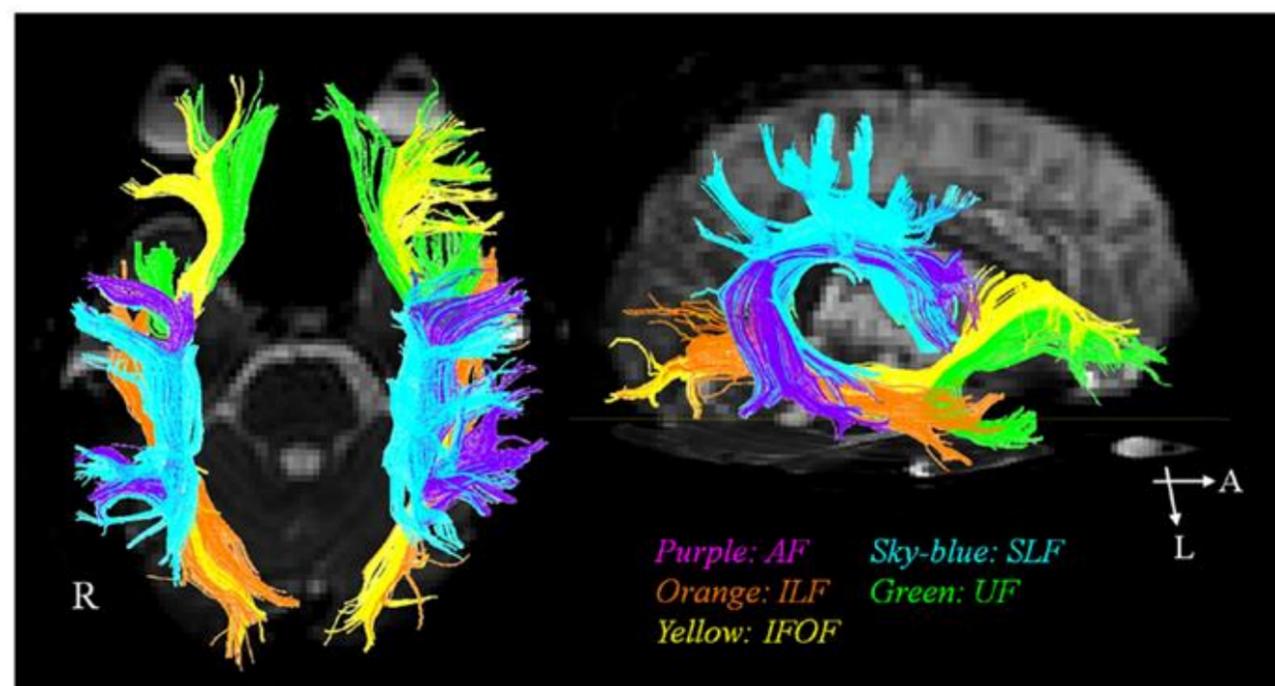
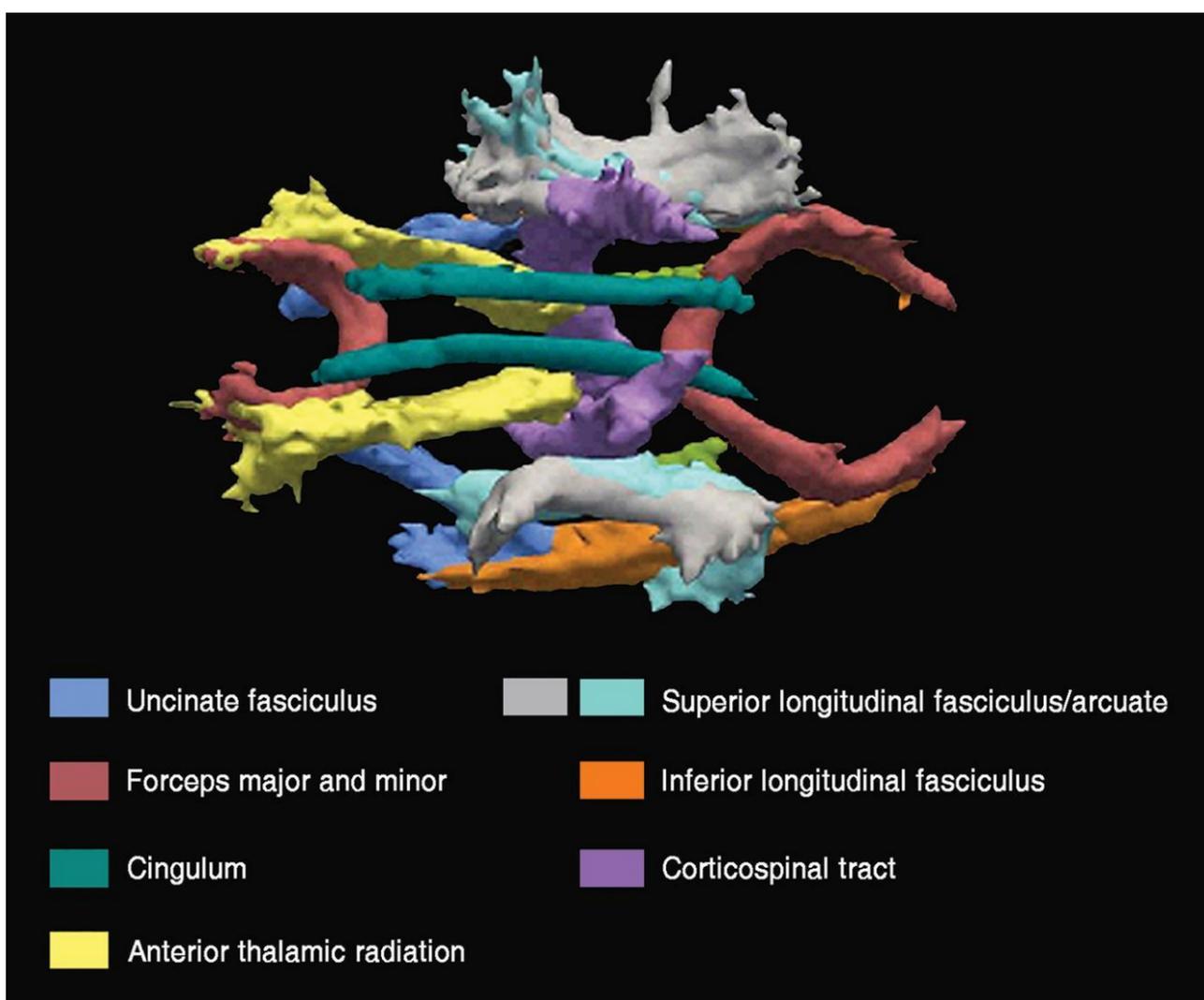
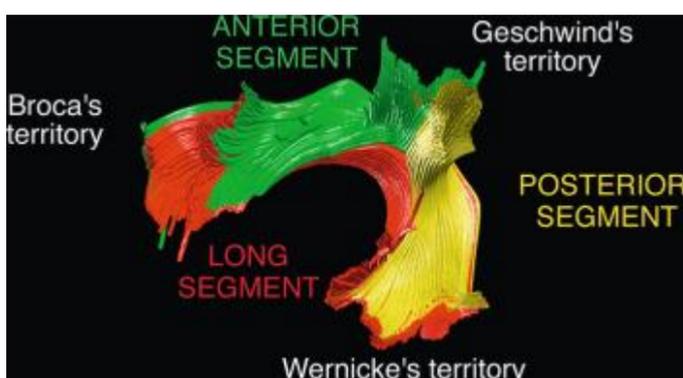
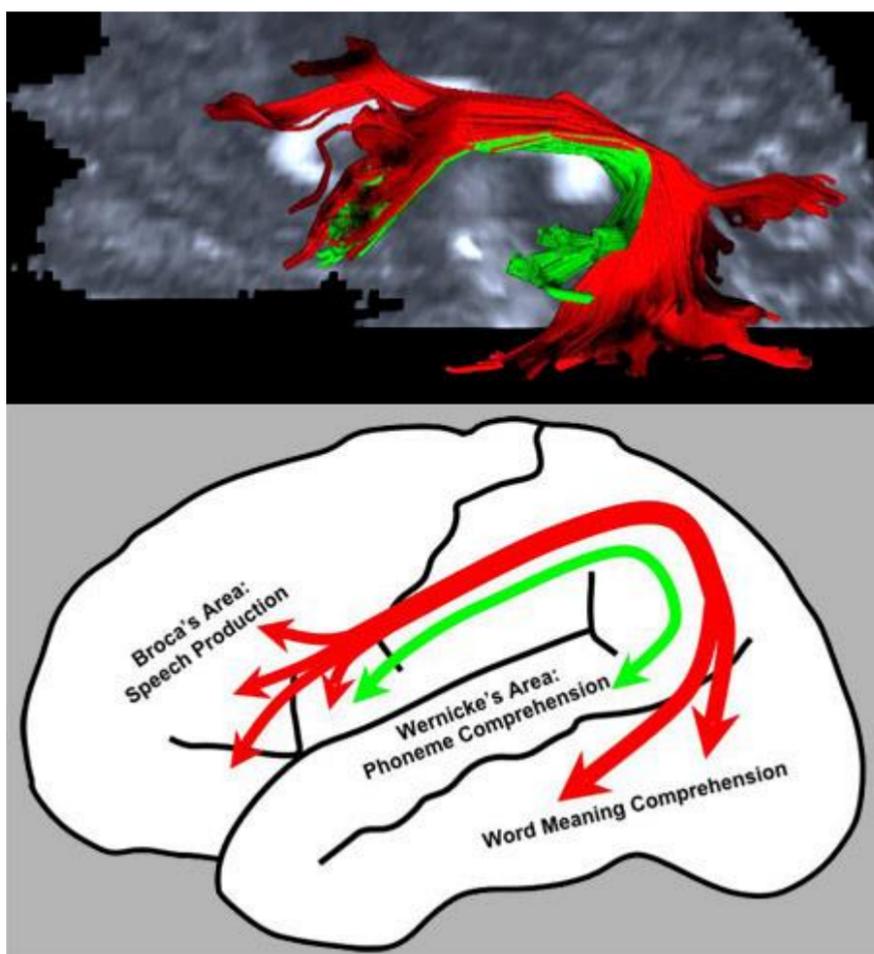
This bundle of **axons** is either not present or substantially smaller in nonhuman primates.^[3] Although the regions to which the arcuate fasciculus connects are still subject to debate, the connectivity of the arcuate has been shown to correspond to various functional areas within the temporal, parietal, and frontal lobes.^[4] Furthermore, the topographical relationships between independent measures of white matter and gray matter integrity suggest that rich developmental or environmental interactions influence brain structure and function, and that the presence and strength of such associations may elucidate pathophysiological processes influencing systems such as language and motor planning.

Common understanding has been that the arcuate fasciculus connects two important areas for language use, Broca's area in the inferior frontal gyrus and Wernicke's area in the posterior **superior temporal gyrus**. As the technique of **diffusion MRI** has improved, this has become a testable hypothesis using brain imaging. Research indicates more diffuse termination of the fibers of the arcuate, both rostrally and caudally, than previously thought. While the main caudal source of the fiber tract appears to be posterior superior temporal cortex, the rostral terminations are mostly in premotor cortex, part of Brodmann area 6.



Glasser & Rilling, 2008,
using DTI





CLINICAL IMPORTANCE

Evidence for the role of the arcuate fasciculus in language use is best represented by **conduction aphasia**, caused by damage to the **inferior parietal lobule** that extends into the subcortical white matter and damages the arcuate fasciculus.^[7] This type of **aphasia** inhibits the patient from repeating unfamiliar sounds. A study by Catani, Jones, and Ffytche (2005) provided the first anatomical evidence for the presence of two pathways between Wernicke's area and Broca's area.^{[8][9]} They found one deep pathway, interpreted to directly connect these two regions, and a shallower pathway that consists of two segments; the anterior segment connects frontal cortex with inferior parietal cortex, and the posterior segment connects Wernicke's area with the inferior parietal cortex. Damage to the direct pathway may produce conduction aphasia, whereas damage to the indirect pathway spares the ability to repeat speech but impairs comprehension. The symptoms of conduction aphasia suggest that the connection between posterior temporal cortex and frontal cortex plays a vital role in short-term memory of words and speech sounds that are new or have just been heard. The arcuate fasciculus connects these two regions and circulates information back and forth, possibly contributing to short-term memory.

In nine out of ten people with **tone deafness**, the superior arcuate fasciculus in the right hemisphere could not be detected, suggesting a disconnection between the posterior superior temporal gyrus and the

posterior inferior frontal gyrus. Researchers suggested the posterior superior temporal gyrus was the origin of the disorder.^[10]

In **stutterers**, the arcuate fasciculus appears to have bilateral deficits that reduce it by one-third or more relative to non-stutterers.^[11] However, there is ongoing debate concerning the contribution of each hemisphere and the presence of hemispheric differences, and diffusion-based evidence of differences between stutterers and controls is not isolated to the arcuate fasciculus.

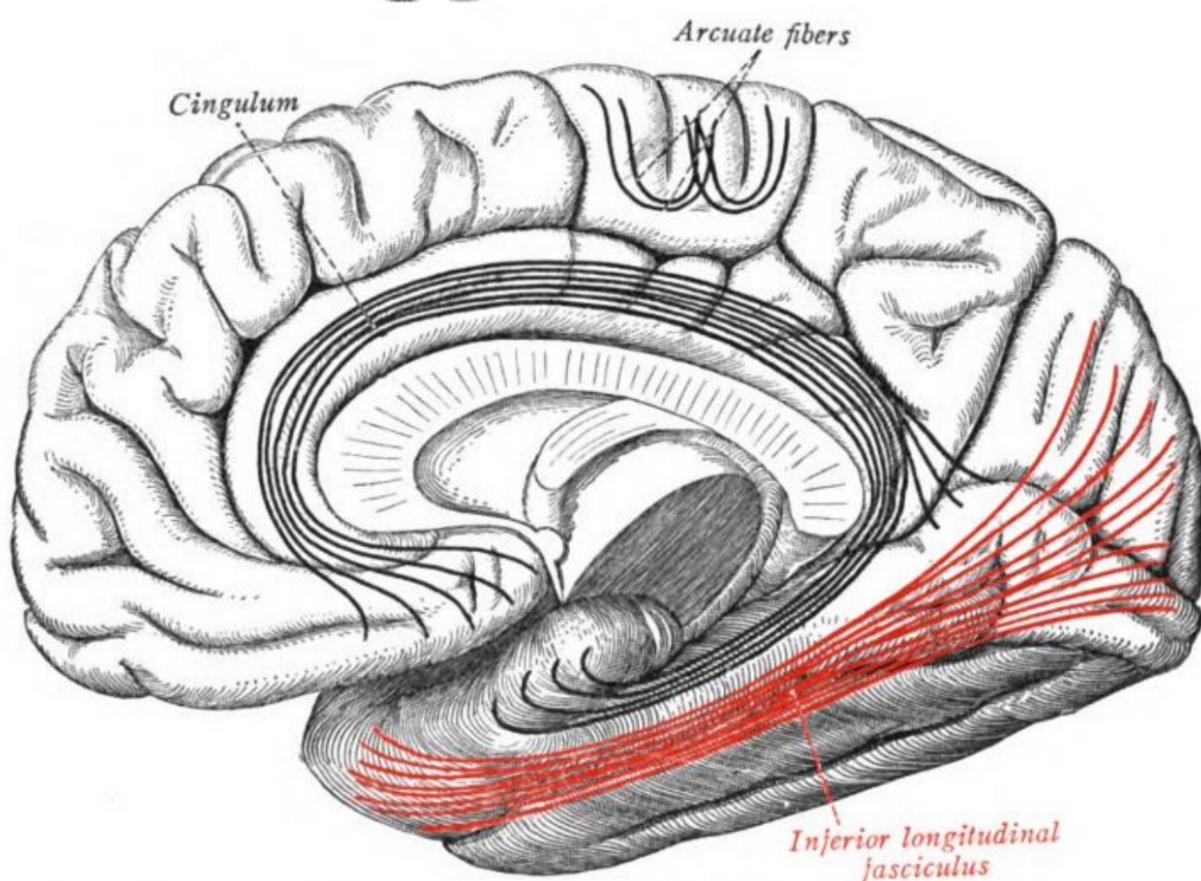
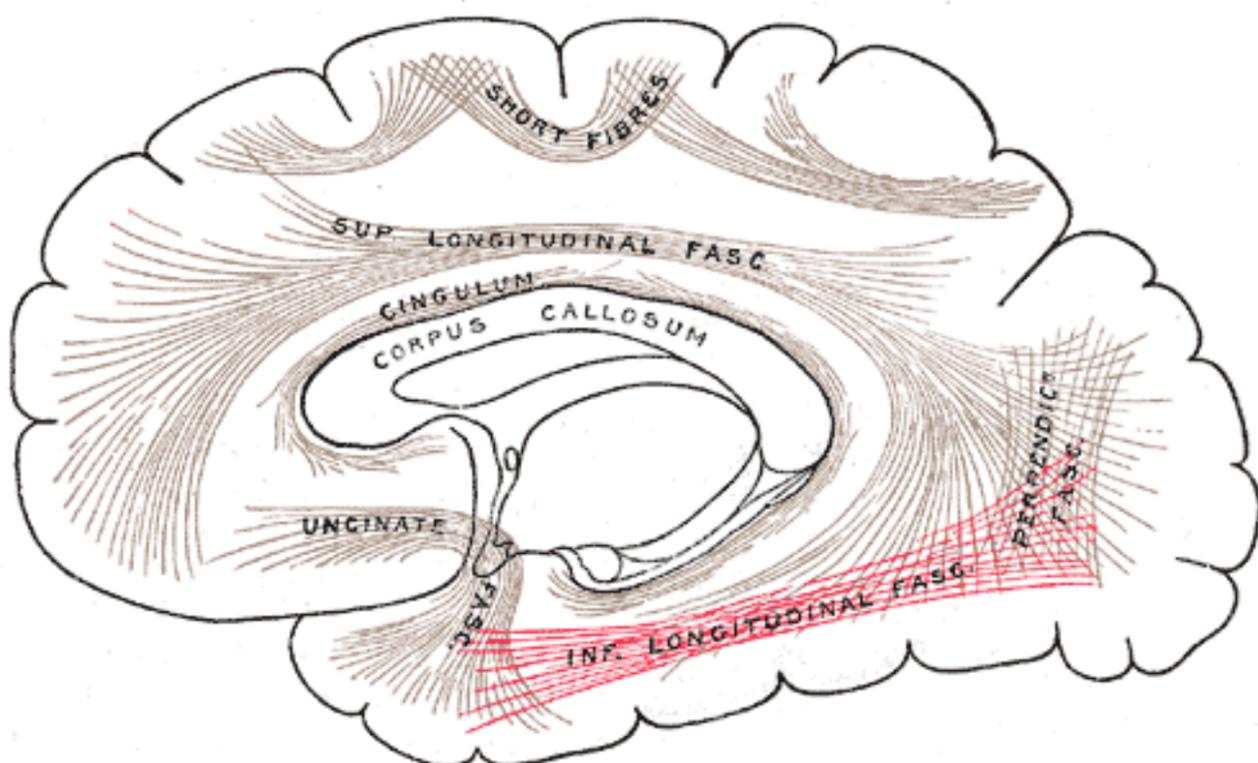
INFERIOR LONGITUDINAL FASCICULUS (ILF, OCCIPITOTEMPORAL PROJECTION)

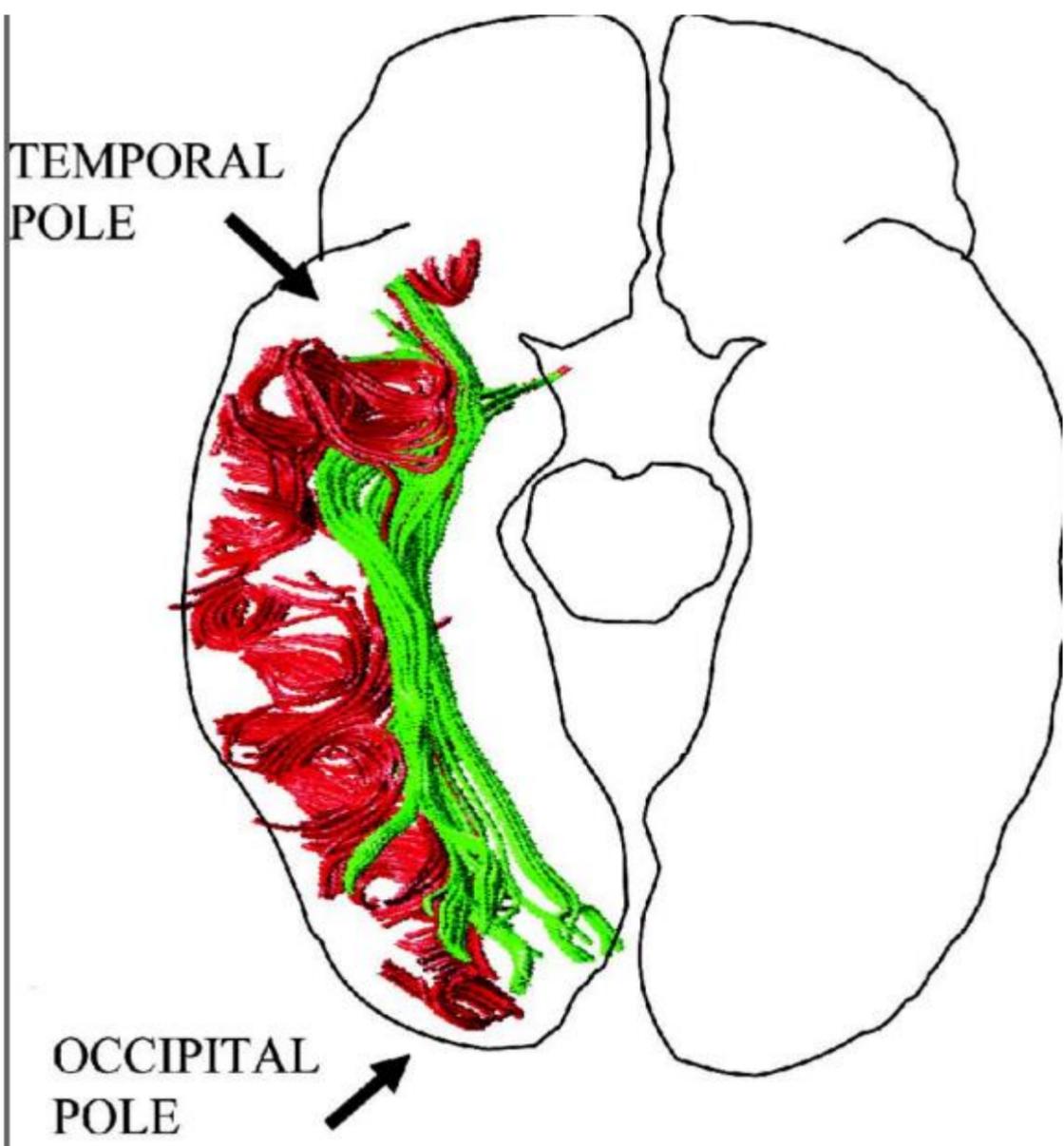
Latin: *Fasciculus longitudinalis inferior cerebri*

ANATOMY

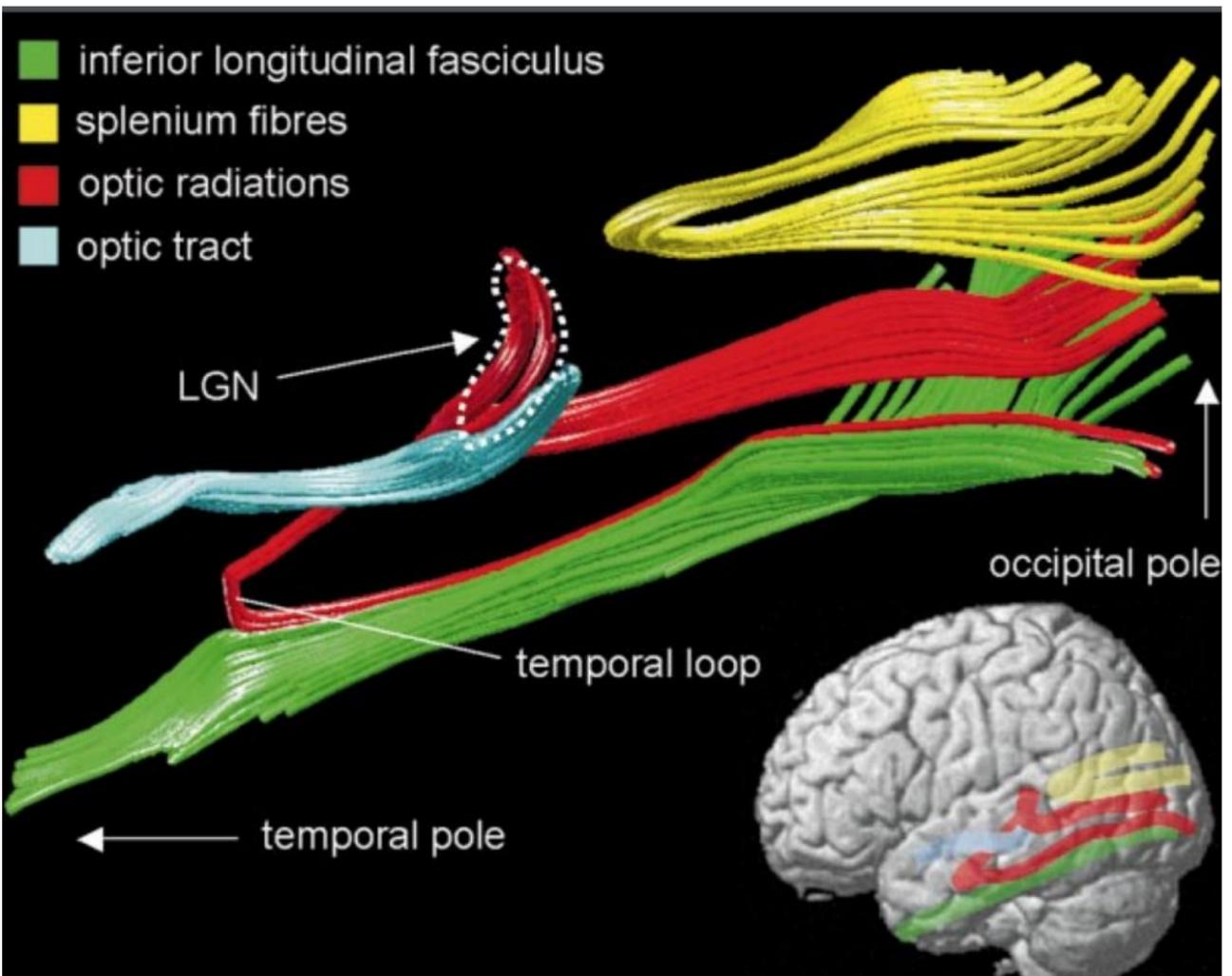
- connects: anterior part of temporal lobe (temporal pole) – fusiform gyrus - occipital lobe (inferior occipital gyrus)
- runs:
 - along the inferolateral walls of the inferior and posterior cornua of the lateral ventricle.
 - laterally and inferiorly above optic radiation fibers.
 - spatially overlaps with the IFOF along part of their pathways.
 - anteriorly joins the uncinate fasciculus to relay information to the orbito-frontal brain

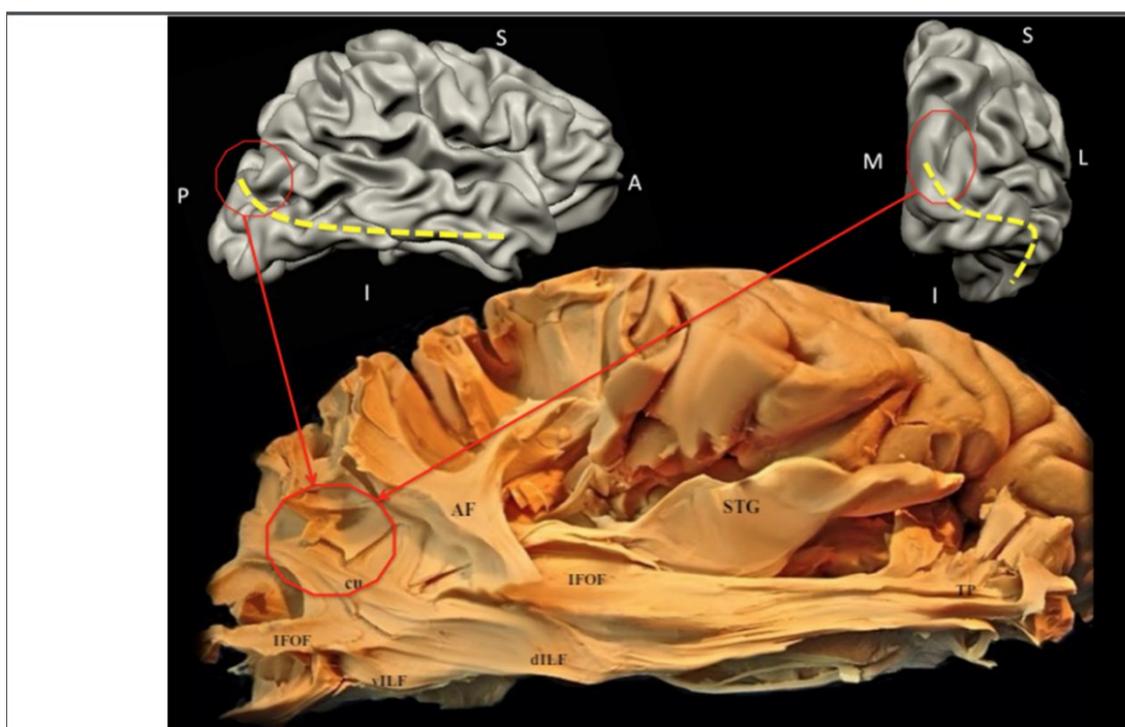
IFOF is direct fronto-occipital pathway
 ILF is indirect fronto-occipital pathway





- U-shaped occipito-temporal projection system
- Inferior longitudinal fasciculus





Latini 2013

dILF: Afferents & Efferents

Includes fibers originating in:

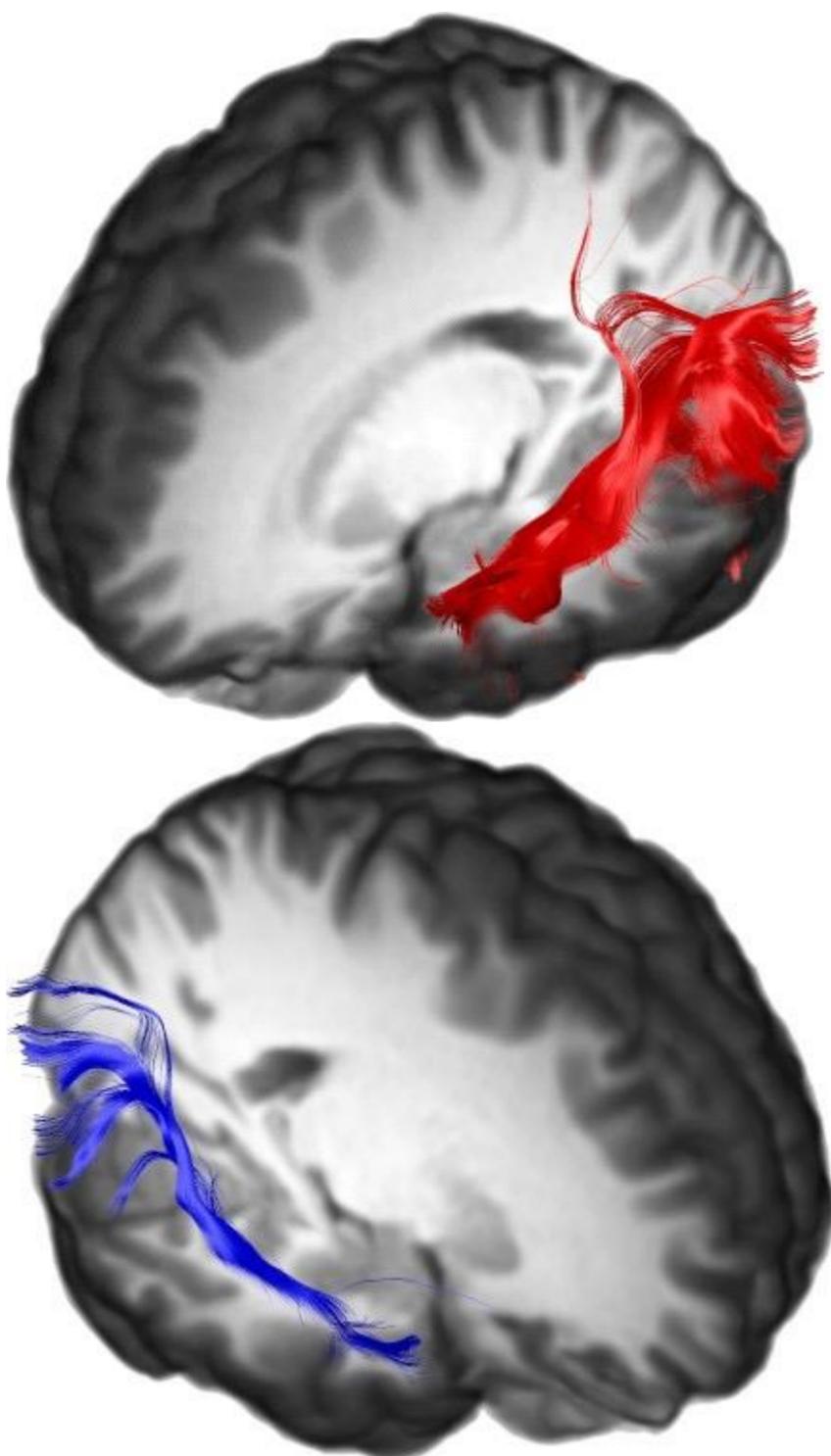
- superior temporal gyrus
- middle temporal gyrus
- inferior temporal gyrus
- fusiform gyrus

these project to:

- lingual gyrus
- cuneus
- lateral occipital cortex
- occipital pole



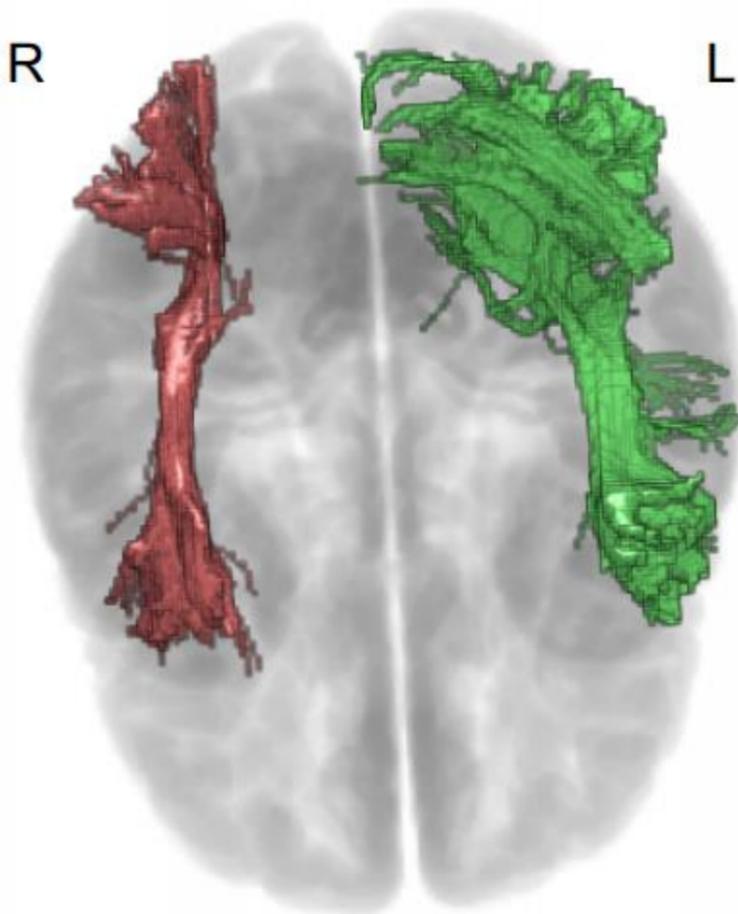
Image from Latini 2013



HEMISPHERIC SPECIALIZATION

Left hemisphere: language

Right hemisphere: face processing



CLINICAL SIGNIFICANCE

Ortibus E, Verhoeven J, Sunaert S, Casteels I, De Cock P, Lagae L. Integrity of the inferior longitudinal fasciculus and impaired object recognition in children: a diffusion tensor imaging study. *Dev Med Child Neurol* DOI: 10.1111/j.1469-8749.2011.04147.x. (Published online).

- compromised ILF integrity in children with visual-perceptual impairment.
- correlations between decreased fractional anisotropy of the ILF and impaired **object recognition**.
- although the authors clearly showed the relationship between ILF integrity and object recognition, based on strong correlations between the ILF and IFOF it is likely that the IFOF also plays a role in the execution of such processes.

Ashtari M, Cottone J, Ardekani BA, et al. Disruption of white matter integrity in the inferior longitudinal fasciculus in adolescents with schizophrenia as revealed by fiber tractography. *Arch Gen Psychiatry* 2007; 64: 1270–80.

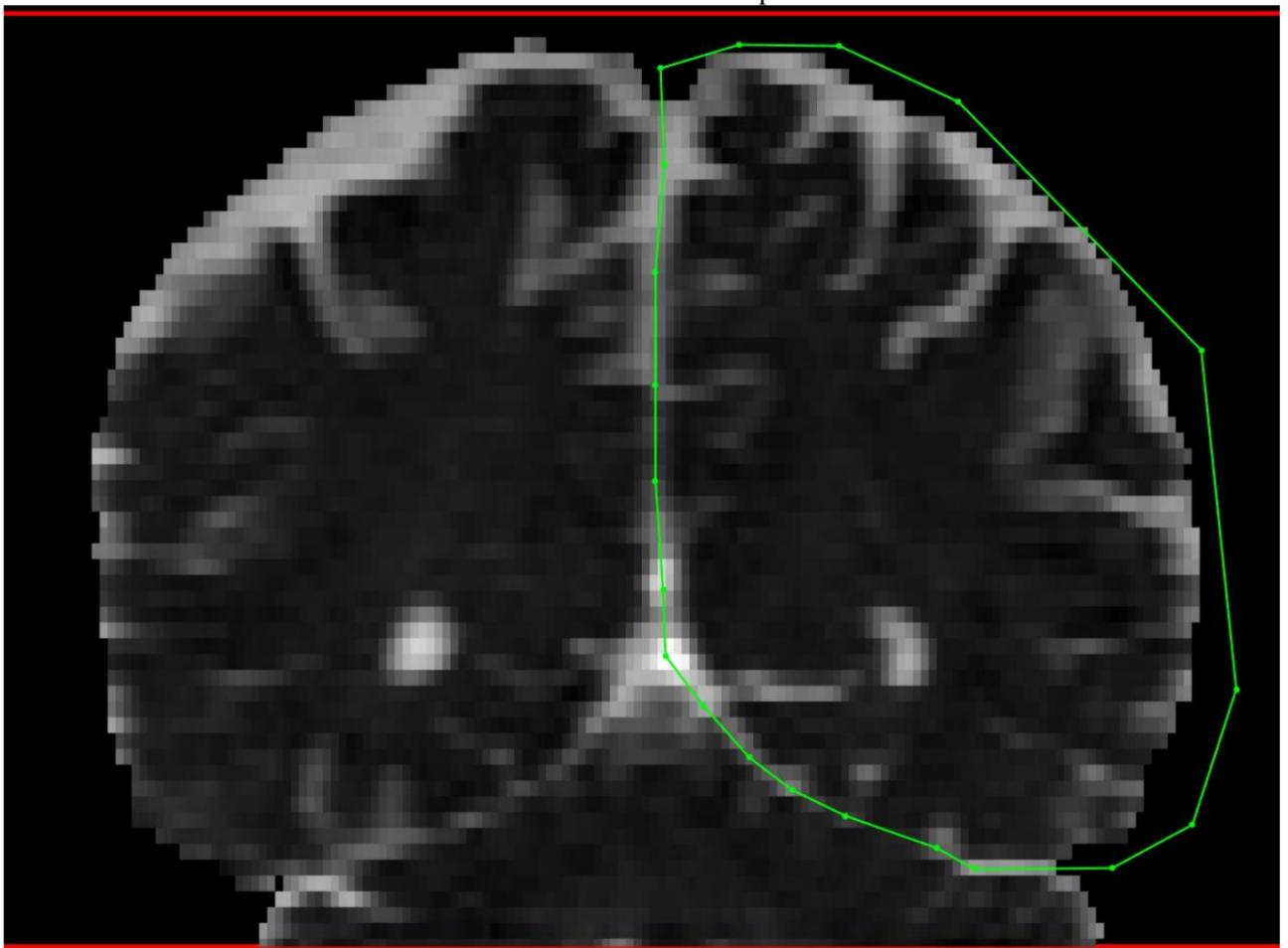
- lower fractional anisotropy in the ILF is reported in a group of adolescent patients with schizophrenia with visual hallucinations

DTI PROTOCOL

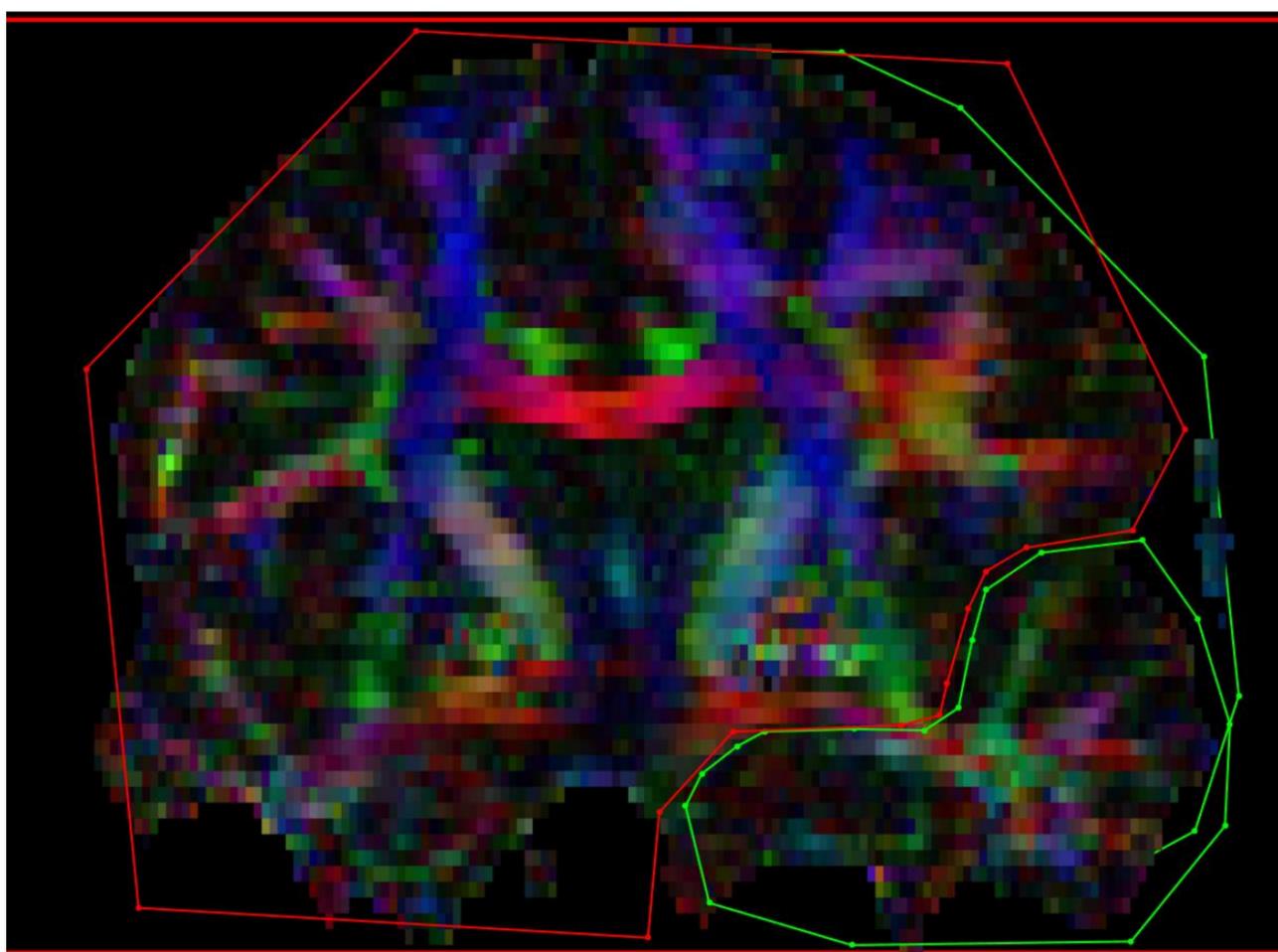
described by Wakana et al.

Wakana S, Caprihan A, Panzenboeck MM, Perry JM, Gollub RL, Hua K, et al. Reproducibility of quantitative tractography methods applied to cerebral white matter. *Neuroimage*. 2007;36:630–44

1. First coronal AND ROI
 - Using a parasagittal slice, the posterior edge of the cingulum (for that side) is identified
 - Create an AND ROI that includes the entire hemisphere

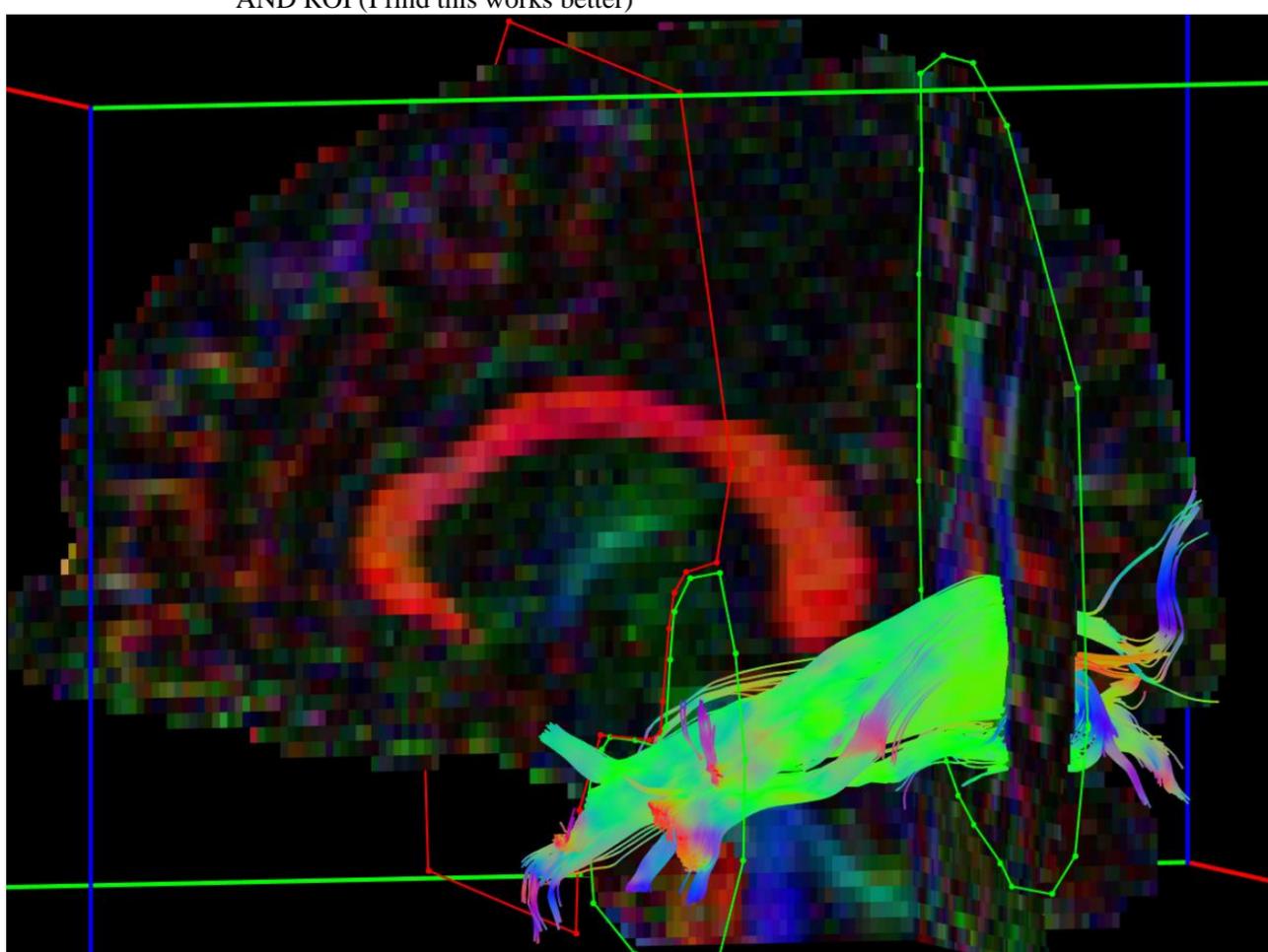


2. Second coronal AND ROI
 - the most posterior coronal slice in which the temporal lobe is not connected to the frontal lobe is selected.
 - A little bit tricky to find... try to find the medial posterior margin of the anterior temporal lobe on an axial slice view
 - this method tends to place the AND ROI too anterior, missing many ILF fibres, so I have to move posterior using the FEFA (DTI) images to guide to the point where ILF branches off from the IFO bundle
 - Be careful not to include the inferior fronto-occipital fasciculus (IFO), which lies above the ILF
 - Create an AND ROI that includes the entire (anterior) temporal lobe.



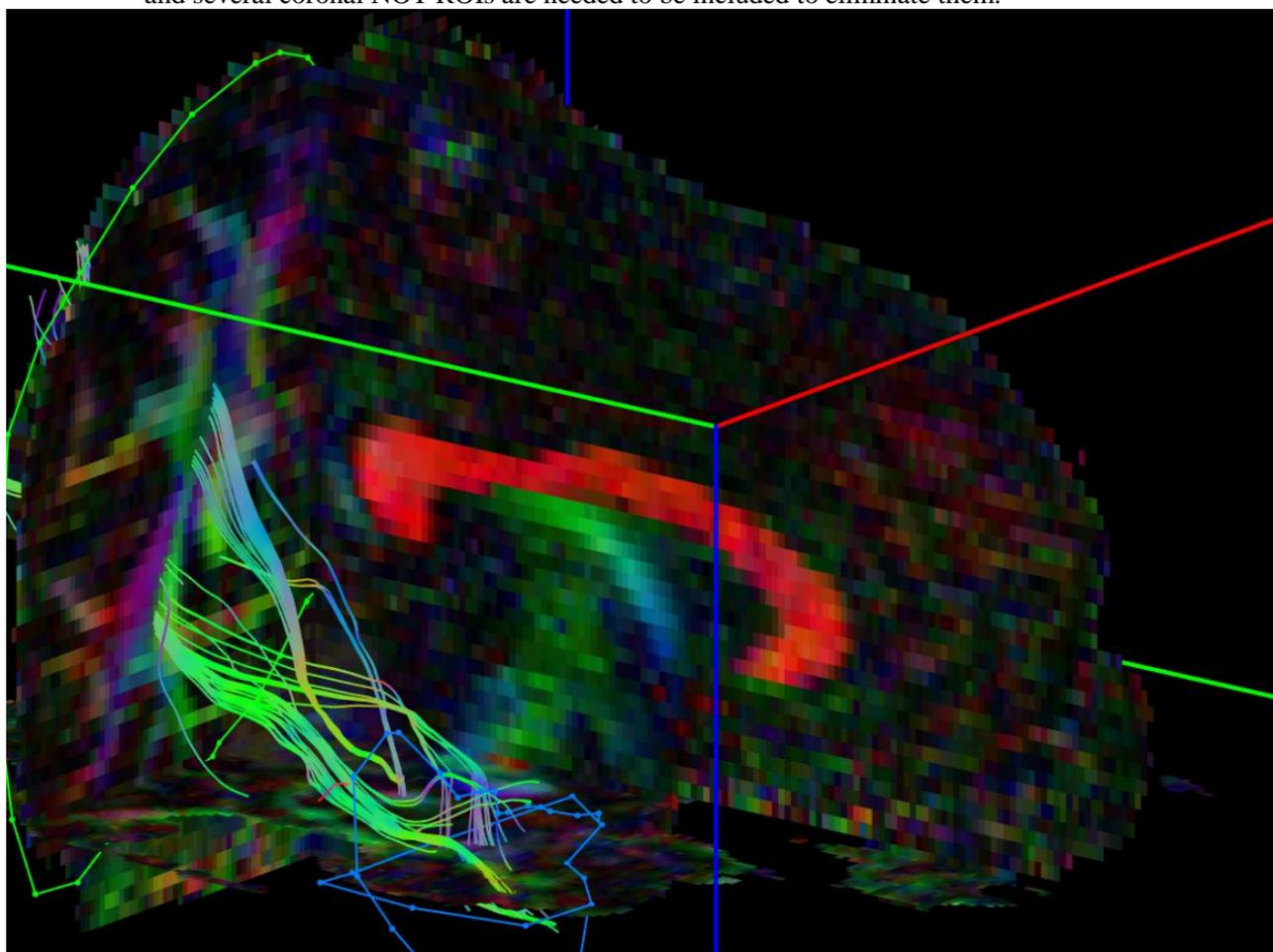
3. Optional coronal NOT ROI – to exclude IFO

- sometimes it is difficult to exclude the IFO from the ILF using the AND ROIs
- in that case, place a coronal NOT ROI, either:
 - anterior to the corpus callosum (CC), covering the whole frontal lobe – analogous to the second coronal AND ROI used to define the IFO
 - or in the same plane as the second coronal AND ROI, excluding everything outside of the AND ROI (I find this works better)



4. Axial SEED ROI

- This method is needed in cases where the angle of the scan acquisition has caused the inferior portion of the anterior temporal lobes to be lost (in which case the second coronal AND ROI captures very few tracts)
- The second (anterior) coronal AND ROI is replaced with a SEED ROI in the same position
- The axial SEED ROI is drawn from the anterior tip of the temporal pole, extending posterior to roughly the posterior margin of the hippocampus (or the midbrain could be used as a reference)
- The disadvantage to this method is that there may be numerous non-ILF tracts included as well, and several coronal NOT ROIs are needed to be included to eliminate them.

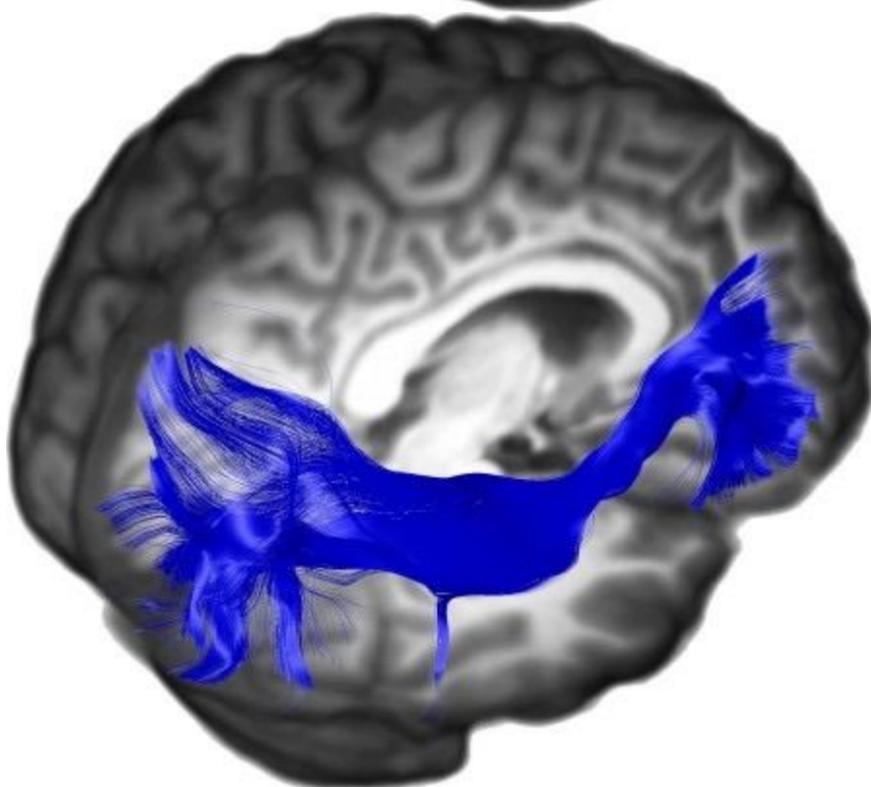
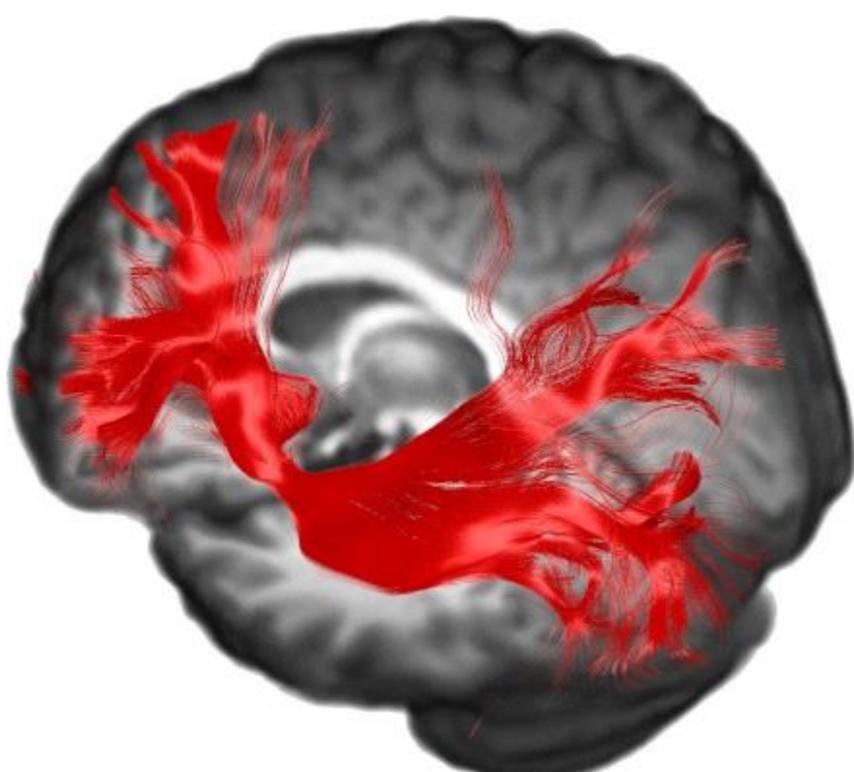
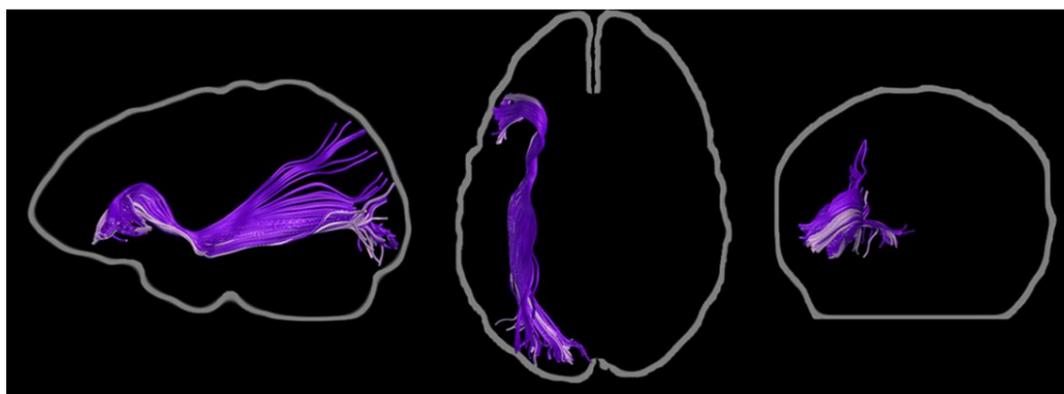
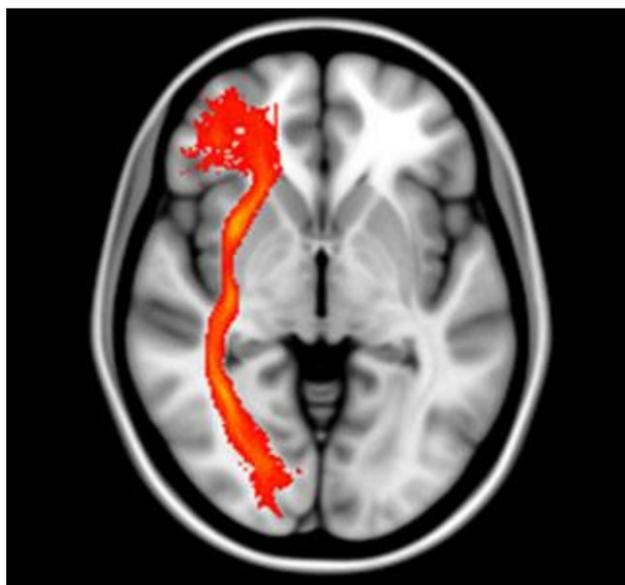


INFERIOR FRONTO-OCCIPITAL FASCICULUS (IFOF)

Latin: fasciculus occipitofrontalis inferior

- connects: occipital cortex - posterior temporal area - orbito-frontal area.
- runs:
 - along the lateral border of the caudate nucleus, on the medial aspect of the corona radiata; medially and above the optic pathways
 - fibers radiate in a fan-like manner and pass into the occipital and temporal lobes lateral to the posterior and inferior cornua.

- spatially overlaps with ILF along part of their pathways.
- IFOF is direct fronto-occipital pathway
 ILF is indirect fronto-occipital pathway

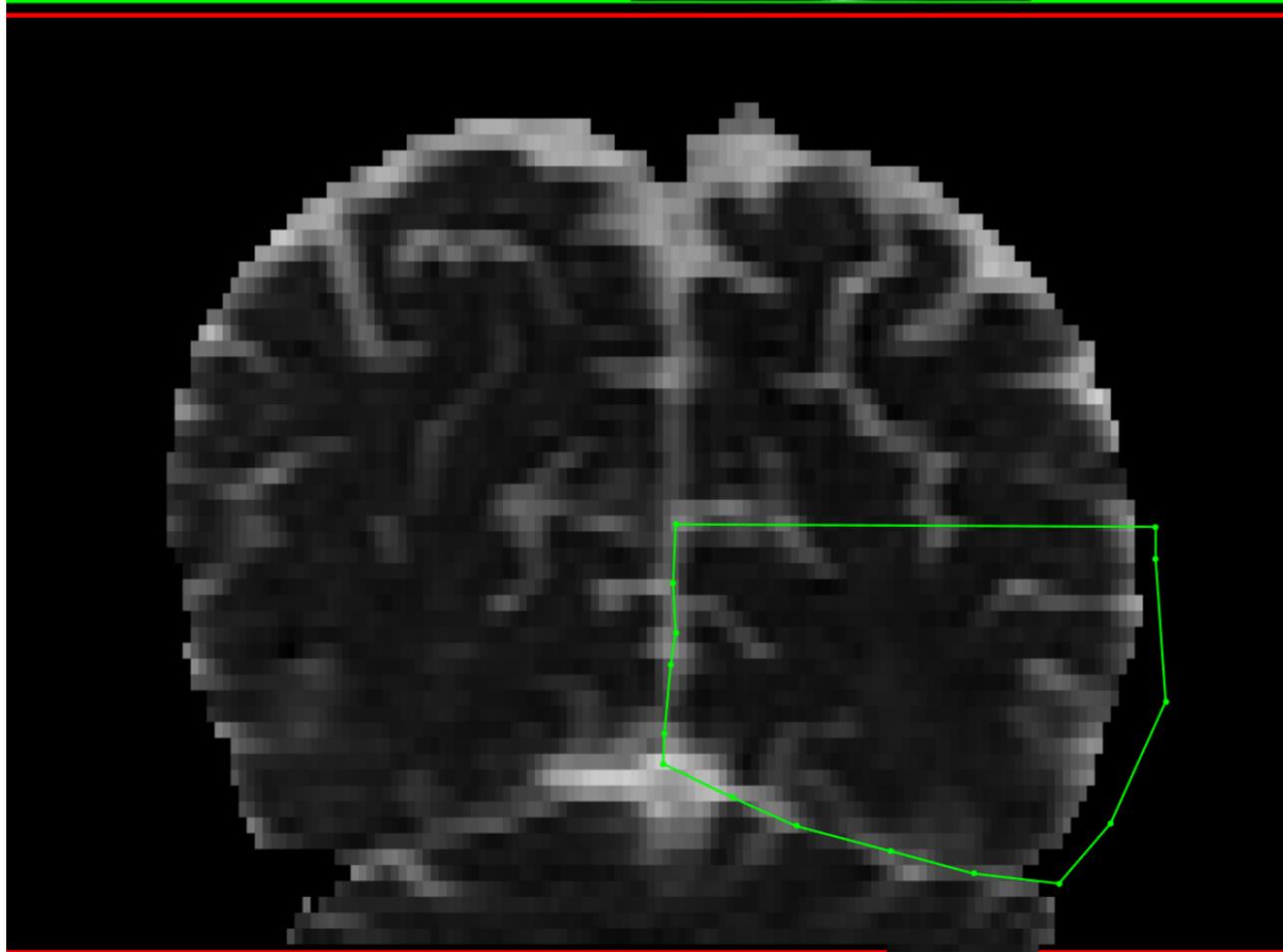
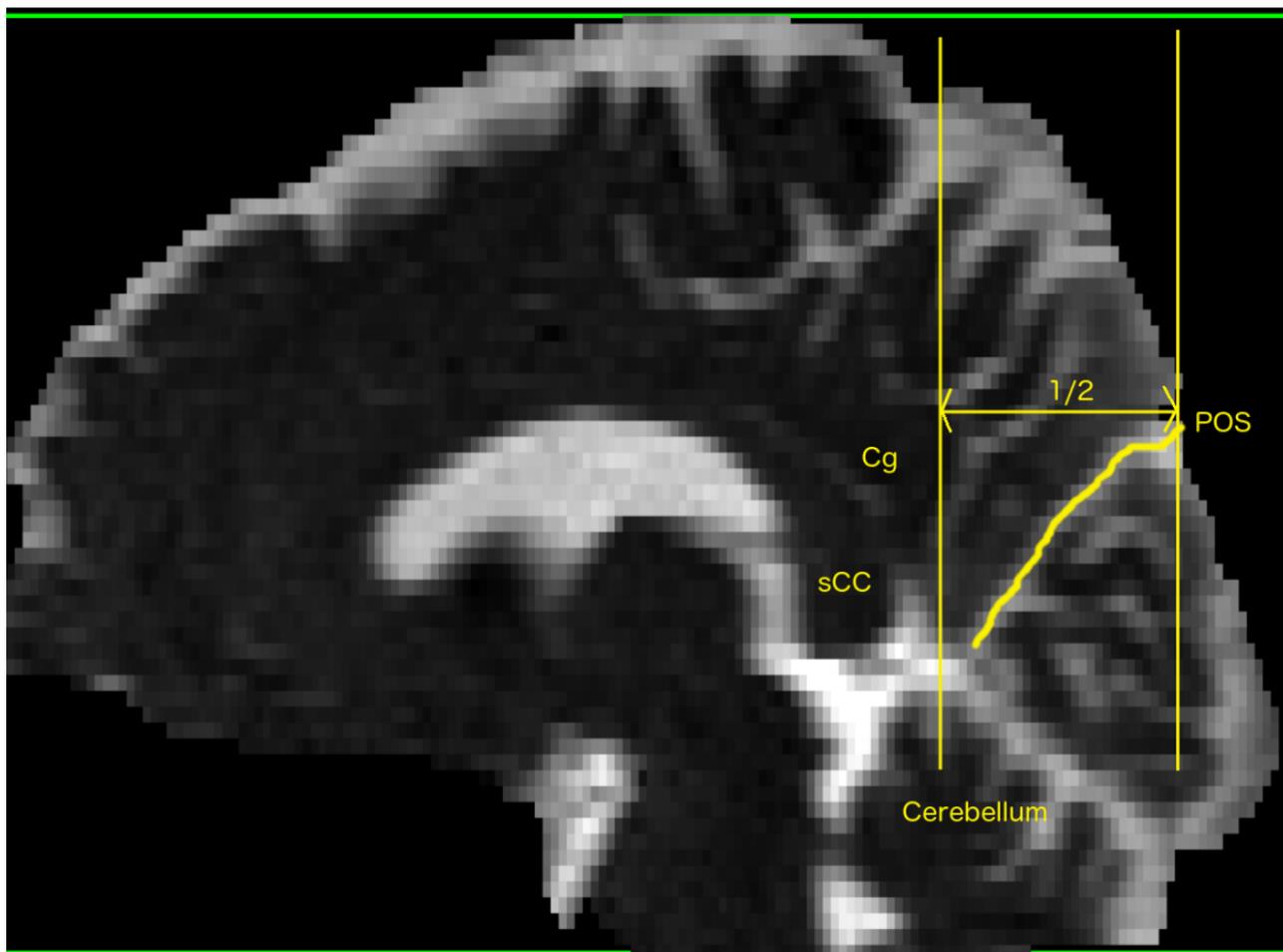


DTI PROTOCOL

described by Wakana et al.

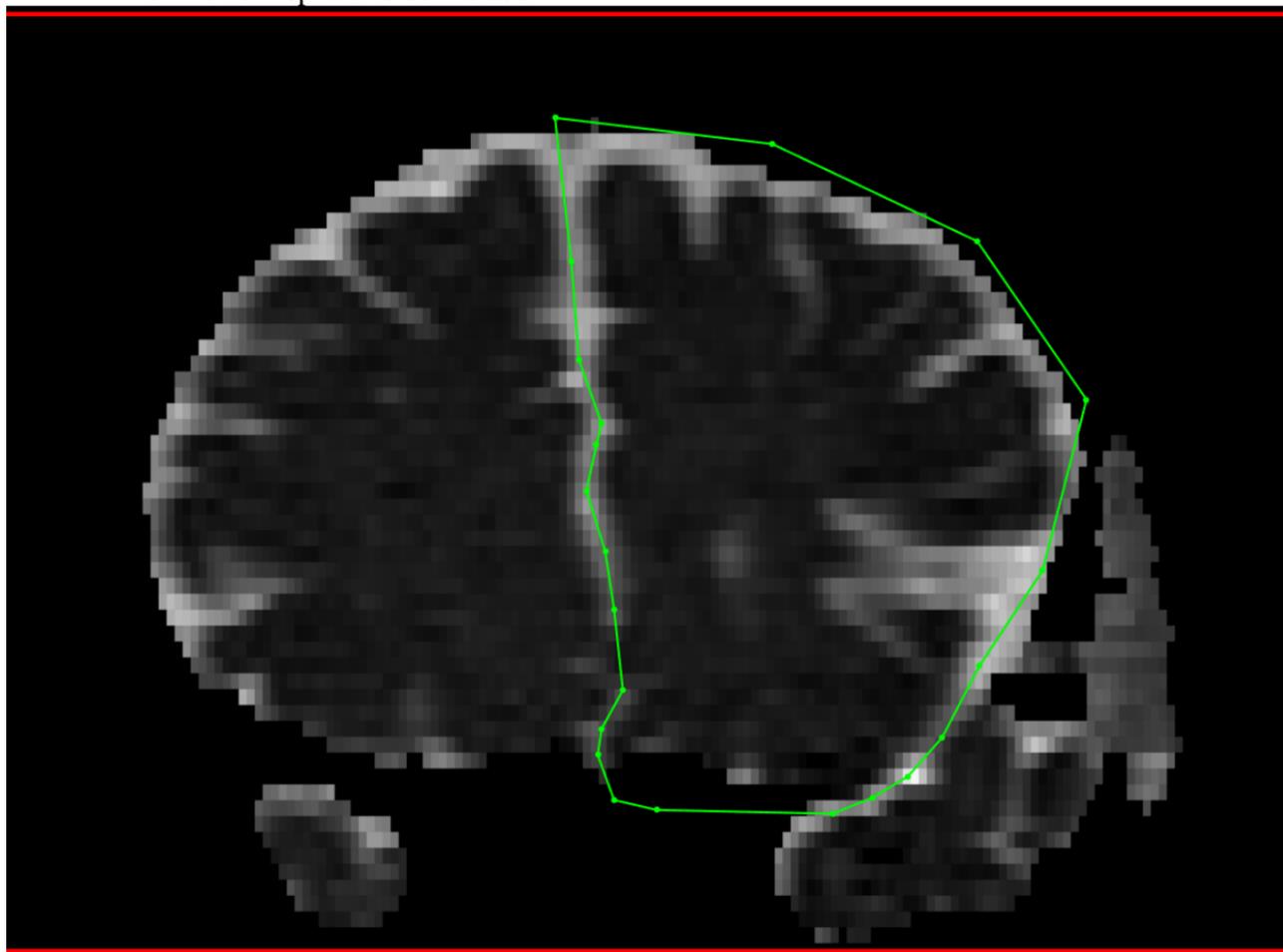
Wakana S, Caprihan A, Panzenboeck MM, Perry JM, Gollub RL, Hua K, et al. Reproducibility of quantitative tractography methods applied to cerebral white matter. Neuroimage. 2007;36:630–44

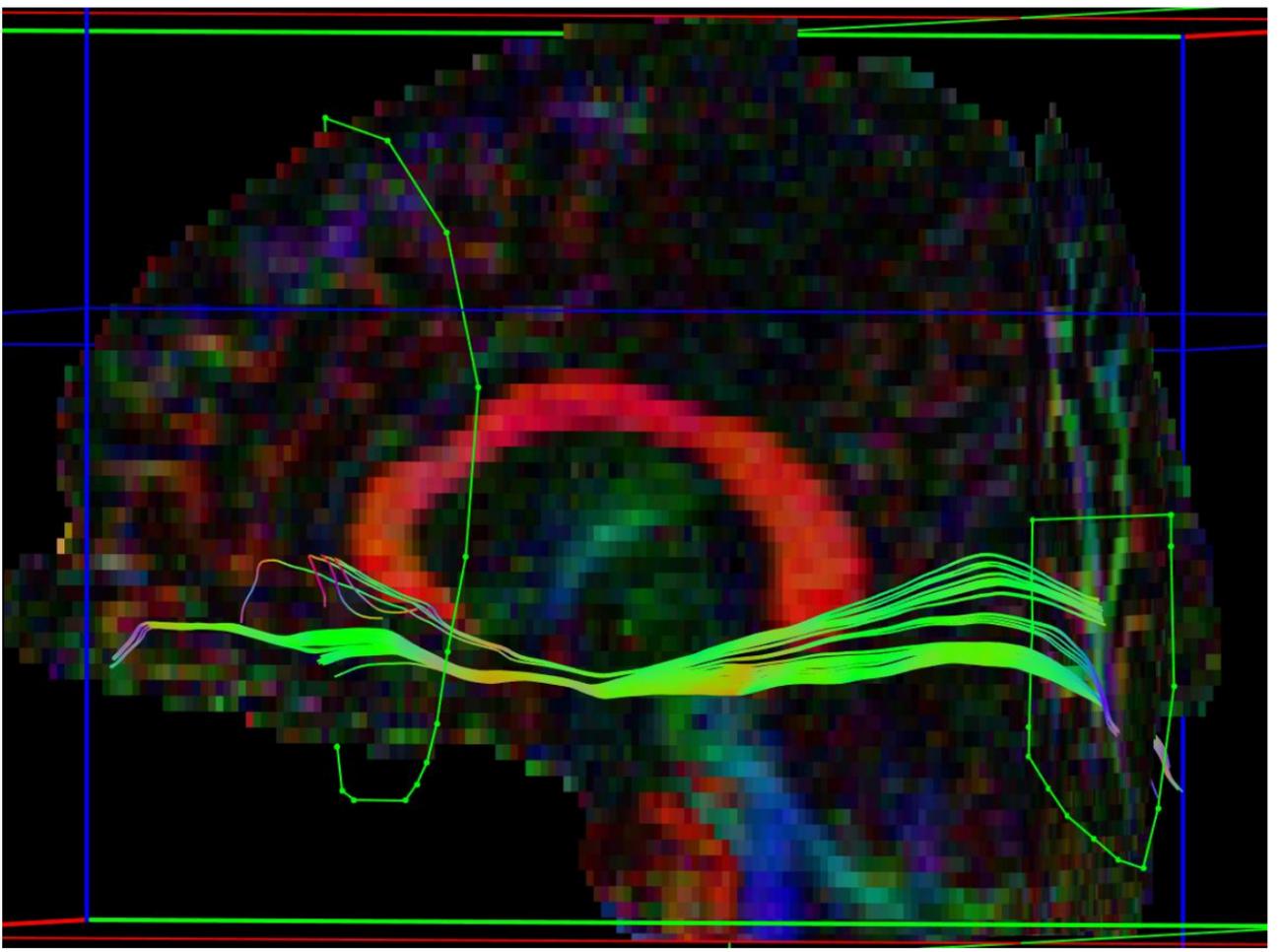
1. First coronal AND ROI
 - On parasagittal view (place on the cingulum)
 - Define posterior edge of cingulum
 - Define posterior edge of parieto-occipital sulcus (POS) (easier to see on non-DW or MD images rather than FEFA color map)
 - Find coronal section on the mid-point between these two planes
 - Draw a coronal AND ROI that delineates the occipital lobe at this level
 - Define the boundary between the occipital and parietal lobes by extending the POS laterally from the parasagittal slice where it intersects the midpoint coronal AND ROI



2. Second coronal AND ROI

- o coronal slice is selected at the anterior edge of the genu of corpus callosum (gCC) and the entire hemisphere is delineated.

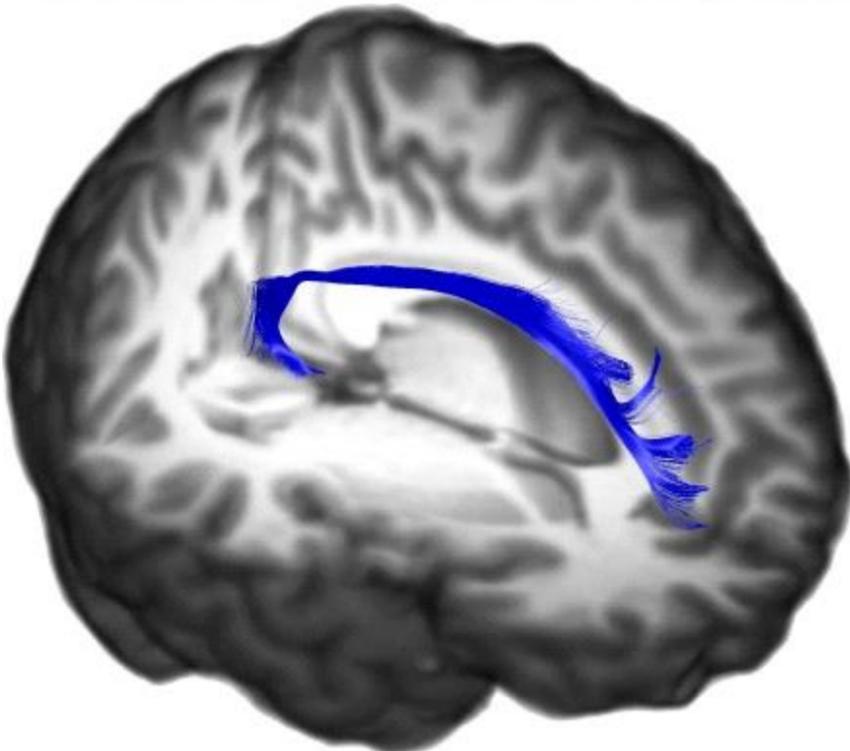
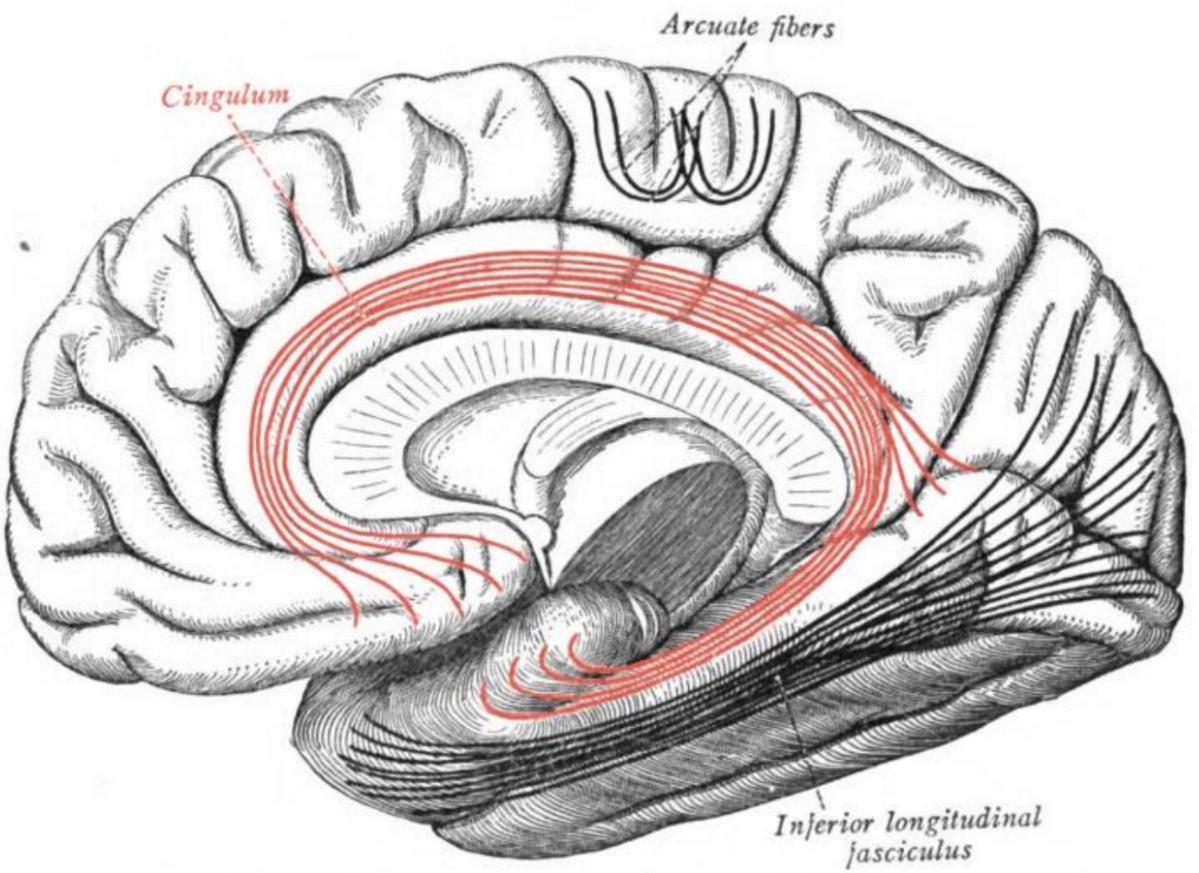
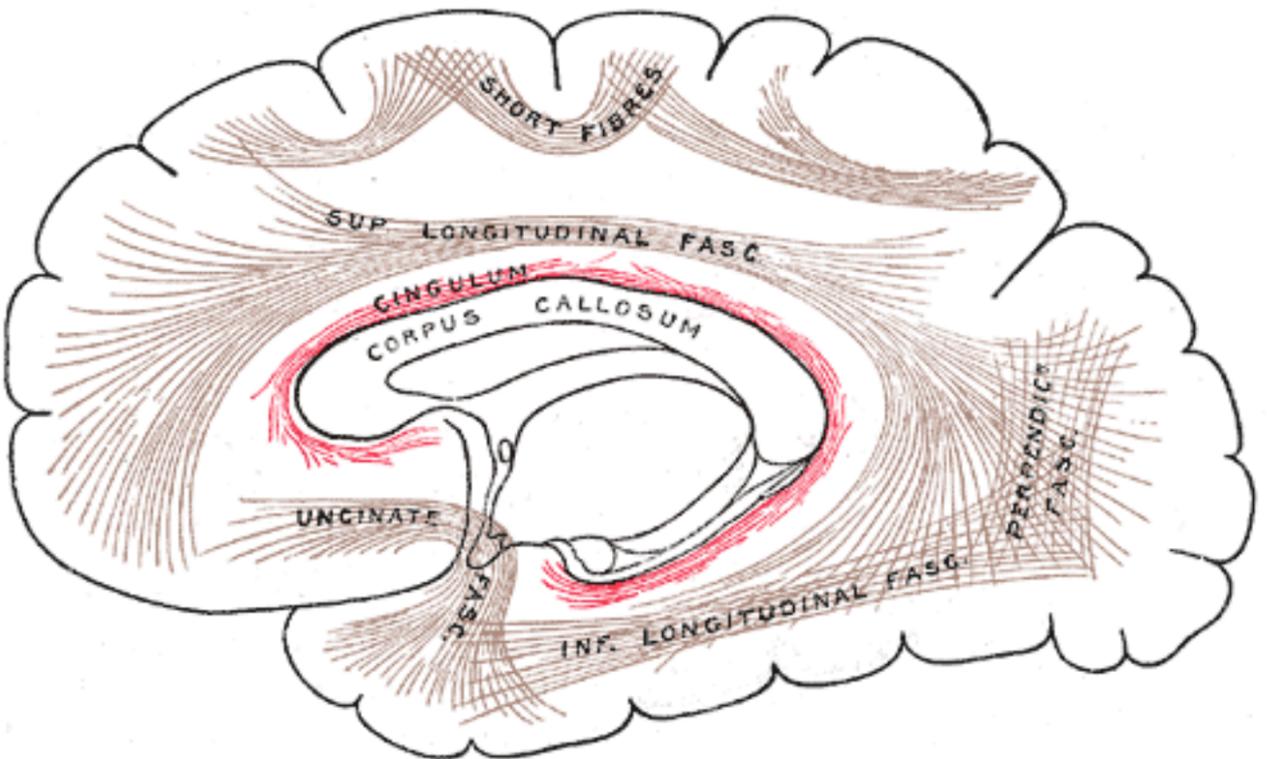


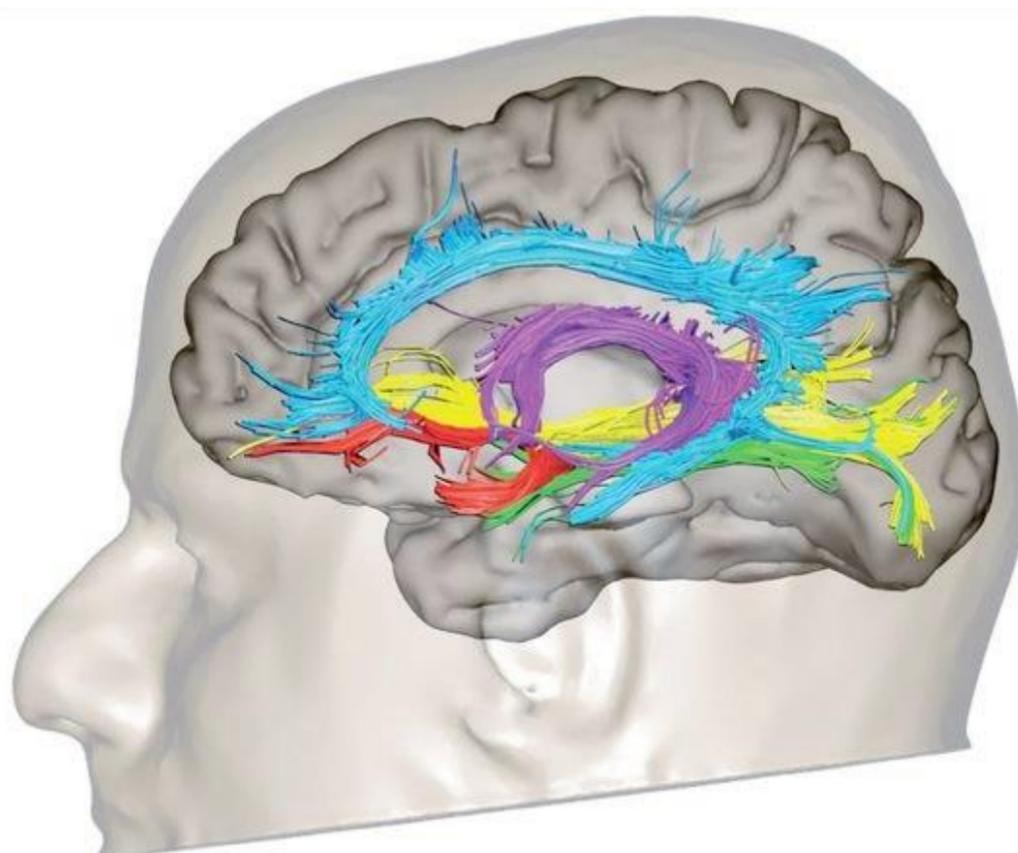


3. NOT ROIs

- o placed as needed to remove fibres from the cingulum and some fibers relayed at the thalamus.

CINGULUM





- Uncinate ■ Inferior fronto-occipital
■ Inferior longitudinal ■ Fornix ■ Cingulum



ANATOMY

subcallosal gyrus → white matter core of the cingulate gyrus → entorhinal cortex, parahippocampal gyrus and uncus

The cingulum is a collection of white matter fibers projecting from the cingulate gyrus to the entorhinal cortex - communication between components of the limbic system. It forms the white matter core of the cingulate gyrus, following it from the subcallosal gyrus of the frontal lobe beneath the rostrum of corpus callosum to the parahippocampal gyrus and uncus of the temporal lobe.

Neurons of the cingulum receive afferent fibers from the parts of the thalamus that are associated with the spinothalamic tract. This, in addition to the fact that the cingulum is a central structure in learning to correct mistakes, indicates that the cingulum is involved in appraisal of pain and reinforcement of behavior that reduces it.

The cingulum was one of the earliest identified brain structures.

The cingulum is described from various brain images as a C shaped structure within the brain that wraps around the frontal lobe to the temporal lobe right above the corpus callosum. It is located beneath the cingulate gyrus within the medial surface of the brain therefore encircling the entire brain. There are two primary parts of the cingulate cortex, as is typical with most brain structures.

FUNCTION

There is the posterior cingulate and anterior cingulate. **The anterior is linked to emotion**, especially apathy and depression. Here function and structure changes are related meaning any change within this structure would lead to a function change, particularly behavioral because of its function involving emotions. Damage to this area can have various effects on mental disorders and mental health. Cingulotomy, the surgical severing of the anterior cingulum, is a form of psychosurgery used to treat depression and OCD.

The posterior section is more related to cognitive functions. This can include attention, visual and spatial skills, working memory and general memory. Because of its location, the cingulum is very important to brain structure connectivity and the integration of information that it receives.

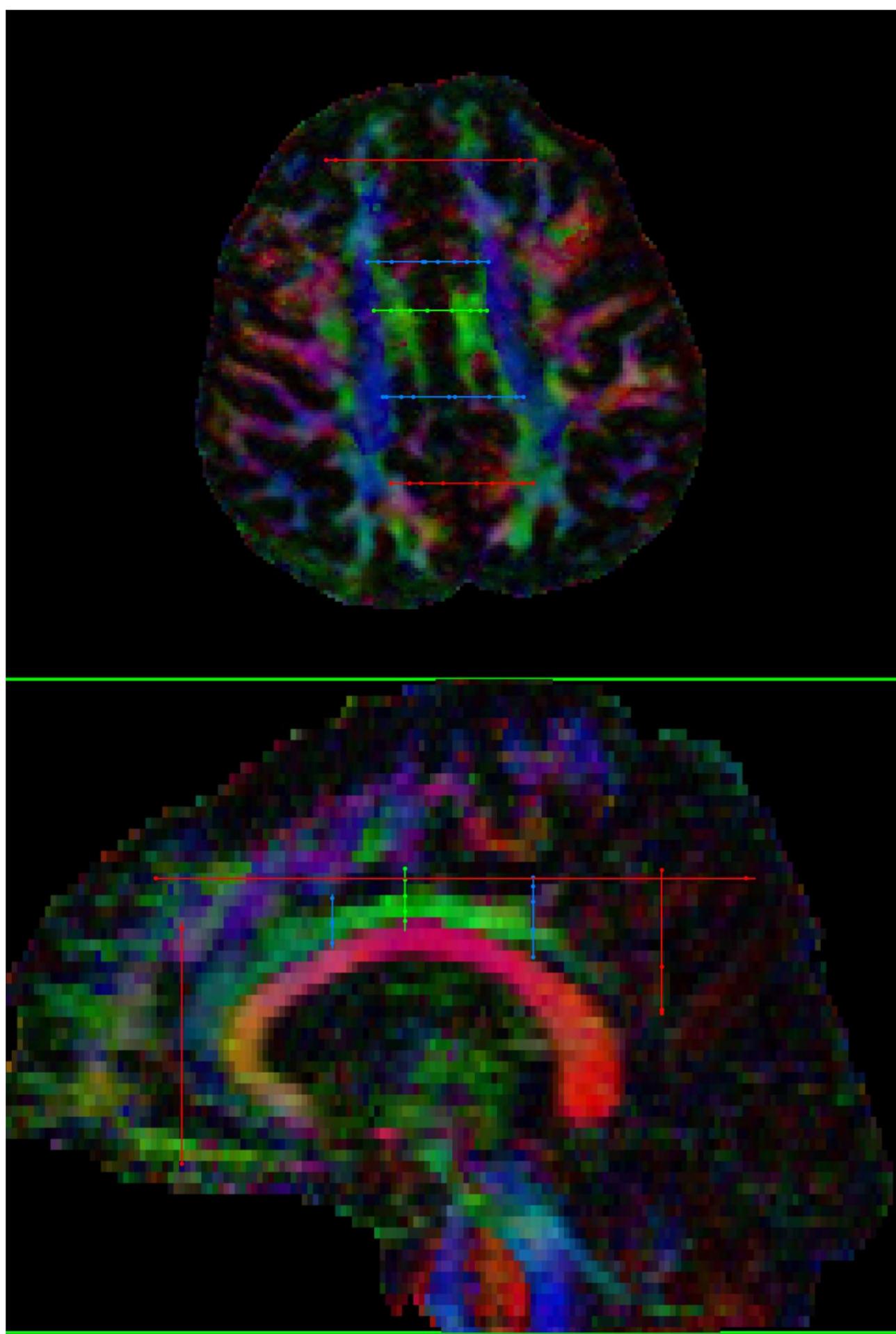
Relation to Cognitive Impairment

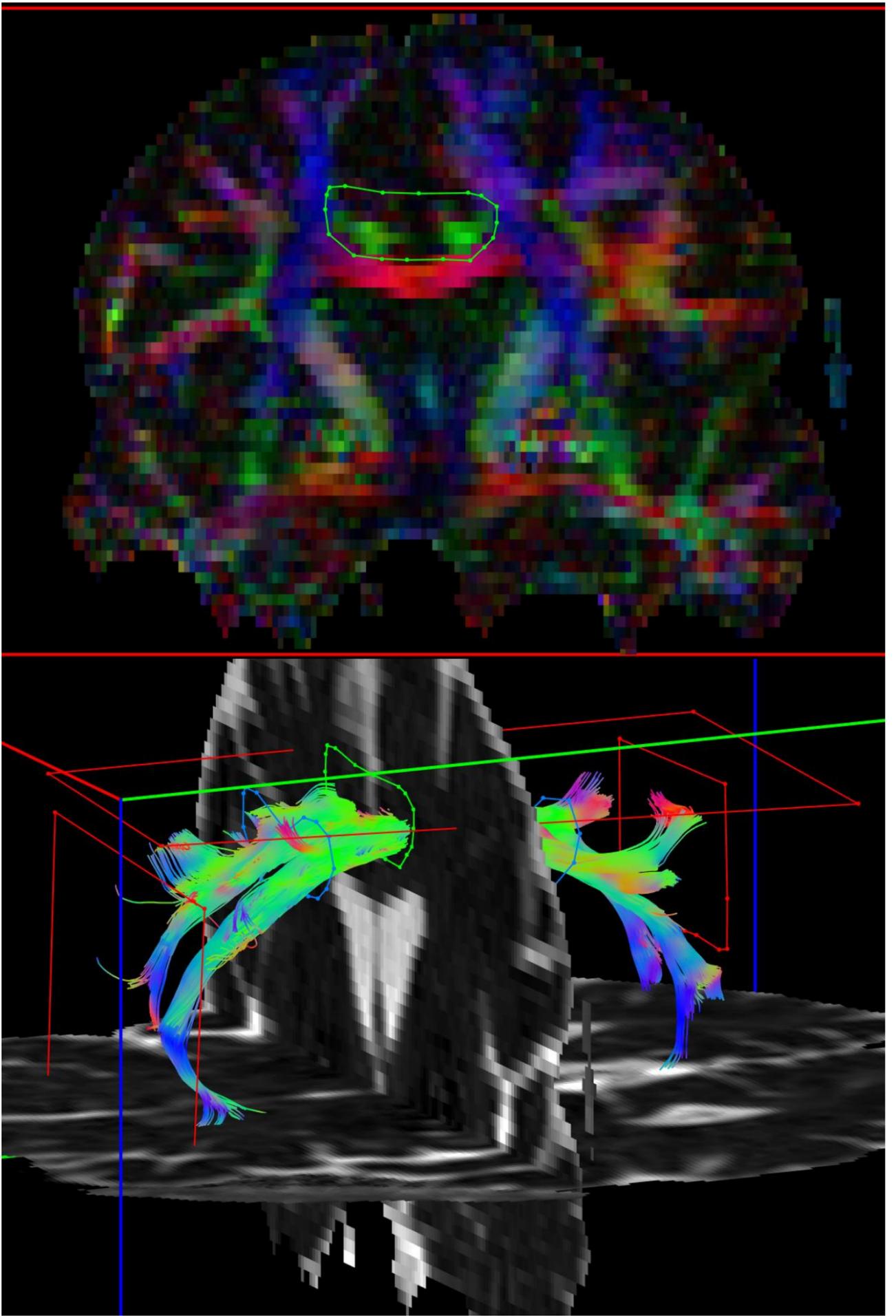
In recent years the cingulum has been associated with various brain disorders and diseases. One such area of interest is the disruption of white matter in the posterior cingulum causing mild cognitive impairment. Using diffusion MRI techniques, researchers have associated mild cognitive impairment with damage to the cingulum. The cingulum is a frontal association tract that could play a critical role because it connects sites repeatedly implicated in cognitive control. The middle segment

of the cingulum contains connections with premotor and motor cortical areas. Another place of importance that explains the cingulum and its relation to mild cognitive impairment is the fact that the cingulum connects to the hippocampus. The cingulum takes memory information and integrates this to other parts of the brain. Damage to the cingulum also simultaneously damages the hippocampus. This is vital because the hippocampus is pivotal in memory storage. Damage to gray matter, bodies of neurons, or white matter of axons in the cingulum therefore can affect humans cognitively because of this damage. Also variations in microstructure of a group of fibers in the rostral cingulum have been shown to be extremely sensitive to performance of cognitive control tasks. White matter pathology of the cingulum represents one of the earliest changes in development of age-related dementia and is currently aiding researchers worldwide to discover more about this relationship.

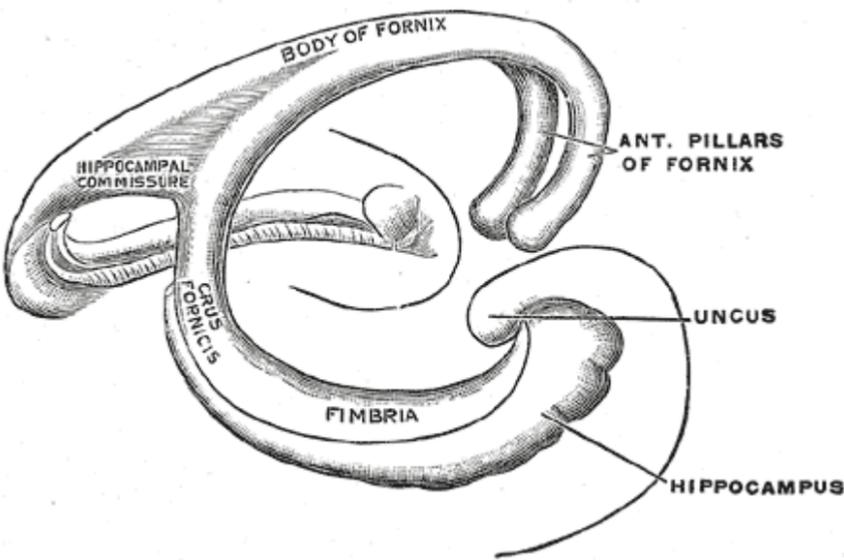
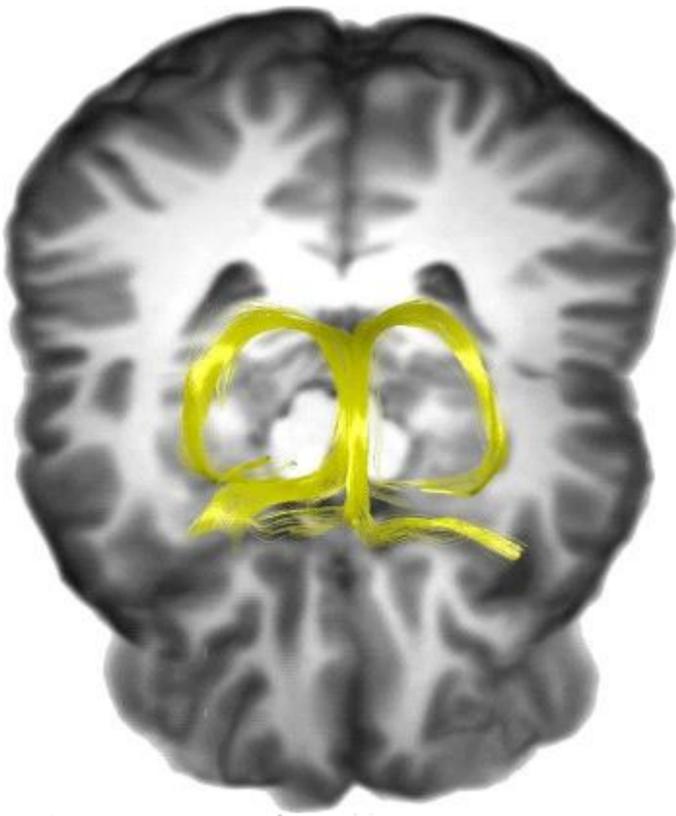
DTI PROTOCOL

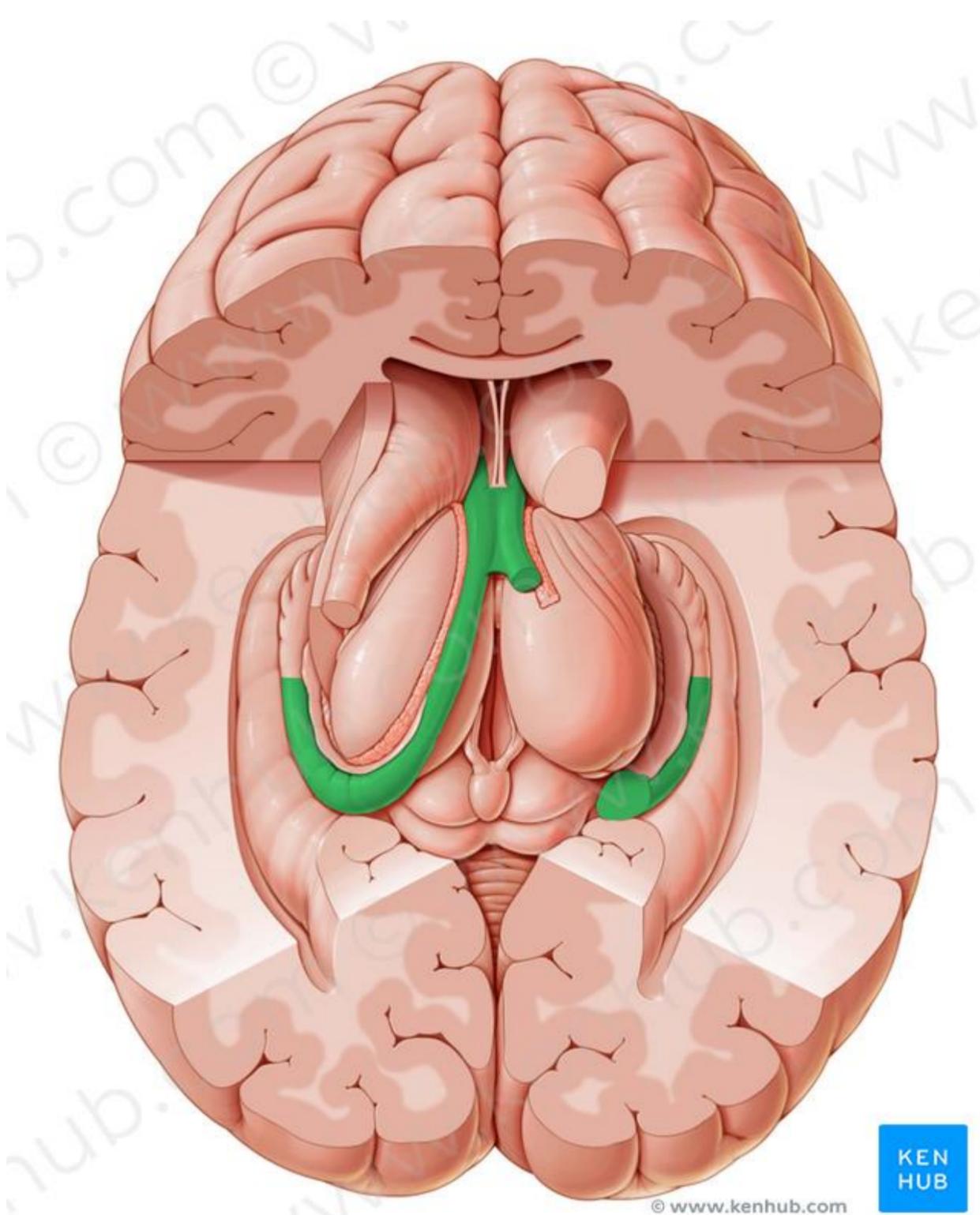
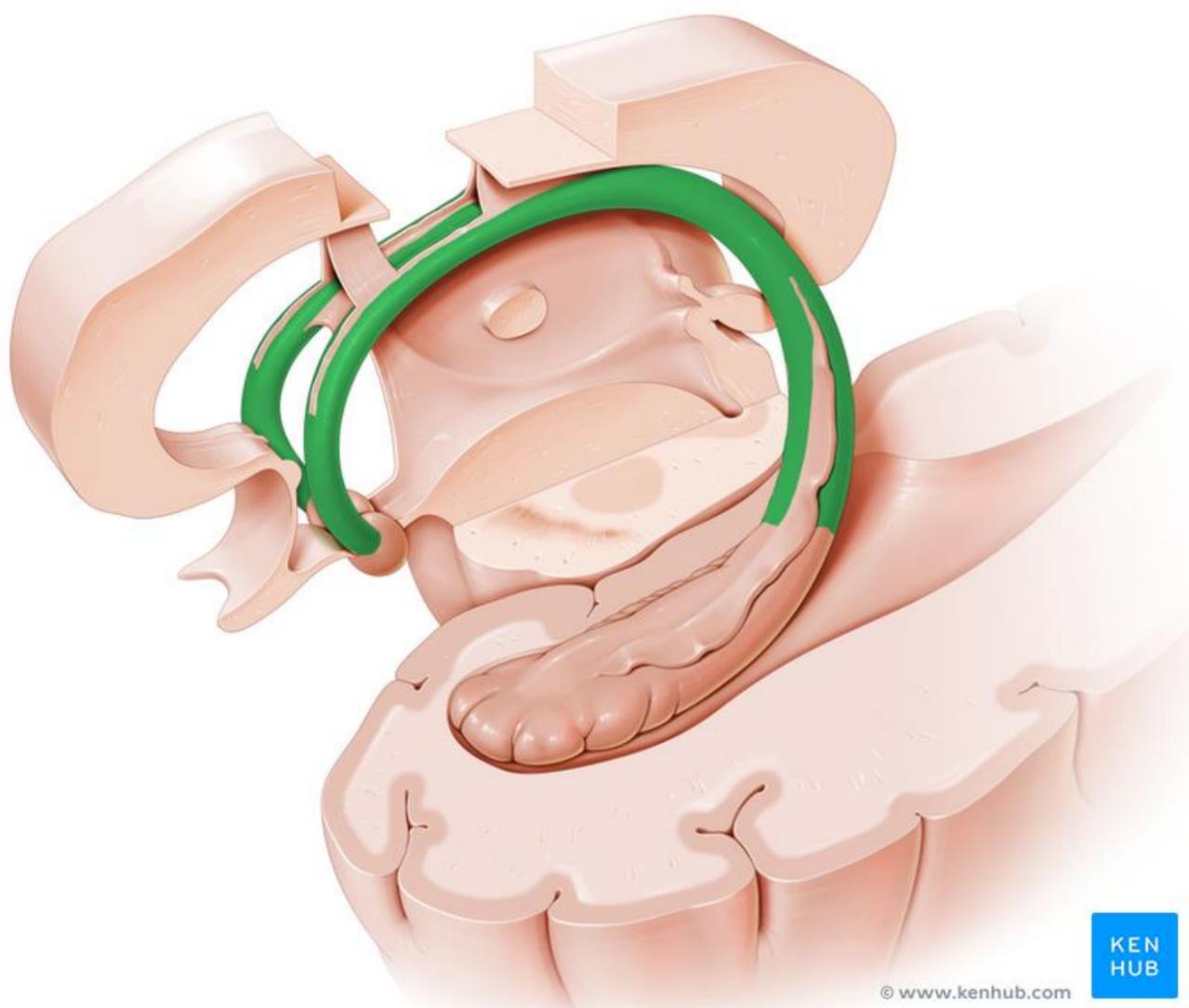
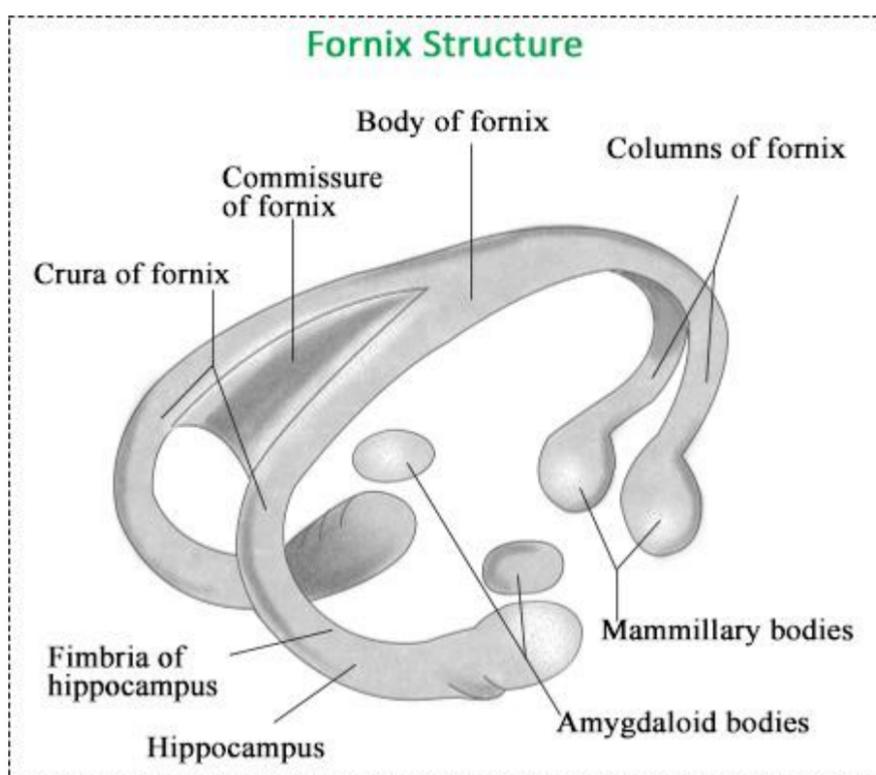
1. coronal AND ROI:
 - drawn at the mid-point of the superior (dorsal) cingulum, includes both cingulum bundles
2. coronal (or axial) SEED ROIs:
 - a pair of ROIs, one anterior, and one posterior to the initial AND ROI
 - depending on the orientation of the cingulum on an individual scan, these might be drawn in the axial or coronal plane
3. various NOT ROIs placed as needed:
 - pair of coronal NOT ROIs placed anterior and posterior to the cingulum
 - axial NOT ROI placed above the cingulum may be necessary
- ...as noted by Concha et al (2005):
 - "Because the fornix and cingulum are adjacent to CSF spaces (ie, the ventricles and interhemispheric fissure), the delineation of the tracts and their absolute diffusion parameters may be adversely affected by partial volume with the rapid, isotropically diffusing CSF. The use of a fluid-attenuated inversion recovery (FLAIR) component before a DTI imaging sequence greatly minimizes CSF signal intensity contamination, though at the expense of a significant increase in acquisition time and a reduction in signal intensity-to-noise ratio"





FORNIX





The fornix (Latin, "vault" or "arch") is a C-shaped bundle of fibers (axons) in the brain, and carries signals from the hippocampus to the hypothalamus.

The **fornix** (Latin: *arch*) is a C-shaped bundle of **nerve fibers** in the **brain** that acts as the major output tract of the **hippocampus**. The fornix also carries some afferent fibres to the hippocampus from structures in the **diencephalon** and basal forebrain.

The fibres begin in the hippocampus on each side of the brain (where they are also known as the fimbria); the separate left and right sides are each called the crus of the fornix. The bundles of fibres come together in the midline of the brain, forming

the *body* of the fornix. The inferior edge of the septum pellucidum (a membrane that separates the two lateral ventricles) is attached to the upper face of the fornix body.

The body of the fornix travels anteriorly and divides again near the anterior commissure. The left and right parts separate, but there is also an anterior/posterior divergence.

- The posterior fibres (called the *postcommissural fornix*) of each side continue through the hypothalamus to the mammillary bodies; then to the anterior nuclei of thalamus, which project to the cingulate cortex.
- The anterior fibers (*precommissural fornix*) end at the septal nuclei and nucleus accumbens of each half of the brain.

Commissure

The lateral portions of the body of the fornix are joined by a thin triangular lamina, named the **psalterium (lyra)**. This lamina contains some transverse fibers that connect the two **hippocampi** across the middle line and constitute the **commissure of fornix** (also called the hippocampal **commissure**).

The terminal lamina creates the commissure plate. This structure gives existence to the corpus callosum, the septum pellucidum, and the fornix. The fornix splits into two columns at the front (anterior pillars), and then splits into two posterior crura. These two crura are joined together through the hippocampal commissure. The beginning of the splitting is called the psalterium or *Lyra Davidis*. The latter name is used because the structure resembles a lyra (or triangular harp): The two crura are the "chassis" of the lyra, and the commissure connections are the fibers.

Columns

The **columns (anterior pillars; fornicolumns)** of the **fornix** arch downward in front of the **interventricular foramina** and behind the **anterior commissure**, and each descends through the **grey matter** in the lateral wall of the **third ventricle** to the base of the brain, where it ends in the **mamillary bodies**.

Crus

The **crura (posterior pillars)** of the fornix are prolonged backward from the body.

They are flattened bands, and, at their commencement, are intimately connected with the under surface of the **corpus callosum**.

Diverging from one another, each curves around the posterior end of the **thalamus**, and passes downward and forward into the **temporal horn of lateral ventricle**.

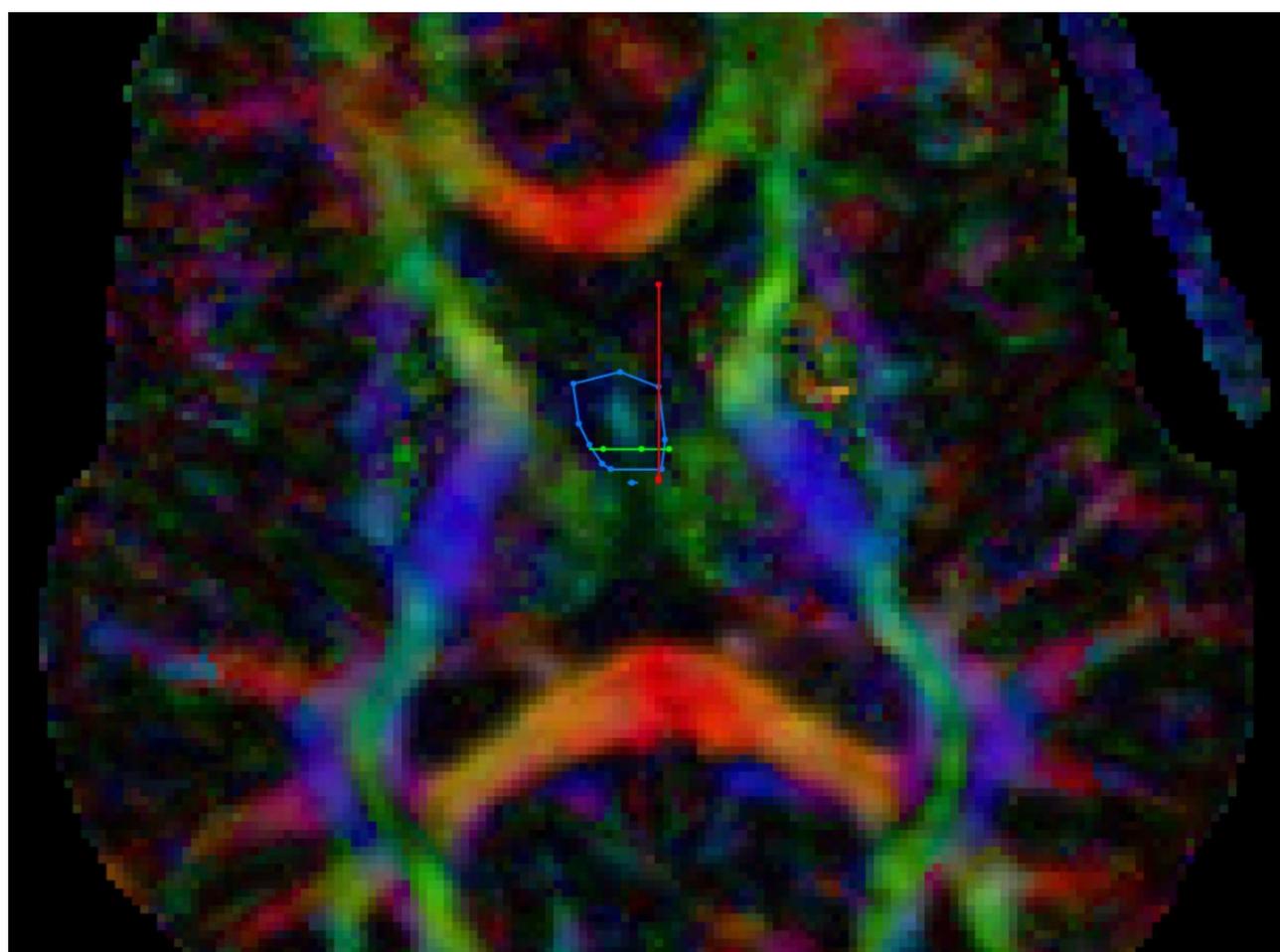
Here, it lies along the concavity of the **hippocampus**, on the surface of which some of its fibers are spread out to form the **alveus**, while the remainder are continued as a narrow white band, the **fimbria of hippocampus**, which is prolonged into the **uncus** of the **parahippocampal gyrus**.

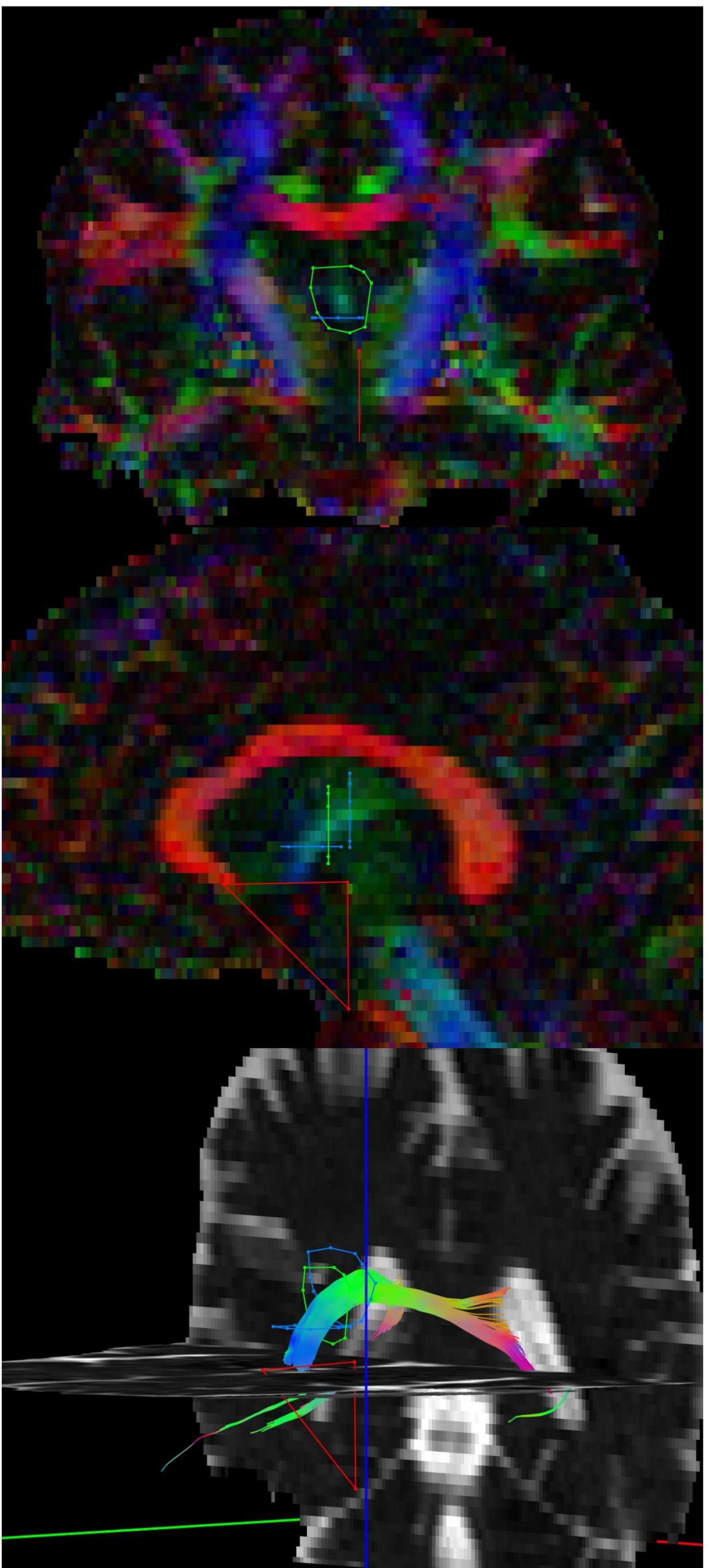
FUNCTION

The fornix is part of the **limbic system**. While its exact function and importance in the physiology of the brain is still not entirely clear, it has been demonstrated in humans that surgical transection – the cutting of the fornix along its body – can cause memory loss. There is some debate over what type of memory is affected by this damage, but it has been found to most closely correlate with **recall memory** rather than **recognition memory**. This means that damage to the fornix can cause difficulty in recalling long-term information such as details of past events, but it has little effect on the ability to recognize objects or familiar situations.

DTI PROTOCOL

1. coronal AND ROI
 - placed on body of fornix
 2. axial SEED ROI
 - placed on column of fornix
 3. coronal SEED ROI
 - placed on body of fornix, posterior to the AND ROI
 4. various NOT ROIs are placed as needed
 - sagittal NOT ROI on the corpus callosum on the midline
 - coronal NOT ROIs anterior and posterior to the fornix
 - axial NOT ROI above the fornix
 - parasagittal NOT ROIs lateral to the column of the fornix (eliminate tracts from anterior commissure)
- note that the crurae of the fornix are difficult to reproduce on conventional DTI images due to their proximity to the ventricles, and resultant contamination by CSF signal
 - Concha et al (2005) described a method of FLAIR DTI that produced superior images, but these images were not acquired in this study
 - "Because the fornix and cingulum are adjacent to CSF spaces (ie, the ventricles and interhemispheric fissure), the delineation of the tracts and their absolute diffusion parameters may be adversely affected by partial volume with the rapid, isotropically diffusing CSF. The use of a fluid-attenuated inversion recovery (FLAIR) component before a DTI imaging sequence greatly minimizes CSF signal intensity contamination, though at the expense of a significant increase in acquisition time and a reduction in signal intensity-to-noise ratio"





CORPUS CALLOSUM

Divided into three segments (Hofer and Frahm 2006):

anterior sixth is the genu of CC (gCC)

posterior quarter is the splenium of CC (sCC)

...everything in between is the body of the CC (bCC)

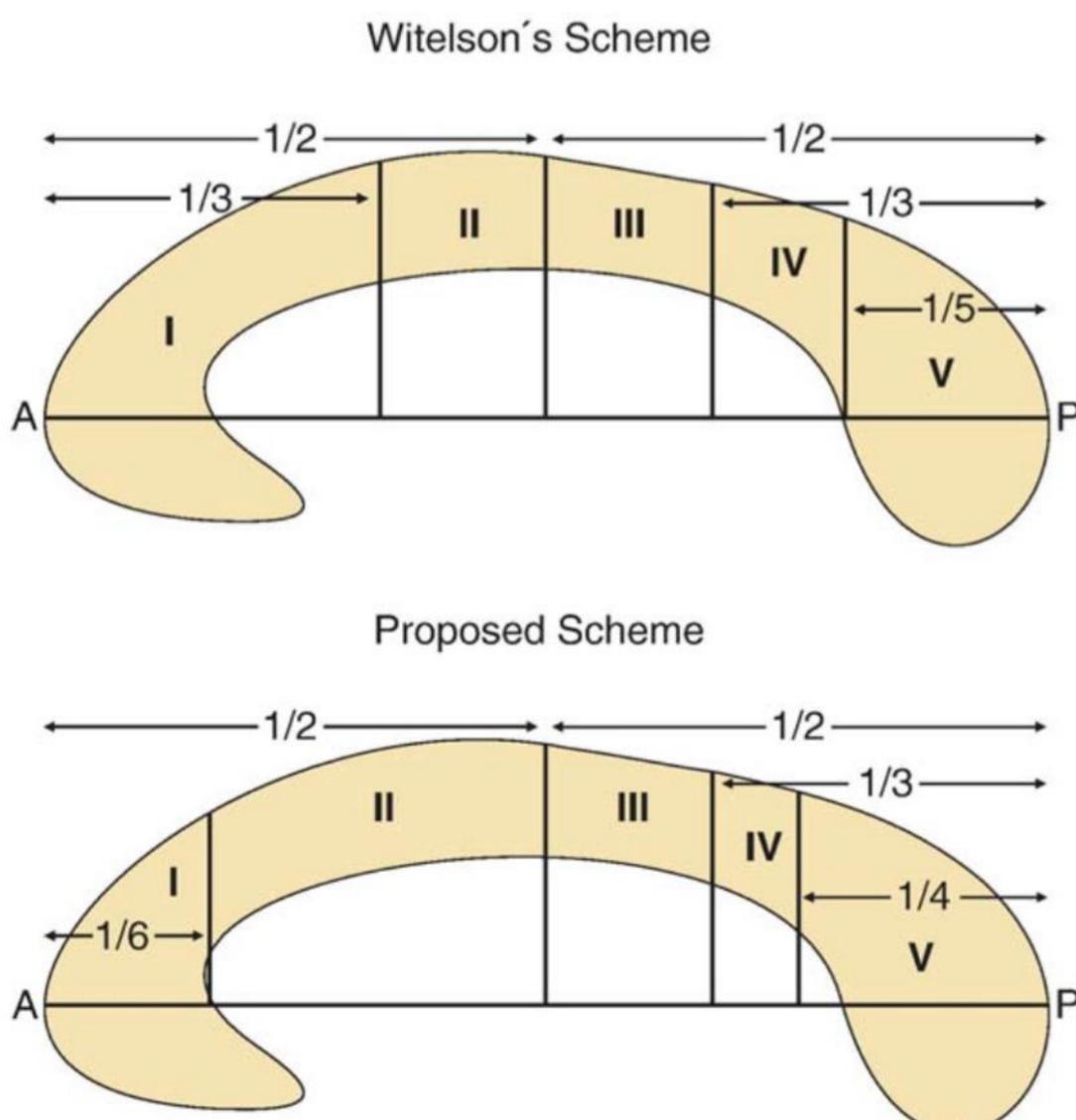


Fig. 3. Topography of the midsagittal corpus callosum. (Top) Witelson's classification. (I) Anterior third: prefrontal, premotor, and supplementary motor; (II) anterior midbody: motor; (III) posterior midbody: somaesthetic, posterior parietal; (IV) isthmus: posterior parietal, superior temporal; (V) splenium: occipital, inferior temporal. A, anterior; P, posterior. (Bottom) Proposed new classification. Region I: prefrontal; region II: premotor and supplementary motor; region III: motor; region IV: sensory; region V: parietal, temporal, and occipital. A, anterior; P, posterior.

Hofer, S., & Frahm, J. (2006). Topography of the human corpus callosum revisited—Comprehensive fiber tractography using diffusion tensor magnetic resonance imaging. *NeuroImage*, 32(3), 989–994. <http://doi.org/10.1016/j.neuroimage.2006.05.044>

OPTIC RADIATION (geniculocalcarine tract, geniculostriate pathway, posterior thalamic radiation)

The **optic radiation** - are axons from the neurons in the lateral geniculate nucleus to the primary visual cortex. The optic radiation receives blood through deep branches of the middle cerebral artery and posterior cerebral artery.

They carry visual information through two divisions (called upper and lower division) to the visual cortex (also called *striate cortex*) along the calcarine fissure. There is one such tract on each side of the brain. If a lesion only exists in one optic radiation, the consequence is called **quadrantanopia**, which implies that only the respective superior or inferior quadrant of the visual field is affected.

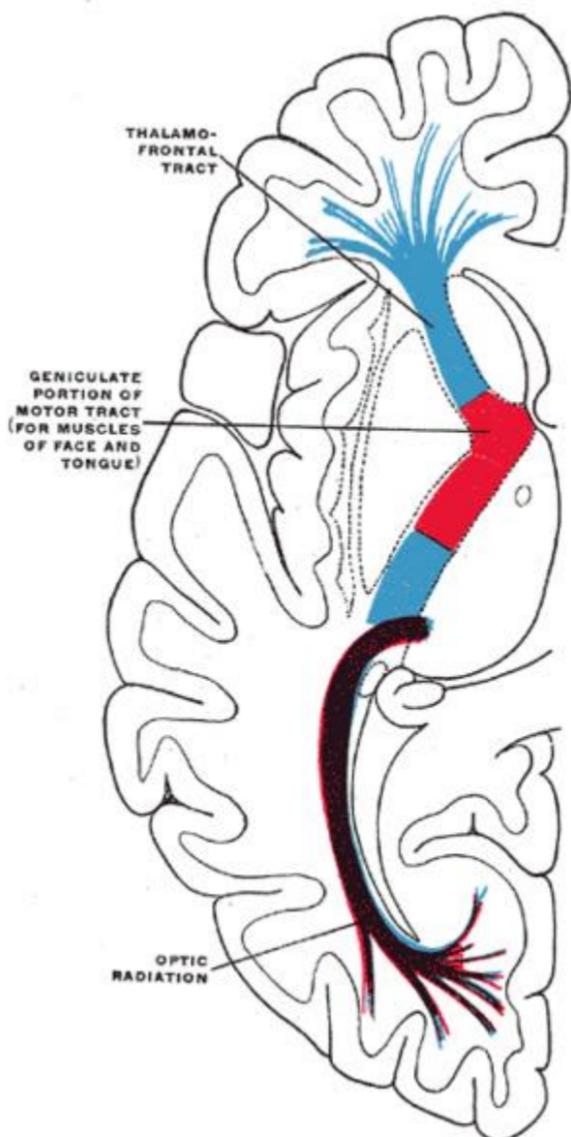
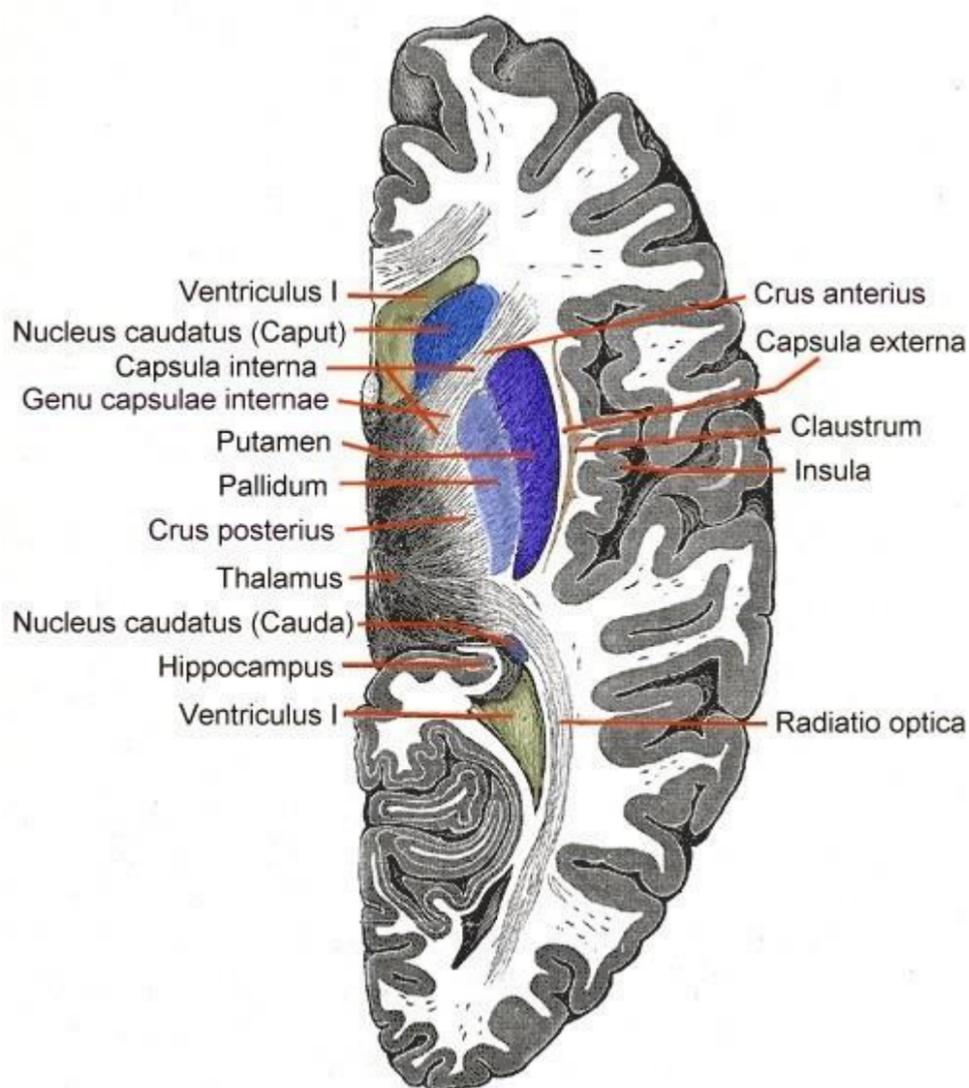
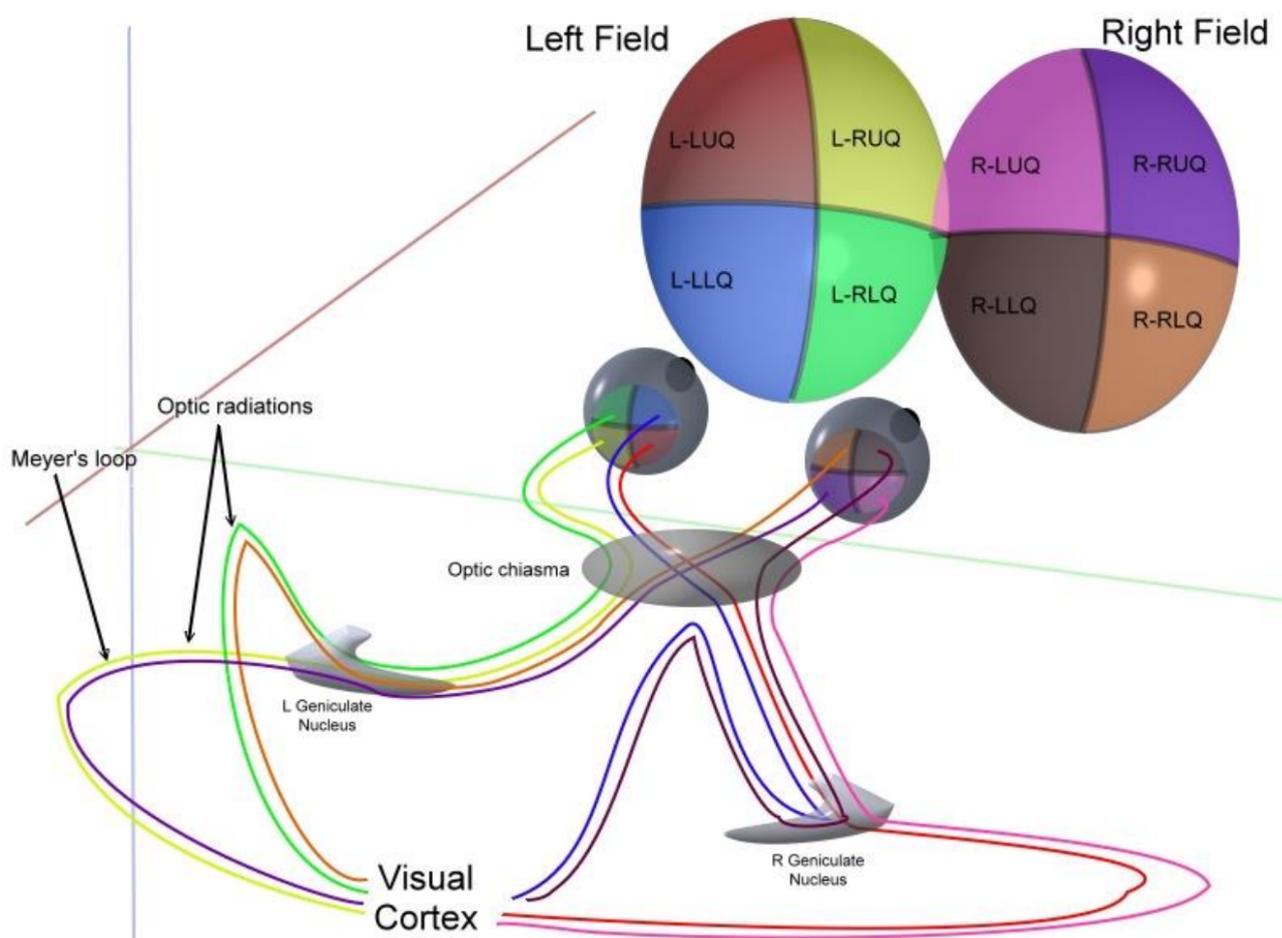
The upper division:

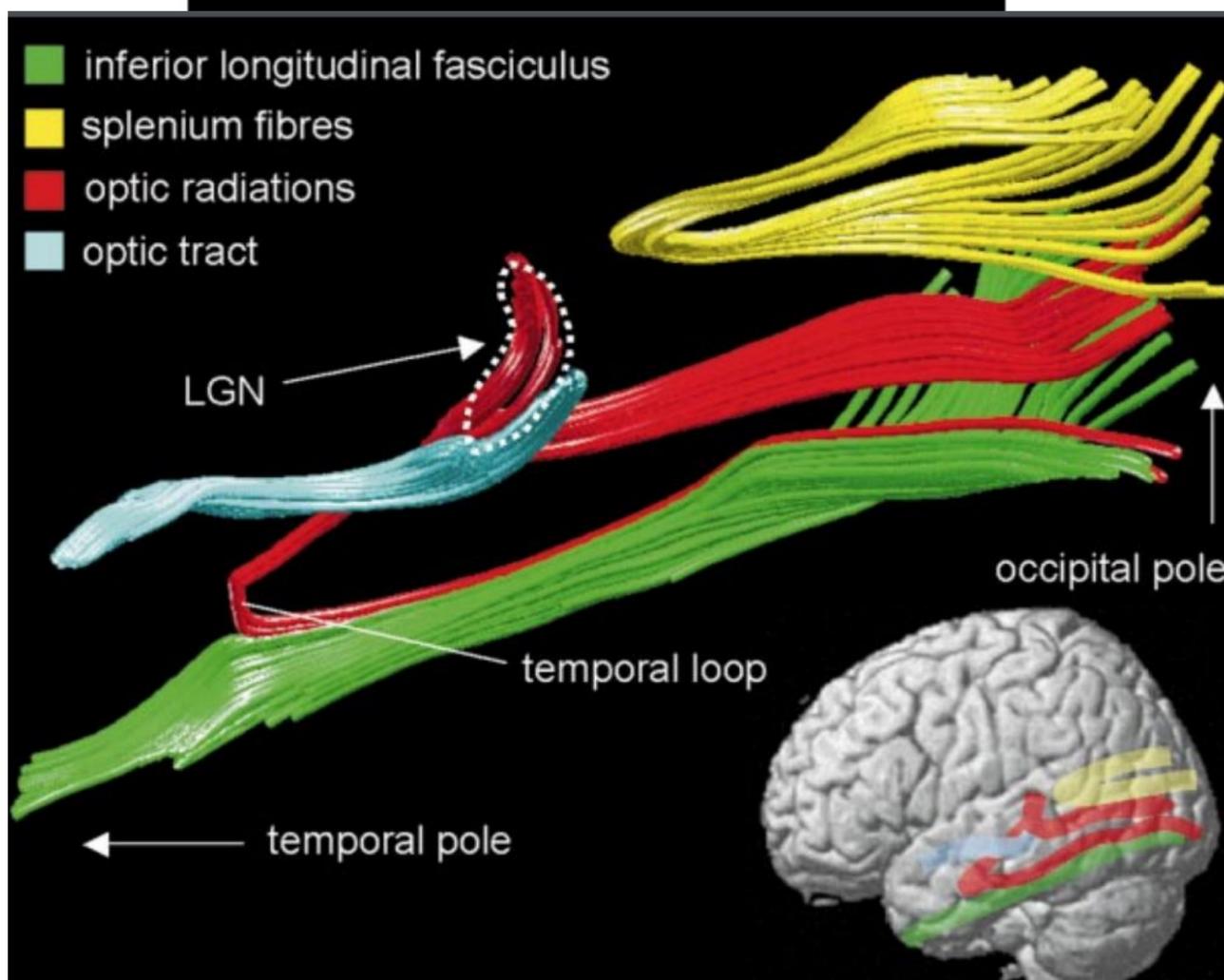
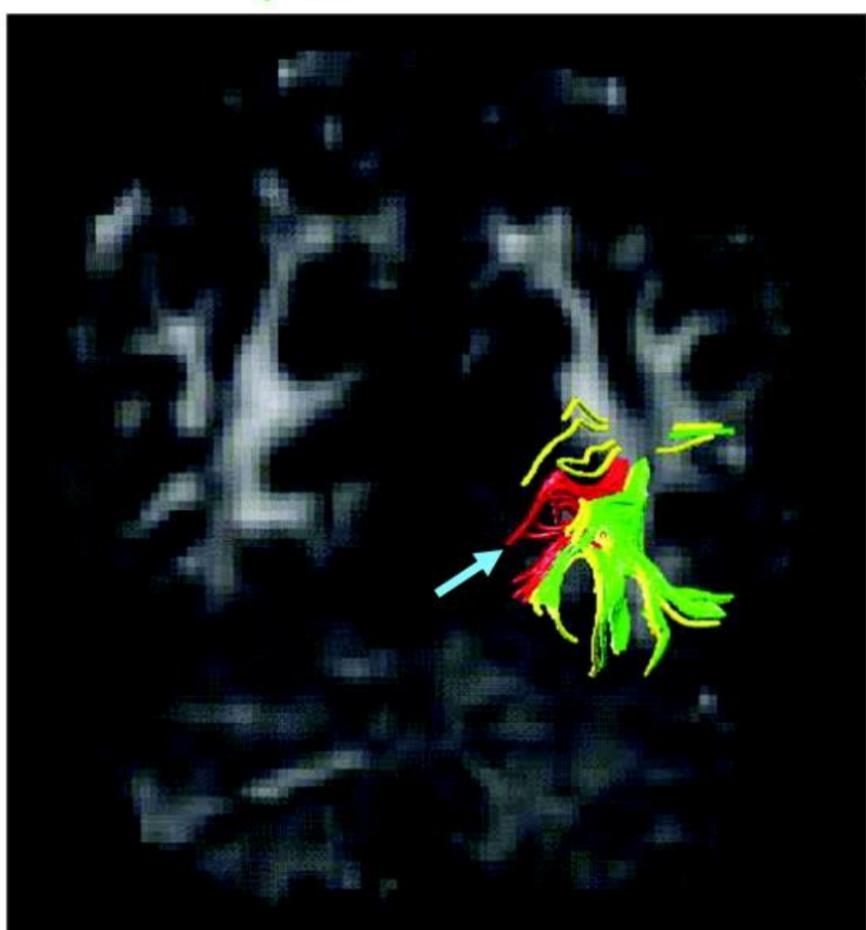
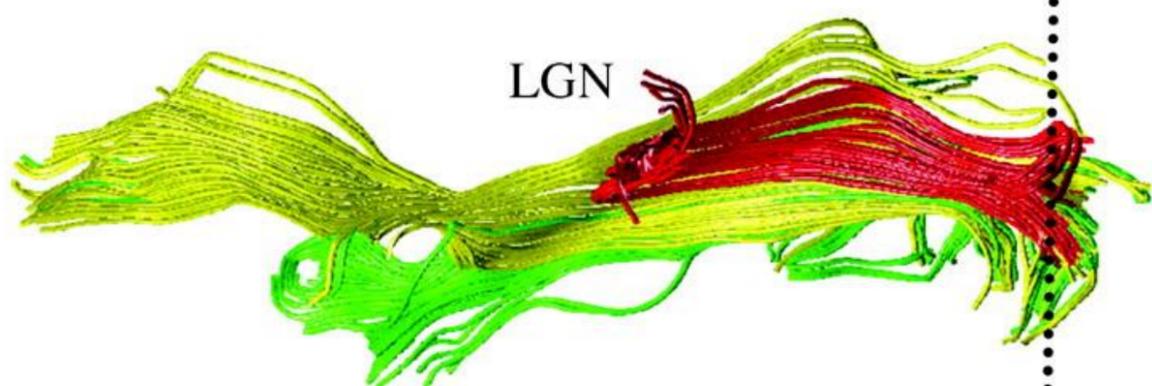
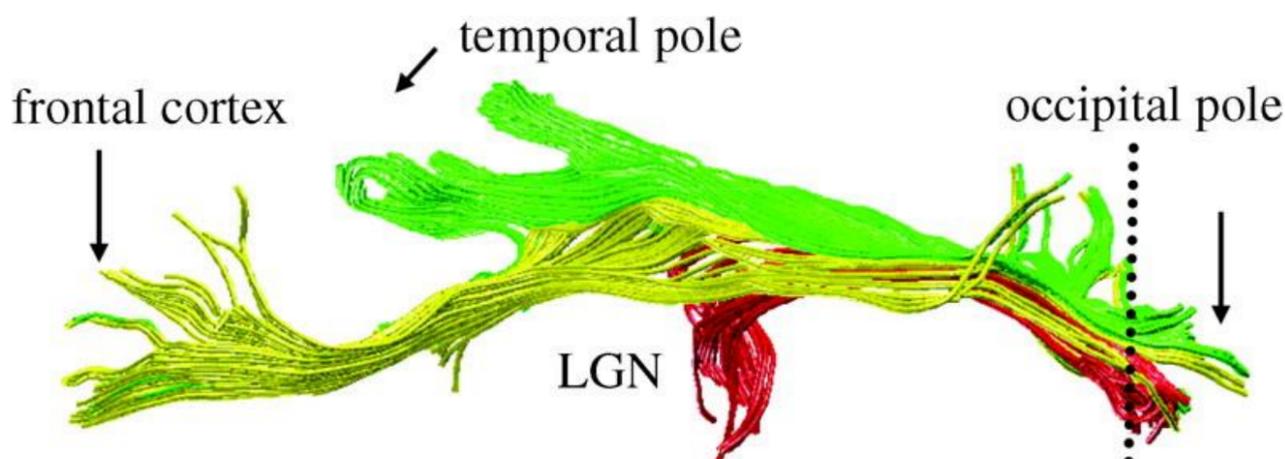
- Projects to the upper bank of the calcarine fissure, called the **cuneus**
- Contains input from the superior retinal quadrants, which represents the inferior visual field quadrants
- Transection causes contralateral lower quadrantanopia
- Lesions that involve both cuneii cause a lower altitudinal hemianopia (altitudinopia)

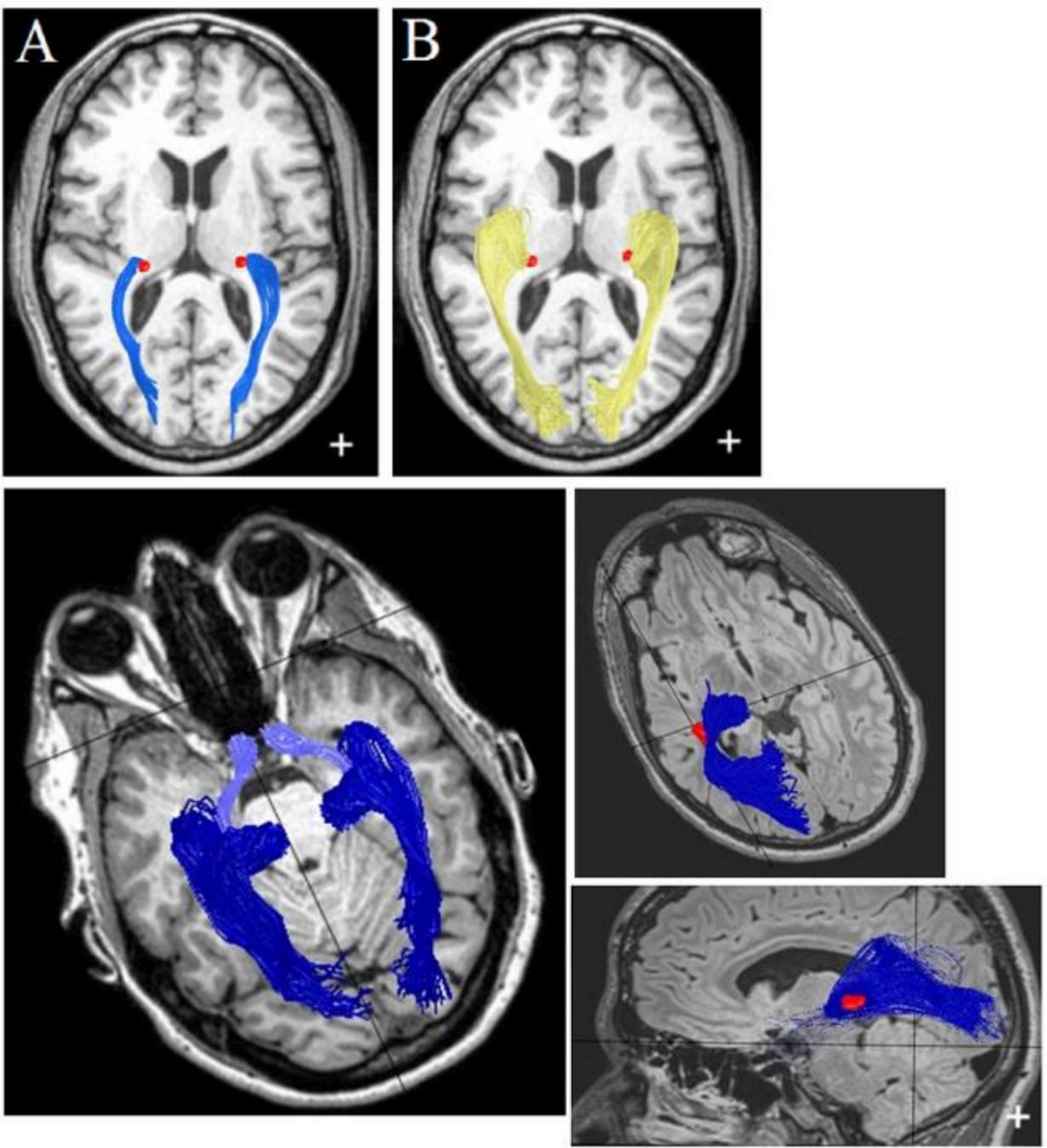
The lower division:

- Loops from the lateral geniculate body anteriorly (Meyer's loop), then posteriorly, to terminate in the lower bank of the calcarine sulcus, called the **lingual gyrus**.
- Contains input from the inferior retinal quadrants, which represents the superior visual field quadrants
- Transection causes contralateral upper quadrantanopia
- Transection of both lingual gyri causes an upper altitudinal hemianopia

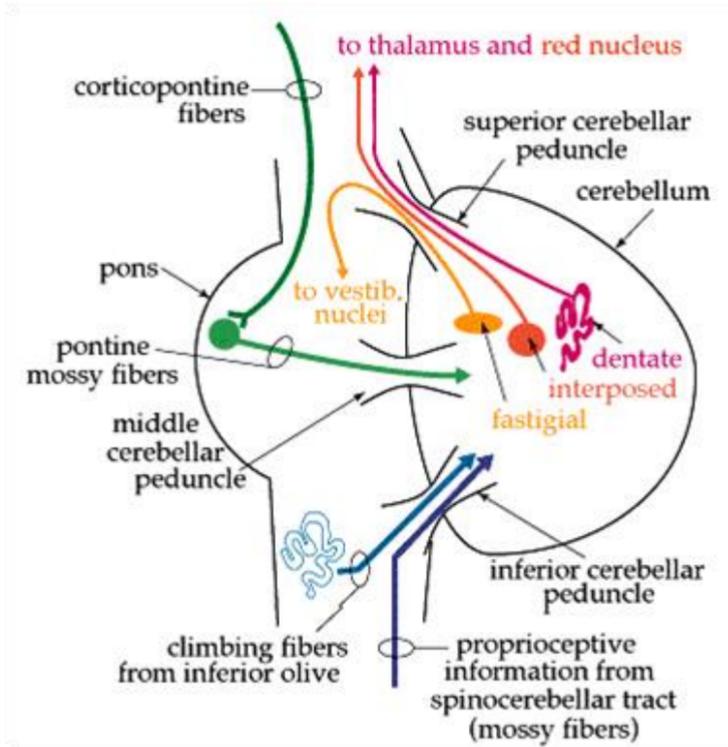
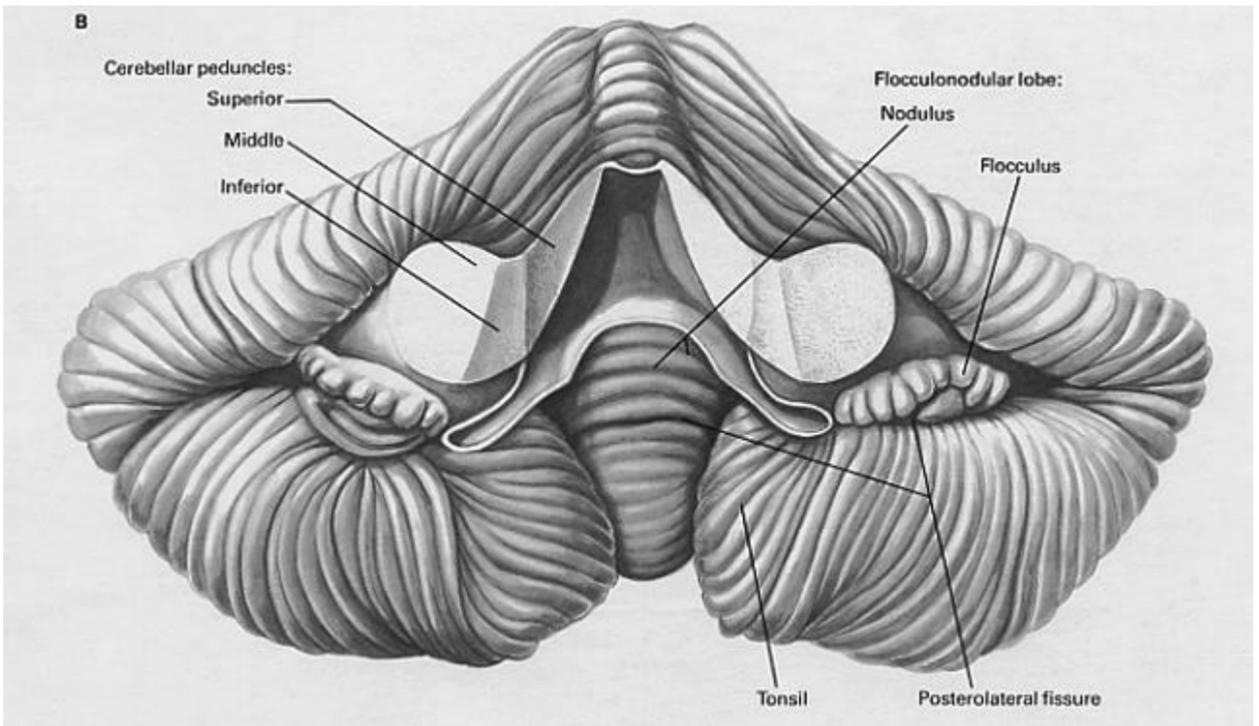
Source	Path	Information	Damage
Fibers from the <i>inferior retina</i> (also called "Meyer's loop" or "Archambault's loop")	must pass through the temporal lobe by looping around the inferior horn of the lateral ventricle .	Carry information from the <i>superior part</i> of the visual field	A lesion in the temporal lobe that results in damage to Meyer's loop causes a characteristic loss of vision in a superior quadrant (quadrantanopia or "pie in the sky" defect.)
Fibers from the <i>superior retina</i> (also called "Baum's loop")	travel straight back through the parietal lobe to the occipital lobe in the retrolenticular limb of the internal capsule to the visual cortex.	Carry information from the <i>inferior part</i> of the visual field	Taking the shorter path, these fibers are less susceptible to damage. Damage caused is characteristically called "Pie in the floor" defect or inferior quadrantanopia.

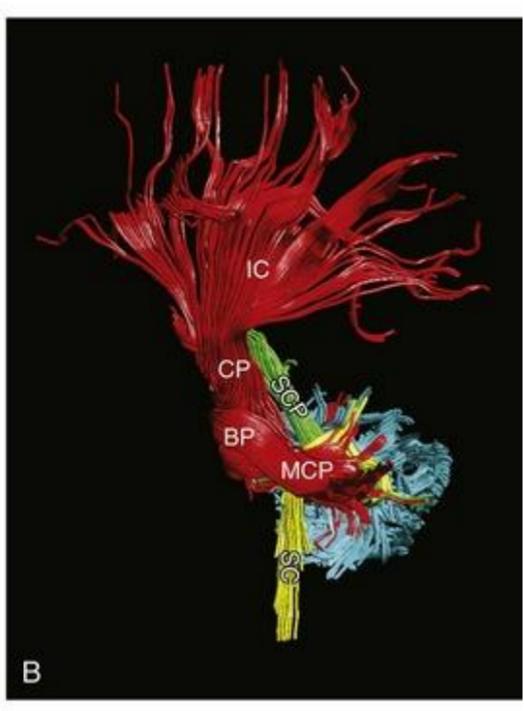
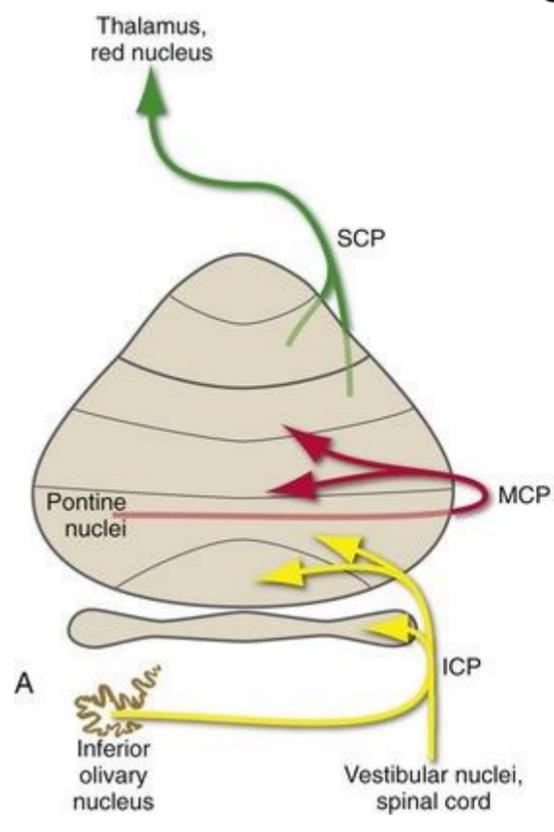
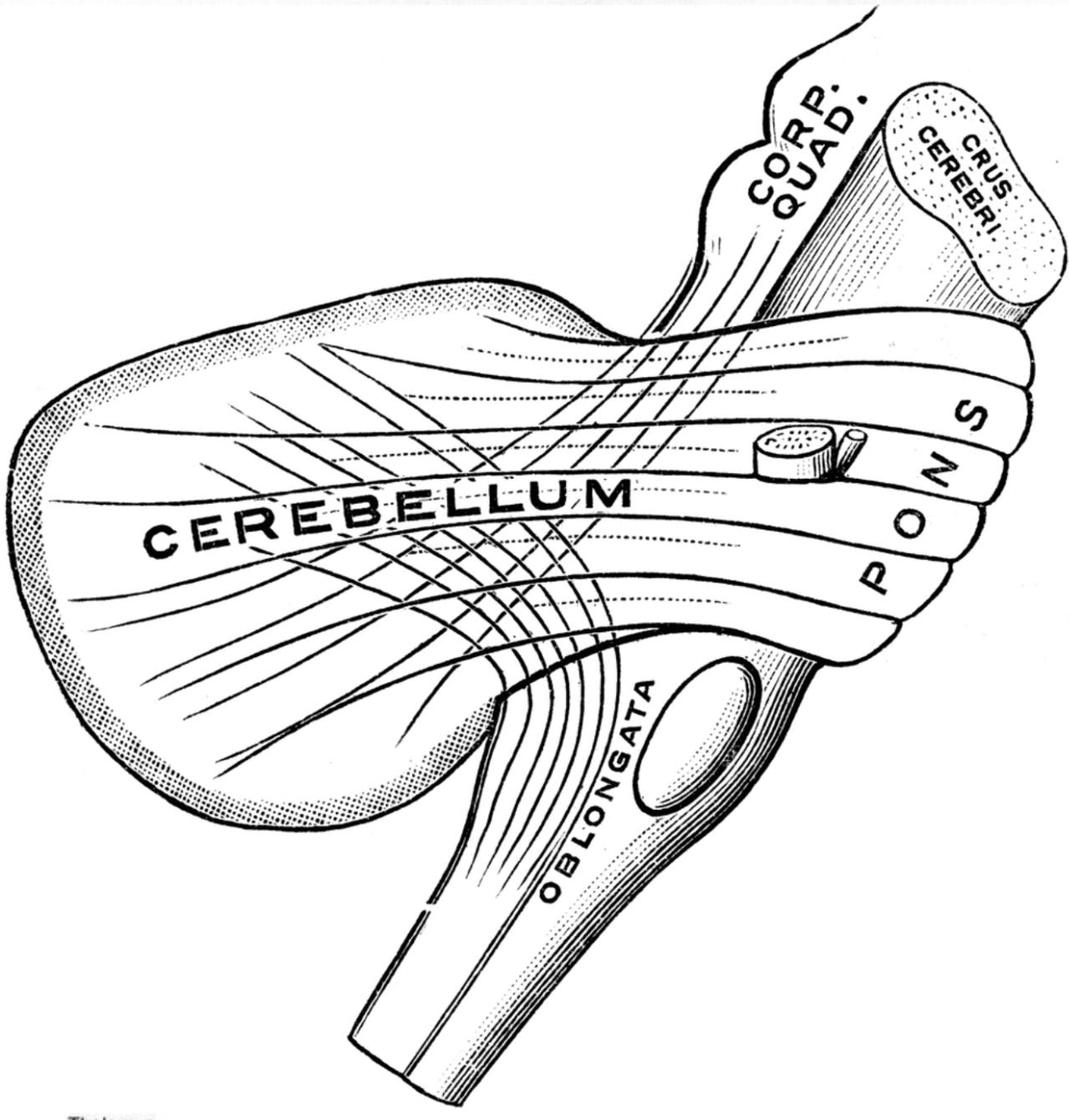
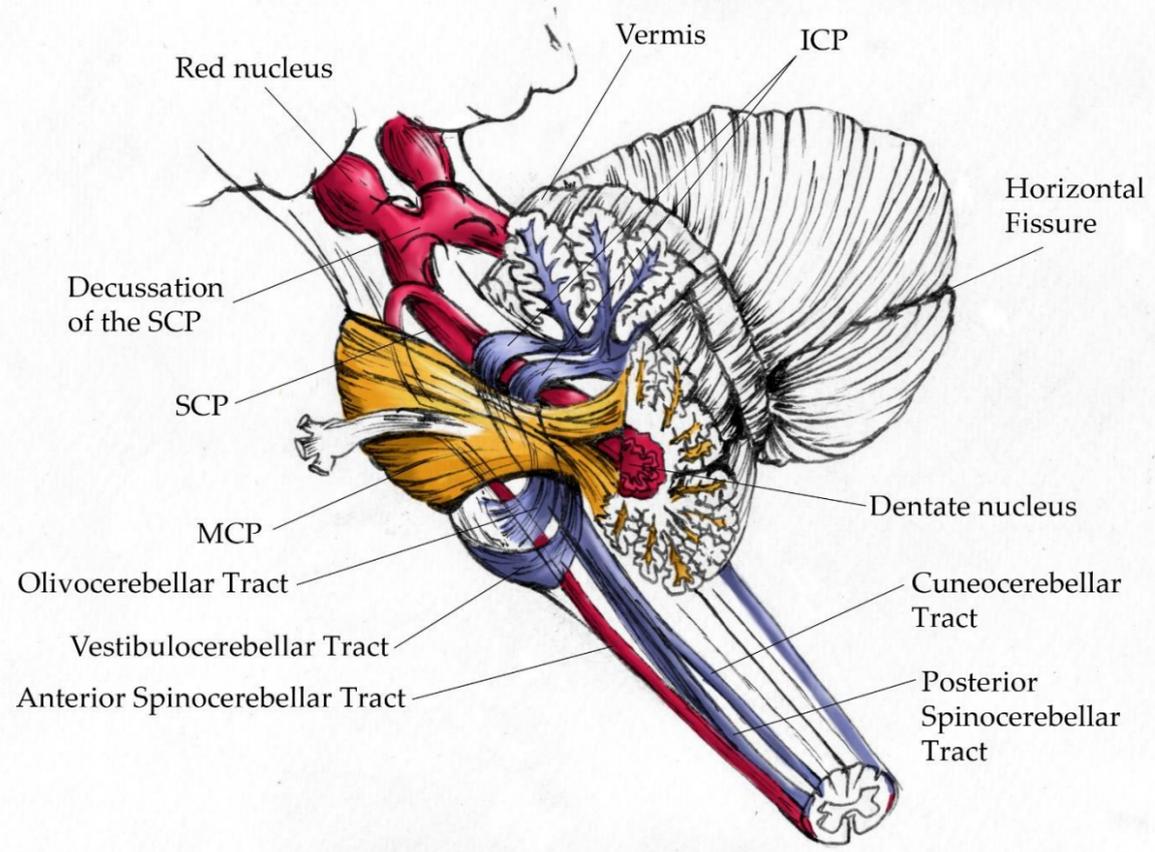






CEREBELLAR PEDUNCLES





SUPERIOR

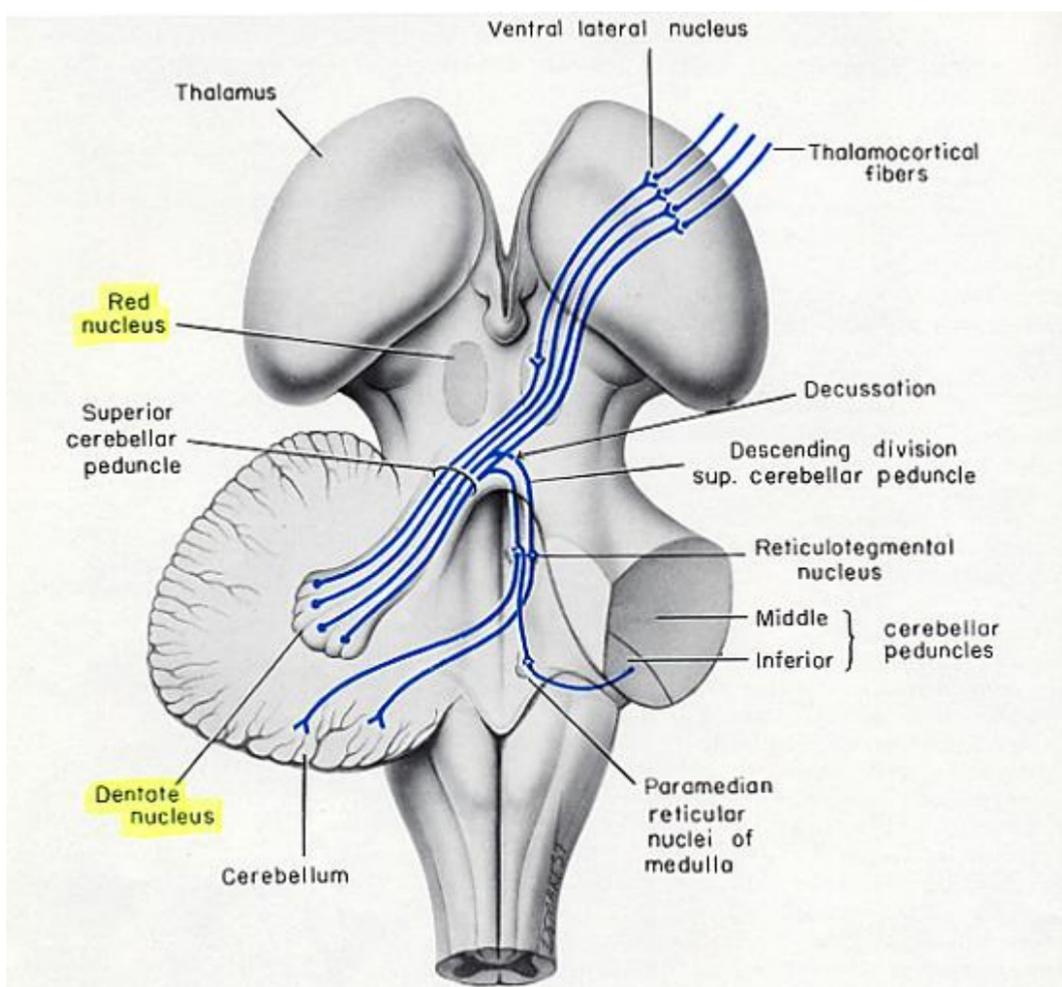
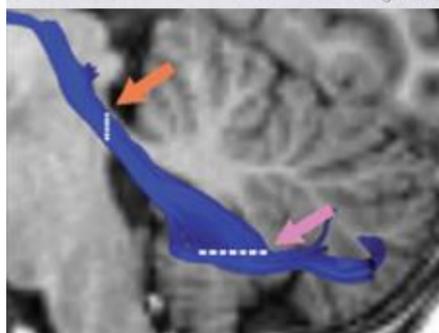


Fig. 7-7. Diagram of the efferent fibers of the dentate nucleus. These fibers, contained in the superior cerebellar peduncle, all decussate in the caudal mesencephalon. Ascending fibers project to the rostral part of the red nucleus and to the ventrolateral (VLo) nucleus of the thalamus. Fibers of the descending division of the superior cerebellar peduncle project to the reticulotegmental nucleus and the paramedian reticular nuclei of the medulla. Descending fibers of the superior cerebellar peduncle constitute part of a cerebello-reticular system that conveys impulses back to the cerebellum. (From Truex and Carpenter, *Human Neuroanatomy*, 1969; courtesy of The Williams & Wilkins Company.)

● SUPERIOR PEDUNCLE (s. brachium conjunctivum)

pagr. masi → EF: DENTATORUBROTHALAMIC fibers
 AF: • ant. spinocerebellar tract, trigeminocerebellar tract
 • Ictocerebellar tract



MIDDLE

MIDDLE PEDUNCLE (s. brachium pontis)

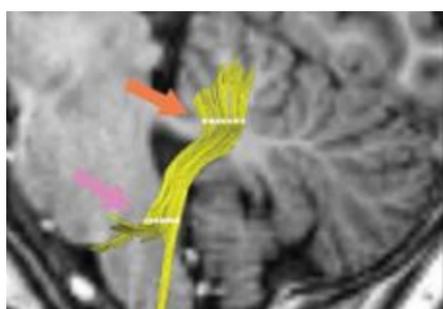
- storiansia
- tik aferentini (neša PONTOCEREBELLAR fibers [danguma - crossed in basiv pontis])



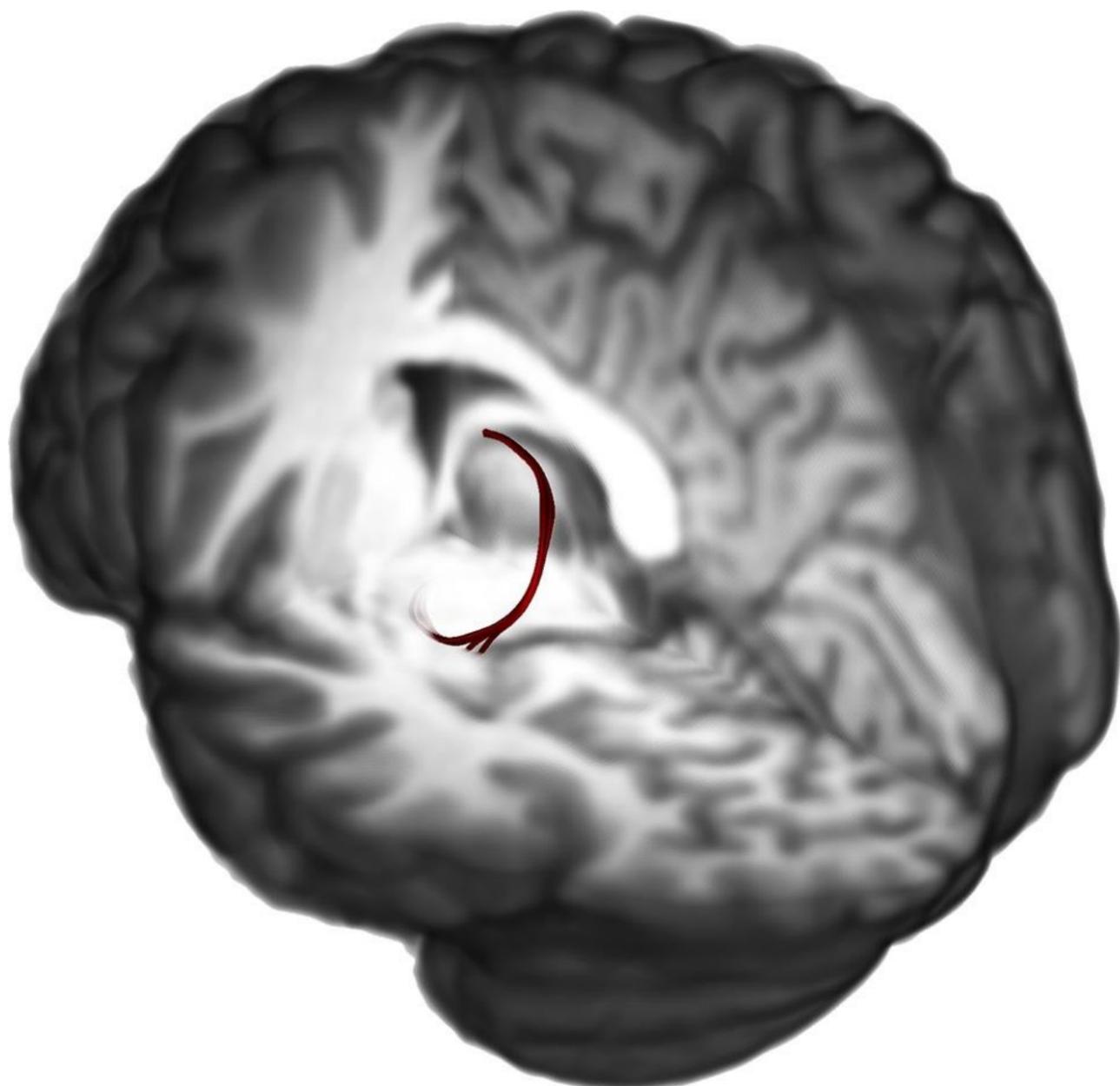
INFERIOR

INFERIOR PEDUNCLE

- paginde aferentini (išsk. cerebellovestibul.)
- eina lateral recess (of rhomboid fossa) dugun, apjuosta n. VIII skaidulā
- sudarīta īs diviņš daļiņš:
 - 1) larger (lateral) bundle - RESTIFORM BODY - aferentivis:
 - post. spinocerebellar tract, cuneocerebellar tract
 - olivocerebellar tract
 - reticulocerebellar tract
 - arcuatocerebellar tract
 - 2) smaller (medial) bundle - JUXTARESTIFORM BODY - smegenelīņi ↔ kyšiai su vestibular nuclei



STRIA TERMINALIS



The **stria terminalis** (or **terminal stria**) is a structure in the brain consisting of a band of fibers running along the lateral margin of the ventricular surface of the thalamus. Serving as a major output pathway of the amygdala, the stria terminalis runs from its centromedial division to the ventral medial nucleus of the hypothalamus.

Anatomy

The stria terminalis covers the thalamostriate vein, marking a line of separation between the thalamus and the caudate nucleus as seen upon gross dissection of the ventricles of the brain, viewed from the superior aspect.

The stria terminalis extends from the region of the interventricular foramen to the temporal horn of the lateral ventricle, carrying fibers from the amygdala to the septal nuclei, hypothalamic, and thalamic areas of the brain. It also carries fibers projecting from these areas back to the amygdala.

Functions

The activity of the bed nucleus of the stria terminalis correlates with anxiety in response to threat monitoring. It is thought to act as a relay site within the hypothalamic-pituitary-adrenal axis and regulate its activity in response to acute stress. It is also thought to promote behavioral inhibition in response to unfamiliar individuals, by input from the orbitofrontal cortex. Bilateral disruption of this pathway has been shown to attenuate reinstatement of drug seeking behaviour in rodents.

Bed nucleus of the stria terminalis (BNST)

The central subdivision of the bed nucleus of the stria terminalis (BSTc) is sexually dimorphic. On average, the BSTc is twice as large in men as in women and contains twice the number of somatostatin neurons. A sample of six male-to-female transsexuals taking estrogen were found to have female-typical number of cells in the BSTc, whereas a female-to-male transsexual taking testosterone was found to have a male-typical number. The authors (W. Chung, G. De Vries, Dick Swaab) also examined subjects with hormone-related disorders and found no pattern between those disorders and the BSTc while the single untreated male-to-female transsexual had a female-typical number of cells. They concluded that the BSTc provides evidence for a neurobiological basis of gender identity disorder and proposed that such was determined before birth.

Criticisms of the former statement suggest the study used an unrepresentative sample and did not adequately control for hormone replacement therapy, which has been shown to influence hypothalamic size, even though the study tried to do this by including non-transsexual male and female controls which, for a variety of medical reasons, had experienced hormone reversal. The statement about the neurobiological basis from birth has later been brought to question, though not refuted, by a follow up study by the same group which found that the sexual dimorphism of the BSTc is not present before adulthood (approximately 22 years of age) even though transsexuals report being aware of their gender identity since childhood.

Reduction of the size of the bed nucleus of the stria terminalis has been observed in pedophilic male perpetrators, in addition to reductions in the right amygdala, hypothalamus and abnormalities in related structures. The authors propose that childhood deficits in the BNST and medial amygdala may cause inhibition of sexual maturity.

BIBLIOGRAPHY for ch. "White Matter Tracts" → follow this [LINK >>](#)