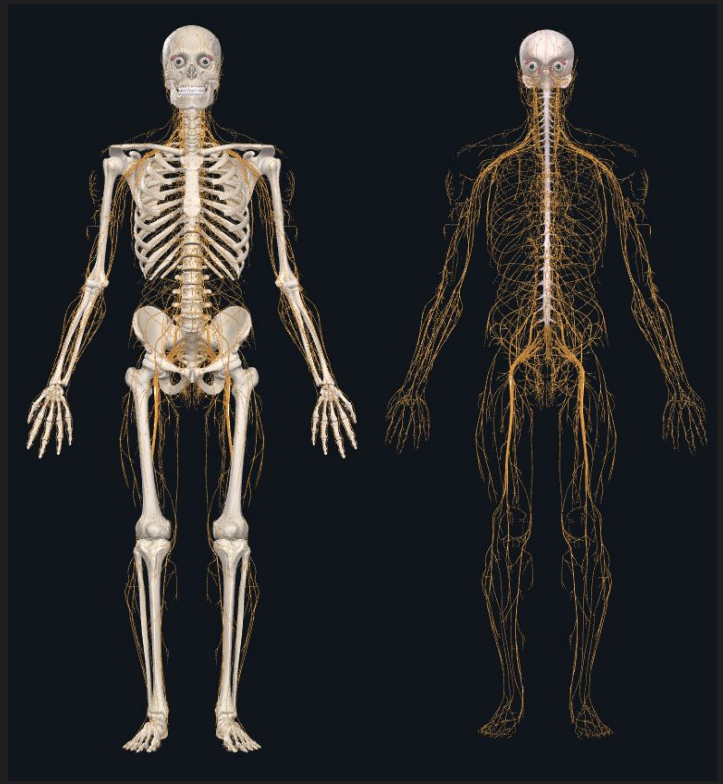
On Split Brains

The Nervous System

Provide a rapid control system → Action potential in nerve fibers

Receive sensory input, integrate and make motor output

Adjusts metabolic operations to create long term changes → Homeostasis



Complete Anatomy 2021

CNS Vs. PNS & Divisions

Nervous system:

- CNS - Brain and spinal cord
- PNS - Peripheral nerves elsewhere

Sensory:

- Somatic
- Visceral
- Special senses

Motor:

- Somatic
- Visceral (autonomic nervous system)
  - Sympathetic
  - Parasympathetic

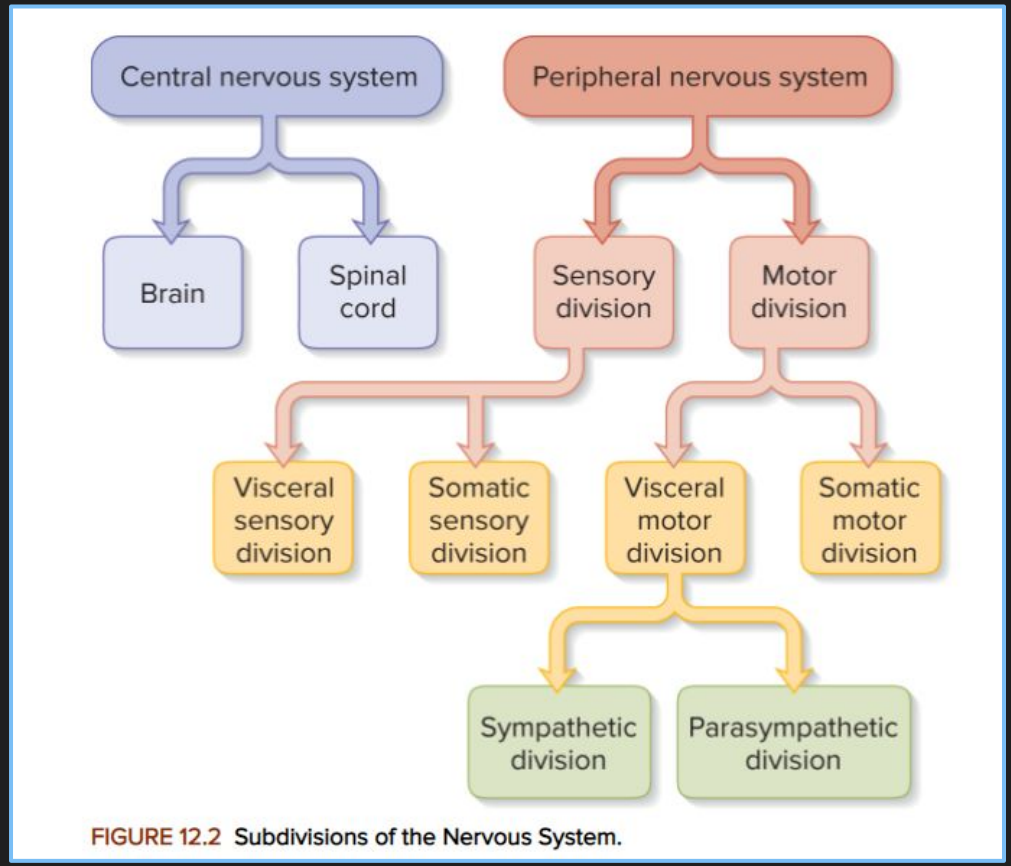


FIGURE 12.2 Subdivisions of the Nervous System.

Saladin Anatomy and Physiology 9th Edition

A Closer Look at The CNS: The Cerebrum

The cerebrum:

- enlarged in humans
- different from other vertebrates;
- high SA:V ratio for integration

White matter (interior) communication tracts:

- association,
- commissural,
- and projection tracts.

Cortex → five lobes:

- frontal, parietal, occipital,
- temporal and insular.
- Limbic lobe?

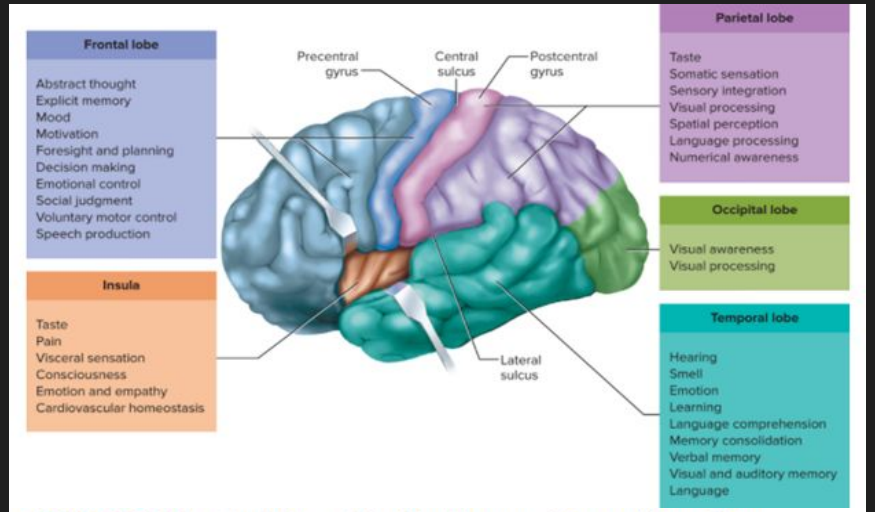


FIGURE 14.13 The Five Lobes of the Cerebrum and Some of Their Key Functions. The frontal and temporal lobes are retracted slightly to reveal the insula. The lists of functions are by no means exhaustive, but help to anatomically locate key functions discussed in this chapter. APR

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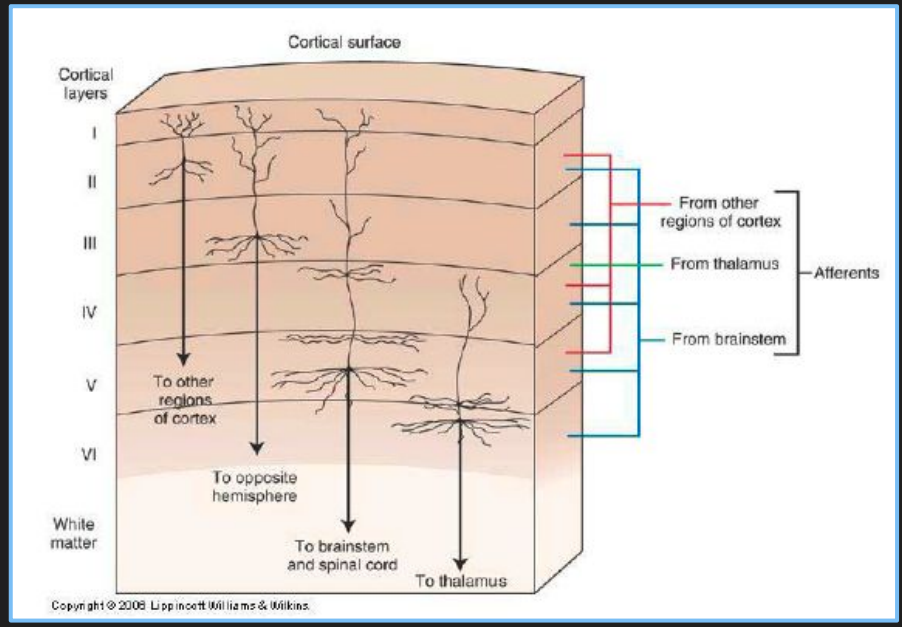
A Closer Look at The CNS: The Cerebrum Continued...

- Gray Matter/Neocortex (exterior)
- Six layers unique to Mammals
- Contains nuclei
  - Cortical Nuclei → Conscious mind
  - Subcortical Nuclei → Unconscious mind



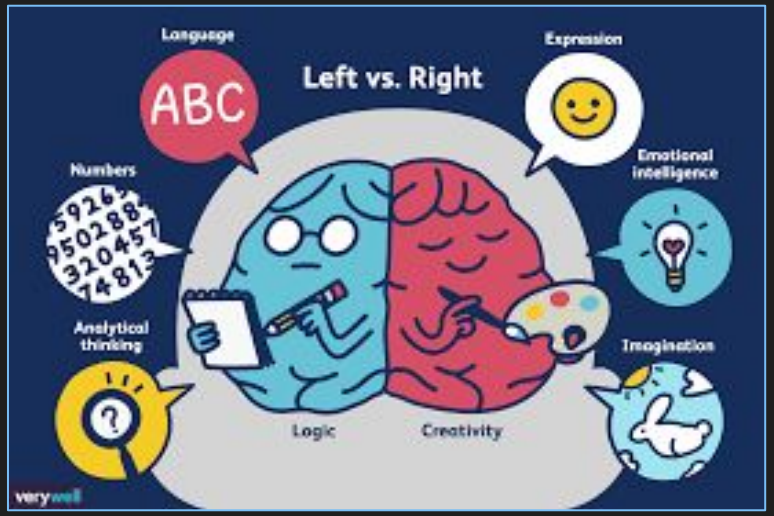
Layers of the gray matter which are unique to mammals

https://www.google.com/url?sa=i&url=https%3A%2F%2Fbiology.stackexchange.com%2F29759%2Fis-the-six-layer-cortex-model-of-the-mammalian-cortex-still-the-most-accepted-mo&psig=AOvVaw3CPIlo8fKcWX1A_WhDZRpe&ust=1612842972693000&source=images&cd=vfe&ved=0CAMQjB1qFwoTCLjBy7ay2e4CFQAAAAAdAAAAABAD

The Cerebrum: Functional Lateralization

Left

- Language,
- analytical abilities,
- calculations,
- naming people and objects
- focused



https://www.verywellmind.com/left-brain-vs-right-brain-2795005

Right

- Facial recognition,
- spatial orientation,
- visual,
- creativity,
- exploratory,
- nonverbal ideation

Cerebrum carries out contralateral integration processes .... But HOW???

The Corpus Callosum!

* Means Tough Body In Latin

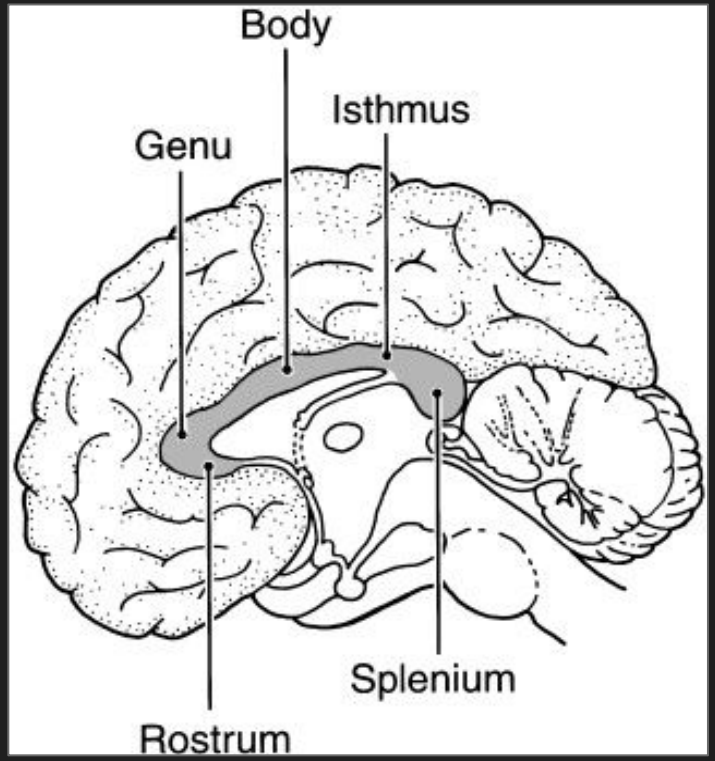
The Corpus Callosum

The major commissural tract in the CNS with more than 200M Nerve fibers

Main function: provide a connection pathway between the two hemispheres.

Four distinct parts:

- **Rostrum**: connects orbital regions
- **Genu**: connects frontal cortices
- **Body**: transverse paths in the cerebral cortex
- **Splenium**: connects the occipital lobes

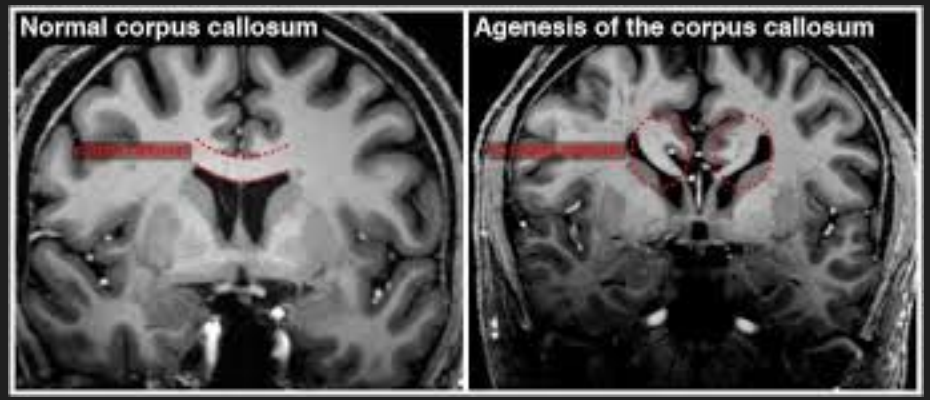


https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.sciencedirect.com%2Ftopics%2Fneuroscience%2Fcorpus-callosum&psig=AOvVaw0BIl07ZTe0eTfgJQROoMFU&ust=1612145472375000&source=images&cd=vfe&ved=0CA0QjhxqFwoTCND2s4KMxe4CFQAAAAAdAAAAABAV

The Corpus Callosum: Physiological Variants

Agenesis

- Partial loss or complete absence of the corpus callosum
- Rare: 3-7 out of 1000
- Good prognosis



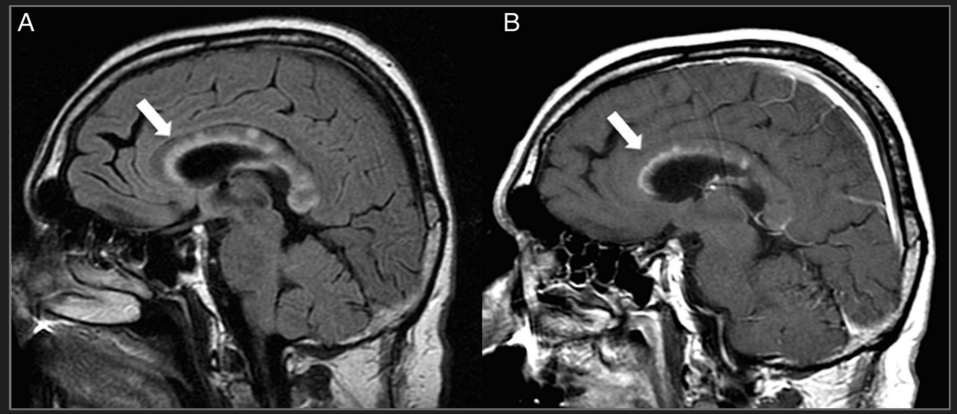
https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.facebook.com%2Fthemassageescapetamworth%2Fphotos%2Fa.245221719292803%2F569761140172191%2F%3Ftype%3D3&psig=AOvVaw1Obex6e-4gQR316q4GdF5q&ust=1612215461483000&source=images&cd=vfe&ved=0CAIQjRxqFwoTCPjV8OaQx-4CFQAAAAAdAAAAABAD

Hypoplasia

- Absent Rostrum part of corpus callosum is absent
- Benign
- No clinical significance

The Corpus Callosum: Clinical significance

- Multiple sclerosis
- Marchiafava-Bignami Disease
- Ruptured aneurysm
- Toxins, some viruses and traumatic brian injuries
- Glioblastomas, lymphomas, metastases…



Demyelination of corpus callosum by Multiple sclerosis

Source: https://jnnp.bmj.com/content/86/12/1374

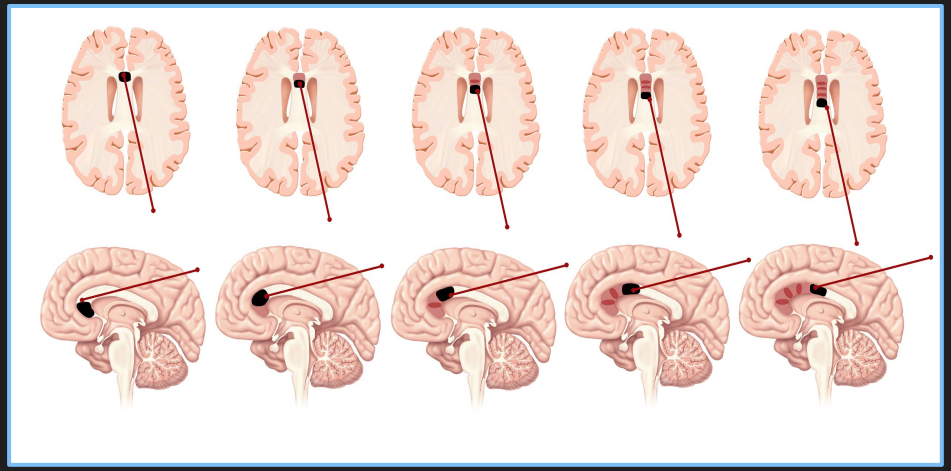
So, **when** is damaging the corpus callosum beneficial?

Corpus Callosotomy, Split-Brain

Corpus callosotomy is a surgical procedure that cuts the corpus callosum, often only partially but sometimes completely.

Used in patients with:

- Severe epeleptic seizure patients
  - Interrupts excitatory pathways
  - Neurotransmitter?
- Low-grade gliomas
  - Less tumor migration



Minimally invasive robotic laser corpus callosotomy

https://www.cureus.com/articles/6101-minimally-invasive-robotic-laser-corpus-callosotomy-a-proof-of-concept

Split Brain Research Timeline

1940
- 1st Split-Brain Surgery by Van Wagenen and Herren :(

1950
- Researchers: No effect on patients' cognitive or behavioral functions.
- Sperry and colleagues found that split-brain greatly impacts functions of the brain of animals

1962
- Philip Vogel and Joseph Bogen more split-brain surgeries; 26 patients :)
  Gazzaniga 'Of Two Minds' Experiment

1970
- Gazzaniga: Left brain involved in speech production.
  Gazzaniga: Right brain involved in language comprehension

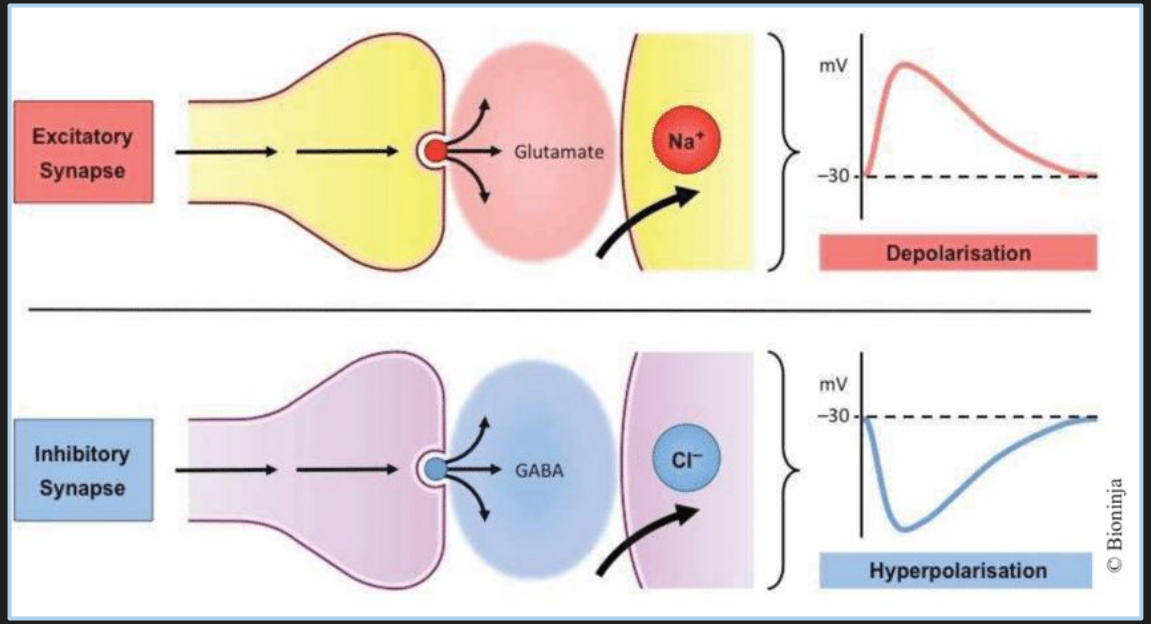
1981
- Sperry won Nobel prize for split-brain discovery
- Gazzaniga developed left brain interpreter theory

Now
- Understanding function of corpus callosum in visual processing and integration
- Role of the right hemisphere in moral reasoning
- Lateralization of function in the brain
- Connectivity and communication in the brain

(Wolman, 2012)

Neurotransmitters Involved in Epilepsy

Glutamatergic neurons are in principal the most common excitatory neurons.



Representation of excitatory and inhibitory synapses

https://www.researchgate.net/figure/Representation-of-excitatory-and-inhibitory-synapses-Ionic-changes-Na-sodium-or_fig1_322750841

GABAergic neurons are in principal the most common inhibitory neurons.

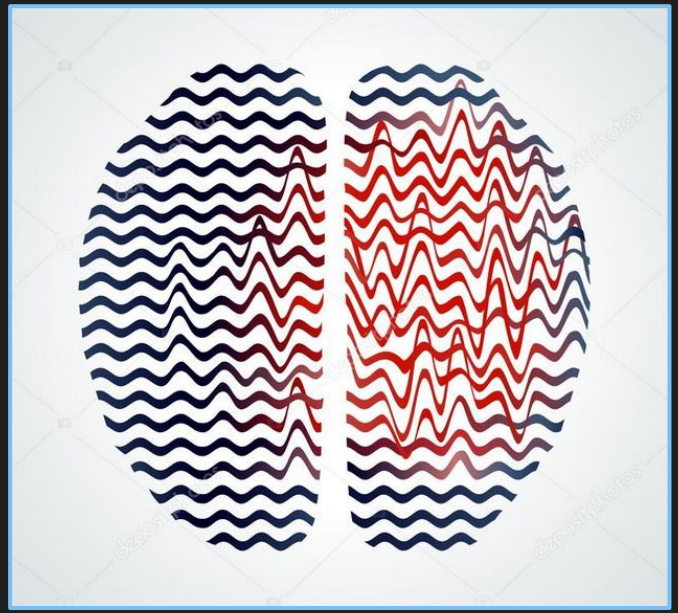
Neurotransmitters Involved in Epilepsy Continued...

"a burst of uncontrolled electrical activity between neurons that causes temporary abnormalities in muscle tone or movements, behaviors, sensations, or states of awareness."

- As defined by Johns-Hopkins

Onset of a seizure is marked by an increase in GABAergic activity.

- An inhibitory transmitter causes uncontrolled excitement?



hypersynchronous event of GABA release essentially exhausts available GABA

brain responds by releasing an unmitigated amount of glutamate

Loss of ability for brain to stop excitatory storm

Early Studies: Electrophysiological Studies

Methods: inducing epileptic fits via electrical stimulation of the cerebral cortex and observed clonic movements from one body part to another

Results: every trial exhibited a similar sequence of epileptic discharge

- Left arm to left leg
- Right leg to right arm

Clonic movements: seizures starting with a loss of consciousness followed by involuntary muscle convulsions usually lasting two to six minutes.

Archives of Neurology and Psychiatry

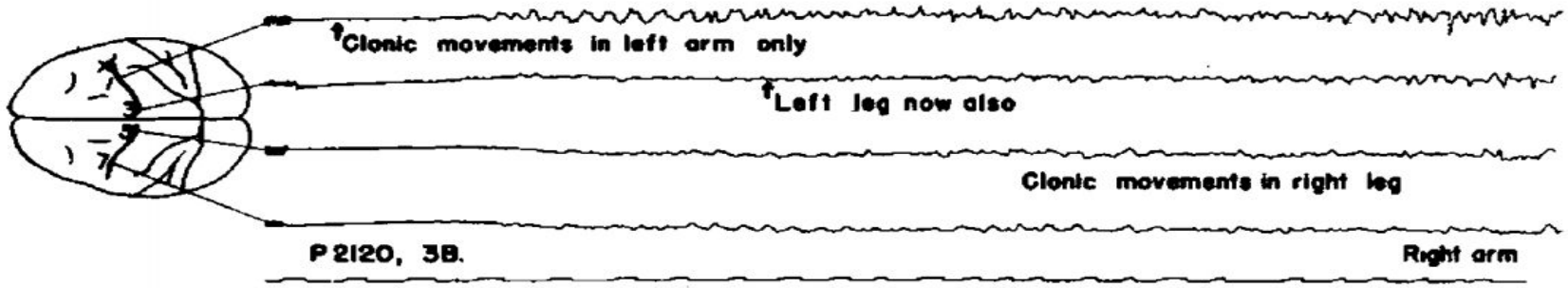
VOLUME 43 MARCH 1940 NUMBER 3

SPREAD OF THE EPILEPTIC DISCHARGE

AN EXPERIMENTAL STUDY OF THE AFTER-DISCHARGE INDUCED BY ELECTRICAL STIMULATION OF THE CEREBRAL CORTEX

THEODORE C. ERICKSON, M.D., PH.D.

MONTREAL, CANADA



Early Studies: Electrophysiological Studies Continued....

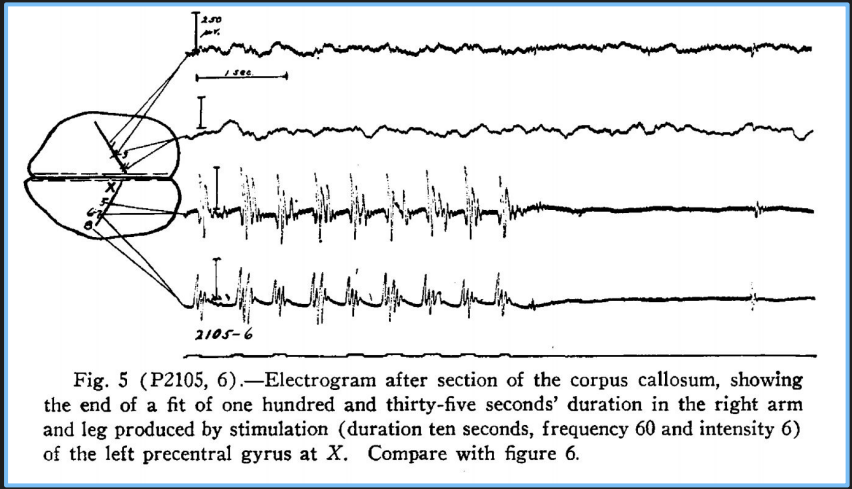


Fig. 5 (P2105, 6).—Electrogram after section of the corpus callosum, showing the end of a fit of one hundred and thirty-five seconds' duration in the right arm and leg produced by stimulation (duration ten seconds, frequency 60 and intensity 6) of the left precentral gyrus at *X*. Compare with figure 6.

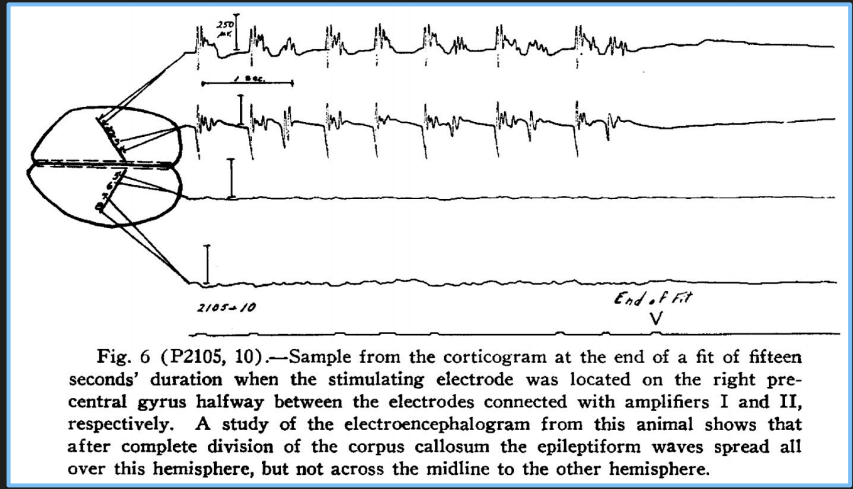


Fig. 6 (P2105, 10).—Sample from the corticogram at the end of a fit of fifteen seconds' duration when the stimulating electrode was located on the right precentral gyrus halfway between the electrodes connected with amplifiers I and II, respectively. A study of the electroencephalogram from this animal shows that after complete division of the corpus callosum the epileptiform waves spread all over this hemisphere, but not across the midline to the other hemisphere.

Longitudinal section of the corpus callosum inhibited communication between the two hemispheres

This study provided foundational information about how the two hemispheres communicate with one another, implying the main route of communication is through the corpus callosum.

Early Studies: Human Patients

Patient had been experiencing epileptic seizures for past 15 years

- At best once per week, worst case 7-10 times per day
- Showed no signs of motor impairment on either side prior to operation
- Only three brief clonic episodes 20 weeks post operation.

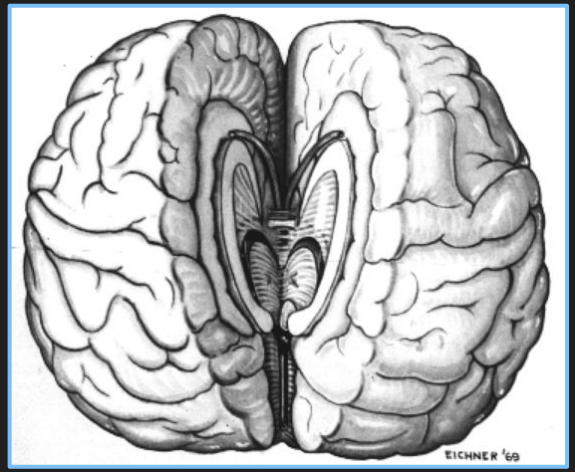
Patient underwent a callosotomy in an attempt to resolve his symptoms.

Some functional effects of sectioning the cerebral commissures in man

By M. S. Gazzaniga, J. E. Bogen, and R. W. Sperry

PNAS October 1, 1962 48 (10) 1765-1769; https://doi.org/10.1073/pnas.48.10.1765

Communicated August 2, 1962



Early Studies: Human Patients; Imparied Tactile Function

Method: patient was blindfolded and asked to manipulate common items.

Results:

- Right side exhibited no impairment
- Left side showed signs of severe agnosia, anomia, and agraphia
- Thumb to finger test:
  - Cross-localization was impossible
  - Tests requiring boths hands could not be done

Example of thumb to finger test result

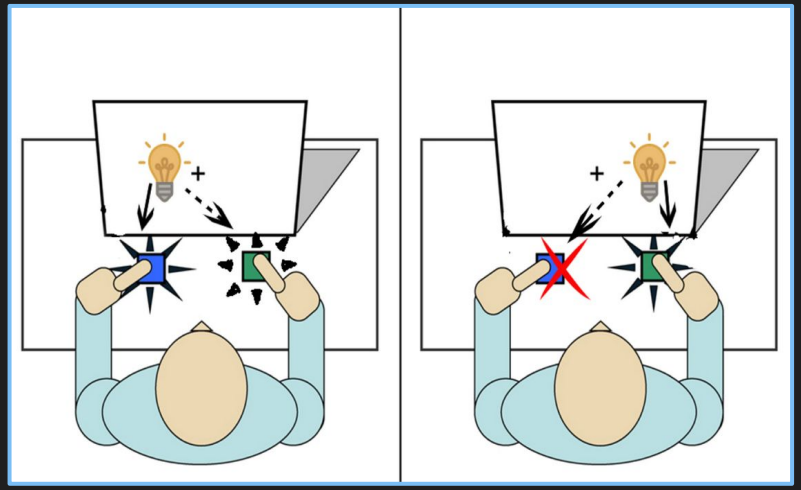
Early Studies: Human Patients; Visual and Visuomotor Tests

Tachistoscope test results:

- Right side successfully identified all images presented
- Left side failed to identify any image presented

Visuomotor test results:

- Right hand was able to respond when light was in right visual field only
- Left hand was able to respond to stimulation to either visual field



Representation of visuomotor test

Early Studies: Human Patients; Refined Motor Function

- Familiar and automatic tasks could be done independently by both hands
- Habitual tasks requiring coordination seemly unaffected
- Left armed failed if interrupted during familiar task or needed in more mindful task

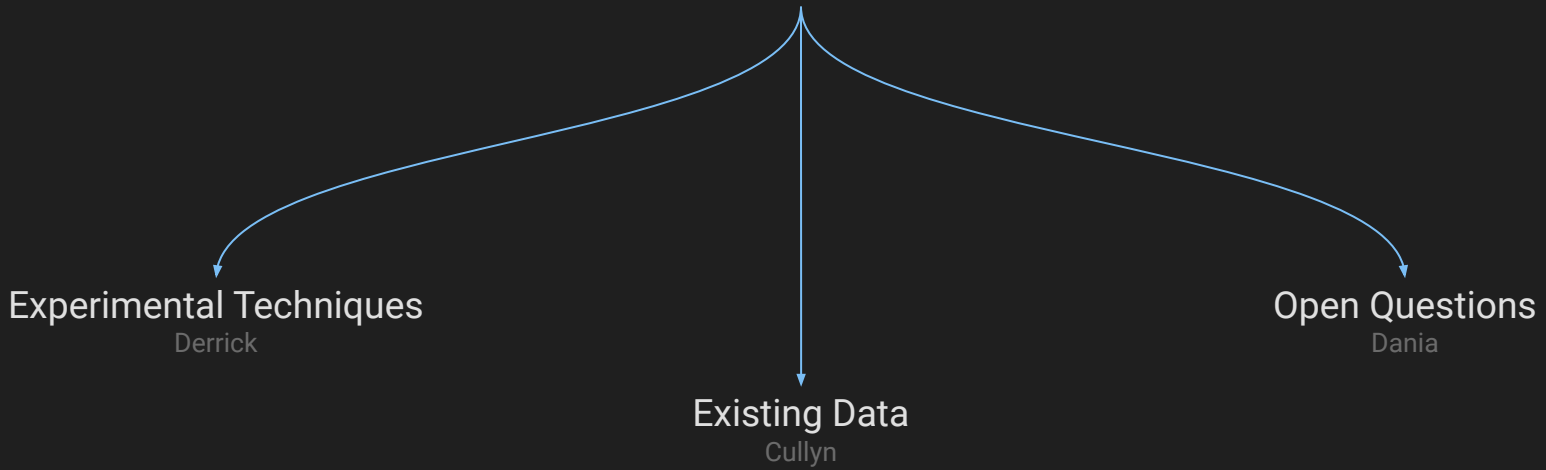
Early Studies: Human Patients; Summarized

Most motor functions retained, as long as they were constrained to the same hemisphere.

Breakdown in motor function only if active coordination was required

Previous eplieptic symptoms mostly resolved

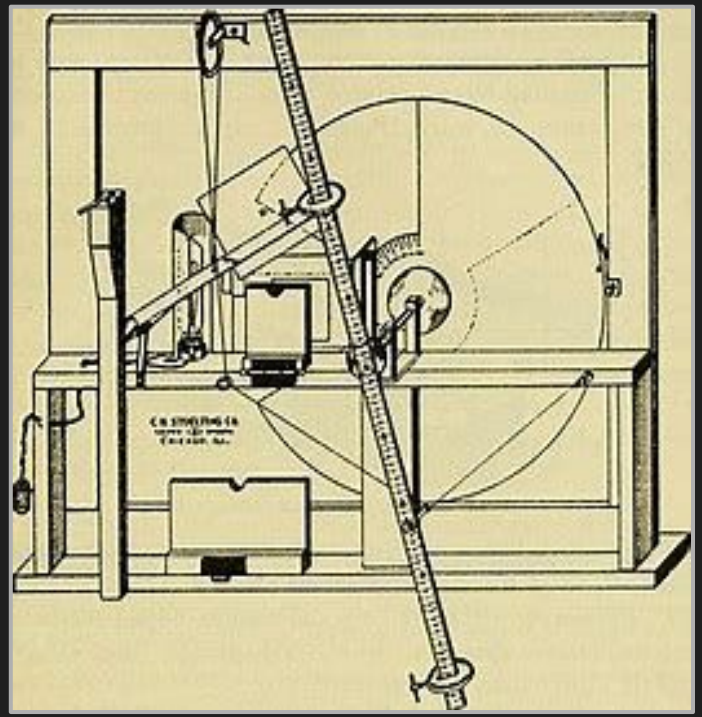
Current State of Research



Experimental Techniques

Before every surgery, it is important to detect to which hemisphere is responsible for speech. One way that scientists use to detect which side of the hemispheres is for speech is by using the Wada test.

Studies of split brain have made neuroscientists discovered many functions of the two hemispheres of the brain such as face recognition.

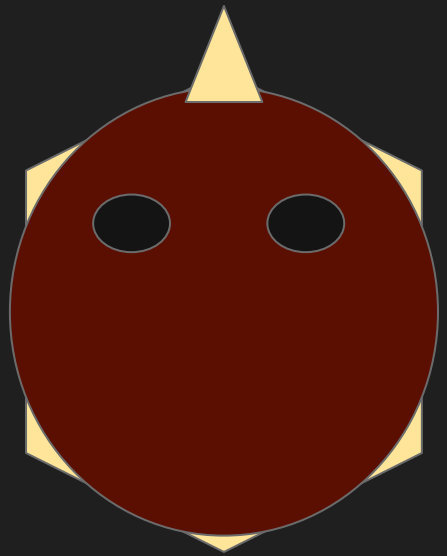


Tachistoscope: used for visual lateralization tests

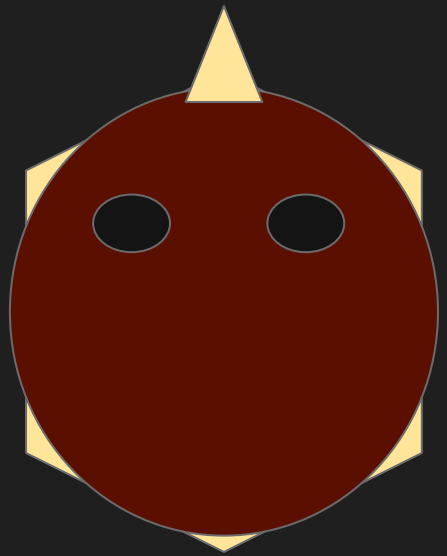
Left Visual Field

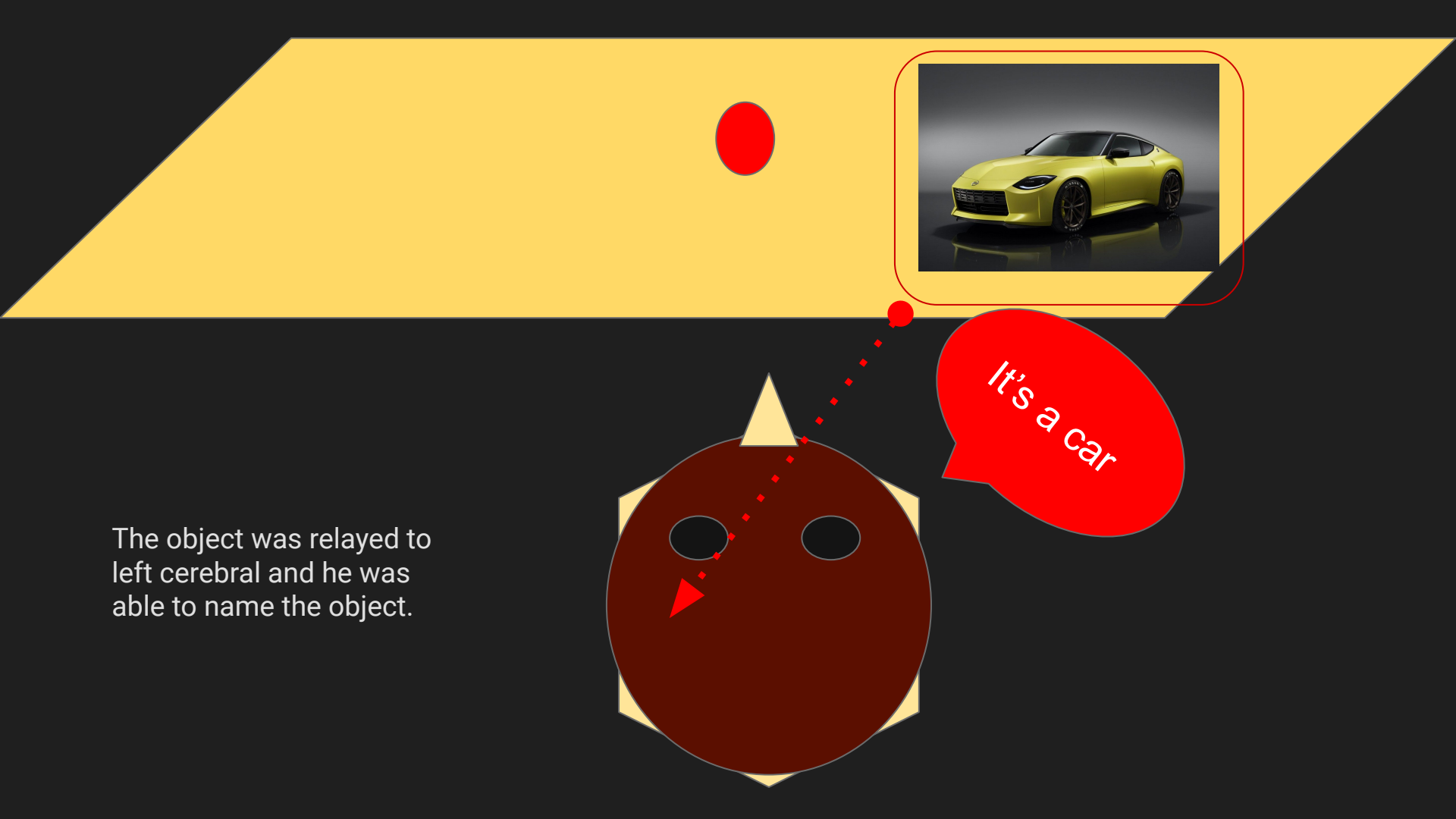
Right Visual Field

This patient has been asked to focus on the middle dot showing on the screen



An object has been shown to one side of the dot



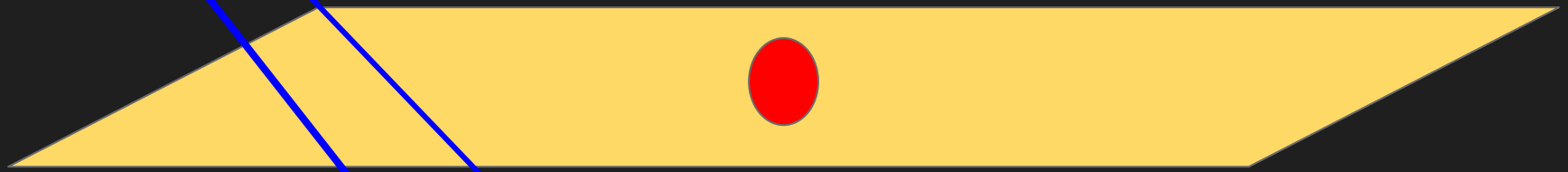


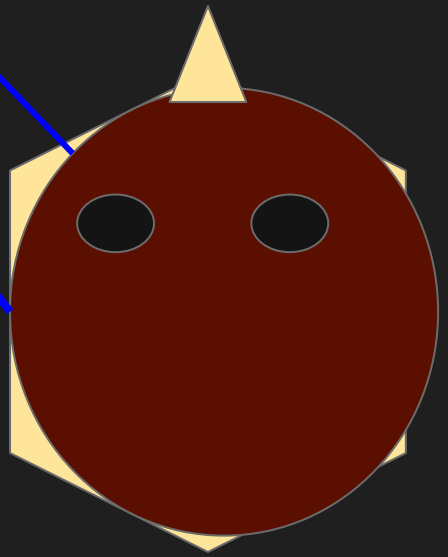
The object was relayed to left cerebral and he was able to name the object.

The object on left visual field was relayed to the right cerebral hemisphere.

I don’t see anything

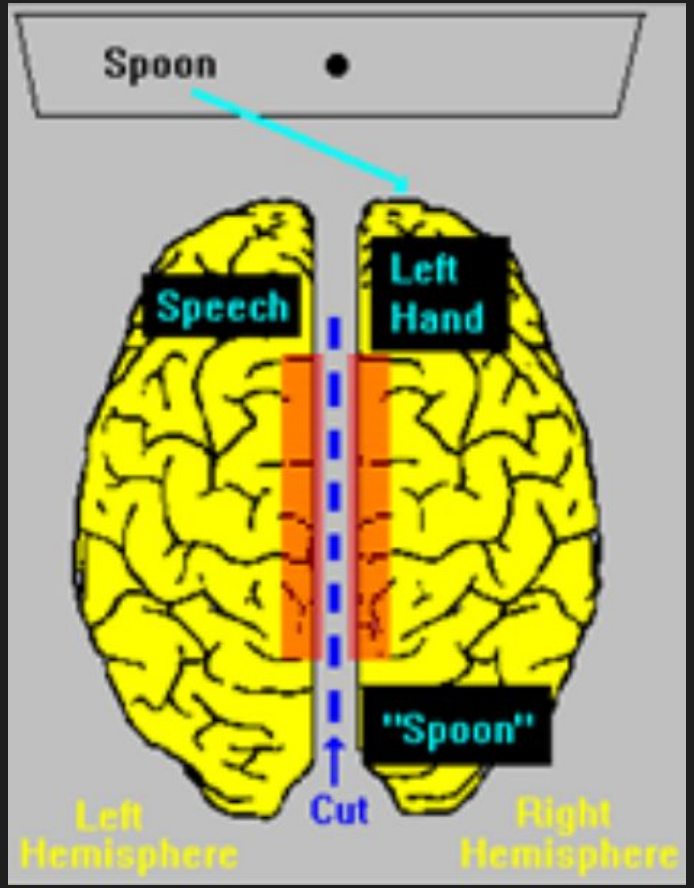
In this case, the patient could not name the object and even claimed that he does not see anything at all.





Here, the patient using his left hand was able to select the object he saw and when asked to draw, he was able to draw it though he does not have conscious memory of it.

Because the corpus callosum is cut off there is no communication between the right hemisphere and left since the left is responsible for speech

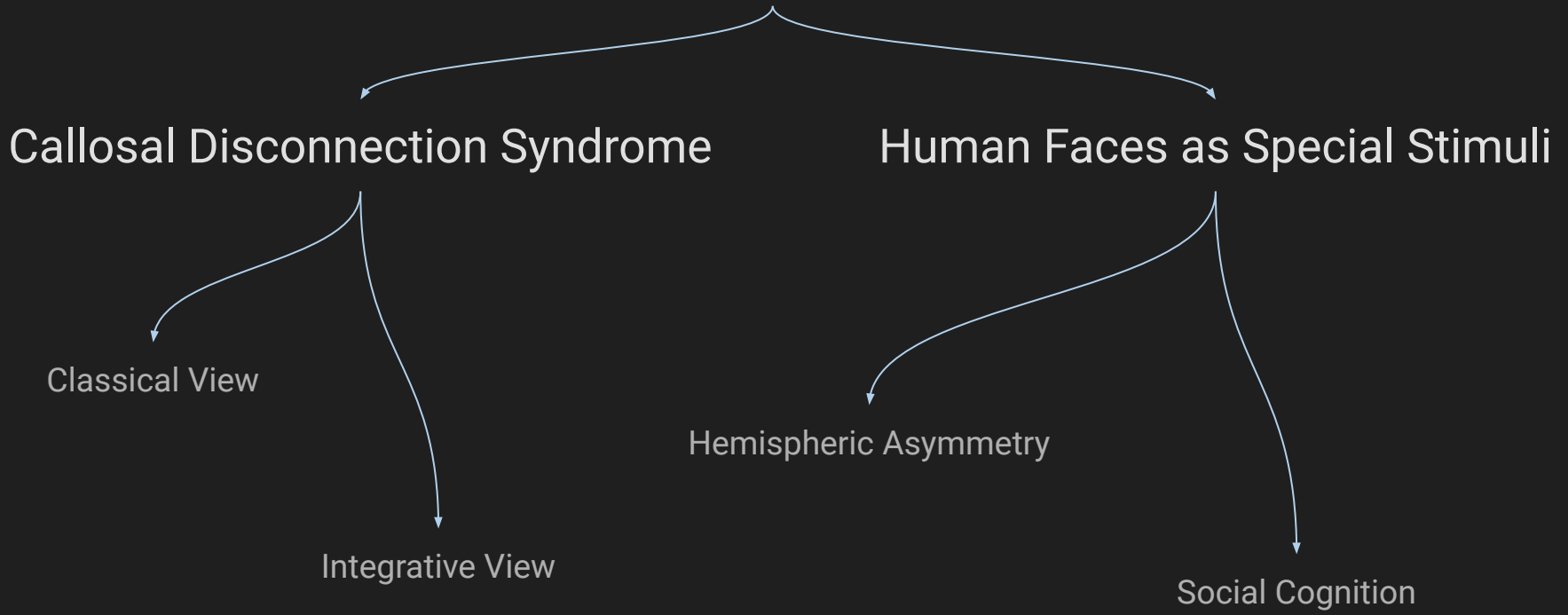


https://faculty.washington.edu/chudler/gif/chi3.jpeg

https://faculty.washington.edu/chudler/gif/chi3.jpeg

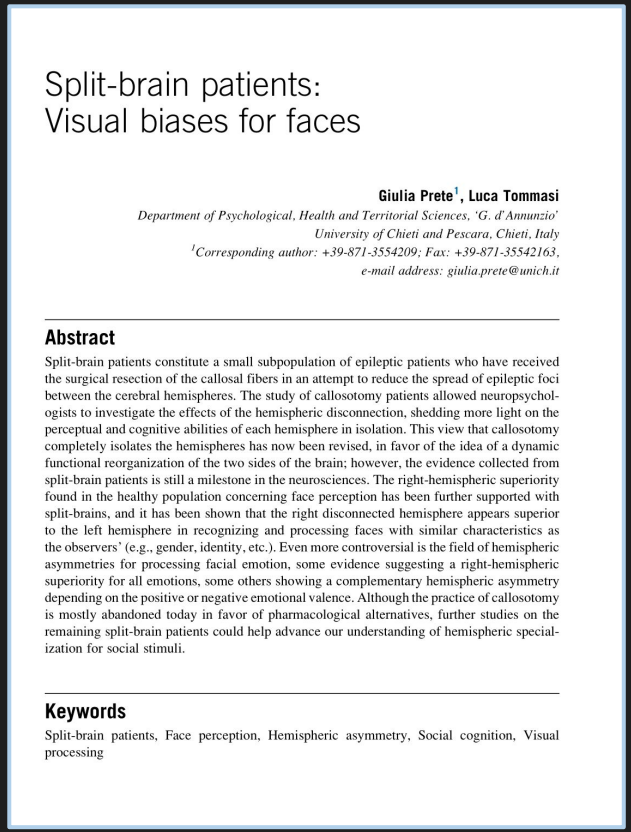
Through these experiments about split brain patients, neuroscientists were able to disclose the importance of hemispheric specialisation in human brains.

Current Paradigm



Department of Psychological, Health and Territorial Science
University of Chieti and Pescara

- Split Brain Patients
- Face Perception
- Hemispheric Asymmetry
- Social Cognition



Split-brain patients:
Visual biases for faces

Giulia Prete[1], **Luca Tommasi**
Department of Psychological, Health and Territorial Sciences, 'G. d'Annunzio' University of Chieti and Pescara, Chieti, Italy
[1]Corresponding author: +39-871-3554209; Fax: +39-871-35542163, e-mail address: giulia.prete@unich.it

Abstract

Split-brain patients constitute a small subpopulation of epileptic patients who have received the surgical resection of the callosal fibers in an attempt to reduce the spread of epileptic foci between the cerebral hemispheres. The study of callosotomy patients allowed neuropsychologists to investigate the effects of the hemispheric disconnection, shedding more light on the perceptual and cognitive abilities of each hemisphere in isolation. This view that callosotomy completely isolates the hemispheres has now been revised, in favor of the idea of a dynamic functional reorganization of the two sides of the brain; however, the evidence collected from split-brain patients is still a milestone in the neurosciences. The right-hemispheric superiority found in the healthy population concerning face perception has been further supported with split-brains, and it has been shown that the right disconnected hemisphere appears superior to the left hemisphere in recognizing and processing faces with similar characteristics as the observers' (e.g., gender, identity, etc.). Even more controversial is the field of hemispheric asymmetries for processing facial emotion, some evidence suggesting a right-hemispheric superiority for all emotions, some others showing a complementary hemispheric asymmetry depending on the positive or negative emotional valence. Although the practice of callosotomy is mostly abandoned today in favor of pharmacological alternatives, further studies on the remaining split-brain patients could help advance our understanding of hemispheric specialization for social stimuli.

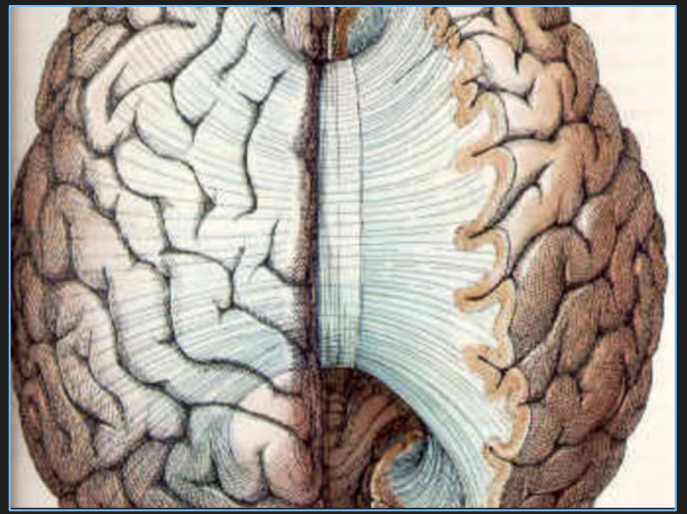
Keywords

Split-brain patients, Face perception, Hemispheric asymmetry, Social cognition, Visual processing

Classical View

Cognitive functions emerge from white matter connections with different cerebral areas.
- Wernicke (1874) and revised by Geschwind (1965a,b)

“a copy of the visual world as seen in one hemisphere is sent over to the other”
- Gazzaniga (1967, p.29)



Gazzaniga, M.S., 1967. The split brain in man. Sci. Am. 27, 24–29.
Geschwind, N., 1965a. Disconnexion syndromes in animals and man I. Brain 88, 237–294.
Geschwind, N., 1965b. Disconnexion syndromes in animals and man II. Brain 88, 585–644.
Wernicke, K., 1874. The aphasia symptom-complex. Breslau, Cohn and Weigert. Translated in: Eling P., Ed. Reader in the History of Aphasia. vol. 4. 1994. Amsterdam: John Benjamins; 69–89.

Integrative View

Corpus callosum is not solely constituted of white matter, it actually contains selectively active cells depending on nature of stimuli presented.
- Fabri et al (2014); Gawryluk et al (2009)

Callosal fibers are both excitatory and inhibitory; some excitatory fibers activate inhibitory interneurons.
- Kinsbourne (2003)

Right-to-left information transfer time was faster than left-to-right.
- Barnett and Corballis (2005)

Barnett, K.J., Corballis, M.C., 2005. Speeded right-to-left information transfer: the result of speeded transmission in right-hemisphere axons? Neurosci. Lett. 380 (1), 88–92. https://doi.org/10.1016/j.neulet.2005.01.025

Fabri, M., Polonara, G., 2013. Functional topography of human corpus callosum: an fMRI mapping study. Neural Plast. 2013, 251308. https://doi.org/10.1155/2013/251308.

Kinsbourne, M., 2003. The corpus callosum equilibrates the cerebral hemispheres. In: Zaidel, E., Iacoboni, M. (Eds.), The Parallel Brain: The Cognitive Neuroscience of the Corpus Callosum. MIT Press, Cambridge, MA, pp. 271–281. Làdavas, E., Cimatti, D., Pesce, M.D., Tuozzi, G., 1993.

Callosal connections are heavily used in interhemispheric communication, utilizing both white matter and bilateral subcortical projections in some informational processing roles, giving rise multiple functional roles in some hemispheric asymmetries.

Hemispheric Asymmetry For Faces

Face processing mainly takes place in the right hemisphere, or more specifically, in the fusiform gyrus located in the right temporal region (fusiform face area, FFA) of the brain.
- Kanwisher and Yovel (2006)

Interhemispheric cooperation in face analysis has been revealed in other studies; suggesting a face-processing network, including:

- FFA and occipital face area (OFA),
- other temporal sites,
- inferior frontal cortex,
- and subcortical structures, such as amygdala and superior colliculus.

- Davies-Thompson and Andrews (2012)

Davies-Thompson, J., Andrews, T.J., 2012. Intra- and interhemispheric connectivity between face-selective regions in the human brain. J. Neurophysiol. 108 (11), 3087–3095. https://doi.org/10.1152/jn.01171.2011.

Kanwisher, N., Yovel, G., 2006. The fusiform face area: a cortical region specialized for the perception of faces. Philos. Trans. R. Soc. Lond. B 361 (1476), 2109–2128. https://doi.org/10.1098/rstb.2006.1934.

Hemispheric Asymmetry in the Disconnected Brain

Right hemisphere superiority was found consistently in processing of faces, mainly in faces sharing the same characteristics as the observer's, and in facial identity/familiarity, but both hemispheres were shown to be commonly used for other tasks.

- Levy et al., (1972); Mason and Macrae (2004); Turk et al., (2002); Uddin et al., (2005); Luo et al., (2011); Prete et al., (2016); Keenan et al., (2003); Preilowski (1977)

The degree of lateralization to one hemisphere is somewhat uncertain in many cases, though there are much data that suggest lateralization depends more on the particular task at hand.

Levy, J., Trevarthen, C., Sperry, R.W., 1972. Perception of bilateral chimeric figures following hemispheric deconnexion. Brain 95 (1), 61.
Mason, M.F., Macrae, C.N., 2004. Categorizing and individuating others: the neural substrates of person perception. J. Cogn. Neurosci. 16 (10), 1785–1795.
Turk, D.J., Heatherton, T.F., Kelley, W.M., Funnell, M.G., Gazzaniga, M.S., Macrae, C.N., 2002. Mike or me? Self-recognition in a split-brain patient. Nat. Neurosci. 5 (9),841–842.
Uddin, L.Q., Rayman, J., Zaidel, E., 2005. Split-brain reveals separate but equal self-recognition in the two cerebral hemispheres. Conscious. Cogn. 14 (3), 633–640.
Luo, B., Shan, C., Zhu, R., Weng, X., He, S., 2011. Functional foveal splitting: evidence from neuropsychological and multimodal MRI investigations in a Chinese patient with a splenium lesion. PLoS One 6 (8), e23997.
Keenan, P.A., Whitman, R.D., Pepe, J., 1989. Hemispheric asymmetry in the processing of high and low spatial frequencies: a facial recognition task. Brain Cogn. 11 (2), 229–237.
Preilowski, B., 1977. Self-recognition as a test of consciousness in left and right hemisphere of “split-brain” patients. Act. Nerv. Super. (Praha) 19 (2), 343–344.

Social Perception and Cognition

Emotional expressions are automatically detected, generating both behavioral and physiological reactions.
- Stefanics et al., (2012); Jessen et al., (2016)

Valence hypothesis (VH): left-hemispheric/right-hemispheric superiority exists for positive and negative emotions, respectively.
- Baijal and Srinivasan, (2011); Davidson et al., (1987)

Right hemisphere hypothesis (RHH): both positive and negative emotional processing takes place in in the right hemisphere.
- Gainotti, (1972, 2012); Levy et al., (1983); Lindell, (2013)

Baijal, S., Srinivasan, N., 2011. Emotional and hemispheric asymmetries in shifts of attention: an ERP study. Cogn. Emot. 25, 280–294.
Davidson, R.J., Mednick, D., Moss, E., Saron, C., Schaffer, C.E., 1987. Ratings of emotion in faces are influenced by the visual field to which stimuli are presented. Brain Cogn. 6, 403–411.
Gainotti, G., 1972. Emotional behavior and hemispheric side of the lesion. Cortex 8 (1), 41–55. 3
Gainotti, G., 2012. Unconscious processing of emotions and the right hemisphere. Neuropsychologia 50 (2),205–218.
Jessen, S., Altvater-Mackensen, N., Grossmann, T., 2016. Pupillary responses reveal infants' discrimination of facial emotions independent of conscious perception. Cognition 150, 163–169.
Levy, J., 1983. Language, cognition, and the right hemisphere: a response to Gazzaniga. Am. Psychol. 538–541.
Lindell, A.K., 2013. Continuities in emotion lateralization in human and non-human primates. Front. Hum. Neurosci. 7, 464.

Current Paradigm: Perception and Cognition, Continued...

Evidence that supports the validity of both VHH and RHH has been found.
- Prete et al (2014b)

Emerging dynamic hypothesis: the number of emotional stimuli could be the main variable influencing hemispheric asymmetries. Increased load is correlated with increasing hemispheric specialization.
- Stone et al. (1996)

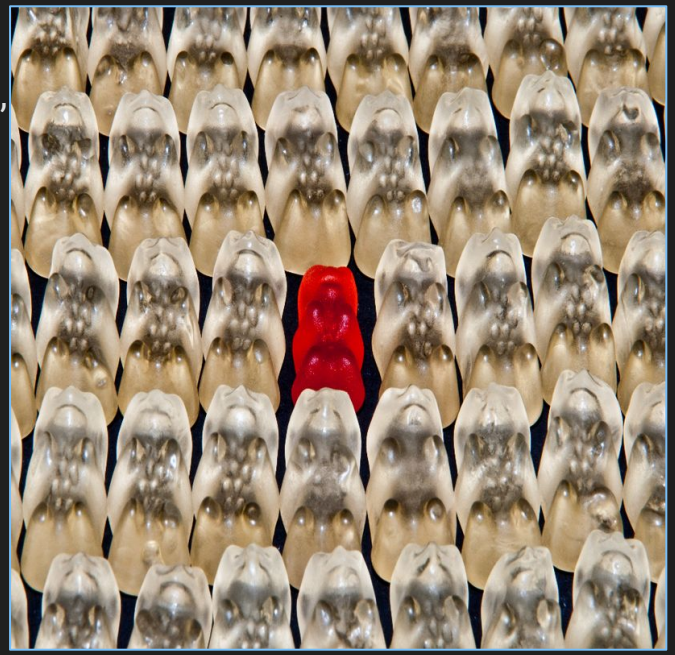
Stone, V.E., Nisenson, L., Eliassen, J.C., Gazzaniga, M.S., 1996. Left hemisphere representations of emotional facial expressions. Neuropsychologia 34 (1), 23–29.

Prete, G., Marzoli, D., Brancucci, A., Fabri, M., Foschi, N., Tommasi, L., 2014b. The processing of chimeric and dichotic emotional stimuli by connected and disconnected cerebral hemispheres. Behav. Brain Res. 271, 354–364. https://doi.org/10.1016/j.bbr. 2014.06.034.

Open Questions: Data Abnormalities

Issues with the procedure:

- Some had all commissures severed (commissurotomy),
- some only having the corpus callosum severed (callosotomy),
- and some falling somewhere in between.



Limitations on current research:

- Impact of handedness,
- language capabilities in the right hemisphere,
- interhemispheric integration prior to surgery and later in recovery,
- and deeper issues causing epilepsy.

Visual Half Field

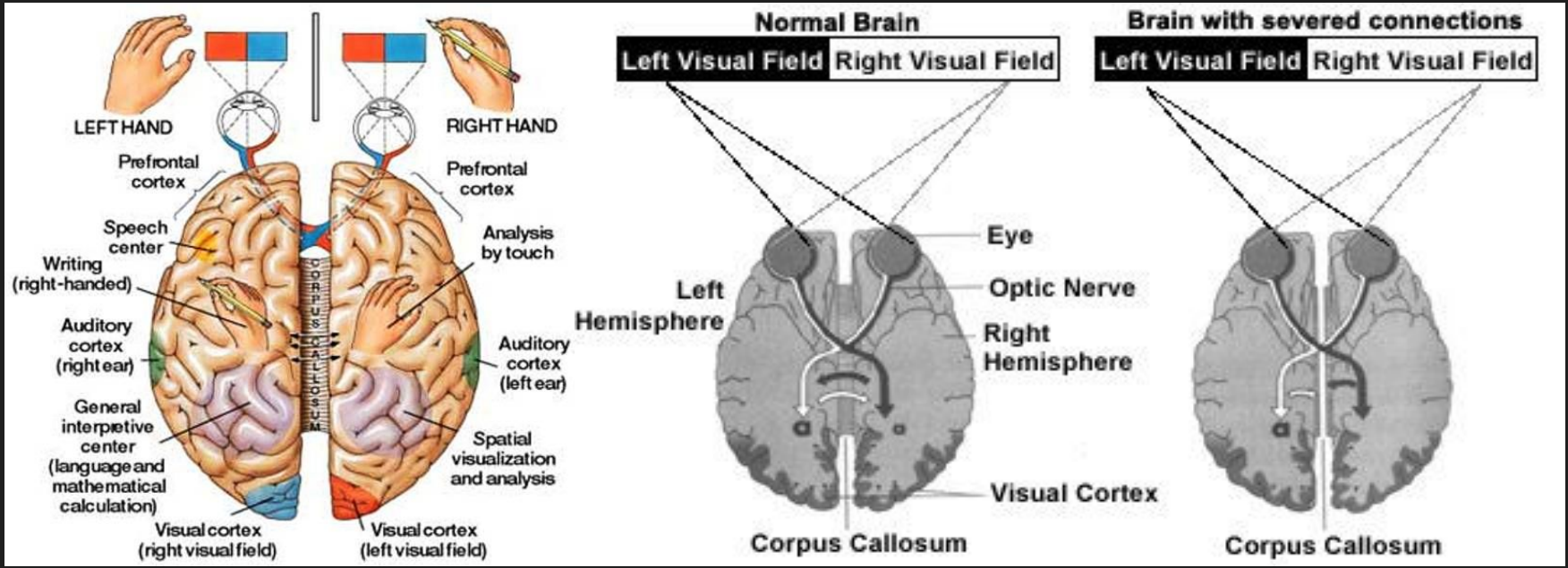
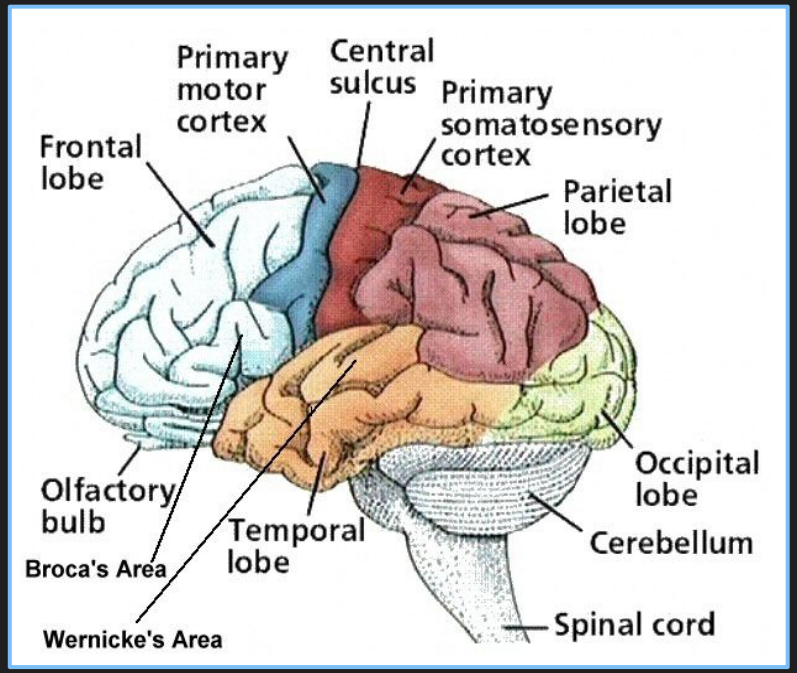


Image sources: Examining Biological Foundations of Human Behavior textbook Field Notes from an Evolutionary Psychologist blog

Corpus Callosum is inferior to the primary motor cortex and somatosensory cortex



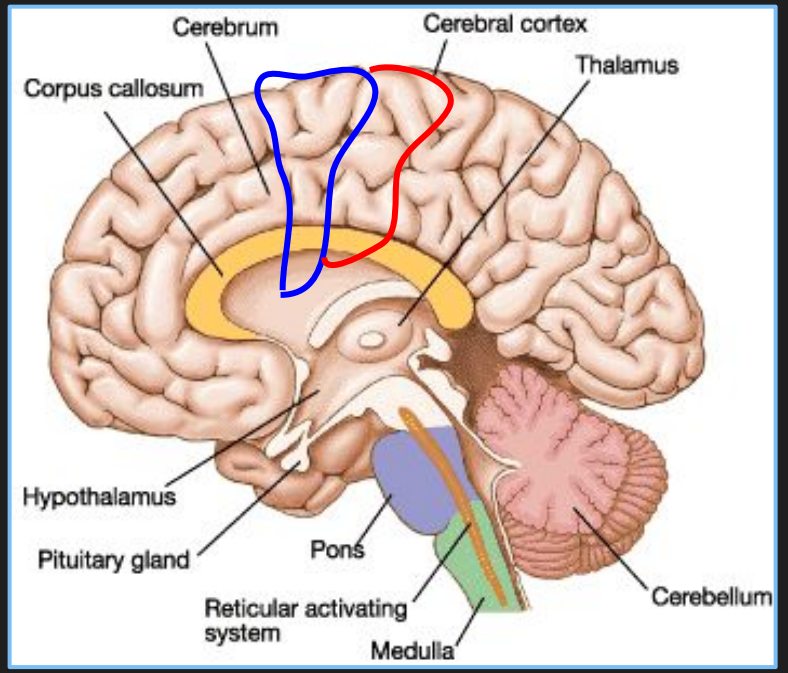


Image sources: clipart-library.com Human physiology academy

Subject Unity

The unified consciousness within one system (one body). Present if all experiences generated in a system belong to one subject, usually in first person. Absent if the system consists of multiple first person experiences.

Global Neuronal Workspace Theory

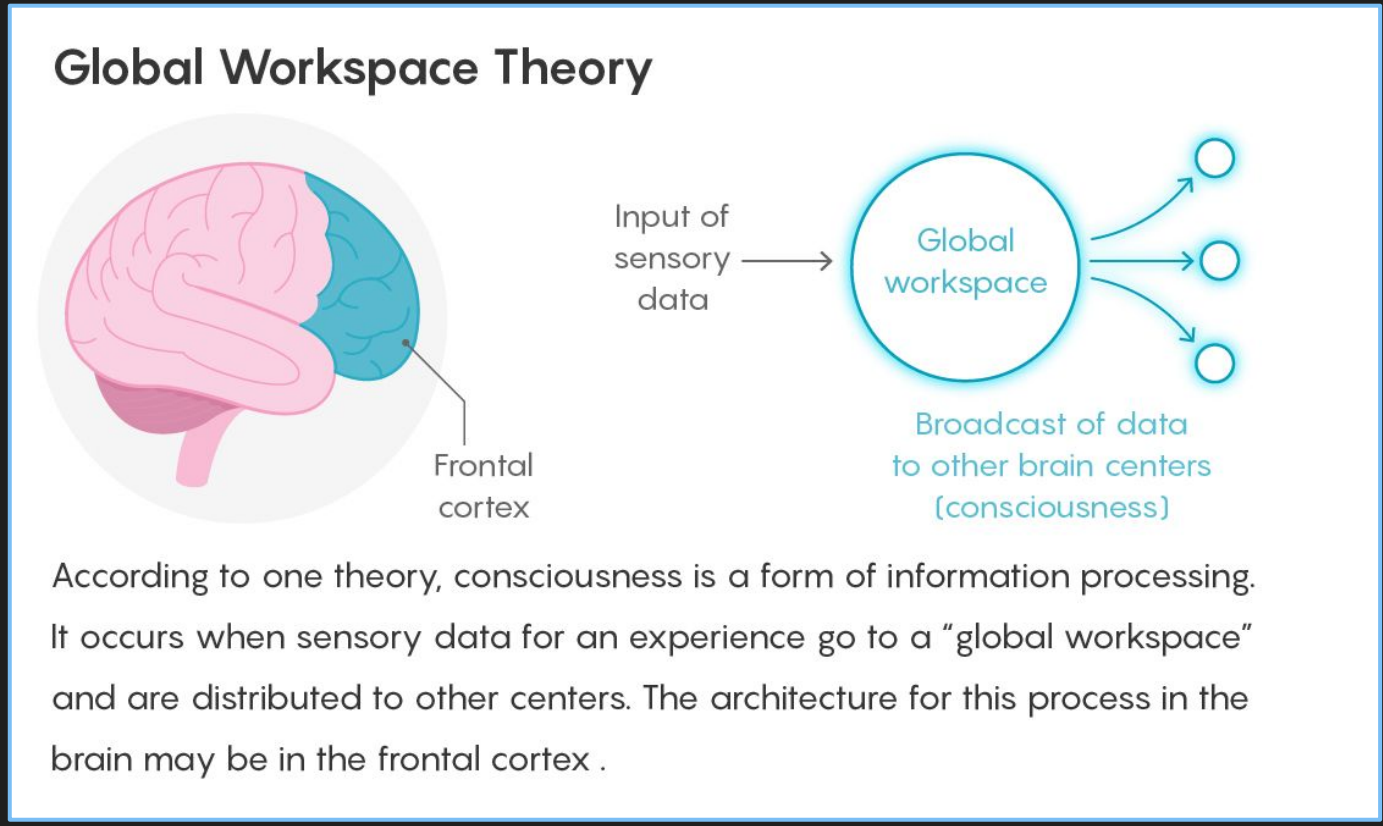


Image source: Quanta Magazine

Integrated Information Theory

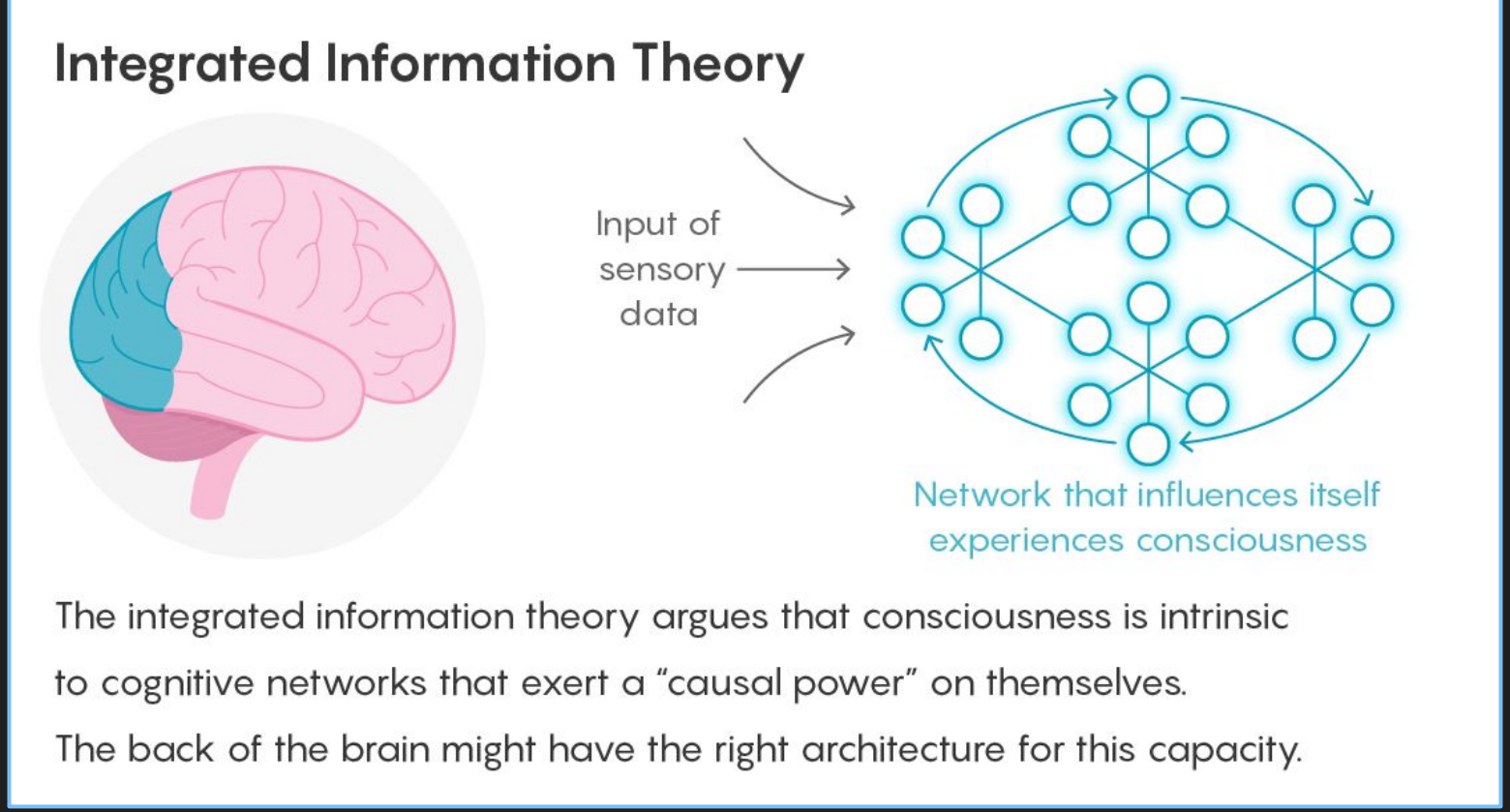


Image source: Quanta Magazine

Recurrent Processing Theory

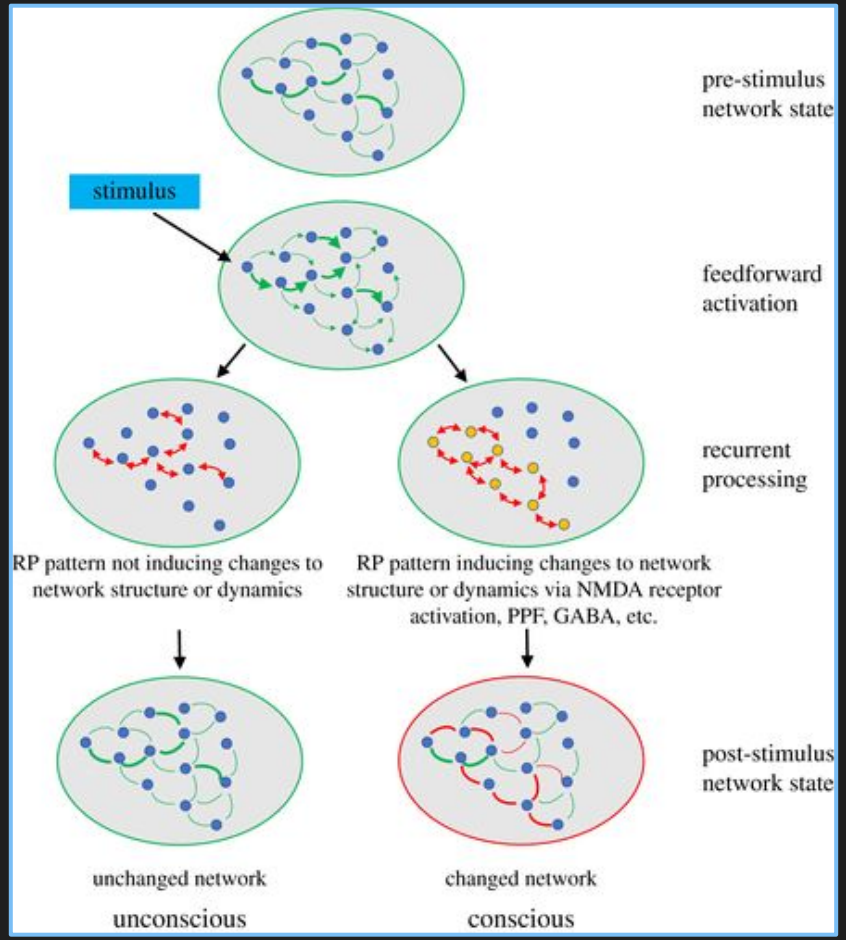
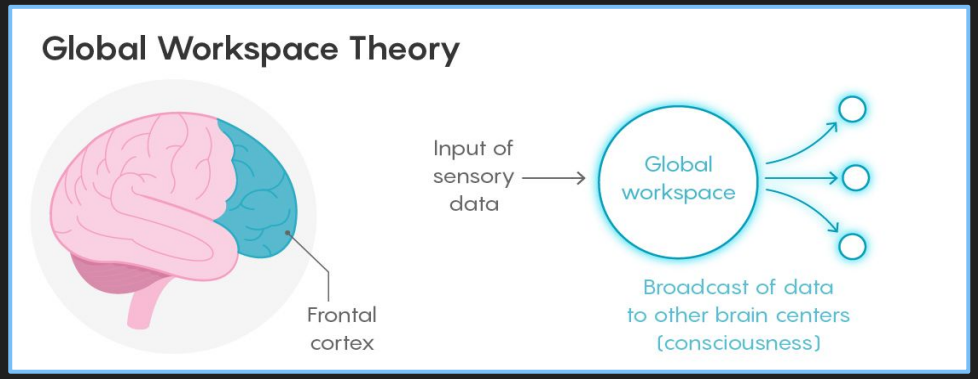
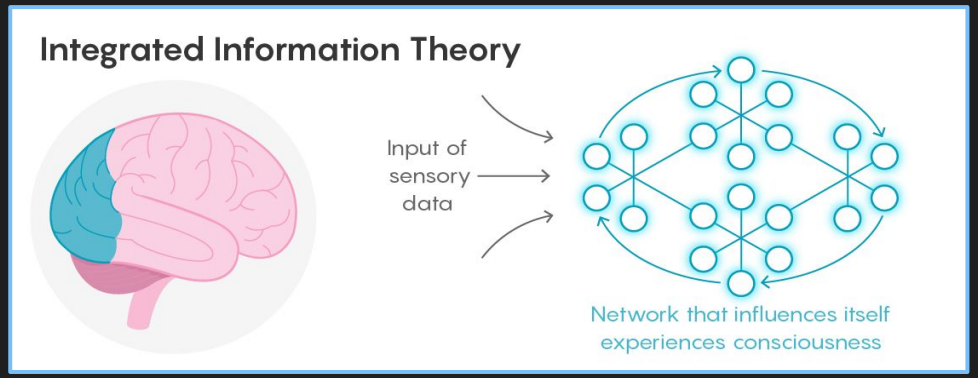
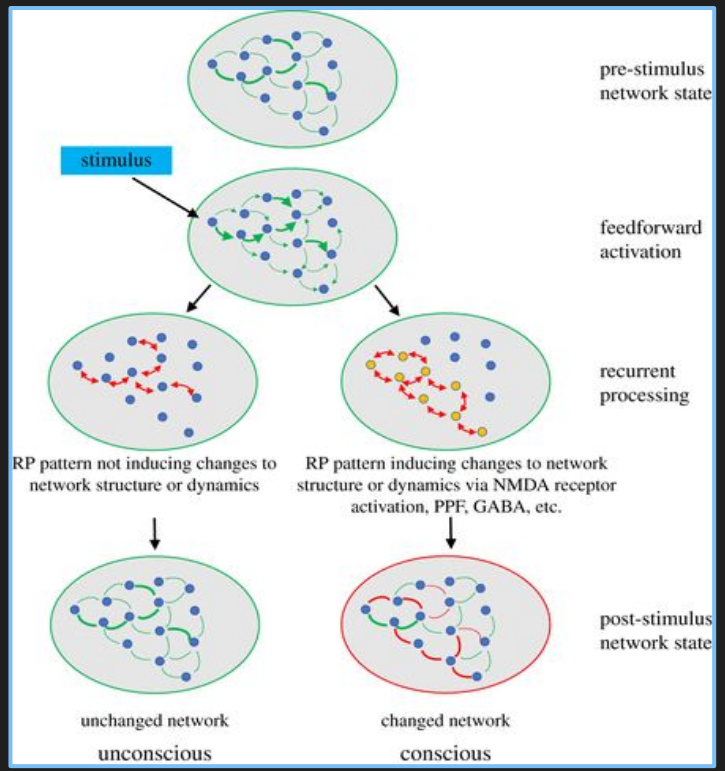


Image source: Royal Society Journals

Theories Revisited

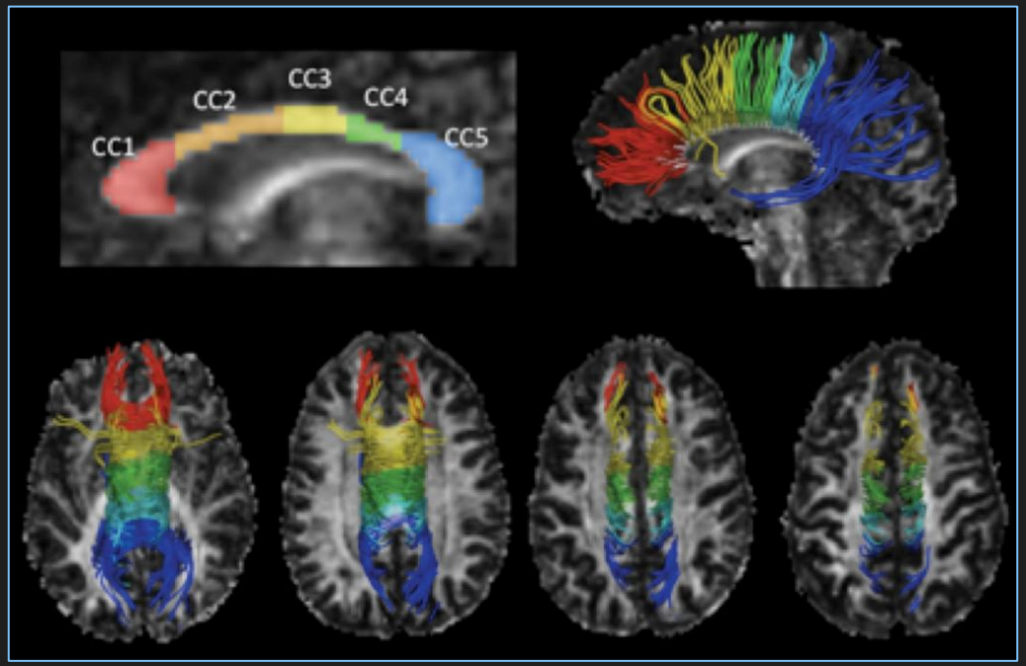






These three theories are helping pave the way for research on how the human mind works in its entirety but also when it has been altered by disease, mutations or surgical intervention.

Conclusion



Corpus callosum segmentation and tractography

https://www.researchgate.net/publication/256611459_Segmented_corpus_callosum_diffusivity_correlates_with_the_Expanded_Disability_Status_Scale_score_in_the_early_stages_of_relapsing-remitting_multiple_sclerosis

References

- Goldstein, A., Covington, B. P., Mahabadi, N., & Mesfin, F. B. (2020). Neuroanatomy, Corpus Callosum. StatePearls. Statepearls Publishing.
- Graf M.R. (2011) Commissures, Cerebral. In: Kreutzer J.S., DeLuca J., Caplan B. (eds) Encyclopedia of Clinical Neuropsychology. Springer, New York, NY.
- Wolman, F. (2012, March 14). The Split Brain: A Tale of Two Brains. Nature International Weekly Journal of Science. https://www.nature.com/news/the-split-brain-a-tale-of-two-halves-1.10213
- Han, S. (2017, June 24). What Does The Corpus Callosum Do? Medical News Today. https://www.medicalnewstoday.com/articles/318065#Conditions-related-to-the-corpus-callosum
- Prete, G., Fabri, M. Foschi, N., & Tommasi, L. (2016). Face gender categorization and hemisphere asymmetries: contrasting evidence from connected and disconnected brains. Neuroscience, 339, 210-218. Doi: 10.1016/j.neuroscience.2016.10.021.
- Liendhard, Dina A., “Roger Sperry’s split brain experiments (1959-1968).” Embryo Project Encyclopedia (2017-12-27). ISSN: 1940-5030. http://embryo.asu.edu/handle/10776/13035.
- De Haan, E. H. F., Corballis, P. M., Hillyard, S. A., Marzi, C. A., Seth, A., Lamme, V. A. F., … Pinto, Y. (2020). *Split-Brain: What We Know Now and Why This is Important for Understanding Consciousness. Neuropsychology Review.* doi:10.1007/s11065-020-09439-3
- Bromfield, E. B., Cavazos, J. E., & Sirven, J. I. (2006). Chapter 1 Basic Mechanisms Underlying Seizures and Epilepsy. In *An introduction to epilepsy*. Bethesda, MD: American Epilepsy Society.
- De Curtis, M., & Avoli, M. (2015). Initiation, propagation, and termination of partial (focal) seizures. *Cold Spring Harbor Perspectives in Medicine, 5*(7). doi:10.1101/cshperspect.a022368
- Gazzaniga, M. S., Bogen, J. E., & Sperry, R. W. (1962). Some functional effects of sectioning the cerebral commissures in man. *Proceedings of the National Academy of Sciences of the United States of America, 48*(10), 1765-1769. doi:https://doi.org/10.1073/pnas.48.10.1765
- Erickson, T. C. (1940). Spread of the Epileptic Discharge. *Archives of Neurology & Psychiatry, 43*(2), 429th ser. doi:doi:10.1001/archneurpsyc.1940.02280030003001