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Radiological and Cadaveric Investigation of the Primary Human Brain Sulci: Morphometric Analysis and Clinical Consequences

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Abstract:

Understanding the connections between different parts of the brain and how they work is a significant focus of current human neuroscience studies. Thanks to advancements in anatomical and functional 3D neuroimaging, what seemed like an insurmountable task a decade ago is now within reach. But before we can create a whole map of the human brain, there are a lot of important questions that need answering. To start, there is a lot of variation in brain anatomy and function from one person to the next, which is why spatial registration and normalisation of brain scans from different people is a hot topic. The second point is that the human brain is spatially and temporally organised at multiple levels, from individual synapses to extensive distributed networks. Neuroimagers face a formidable technical difficulty in integrating these different levels, and solving this problem is a challenging theoretical one in neuroscience. Curiously, similar problem has arisen in functional imaging population studies, where averaging functional images of diverse people became necessary because to the low signal-to-noise ratio of positron emission tomography (PET) images. links between the structure and function of the human brain, both at the macroscopic and microscopic levels, to highlight the significance of the connection between the individual's anatomy and function. The requirement for a shared neuroanatomical reference frame is becoming more pressing as database projects incorporate data from cytoarchitectony, electrical stimulation, electrical recordings, and functional imaging methods such as functional magnetic resonance imaging (fMRI), event-related potentials, magnetoencephalography, electroencephalography, and functional magnetic resonance imaging (PET).

Keywords : Human Brain Sulci, Morphometric Analysis, Radiological Study.

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Introduction

The ancient Egyptians were the first to describe the cerebral cortex, but it wasn't until the early 1800s that it was thought to have no function. Until recently, scientists thought the brain's tangled surface probably didn't house any significant functions; instead, they thought the ventricular structures now understood to contain only physiological fluid—were responsible for localising mental activity. There was no specific arrangement or design to the gyri; instead, they were shown as tiny intestines or like macaroni. Only the Sylvian fissure on the surface of the cerebral hemisphere has been named. Anatomists' efforts towards the close of the nineteenth century provided the bulk of what is known about the macroscopic structure of the human brain [1, 2]. Back then, there was no way for researchers to resection a brain in a different direction after the first dissection, and they only had access to a small number of cadaver brains.

So, they used one hemisphere to depict the coronal views, another for the axial views, and a third for the sagittal views—all because they required a second brain. Furthermore, there was no officially established method for slicing the brain, and deformities occurred upon removal from the skull. These caveats notwithstanding, the anatomists performed groundbreaking work that laid the groundwork for contemporary brain anatomic labelling. It was within the French neurological school, and especially Déjerine's detailed descriptions of the brain, that a systematic system of anatomical names was established, marking the beginning of modern cerebral anatomy. Be aware, nevertheless, that anatomical labelling is still muddled by nomenclature variation. Specifically, various names can be used to the same structure. For instance [3-5], the angular gyrus is known by several names, including "plicourbe" or inferior parietal gyrus, and it is frequently called Brodmann's area 39. However, the latter name does not relate to anatomical structure at the macroscopic level, but rather to a cytoarchitectonic area that can only be described by microscopic features.

Brain Dimensions and Outline

Within the skull rests the human brain, a delicate organ weighing in at about 1400g. The brain is encased in protective membranes known as the meninges, which comprise a thick outer layer known as the dura mater, a thin inner layer known as the pia mater, and an intermediate layer known as the arachnoid, which is composed of fibres. The brain is encased in a transparent fluid called cerebrospinal fluid (CSF), which serves multiple purposes, including nourishing the brain and emptying excess fluid. Both sides of the brain, along with the brainstem and cerebellum, make up the brain's fundamental architecture. The falx cerebri, a membrane septum that divides the two cerebral hemispheres, is located within a longitudinal fissure that is also known as the interhemispheric fissure. The cortical or grey matter surfaces of the two seemingly symmetrical cerebral hemispheres house the neuronal bodies. A series of crests, or gyri, and fissures, or sulci, that separate them characterise the extremely intricate surface of the hemispheres. White matter, composed of strands of fibres that extend from neuronal bodies, lies beneath this grey layer. The myelin sheaths these fibres, which are actually axons [6-9]. The corpus callosum is a wide commissure of white-matter tracts that connects the two halves of the brain. Bear in mind that there is extra grey matter in the brain's core that does not belong to the cortex. The grey nuclei are huge collections of neurones that make up the deep grey matter. Both hemispheres contain the caudate nucleus and the lenticular nucleus, the latter of which can be further divided into the pallidum and putamen. The thalamus and a few smaller nuclei, like the subthalamic and red nuclei, are other notable deep grey matter nuclei. It is usual practice to divide the hemispheres into six lobes, with four of these lobes being named after the corresponding skull bones. The problem with anatomical nomenclature begins here, since the boundaries between the lobes are not always clear. In this article, we will go over the five main brain regions as they appear on the outside of one half of a human brain. At the very front of the brain lies the frontal lobe, which is clearly bordered on the back by the Rolandic sulcus and on the bottom by the Sylvian fissure. Contrarily, not all physical features serve as the basis for the divisions of the parietal, temporal, and occipital lobes. As seen in the example, the boundary between the occipital, parietal, and temporal lobes is typically delineated by a virtual line (yellow dashed line) that descends from the parieto-occipital sulcus (which is only visible on the inside of the brain) all the way to the incisure of Meynert [10-13]. Similarly, there has to be some arbitrary norm for where the temporal lobe meets the parietal lobe: The point where the Sylvian fissure turns vertical (blue dashed line) is chosen as the beginning point for a horizontal line. It should be stressed that these virtual limitations are not supported by anatomy [14, 15], histology, or function. The insula, a little triangular region of cortical tissue that is obscured by the Sylvian fissure, makes up the fifth lobe. According to Broca, the cingulate and subcallosal gyri, the hippocampus and parahippocampal gyri, and the dentate gyrus are all part of the limbic lobe, the sixth hemisphere that has vast convolutions.

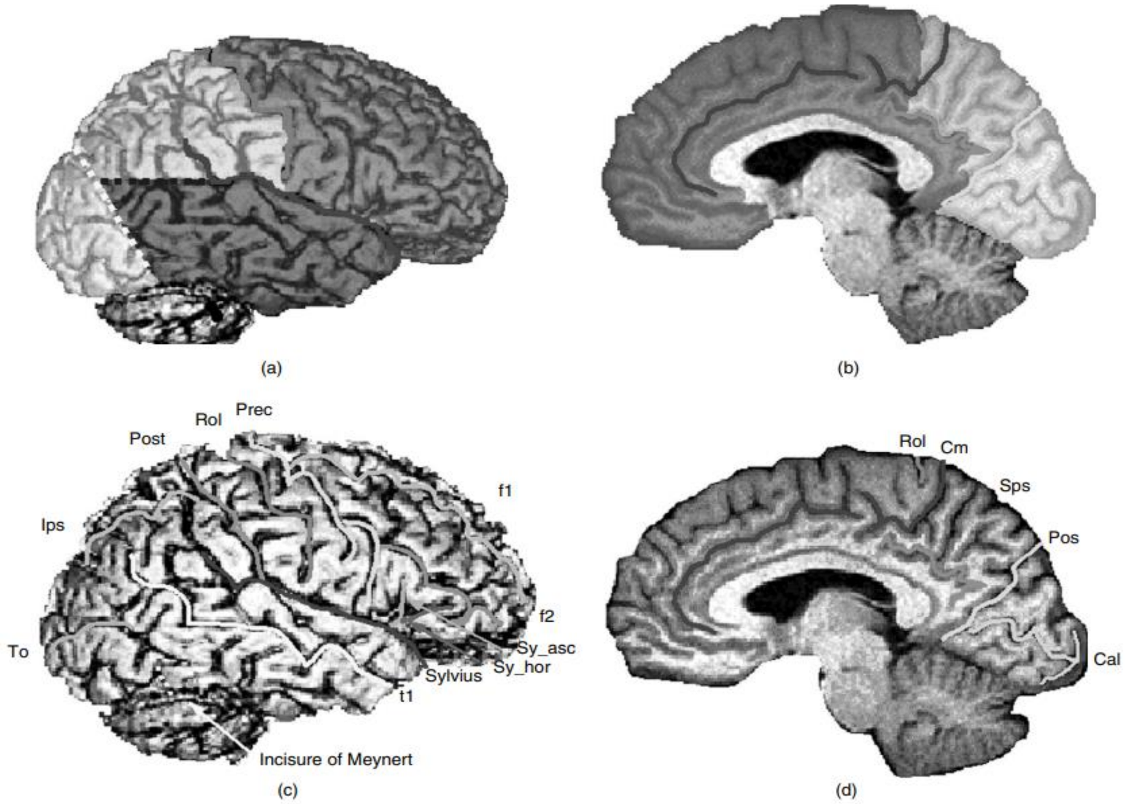
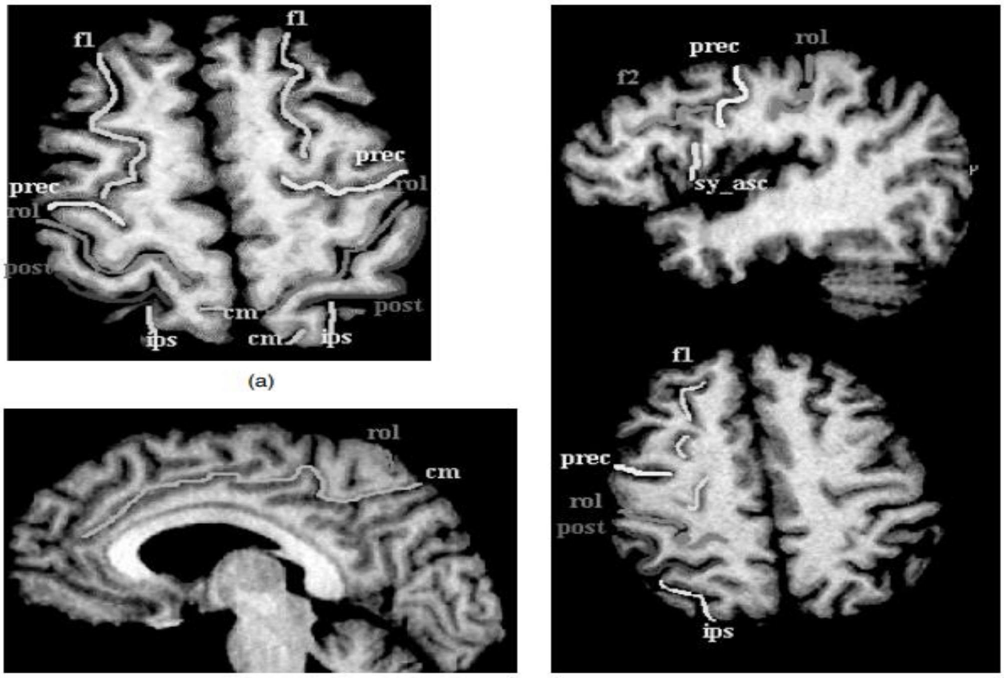


Figure 1. (a) Separable map of the outside of a hemisphere of the brain. The four hemispheres are represented by the colours red, blue, green, and yellow, respectively. (b) Lobar partition of the hemispherical interior. The limbic lobe and the cingulate gyrus, which extend throughout the whole interior of the hemisphere, are depicted in pink. Nestled just under the cingulate gyrus lies the crescent-shaped corpus callosum. The insula, a type of lobe, is obscured in this representation. Grey represents the cerebellum, which borders the underside of the brain. (c) Major sulci of the external hemisphere (to: transverse occipital, tl: superior temporal, sy_hor: horizontal branch of the Sylvian fissure, sy_asc: vertical branch of the Sylvian fissure, f2, inferior frontal sulcus, f1, superior frontal sulcus, post: postcentral sulcus, rol: Rolando, prec: precentral sulcus, and ips: interparietal sulcus). (d) Subparietal sulcus and the Sylvian fissure, as well as the calcarine fissure, the cingulate sulcus, and the sps, which are internal hemisphere major sulci (rol, pos, cal, cm, cingulate, ramus, etc.).

Sylvius and Rolando Sulci

As the second sulcus to develop throughout ontogenesis, the Sylvian fissure is both wide and deep. Because it follows an anteroposterior route throughout the brain, beginning at the base and working its way up, it is simple to spot. It begins at the boundary between the temporal lobe and the frontal lobe, continues along a continuous path, and then splits into two sulci at its posterior end. A tiny one with a downward curve is one of them. As it rises into the parietal lobe, the second bigger one, known as the final ascending segment of the Sylvian fissure, forms nearly a right angle. The Rolandic Depression: An extremely significant sulcus, the Rolandic sulcus (also referred to as the central sulcus) defines the border between the frontal and parietal lobes and the motor and sensory cortices. There are a few different approaches of locating it [16-20], and this article lays out three different strategies for doing so in the context of specific MRI scans of the body that show the Rolandic sulcus. The Rolandic sulcus has a classic notch on higher axial slices. but never forms a connection with any of the adjacent sulci that travel in the opposite way, like the intraparietal or superior frontal sulci. Its permanent location is between the precentral and postcentral sulci, two parallel structures.

At the vertex level, these three sulci form a pretty characteristic pattern. Paramedial sagittal slices show the Rolandic sulcus as a notch on the upper half of the hemisphere, immediately before of the callosomarginal sulcus's ascending end. Starting from the ascending branch of the Sylvian fissure (found in the frontal lobe near the most anterior region of the fissure) and moving backwards on lateral sagittal slices, the third sulcus encountered is the Rolandic sulcus. It should be noted that the Rolandic sulcus, as illustrated in, does not truly connect the Sylvian fissure; rather, it ends just short of it. Finding the precentral and postcentral sulci, which run anteriorly and posteriorly, respectively, parallel to Rolando, becomes straightforward once the Rolandic sulcus has been located. It should be mentioned that the precentral sulcus is usually bifurcated, with the inferior portion being located more anteriorly [21-25]. as well as crossing the sulcus of the superior frontal bone. On the opposite side of the Rolandic sulcus, where the intraparietal sulcus and post central sulcus meet, this configuration is frequently mirrored posteriorly.



(a)

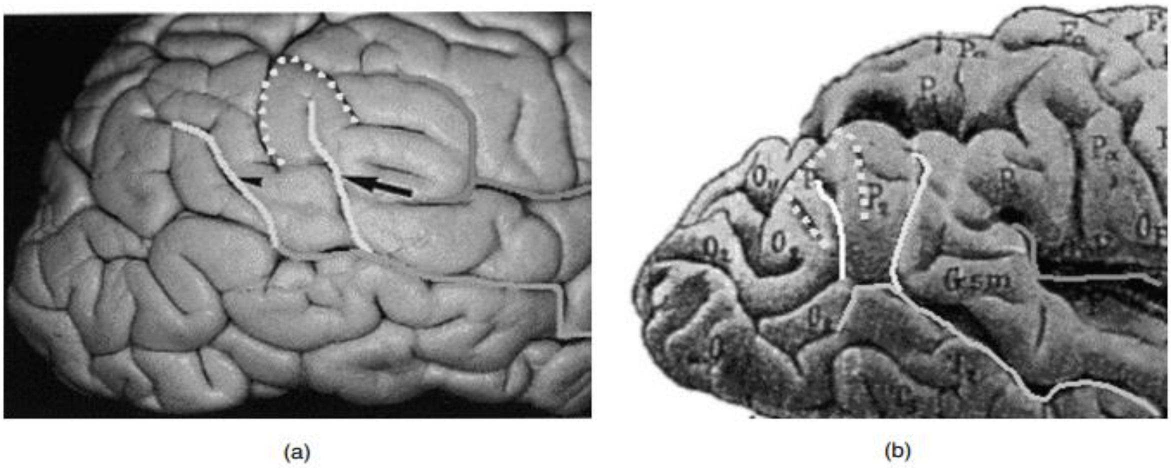
(b)

(c)

Figure 2. The Rolandic sulcus features as shown on various MRI slices. (a) Rolando identifies himself on the upper axial slices. Rolando stands out in red, while the precentral sulcus, postcentral sulcus, intraparietal sulcus, superior frontal sulcus, green, and callosomarginal sulcus are all brightly coloured. (b) A paramedial sagittal slice reveals the Rolandic sulcus. (c) The lower Rolandic sulcus can be seen on the outside parasagittal slices.

Sulci for Parcellation of the Different Lobes

When compared to its size, the frontal lobe possesses an unusually small number of consistent sulci and gyri. Nestled between the Rolandic and precentral sulci, the most posterior gyrus is the precentral gyrus. It houses the motor cortex and a portion of the premotor cortex. The frontal lobe contains the precentral sulcus and two other prominent constant sulci, the superior frontal sulcus (f1) and the inferior frontal sulcus (f2). These sulci enable the delineation of three gyri: the superior, middle, and inferior frontal gyri. On axial slices, the superior frontal sulcus is deeply located and often crosses paths with the precentral sulcus. It stands out on an external hemispheric surface reconstruction due to its extreme symmetry. On parasagittal slices, the precentral gyrus and the inferior frontal sulcus converge posteriorly. It then continues horizontally till it reaches its low point in the inferior frontal pole. Locating beneath the inferior frontal sulcus, the inferior frontal gyrus is corresponding to Broca's area on the left side of the brain. Divided into three sections by the Sylvian fissure's ascending and horizontal branches, it is known as the pars opercularis behind the ascending branch, the pars triangularis in the space between the two branches, and the pars orbitaris below the horizontal branch. Interindividual and interhemispheric sulcal variability is most pronounced in the parietal lobe [26-28]. The inferior parietal gyrus and the superior parietal gyrus are its two primary gyri. Due to its anterior limitation by the postcentral sulcus, internal limitation by the internal boundary of the two hemispheres, and inferior limitation by the intraparietal sulcus, the superior parietal gyrus is easily identifiable. On the other hand, P2, or the inferior parietal gyrus, is a very intricate and dynamic structure. The angular gyrus, the supramarginal gyrus—the circumvolution around the Sylvian fissure's end—and, on sometimes, some intervening cortex are all found here. The angular gyrus, which is known as the "plicourbe" by French anatomists like Déjerine and as Brodmann's area 39 by scientists used to cytoarchitectonic nomenclature, is a prime example of this variability and the challenges that can arise when attempting to categorise similarities and differences between different subjects or even different hemispheres. When the superior temporal sulcus has just one posterior termination, the angular gyrus is easy to spot. Here, it merely encircles the superior temporal sulcus (t1) at its narrowest point, where the temporal, parietal, and occipital cortices meet. On the other hand, the superior temporal sulcus ends in both the left and right hemispheres in half of the cases. Some writers state that in that arrangement, the anterior occipital sulcus—the more posterior of the two ends—forms the anterior boundary of the angular gyrus, whereas the more anterior end of the superior temporal sulcus defines the posterior end. In the meanwhile, other writers state that the angular gyrus revolves around the angular sulcus, which is the more anterior parallel ending. Because the angular gyrus is located in the occipital lobe in one arrangement and the parietal lobe in the other [28-31], these anatomical distinctions are significant. "Its boundaries with occipital and temporal regions are ill-defined," Brodmann said, admitting that even he had trouble providing a cytoarchitectonic description of the angular gyrus. The anterior occipital sulcus limits Brodmann's area 39 to the posterior part of the parietal lobe in his famous brain picture that popularised cytoarchitectony as a foundation for functional anatomy.



(a) (b)

Figure 3. As an illustration of the challenges associated with establishing homologies between hemispheres or people, consider the angular gyrus. a) The angular gyrus, which is located at the end of the superior temporal sulcus (light blue), is also called the "pli courbe" or Brodmann's area 39. In half of the cases in the left hemisphere, the superior temporal sulcus displays a double parallel ending, which is solid green and yellow. When it has a single ending, it is easy to detect. The angular sulcus, which is solid green and centres the angular gyrus, is sometimes thought by some writers to be the anterior parallel termination. (b) According to other writers, the anterior occipital sulcus (yellow) is the best place for the angular gyrus to be located, since it is the posterior parallel termination. There are two possible arrangements for the location of the angular gyrus: one in the parietal lobe and the other in the occipital lobe.

Sulci for Parcellation

Frontal Cingulate Each of the three gyri located in the temporal lobe—the superior, middle, and inferior gyri—are separated from one another by two sulci, the superior and inferior temporal sulci, respectively. Even though it can be divided into two parts, the superior temporal sulcus is always there and runs horizontally parallel to the Sylvian fissure, making it easy to spot. On average, there are three segments that make up the inferior temporal sulcus, and each segment might terminate in a different way: Depending on the situation, it can terminate at the preoccipital incisure of Meynert, the anterior occipital sulcus, or the lateral occipital sulcus (30% of the time), or it might form a plide passage between the two gyri (which it separates) (30%). As this example shows, defining a standard method to detect a sulcus and, by extension, to identify homologies between individuals and between hemispheres, can be quite challenging [32-35]. Therefore, there will be some fuzziness along the posterior borders of the inferior temporal gyrus and the inferior occipital gyrus, as well as the middle and inferior temporal gyri. So, this sulcus isn't a good reference point for brain alignment tasks.

Constant Sulci on the Brain's Inside

The callosomarginal or cingulate sulcus, the parieto-occipital sulcus, and the calcarine sulcus are the three main sulci that can be reliably recognised on the inside of the hemisphere. Primary sulci do not exhibit much variety, as will be explored in greater depth later. Because of their depth, characteristic hemispheric path, and easy identification by isolated sagittal slice, they are easily identifiable. An very deep sulcus, the parieto-occipital sulcus splits the internal occipital lobe from the parietal and internal temporal lobes and spans the posterior half of the hemisphere. As a landmark, it generates a notch on the brain's exterior that divides the occipital and parietal lobes in an arbitrary fashion. and then continues in a straight line heading anteriorly and downwards. It meets the end of the calcarine sulcus halfway along its length. Another linear structure, the calcarine sulcus extends from the occipital lobe's tip to the parieto-occipital sulcus's midway. Cingulate sulcus or callosomarginal sulcus: The cingulate sulcus, also known as the callosomarginal sulcus, runs perpendicular to the corpus callosum's upper surface. It begins beneath the beak-shaped rostrum of the corpus callosum and follows a backwards path to the posterior part of the callosum. There it forms an angle to join the upper edge of the internal surface of the hemisphere almost behind the Rolandic sulcus [36-39]. The paracingulate sulcus is its left-hemisphere counterpart; it is frequently bilateral. Following the initial path of the cingulate sulcus posteriorly along the corpus callosum, the subparietal sulcus continues along the same path.

Differences in Brain Structure

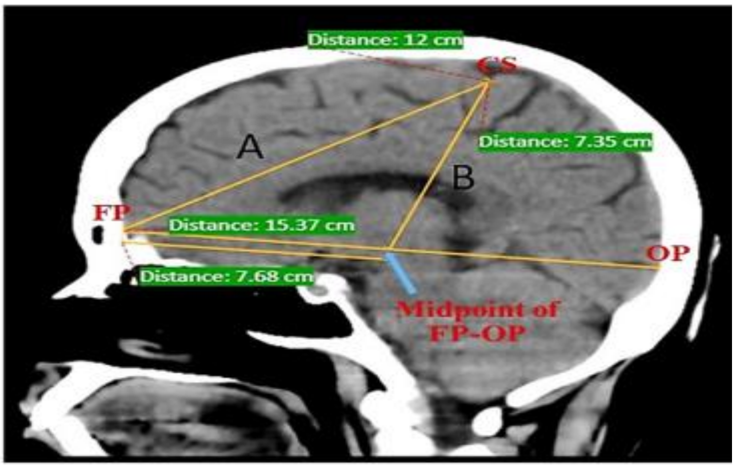
Our description of the cortical surface had to incorporate the most challenging component of cerebral anatomy—individual anatomical variability—just to establish a basic uniform scheme of nomenclature. Anyone wishing to assess the efficacy of inter-subject registration and normalisation into a shared area must take this variability into serious account. When the sulci form throughout development has some bearing on the amount of gyral and sulcal variability. Compared to those that emerge later in gestation, the main and secondary sulci are more stable and present early in brain development. The inter hemispheric fissure occurred in the eighth week of gestation, followed by the Sylvian fissure and the callosal sulcus in the fourteenth week, the parieto-occipital sulcus in the fifteenth week, and finally the Rolandic sulcus and the calcarine fissure in the sixteenth week. As the corresponding gyri develop from the 24th to the 28th week of gestation, the precentral, middle temporal, postcentral, intra-parietal, superiorfrontal, and lateral occipital sulci do as well. The most variable sulci are those that occur later in the pregnancy, after the 28th week. As mentioned before, the inferior temporal sulcus is a tough spot to find in the temporal lobe because it doesn't show up until the 30th week of gestation and has a huge amount of variation in the amount of segments and duplications. The transverse temporal gyrus, inferior temporal gyrus, orbital gyri [40-45], and, as mentioned before, the angular and supramarginal gyri—tertiary gyri with more complexity—develop during the last trimester of foetal life. We have previously highlighted Ono's work extensively because of the intriguing approach he has taken in describing sulcal variability, which requires access to many brain specimens. Using data from 25 brain samples taken during autopsies, Ono created the first statistical effort to characterise sulcal variability and the sole complete atlas of the cerebral sulci. Based on factors such as the incidence rate in each hemisphere, the number of interruptions, side branches, and connections, variations in shape, size, and dimensions, and the relationship to parenchymal structures, this author outlined the sulcal variability of the main constant sulci. Though informative, the methodology of this descriptive work is lacking; for example, the only images offered are of the brain's surface, and the authors don't specify how deep the sulci are. Also, there is no three-dimensional rendering since it is an atlas made of paper. One must employ a strategy that permits a common description of any brain in order to circumvent these restrictions. Chapter 38, "Talairach Space as a Tool for Intersubject Standardisation in the Brain," describes variations of this concept that Jean Talairach created.

Sulcal Variability in Stereotactic Space

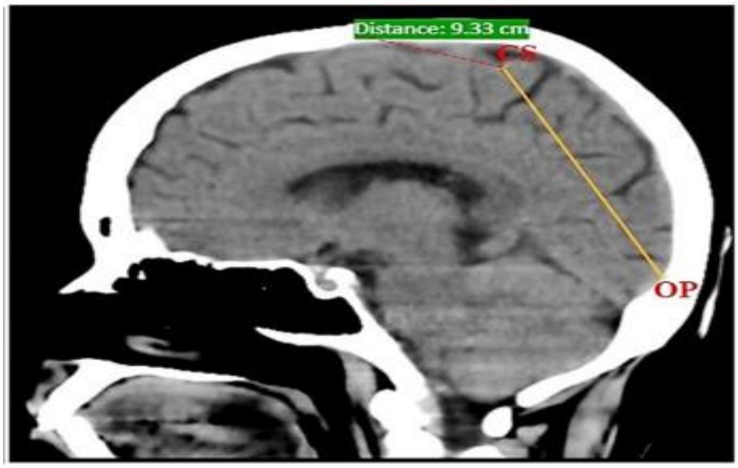
When it came to severe cases of Parkinson's tremors, neurosurgeons could only do functional surgeries, such as thalamic surgery, according to a methodology that Jean Talairach finalised in the early 1970s. Anterior commissure (AC) and posterior commissure (PC) were identified as markers creating a reference space that any brain could be placed into; this was the basis of the approach. In an era before tomographic imaging was available, Talairach used a combination of teleradiography—which preserved the brain's actual dimensions—and ventriculography—which revealed the positions of the anterior and posterior commissures—to define these landmarks and explain how they relate to specific anatomical structures. His preliminary cadaveric studies revealed large inter-individual differences [46-51] in brain size, but consistent inter- and intra-telencephalon correlations to AC, PC, and the AC-PC line. His subsequent definition of a proportionate grid localisation scheme was a groundbreaking step towards statistically describing anatomy. Using this technique, an atlas may be used to help define any brain structure and three coordinates (x, y, and z) can be assigned to it. Talairach was the first to use this proportionate system to explain the statistical architecture of sulci; in his Stereotactic space, he initially evaluated the anatomical variability of sulci and found that the left Rolandic sulcus measured about 20 mm. Based on tomographic magnetic resonance imaging, more recent estimations of sulcal variability in this Stereotactic area are still somewhat large, ranging from 12 to 20 mm. It is important to stress that the Stereotactic space is an essential part of this variant. those closer to the anterior cingulate cortex (ACC) or posterior insula (PC) show less fluctuation than those around the cortex's periphery. This text demonstrates these two points. As a result of inherent sulcal and gyral variability as well as bias in the normalisation method, the accuracy of localisation in the Stereotactic space is restricted to around 1 to 2 cm. The common space was entered into by means of linear deformations in this study. With the advent of new algorithms that enable a more exact alignment of one brain to the target brain, the intersubject sulcal variability in the Stereotactic space has been reduced. Anatomical landmarks like sulci have been used to validate these and show how they affect anatomical variability. This exemplifies the practical application of anatomy to brain averaging and shows how techniques for improved brain registration can decrease residual sulcal variability following normalisation into the Stereotactic space. Anatomical magnetic resonance imaging (aMRI) has brought a new light on a long-lost subject: the Talairach system's capacity to provide a statistical description of the human body. Using sagittal slices of the middle brain from healthy volunteers, Paus's study provides a good illustration. He painstakingly traced the calloso-marginal sulcus (also known as the cingulate sulcus) and, if present, the paracingulate sulcus in each of the 247 participants. To make them consistent with the Talairach space, he next normalised these ROIs. His ability to do this allowed him to create probabilistic maps of these sulci, one for each hemisphere, as demonstrated in. He found that the paracingulate sulcus was more prominent on the left side of the brain, which he connected to the involvement of the left cingulate cortex's anterior section in language tasks [52-55]. The left-to-right asymmetry in the white matter quantity of Heschl's gyrus—the site of the primary auditory area in each hemisphere—was linked to the left-to-right asymmetry in the left temporal cortex specialisation for language in a different study conducted in stereotactic space. Modern practice suggests using the Montreal Neurological Institute's templates to standardise neuroanatomical volumes rather than the postmortem reference brain used by the Talairach space atlas. Both the average template for spatial normalisation and the single subject template for anatomical labelling are essentially based on the Talairach space, although they do not correspond to the size and shape of the Talairach brain. Statistical Parametric Mapping (SPM) (http://www.fil.ion.ucl.ac.uk/spm/) and the International Consortium for Brain Mapping (ICBM) (http://www.loni.ucla.edu/ICBM/) both use the MNI stereotaxic space as a reference system for their analyses of functional and anatomical datasets. Probabilistic maps and atlases of sulci and gyri with complicated morphology and a large intersubject variability, such as the inferior frontal gyrus, have been created by generalising statistical neuroanatomy studies based on this reference system. How these anatomical landmarks are acquired, as well as the intersubject variability of the chosen anatomical component, determine the accuracy of these probabilistic sulci maps. The majority of the time, high-resolution MRIs have these landmarks manually defined. But new efficient methods have been evaluated in recent years, and now significant sulci and gyri may be automatically detected and labelled. The field of statistical neuroanatomy has advanced in part due to the ever-improving methods used to analyse brain structures. In order to explore the structural changes between populations over the entire cortex, not just on a priori chosen landmarks, new methodologies like Voxel-Based Morphometry (VBM) have been developed [57-61]. Regional variations in brain compartment density can be automatically and reproducibly quantified using this method. Using this general method, Sowell demonstrated that the frontal cortex experiences an increase in myelinization that allows adults to perform cognitive tasks more efficiently, and that young adults (age = 25.6 years) have lower frontal and temporal mean grey matter density than adolescents (age = 13.8 years). Modern applications of VBM extend to statistical analysis of massive polymorphic datasets encompassing biological, clinical, behavioural, and neuroanatomical information in an effort to identify genetic risk factors for neurodegenerative diseases and nonpathological neuroanatomical factors like age and sex.

Clinical implications and morphometric study of the primary brain sulci

Radiologists have no trouble identifying the cerebrum's sulci and gyri, but surgeons have a hard time pinpointing their exact locations during procedures due to anatomical differences and the fact that they must access the sulci through a tiny opening. Hence, this work was conducted to identify the primary brain sulci utilising a variety of anatomical markers in CT scan pictures and cadaveric brain samples. In the brain, a network of folds called gyri divides the intricately layered surfaces of the two hemispheres, a process known as cerebral sulci. The sulci are the subarachnoid space's extensions. When they are deep and congruent with anatomy, they are called fissures. There are small, interconnected gyri (transverse gyri) on the wall of the principal sulci, which are 1-3 cm deep. Based on the main cerebral sulci and gyri, the brain's lobes are classified as frontal, parietal, occipital, temporal, insular, and limbic. Each cerebral hemisphere is divided into superior (basal), middle (medium), and superolateral (top) surfaces by inferolateral, medial orbital, and medial occipital boundaries. In most cases, the sulci on the inferior and superolateral surfaces of the hemisphere point towards the nearest ventricular cavity. Thus, they are sometimes referred to as the principal microanatomical borders in neurosurgery, as they facilitate access to the ventricles or deeper lesions during surgery. In most cases, the lateral fissure, along with the central, callosal, calcarine, parieto-occipital, and collateral sulci, is continuous. All healthy people have plainly discernible links between the most consistent sulci and the most important functional regions. Early and distinct development occurs in the deepest sulci areas. Surface folds become more complex and changeable later on. There is a lot of homogeneity among the many kinds of sulci in deeper brain tissues, and quantitative studies of individual diversity have shown that. Deeper sulci exhibit less individual variance in comparison to shallow sulci. The central sulcus (CS) divides the frontal and parietal lobes of the brain. The precentral and postcentral gyri, the primary motor and somatosensory areas of the cortex, are divided by it. Starting at or close to the hemisphere's superomedial border (SMB), roughly behind the midpoint of the frontal pole (FP) and occipital pole (OP), the CS winds its way forward and downward in a sinuous fashion, usually ending just above the posterior ramus of the lateral sulcus (LS). The CS is frequently continuous [62-65], like an extended S, throughout both cerebral hemispheres. The LS is the most noticeable distinguishing feature on the cerebrum's superolateral surface. Due to the ease with which numerous brain lesions can be accessed via the sulcus and the sylvian cistern that lies beneath it, this passageway is the most often utilised microneurosurgical corridor. The term "anterior sylvian" (AS) refers to the point where the first, second, and third rami of the LS meet. The AS point is surgically significant due to the presence of the medial cerebral artery branches in its deeper region and the temporal and frontal veins 10–15 mm in front of it. One of the most important areas of the brain, the occipital lobe regulates eye movement. The sensory capacities and visual pathway integration of this lobe are usually the main points of examination. On its inner side, the calcarine sulcus (CalS) and the parieto-occipital sulcus (POS) cross. The striate cortex (region 17), situated in deep regions and close to the CalS, continues for a short distance (about 1 cm) to the lunate sulcus (LunS) on the cerebrum's lateral side. The "Y" form makes the CalS and POS simple to spot. Both the CalS and the POS are shown at the back of the "Y" shape, with the stem representing the front and the two arms the back. An elevation, the calcaravis, is visible in the posterior horn of the lateral ventricle. This elevation is associated with the deeply folded cortical region of the anterior segment of the CalS. Starting on the medial surface of the CalS, the POS continues to the SMB, then ascends and descends before ending on the superolateral surface. The LunS, which isn't constantly there and is usually oriented vertically, encounters the CalS every so often. By detecting these sulci, magnetic resonance imaging (MRI) helps to map the different striated areas in the occipital lobe. There are, nevertheless, significant differences among these sulci.6 While magnetic resonance imaging (MRI) makes it easy to identify the brain's sulci and gyri, surgical procedures can be challenging due to anatomical variations, the small opening through which the sulci are approached, and the presence of nearby structures like the arachnoid mater, cerebrospinal fluid, and arteries.2 The CS and LS sulci are the two most noticeable on the cerebrum's superolateral surface. The POS divides the parietal lobe from the occipital lobe; the medial surface of the occipital lobe prominently displays the CalS. In order to get closer to the deeper structures, many research have measured the length, depth, and form of the cerebral sulci. There have been numerous MRI and cadaveric brain specimen investigations into different cerebral sulci that we are aware of. But CT has not been employed in any of these trials. Thus, the present investigation set out to quantify the primary brain sulci using a variety of characteristics in CT scans and cadaveric specimens in order to aid radiologists, anatomists, and surgeons in their localisation of these structures and their surrounding functional regions [66-68]. Radiologists and surgeons should be able to access deeper structures, such ventricles and subcortical lesions, and operate on the crucial functional areas close to the sulci if they understand the measurements of these sulci.



A. CS to FP, B. Midpoint of FP-OP to CS



CS to OP

Figure 4. Measurements of the central sulcus in CT scans.

Brain Asymmetries

Because there is a great deal of variation in the gyrification process between the two hemispheres of the brain, it is not unexpected that these two regions grow differently. The fact that many of these cerebral asymmetries are systematic and, even more concerning, are present at birth suggests that their occurrence is not a result of random chance. Now it's tempting to connect these asymmetries to the well-known functional asymmetries in the human brain. This is especially true because the area around the Sylvian fissure's termination, which is often thought of as Wernicke's area, is one of the most asymmetrical locations in the brain. Eberstaller (1881) or Cunningham (1892) noted that the Sylvian fissure was shorter in the right hemisphere, the first reliable account of this region of brain asymmetry from the late 19th or early 20th century. Similar anatomical findings in several monkey species, who do not possess human language, disproved this hypothesis, thereby disproving that this discovery was related to the functional asymmetry of language (the latter). Prior to Geschwind and Levitsky's 1968 reexamination, anatomical asymmetries were really thought to be anecdotal. The length of the planum temporale, a triangular plane of secondary auditory cortex located behind the first Heschl's gyrus, was measured after they exposed the superior surface of the temporal lobe by cutting through the Sylvian fissures. They found that 65 out of 100 brains were asymmetrical to the left, while 11 showed asymmetry to the right. Additionally, they referenced prior research that had similarly shown that monkeys in that area did not exhibit any asymmetry. Geschwind, Levitsky, and Galaburda all came to the conclusion that the planum temporale was a structural indicator of left hemispheric language specialisation. A technique to quantify the planumtemporale surface in healthy volunteers was developed by Steinmetz eighteen years later, with the advent of aMRI. Before anything else, he proved that right-handers really do have a leftward asymmetry. later proved that left-handed people have less of this asymmetry due to the lower incidence of left-hemispheric specialisation. Using comparable MRI planimetry methods, researchers researching primate brains rediscovered Sylvian fissure asymmetries. Instead than disproving Geschwind's theory, it was assumed that this imbalance would show that large apes possessed a language ancestor that was similar to human language. There is a greater purpose to studying cerebral anatomical asymmetry, and that is to understand the possible link between structural and functional diversity. However, functional asymmetry is not confined to language, and physical asymmetry is not confined to the solitary planum temporale either. We were able to piece together a picture of the pattern of cortical asymmetries in humans with the advent of whole brain automated aMRI processing tools [69, 70], which often corroborated prior results from postmortem or radiographic observations. An axial torsion known as the "Yakovlevian torque" predominates in this pattern, making the left occipital lobe more prominent and its apex frequently crossing the sagittal line, while the right frontal lobe projects to the level of the orbito-frontal region. Because of the marks they make on the endocranial surface, these two characteristics are known as the occipital and frontal petalia, respectively. They go hand in hand with occipital and frontal lobe volume asymmetries. This widespread phenomena is associated with multiple other asymmetries; for example, pneumoencephalography was the first to show that the occipital horn of the left lateral ventricle reaches farther back in the left hemisphere. Sulcal pattern analysis also uncovered a number of sulci in the left temporo-parieto-occipital area shifting anteriorly and upwards; this is especially true of the superior temporal sulcus's posterior ascending branch and the Sylvian fissure's terminus. In addition to being longer in the left hemisphere, the superior temporal sulcus is deeper in the right. The central sulcus is more deeply located in the left hemisphere in right-handed men than in left-handed or female people, although this difference is not due to handedness or sex alone. Through the advancement of Diffusion Tensor Imaging, we were also able to study large-scale white matter tract asymmetries. An intriguing discovery is the leftward asymmetry of the arcuate fascicle, a crucial communication pathway connecting the production and comprehension linguistic poles. Histological approaches have also demonstrated microstructural asymmetries. Each hemisphere of the auditory cortex has its own unique columnar organisation; for example, the left hemisphere's neuronal ensembles (columns) are more widely spaced out than the right hemisphere's, which may indicate superior processing power [71, 72]. Some studies found that the left hemisphere has more big pyramidal cells, which are involved in connections between the cortex and the rest of the brain. Language sound processing may also be facilitated by a left-hemispheric imbalance in the degree of myelinization of the superior temporal lobe. The size of language-related bundles or cortical areas may show a leftward asymmetry, which could be consistent with macrostructural findings.

The Role of Macroscopic Anatomy in Cytoarchitectonic Microanalysis

The cytoarchitecture, or microscopic anatomy, of a brain region was thought to be a direct indicator of that region's function prior to the development of functional imaging. When thinking about the portion of the brain called Brodmann's area 4, which is also called the primary motor area and where deficiencies in motor control can be caused by lesions, this notion becomes more solid. The main visual area in the calcarine sulcus is an example of how cytoarchitectonic structure and function do not perfectly overlay, even for primary cortical regions (those that receive direct sensory input or create direct motor output). In any case, microanatomy is a milestone on the road to elucidating the cortical functional architecture. To get a better grasp on this topic, researchers have looked into the connections between myeloarchitecture, neurotransmitter receptor densities, enzyme densities, and cytoarchitecture, among other things. Their findings lead them to the conclusion that there should be more than one criterion used to identify a functional cortical field. The relationships between macroanatomy and cytoarchitecture were investigated by

Rademacher et al. in 20 hemispheres. They demonstrated that architectonic fields frequently exhibit a characteristic relationship to sulcal and gyral landmarks that can be defined with aMRI. This work is particularly noteworthy if architectonic fields are defined based on neuronal density. In one group, the variation in these relationships was highly foreseeable from outwardly visible landmarks; in the other, the variation between individuals was most noticeable in terms of gross individual landmarks.

Even while Tpt extends beyond the planum's limits towards the external and posterior parts of the superior temporal gyrus, a continuous link between cytoarchitecture and macroanatomy also applies to the planum temporale, which nearly covers the cytoarchitectonic area Tpt. Last but not least, in the inferior frontal gyrus, some writers have argued that Brodmann's area 45 and the pars triangularis and 44, respectively, form a strong agreement. There is no clear correlation between cytoarchitectural differences and specific anatomical features in higher-order cortices, such those in the frontal lobes. As an example, there is a great deal of individual variation in the size and location of Brodmann's regions 9 and 46. Broadly speaking, changes in microanatomy appear to reflect changes in macroanatomy in language and primary cortical regions, although this tight coupling weakens in higher-order integrative cortical regions. This might be associated with the fact that learning and environmental factors exert a greater impact on the maturation of higher-level functions than on their main counterparts. Zilles and Roland, on the other hand, think that there is scant evidence to indicate a connection between macro- and microanatomy, hence they disagree with this viewpoint. By employing robust registration software that can standardise a three-dimensional MRI brain volume—even down to the depths of the sulci—they hope to remove macroscopic anatomic variability as an issue, allowing them to approach the question of relationships between microarchitecture and function.

They have selected a template brain that best represents their MRI database, and any brain may be put onto it. The authors' method is crucial since it unites databases for myeloarchitectonic, cytoarchitectonic, and receptor pictures. In order to build this database, it was necessary to evaluate an observer-independent method for microstructural parcellation of cerebral cortex. This method is useful for cytoarchitectonics because it identifies automatic boundaries between cortical areas, unlike the qualitative classical visual microscopic examination of histological sections. This latter factor has helped explain why various writers' maps of the brain don't always agree on the same number, location, and shape of cortical areas. Probabilistic cytoarchitectonic maps, in contrast to traditional individual cytoarchitectonic maps, furthermore give strereotaxic data regarding the position and variability of microstructural regions in a reference space such as MNI. To improve the structural information underlying functional imaging tests, the generated probabilistic maps of microarchitecture can be directly compared with functional probabilistic maps. A specialised toolbox has been created by Zilles's group and is now part of popular neuroimaging software packages like SPM. This will make it easier to integrate and handle multiscale neuroimaging datasets. An intuitive approach for merging functional imaging data with a probabilistic cytoarchitectonic map is provided by this toolbox. and analysis of magnetoencephalographic sources.

The Role of Fine-Grained and Large-Scale Anatomical Variability in Different Functional Areas

Using limited affine transformations, the first approaches to studying brain function with positron emission tomography (PET) relied on skull teleradiography inside the PET suite to bring the separate brains into a shared area, the so-called Talairach stereotactic space. using the structural data already included in the pictures. After the functional pictures were placed in this shared area, a brain atlas—typically the Talairach atlas—was used to pinpoint the locations of the identified activations; however, the precision of this localisation was affected by heterogeneity between individuals following normalisation. Because of the limitations of current methods, functional imaging researchers have to ignore the potential functional effects of anatomical heterogeneity. However, this issue of interindividual variability and the impact of normalisation on individual and averaged images has recently come to the forefront due to the development of improved normalisation processes. As a result, several groups decided to build interindividual averaging approaches that divided the brain into anatomical regions of interest in order to take individual variability into consideration. These ROIs were manually identified and used as an anatomical filter for the intersubject averaging. Unfortunately, these methods were seldom employed with PET due to their high execution time, low spatial resolution (limited to the size of the ROI), and inability to directly compare results provided in stereotactic coordinates. The development of functional magnetic resonance imaging (fMRI) in the 1990s, on the other hand, made it routine to identify activations in individual people; moreover, these activations are frequently localised within the subject's own anatomy. To better understand the connections between structure and function, two new tools have emerged: anatomically defined ROIs and individually identifiable anatomic locations of functional activation. Anatomical landmarks and their associated functions in primary cortical areas have been the focus of the majority of research on this topic. Two studies pertaining to the Rolandic sulcus will be presented first. Anatomists had manually measured the Rolandic sulcus length on a three-dimensional reconstruction of its surface, which led to the first hypothesis. They postulated that the cortical hand representation might be a curve called the genu of the Rolandic sulcus, which related to an abnormally large surface area. After two-dimensionally registering the activated areas onto the relevant MRI axial slices, they showed that the hand area was actually positioned at the level of the Rolandic genu in each individual using a vibration paradigm with PET to test this hypothesis. Another group has shown that the Rolandic sulcus, which was manually outlined on T1 weighted axial MRI slices, can be divided into three sections that are associated with functional anatomy. This is because the middle segment, which contains Rolando's genu, corresponds to the hand area detected using the same vibration paradigm with PET. Area V5, the human visual motion area, was the subject of a very illustrative study by Watson et al. on the visual system's structure-function correlations. In the initial publication [88], the scientists pinpointed the individuals' colour and motion regions and noted that there was still a lot of individual variation when it came to where V5 was located in stereotactic space. After identifying V5 in each person and registering it onto their MRI, they continued their investigation into the architecture and function of this functional area. The authors of the article highlighted the fact that the posterior continuation of the inferior temporal sulcus can take on many anatomical forms, but they also proved that V5 is consistently related to this area of the occipital lobe. The fact that this sulcus was demonstrated to emerge during the 30th week of gestation by Bailey and von Bonin is consistent with this macroanatomic diversity. Watson et al. highlighted that this sulcus matches closely to the field of early myelination in the developmental atlas of Fleschig, which is in line with the earlier argument that a cortical field should be defined on the basis of several indicators. This finding lends credence to the theory that early-stage functions, like vision, stick closely to both macro- and microanatomy, even when the latter exhibits a great deal of variability on its own. The relationship between functional anatomy and gross physical landmarks becomes less clear as one progresses into higher-order cognitive activities. On the other hand, there is an exception where intimate connection is maintained, and that is the frontal language areas. Six male volunteers, all of whom were right-handed, were examined by multiple PET centres as part of a coordinated European effort that used the same paradigm for word formation. An activation site limited to the left inferior frontal gyrus was shown by the average result in our study. Nevertheless, when looking at each person separately, we found that one of the six had stimulated just the right inferior frontal gyrus considerably. Researchers found that this activation was situated close to the ascending branch of the Sylvian fissure, in a region that was a perfect symmetrical homologue of the left hemisphere region stimulated in the other patients. Using the identical task, a different European group showed that, in five out of seven people, there was a consistent association between activation and this branch through individual atomofunctional analysis. If we think of anatomy as a record of the developmental antecedents of cognitive functions, we might look for connections that might extend beyond the local area to investigate the possibility of a connection between structural and functional pictures. Our work on the hemispheric organisation of language is as follows. Because the planum temporale asymmetry becomes apparent after the 32nd week of gestation. It is possible that this early physical asymmetry represents the functional hemisphere dominance for language, since non-right-handers may not exhibit the prevalent leftward asymmetry. We correlated the planum temporale surface area with the functional maps for language comprehension in ten people, five of whom were non-right-handed, to test this hypothesis. Although the temporal pole is distant from the planum, our results demonstrate that functional responses assessed with PET in left temporal regions are bigger in relation to the size of the left planum temporale. Because of this finding, anatomical variability is now more than simply a statistical variable that muddies functional or anatomical picture averaging. A second set of 20 participants confirmed the first set's findings about the effect of the left planum temporale surface on linguistic comprehension area asymmetries. Furthermore, we found that 60% of the variation in the asymmetry of activations during tale listening was explained by a combination of handedness, left planum temporale surface, and brain sizes. This highlights the significance of anatomical constraint in the creation of functional networks.

CONCLUSION

Because studying function in isolation from structure is meaningless, the significance of anatomy is undeniable. While macroscopic anatomy may be a potential obfuscator of results from functional or microscopic investigations, it is also a powerful and exciting tool for functional image analysis on many levels. Actually, multiple fields can find common ground in anatomy, which serves as a general framework for understanding how the brain works. On the other hand, neuroanatomy shouldn't be treated like a landmark system. As shown, for instance, by variations in grey matter density with learning or competence, investigations of interindividual variability of brain anatomy per se can disclose essential keys of brain organisation. Furthermore, a highly promising strategy for comprehending the brain's large-scale organisation is the study of functional and anatomical covariation. One example is how anatomical restrictions influence the functional architecture of the brain in language activities. This is illustrated by the fact that brain volume and individual size of the left planum temporale account for some of the interindividual functional variability. We think this strategy, which advocates for multimodal brain atlases and "tedious anatomy," will help neuroanatomy get back on track. Using CT scans and cadaveric brain samples, the morphometry of the four primary sulci of the cerebral hemisphere was examined. One metric was identified as significantly different between the two groups in the cadaveric specimens. Contrarily, CT revealed numerous characteristics that differed significantly, suggesting asymmetry between the two sides of the brain. Some of the geographical locations studied had strong correlations to the underlying structures. To better access deeper structures like ventricles and subcortical lesions, radiologists and surgeons might benefit from knowing the dimensions of these sulci. To better localise the sites of sulci and functional regions, functional CT scans were used to correlate measurements with cadaveric specimens. Previous research has looked at the morphometry of cerebral sulcus in cadaveric brain samples, and while some MRI studies have linked sulci, none have employed CT, thus we think our study fills a significant need.

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