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"THE MAN WHO MISTOOK HIS WIFE FOR A HAT" -NEUROANATOMICAL ANALYSIS-

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Summary

Prosopagnosia is a type of visual agnosia characterized by the inability to recognize faces. In functional diagnostic studies, face recognition and interpretation are primarily, but not exclusively, attributed to the fusiform, lingual, and parahippocampal gyri of the temporal lobe, supplied by branches of the posterior cerebral artery. This article delves into the neuroanatomical bases of this type of visual agnosia, as well as into its most common etiologies, clinical approach, and imaging findings.

Keywords: *prosopagnosia; visual agnosia; neuroanatomy; temporo-occipital lobe*

Background

"The Man Who Mistook His Wife for a Hat"1 is a renowned story by the British neurologist and author Oliver Sacks, homonymous of the work he published in 1985. It tells the story of a distinguished musician and teacher, who starts to exhibit "certain errors" and "strange problems" because of his inability to distinguish the faces of the people around him. The musician, who seemed to "approach his surroundings with his ears but not his eyes," was able to distinguish each structure individually, however, he was unable to integrate the structures as a whole, that is, he did not identify the face the structures constructed nor the expressions, confusing even familiar faces, like that of his wife with inanimate objects, such as his hat. Also, since he was not able to recognize himself in a photo or the mirror, he identified his surroundings through touch, smell, and hearing, but not sight. It seemed that the visual deficit also compromised his imagination and his visual memory. However, taking advantage of his great musical talent, he managed to compensate for his deficit with melodies and patterns when performing his daily activities, such as eating or getting dressed.

Goals

Oliver Sacks's story is a detailed and surprising clinical case of a type of visual agnosia known as prosopagnosia or the inability to recognize faces. The objective of this paper is to address the characteristics of this condition and its neuroanatomical bases.

Methods

A narrative review of visual agnosia and its neuroanatomical bases was carried out in neuroanatomy books and neuroscience scientific journals, with a special emphasis on the visual pathway, cortical integration, subcortical connections, and relevant vascularization. To improve our understanding, the information was complemented with anatomical models of brain dissections as teaching material.

Results

Visual agnosia

Agnosia is the loss of the ability to identify, through one or more senses (sight, taste, hearing, smell, or touch), objects that have been previously identified, recognized, and stored in perceptual memory. This condition does not correspond to an alteration in the afferent pathways of sensory modalities, attention, memory, or language.[2] In general, visual agnosia is the most frequent and understood.[2,3] This could be because sight is the most developed sensory modality in humans4 and the one on which humans depend the most since it provides both, a direct experience of the world and feedback, allowing us to relate to the world around us.[5]

Visual agnosia corresponds to a perceptual disorder secondary to a lesion in the brain parenchyma that affects visual recognition or interpretation of objects, although the visual pathway, campimetry, visual acuity, and color perception are intact.[3] The displayed objects or scenarios may be completely indecipherable or meaningless since it is impossible to analyze visual primitives, such as lines, curves, colors, or shapes.[6] However, the identification of those same objects through other senses is preserved.

Like other agnosias, it is classified into two types according to the processing mechanism involved: it may be an apperceptive visual agnosia, in which the shapes of objects are not identified or discriminated against and, in severe cases, it can simulate amaurosis,[4] or associative visual agnosia, in which, although the object is identified, it cannot be interpreted, understood, or linked to previous experiences.[2]

Prosopagnosia

It constitutes a type of visual agnosia characterized by the inability to recognize faces, even those of familiar or famous people, as well as a limitation in identifying expressions, such as joy or fear.[7] Sometimes it is possible to recognize non-facial features, such as hair color, the way of walking or dressing, which help to identify a person.[8] The ability to recognize faces and expressions transcends gender, age, culture, and race, being essential for the social interaction and empathy that characterize human beings.

Epidemiology

Less than 1% of patients with neurological disorders present pure agnosias, the most common being visual agnosia.[9] Isolated prosopagnosia is rare, however, cases of congenital prosopagnosia have been described, affecting up to 2.5% of the general population,[10] and they may even be associated with other disorders, such as hemineglect, achromatopsia, or general visual agnosia.[3, 4]

Etiology

Agnosias are the result of different types of lesions in the cerebral cortex in association with or in sensory processing areas, mainly the posterior parietal and occipitotemporal cortex.[2] The time of onset of the disease derives from the type of injury, the association with other neurological deficits, and the paraclinical findings. Cases of acute visual agnosia are related to infarction of the posterior cerebral artery (PCA),[11, 12] infections, or head trauma.[13] On the other hand, gradual alterations are usually associated with tumors, carbon monoxide poisoning, or dementia, such as Alzheimer's or frontotemporal dementia,[14] and even cases of hereditary prosopagnosia secondary to alterations in the occipitotemporal cortex have been described.[10,15]

Pathophysiology

Anatomically, the lesion of visual agnosia will not be located in the primary visual cortex, but instead in the associative visual cortex or its connections, including areas of the occipital, parietal, and temporal lobes.[4] In the case of prosopagnosia, bilateral lesions have been described in the cortex, mainly in the fusiform gyrus (Brodmann area 37) and parahippocampal, or less frequently, unilateral lesions of the dominant hemisphere.[16,17] Likewise, the lingual gyrus[7] and the anterior portion of the right temporal lobe are infrequently described.[3,13] These areas could be affected by any of the etiologies described above.

Neuroanatomical bases

Visual route

Vision is a large and complex system that involves multiple structures, connections and cognitive functions, converting them into a conscious process. This system usually remains intact in visual agnosias. The process begins with the photoreceptor cells of the retina capturing an image, then the visual stimulus is encoded and the axons travel from the ganglion cells that form the optic nerves, which cross the information captured in the visual retina at the level of the optic chiasm, continuing through the optic tracts until they synapse in the lateral geniculate bodies of the thalamus, and continue through the superior and inferior geniculocalcarine radiations to the calcarine fissure of the occipital lobe, which corresponds to the primary visual cortex[18, 19] (Figure 1 .TO).

Visual association cortex

Once the image is formed in the primary visual cortex, it must go to the corresponding association cortex to be recognized and consciously interpreted, in this area it will be compared with images previously stored in the memory.[4]

Two main processing pathways are described: a ventral pathway, which allows to perceive an object, recognize it, and relate it to a meaning, connecting primary visual areas with the inferior temporal cortex, and a dorsal pathway, which allows to spatially locate the object and relate to it through the body, connecting with the intraparietal sulcus of the posterior parietal cortex.[5,20] In particular, prosopagnosia is usually included within perceptual or ventral visual pathway syndromes.[4]

Occipitotemporal cortex

The basal surfaces of the temporal and occipital lobes continue with each other without a clear anatomical division and also share several functions, which is why they are named as a unit: the occipitotemporal cortex.

The temporal lobe is located below the lateral or Sylvian fissure, classically divided into five gyri (named T1 to T5) and four sulci (t1 to t4)21 (Figure 1.B).

In turn, the lateral surface is composed of the superior (T1), middle (T2), and inferior (T3) temporal gyri, divided by the superior (t1) and inferior (t2) temporal sulci, which are arranged parallel to the lateral or Silvio fissure. T3 is continuous posterior to the inferior occipital gyrus without clear demarcation. Concerning the lower edge of the cerebral hemisphere, between the temporal and occipital lobes, we locate the region of the preoccipital notch (Figure 1.C).

The inferior or basal surface of the temporal lobe has a concave shape in an anteroposterior direction, in a way that it is continuous with the basal surface of the occipital lobe and rests on the floor of the middle cranial fossa and the tentorium.[21,22] It is composed from lateral to medial by the ventral part of the lateral occipitotemporal gyrus (T3), the medial or fusiform temporo-occipital gyrus (T4) and the parahippocampal gyrus (T5), separated by the occipitotemporal sulcus (t3) and the collateral sulcus (t4) respectively (Figure 1.D).

This region of the inferior temporal in humans is specialized in the processing and visual recognition of objects, and in the discrimination of body parts and faces,[23, 24] in addition to being associated with sensory integration and memory.[25,26] The parahippocampal gyrus and the anterior portion of the collateral sulcus are part of the limbic system related to memory.[21]

According to functional magnetic resonance studies, the fusiform gyrus is the most active in most individuals when exposed to a face-type visual stimulus, compared to objects of other categories.[27] For this reason, the fusiform gyrus plays a fundamental role in the pathophysiology of prosopagnosia. This spin was first described in 1854 by Emil Huschke, [28] who coined the term "fusiform" due to its spindle shape, being wider in the middle than at the ends. At its posterior end, it fuses with the inferior temporal gyrus, the lingual gyrus, and the posterior branch of the cuneus. Functionally, three portions related to connection patterns have been described: the medial portion seems to be involved in low-level visual processing, the lateral portion corresponds to the high-level categorization type, and the anterior portion corresponds to visual-semantic processing. Bilateral lesions of the lingual gyrus, parahippocampal gyrus and fusiform gyrus, or their irrigation by the PCA, are related to prosopagnosia.[24]

The occipital lobe, for its part, is located posterior to the parieto-occipital sulcus, above the tentorium. Of all the cerebral lobes, the occipital tends to have less defined sulci and greater anatomical variation.[21]

On the superolateral surface, three gyri are described with a transverse arrangement that converges posteriorly at the occipital pole. These occipital gyri are called superior (O1), middle (O2), and inferior (O3), and are separated from each other by the superior occipital sulcus, which is the continuation of the intraparietal sulcus and the inferior occipital sulcus.

On the medial surface, there is a better definition of the sulci which encompasses the cuneal (or cuneus) and lingual (or medial temporo-occipital) gyri, separated by the calcarine fissure. The latter begins on the splenium of the corpus callosum, limiting the cingulate gyrus with that of the parahippocampus. This area corresponds to the primary visual cortex19 (Figure 2).

The occipital lobe is connected by folds to the parietal and temporal lobes. The first parieto-occipital fold connects with the parietal and superior occipital gyri. The second fold is a posterior extension of the angular gyrus that converges with the middle occipital gyrus, and sometimes with the superior one. While the first temporo-occipital fold connects the middle temporal gyrus to the inferior occipital gyrus, the second fold connects the inferior temporal gyrus to the inferior occipital gyrus.[21,29] These white matter connections are essential to understanding the neural networks that enable the cognitive functions of association and integration of sensory modalities (Figure 3).

Blood supply to the occipitotemporal cortex

The temporal lobe has mixed irrigation between the anterior cerebral circulation (ACA), through the internal carotid artery, and the posterior one, through the vertebrobasilar system.[30] The insular portion of the middle cerebral artery is responsible for supplying the anterolateral portion of the temporal cortex through the superior temporal branches anterior, middle, and posterior, and is associated with branches of the anterior choroidal artery toward the anterior end of the gyrus,

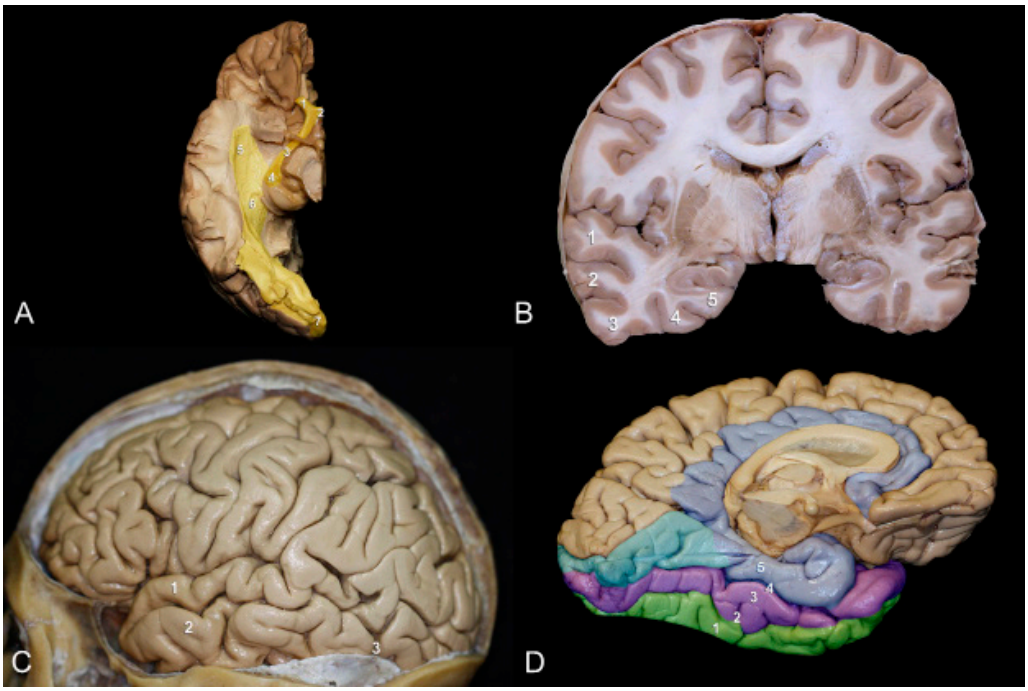

Figure 1. A. Dissection of the visual pathway by Klingler method: 1) optic nerve, 2) optic chiasm, 3) optic tract, 4) lateral geniculate nucleus, 5) Meyer's loop, 6) geniculocalcarine radiations, 7) cortex of the occipital lobe. B. Coronal section at the level of the mammillary bodies (Charcot section). It is identified: 1) T1: superior temporal gyrus, 2) T2: middle temporal gyrus, 3) T3: lateral aspect, inferior temporal gyrus, ventral aspect, lateral occipitotemporal gyrus, 4) T4: medial occipitotemporal gyrus, 5) T5: gyrus parahippocampal. C. Dissection of the lateral aspect of the cerebral hemisphere: 1) T1: superior temporal gyrus, 2) T2: middle temporal gyrus, 3) preoccipital notch region. D. Ventral aspect of the temporal and occipital lobes: 1) T3: lateral occipitotemporal gyrus, 2) occipitotemporal sulcus, 3) occipitotemporal (fusiform) gyrus, 4) collateral sulcus, 5) parahippocampal gyrus.

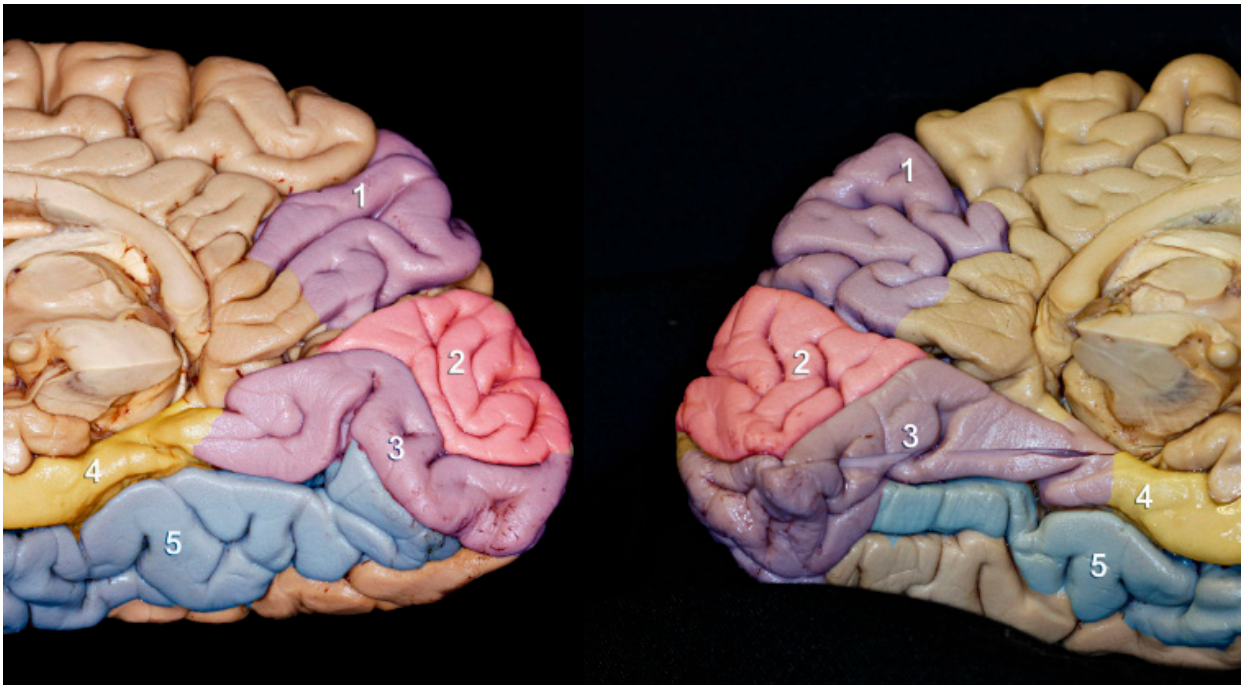

Figure 2. Medial aspect of the right and left hemisphere, occipital and temporal lobes: 1) precuneus, 2) cuneus, 3) lingual gyrus, 4) parahippocampal gyrus, 5) medial occipitotemporal gyrus.

parahippocampal, uncus, amygdala, and temporal horn of the lateral ventricle. The inferoposterior portion is supplied mostly by branches of the PCA, as is the occipital lobe.

In 2012, Martinaud et al.[11] analyzed 31 patients with a history of PCA infarction, in 23 of them they found visual field defects, 20 presented visual agnosias of different types, and 10 showed difficulty in recognizing faces, which could or not be associated with the recognition of objects from other categories, especially when the affected territory corresponded to the fusiform and parahippocampal gyri. This study suggests that visual agnosias following PCA infarctions are more common than usually believed.

Anatomy of the posterior cerebral artery

The PCA arises at the bifurcation of the basilar artery at the level of the interpeduncular cistern. This bifurcation can be located between the mammillary bodies and the pontomesencephalic junction (Figure 4.A). The PCA is originally related to the nerves of the extraocular muscles: oculomotor (III) and trochlear (IV), subsequently surrounding the brain stem through the crural and ambiens cisterns until reaching the quadrigeminal cistern. It supplies not only the posterior part of the cerebral hemispheres but also portions of the thalamus, midbrain, choroid plexuses of the occipital portion of the lateral ventricles and the third ventricle.[22]

The path of the ACP is divided into four segments[22] with their respective branches (Figure 4.B, C):

-P1 or precommunicating segment: from the basilar bifurcation to the junction with the posterior communicating artery (AcomP). It has an average length of 7 mm. Branches:

1. Perforating arteries of the thalamus: passes through the posterior perforated substance.
2. Short and long circumflex arteries.
3. Branch for the quadrigeminal plate.
4. Branches for the mesencephalic tegmentum.

-P2 or postcommunicating segment: begins in the AcomP, runs through the crural and ambiens cisterns and ends lateral to the posterior edge of the midbrain. It is divided into two subsegments, each approximately 25 mm long:

1. An anterior part (P2a) also called crural or peduncular segment
   a. Hippocampal artery: supplies uncus, anterior parahippocampal gyrus, hippocampus, and dentate gyrus.
   b. Anterior temporal artery.
   c. Peduncular perforating arteries.
   d. Posteromedial choroid artery: directed to the choroid plexuses of the lateral and third ventricles.
2. A posterior part (P2p) or lateral mesencephalic segment or ambiens.
   a. Thalamogeniculate arteries.

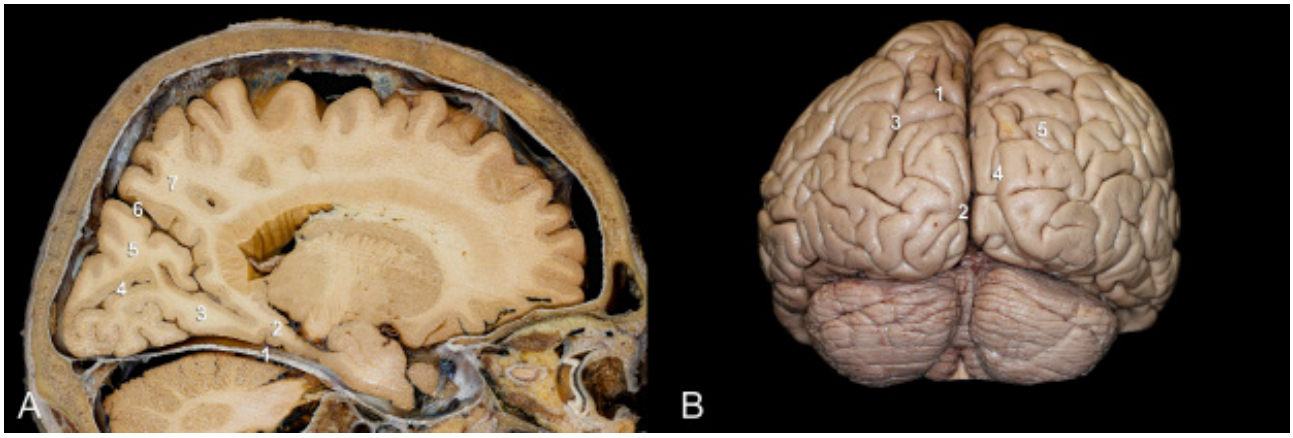

Figure 3. A. Parasagittal section: 1) tentorium, 2) parahippocampal gyrus, 3) fusiform gyrus, 4) calcarine sulcus, 5) cuneus, 6) parieto-occipital sulcus, 7) precuneus. B. Posterior surface of the occipital lobe: 1) parieto-occipital fissure, 2) calcarine fissure, 3) intraparietal sulcus, 4) sulcus lunatum, 5) superior parietal lobe.

-P3 or quadrigeminal segment: from the posterior edge of the lateral surface of the midbrain and the cisterna ambiens, running through the lateral part of the quadrigeminal cistern until ending at the anterior limit of the calcarine fissure. It has an average length of 2 cm. Terminal branches:

a.Calcarine artery: runs through the calcarine fissure to the occipital pole, gives fan-like branches directed towards the lingual gyrus and the lower portion of the cuneus. Supplies the primary visual cortex.

b.Parieto-occipital artery: runs through the parieto-occipital fissure to supply the posterior parasagittal region, cuneus, precuneus, lateral occipital gyrus and portion of the paracentral and superior parietal lobes.

-P4: begins at the anterior end of the calcarine fissure giving cortical branches:

a.Splenic artery: for the splenium of the corpus callosum. It anastomoses with branches of the pericallosal artery of the ACA.

b.Inferior temporal arteries:

1.Anterior: supplies the anteroinferior surface of the temporal lobe towards the temporal pole.

2.Median (uncommon): supplies the inferomedial surface of the temporal lobe.

3.Posterior: obliquely towards the occipital pole and lingual gyrus.

4.Common (uncommon): single alternate branch that supplies most of the inferior surface of the temporal and occipital lobes.

Venous drainage of the occipitotemporal cortex

The lateral aspect of the temporal lobe is drained by the superficial and deep middle cerebral veins towards the sphenoparietal sinus or cavernous sinus, and by the minor anastomotic vein or Labbé towards the transverse sinus. The drainage of the lateral aspect of the parieto-occipital cortex occurs through the ascending cortical veins towards the superior sagittal sinus, while that of the ventral aspect of the temporo-occipital region occurs through the basal vein of Rosenthal towards the cerebral magna vein or vein of Galen, and through the temporal veins towards the tentorium[24] (Figure 4.D).

Clinical and diagnostic approach

Agnosias in the initial stages may go unnoticed or be confused with other neurological disorders. Generally, it is the caregivers or family members who recognize that there is some alteration in the patient, while the patient ignores his or her deficit. Sometimes, agnosia can be so severe that it can limit the patient's functioning, preventing him from completing daily activities or interacting with his environment.[2]

A complete history and a thorough neurological examination that evaluates the ability to recognize and name objects previously known through the senses are key. In-depth assessments of perception, association, memory, and cognition are typically performed by neuropsychologists. Primary deficits in sensory modalities, aphasia, dementia, or delirium must also be ruled out.[31]

When the disorder is of an associative type, the patient will be able to draw or copy objects that he or she identifies, as well as recognize if two objects are similar in the "pairs game."[4] In prosopagnosia, photographs of family members, friends, famous people or even from the patient himself should be used, as well as testing for the identification of facial expressions during a movie scene or in a magazine.

Some tests to evaluate prosopagnosia are the Warrington Recognition Memory Test[32] from 1984 and the Benton Facial Recognition Test[33] from 1983, as well as the Cambridge Face Memory Test (CFMT) from 2004 (Figure 5). The latter builds on the strongest points of the two previous tests and has better diagnostic performance.[34] The CFMT evaluates the identification of faces without objects or external characteristics that facilitate their recognition, such as clothes or hairstyles. A positive result corresponds to the inability to correctly recognize at least 50% of them.[2]

These findings should be complemented with diagnostic imaging studies that rule out vascular, inflammatory, or tumor lesions[2] and allow for possibilities of medical-surgical treatment. In simple tomography and MRI, infarctions of PCA territories can be found, while in functional magnetic resonance studies with diffusion tensor imaging, positron emission tractography (PET), changes in the functional activity of people with prosopagnosia can be evidenced,[35] not only in specific areas of the cerebral cortex but also in connection areas and white matter.[35, 36]

The fusiform gyrus is the region of greatest activity when an individual visualizes a face,[27, 37] in contrast to visualizing other objects. Furthermore, connections have been described between the fusiform gyrus and posterior areas of the lingual gyrus and inferior and middle temporal gyri involved in the processing and interpretation of complex visual information,[38] with parallel connections to the auditory network of the

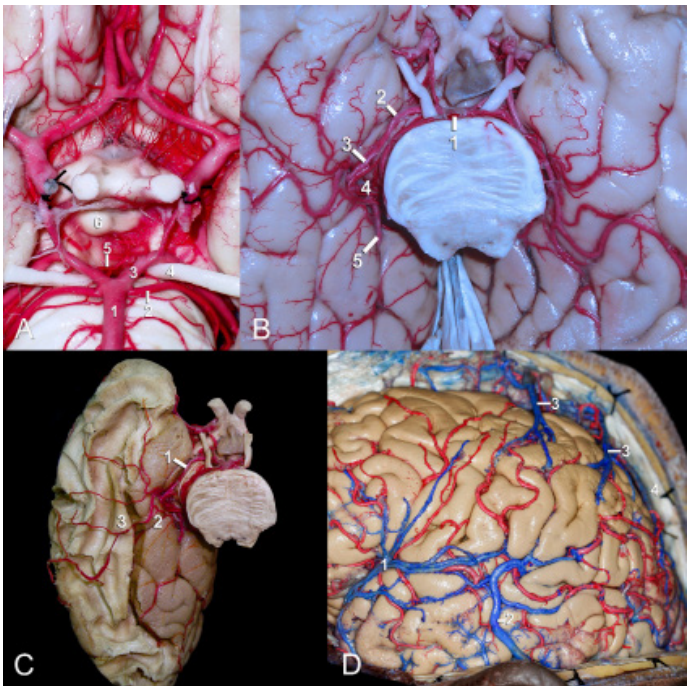

Figure 4. A. Posterior cerebral artery: 1) basilar artery, 2) superior cerebellar artery, 3) P1 segment of the PCA, 4) oculomotor cranial nerve, 5) posterior thalamoperforating artery, 6) mammillary bodies. B. Ventral aspect of the temporal and occipital lobe and its relationship with the posterior cerebral artery: 1) basilar artery, 2) segment P2a, 3) segment P2p, 4) segment P3, 5) segment P4. C. Dissection of the temporo-occipital region by Klingler method and cerebral vascular injection with latex. White matter and gray matter supply of the ventral aspect of the temporo-occipital region: 1) posterior cerebral artery, 2) parahippocampal gyrus, 3) inferior longitudinal fasciculus. D: 1) superficial middle cerebral vein, 2) minor anastomotic vein (Labbé), 3) ascending cortical veins, 4) superior sagittal sinus.

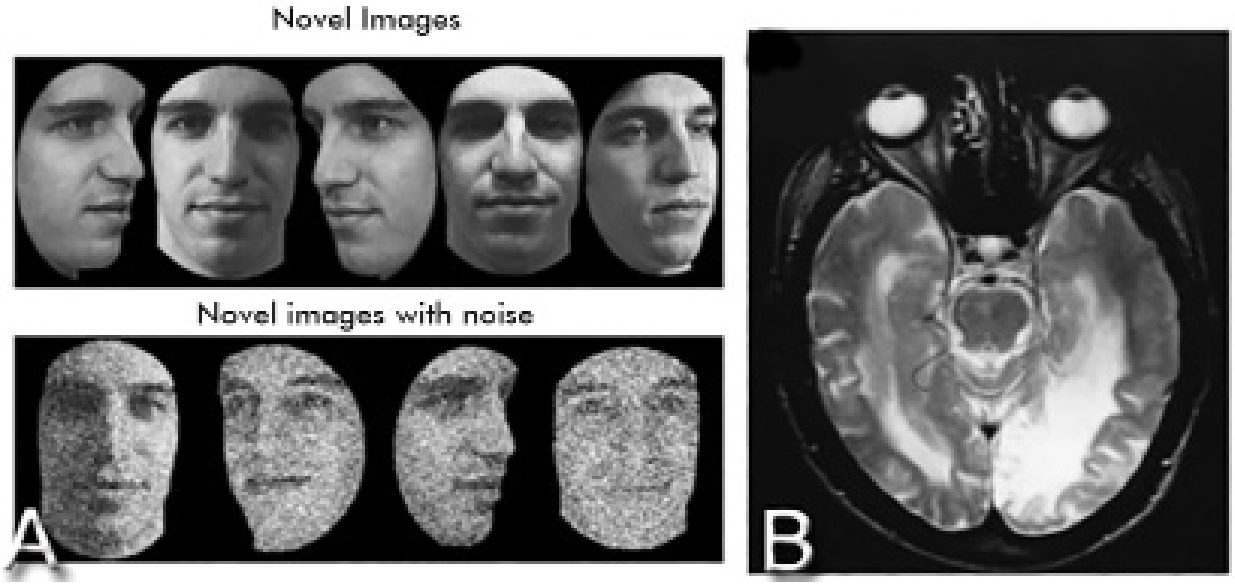

Figure 5. A. Cambridge Face Memory Test.[3, 4] b. Axial section of simple T2-weighted brain MRI in a patient with prosopagnosia due to PCA infarctions, mainly in areas of the fusiform and lingual gyri.[12]

superior temporal gyrus and posterior insula.[27] Therefore, the human perception system is capable of capturing combined sensory signals. In this regard, synchronous audiovisual signals activate the fusiform gyrus more than asynchronous ones.

On the other hand, the "familiarity" function, related to bibliographic data and affective responses associated with memories, has been located in anterior and medial temporal regions with the right temporal pole.[35, 39] In turn, the interpretation of facial expression involves connections with neurons in the superior temporal sulcus[40] in addition to networks outside the occipitotemporal cortex that allow emotional processing, mainly the amygdala, the insula, and the striatum.[35]

Conclusions

This review on prosopagnosia reflects the importance of neuroanatomy in clinical applications, as well as the study of and the interdisciplinary approach to neurological disorders. Properly identifying cognitive deficits and their anatomical alterations will allow specific medical-surgical management and comprehensive rehabilitation to improve the quality of life of patients and their caregivers.

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