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# Comparative Topographical Description of the Central Nervous System of the Macaw (*Ara ararauna*) and the Owl (*Tyto furcata*)

## Descripción Topográfica Comparativa del Sistema Nervioso Central del Guacamayo (*Ara ararauna*) y el Búho (*Tyto furcata*)

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**SUMMARY:** The study of animal neurology has historically focused on the closest descendants of humans, such as monkeys and chimpanzees. Because of this, the neurology of birds remains poorly studied and understood by humans compared to other groups of animals. Thus, the objective was to describe the central nervous system to better understand its functioning, correlating the findings with the role it plays in the physiology and biology of birds, comparing species with different behaviors between herbivores and carnivores, filling gaps in the literature serving as subsidy for future research.

**KEY WORDS: Birds. Brain. Nervous system.**

## INTRODUCTION

In research on the central nervous system – CNS, three main forms of study stand out, namely: neuroanatomy – studying that of its already developed structures (Sarnat & Netsky, 1981), ontogenesis – studying the development of the organism, and phylogenetics (Darwin, 1973) – studying the evolution of species through paleontology (Gould, 2001) and comparative anatomy (Gould, 2002). Regarding the evolutionary process, changes occur mainly due to environmental factors that influence all living beings, and not through simple terminal additions of new structures. The main common denominators of evolutionary processes are adaptation, the expansion of diversity and the increase in complexity (Darwin; Gould, 1997).

Belonging to the psittacidae family, the macaw has one of the most developed brains among birds (Bejcek & Stastny, 2001). The ability of psittaciformes to understand abstract concepts, point out which objects are the same and which are different using various criteria such as color, size, shape and material and even the ability to associate letters and their combinations with sounds have been proven (Herrick, 1924; Pepperberg, 1987, 1999). Another characteristic of the *Ara ararauna* species is that they live in groups and develop lasting relationships with other individuals of the same species, pointing to a complex social organization (Clayton & Emery, 2015), noting that the evolutionary development of brain structures is closely related to behavior and cognitive functions (Brodal, 1981), being the macaw endowed with great scientific, economic and preservationist importance due to its remarkable adaptability in captivity (Bejcek & Stastny).

The owl can live in a wide variety of habitats, mainly in open and semi-open environments, but it has also adapted to urban environments, being able to live in larger church and house ceilings (Menq, 2022). They are predominantly

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nocturnal, being difficult to find. They prefer to leave the nest in hot climates to hunt, and their food ranges from rats to small birds (Sick, 2001), although their food is preferably based on rodents. This bird has great importance in the control of rats in some regions. In addition to rodents and birds, this species can also feed on bats, amphibians and reptiles and, among invertebrates, insects end up being the most consumed, and in some regions there may be species that feed on crustaceans and worms (Ruschi, 1979). Regarding behavior, the owl can swing its body laterally and when threatened, it throws itself on its belly, facing danger, with its claws facing forward (Sick). It has a slender silhouette and large head, prefers to hunt at night and sometimes at dusk, its scream is harsh (Ridgely *et al*., 2015). In the nest, communication with the chicks starts early, the mothers chirp to the chicks still inside the eggs, so when the chicks open their eyes for the first time they turn to the parents or siblings and try to respond to the sounds they hear, they also tend to stare at the mother when they want food or her attention (O'Brien, 2008). Studies on the general biology of this species are very scarce, with just enough research in the areas of food ecology (Andrade *et al*., 2012).

Even with small brains, many birds have cognitive abilities that equal or surpass those presented by mammals (Reiner *et al*., 1998), such characteristic has favored studies related to its morphology, especially those involving the brain, a very important organ for acting in the regulation of the various systems of the organism, in addition, there are still gaps in the literature regarding this aspect, and such investigation is of paramount importance to help its zootechnical and sanitary management.

Thus, the objective was to identify and compare the topographical and morphometric anatomy of the brain of the macaw and the owl, being relevant to the expansion of knowledge about the central nervous system of birds, such results may be useful for the anatomopathological study of the species, assist research in the clinical and surgical area, subsidize new studies, being an important parameter for a better understanding of its organization and morphology.

## MATERIAL AND METHOD

Three (3) brains of *Ara ararauna* and *Tyto furcata* were used, belonging to the collection of the Anatomy of Domestic and Wild Animals, Faculty of Veterinary Medicine and Animal Science, University of São Paulo. Macroscopic analysis was performed to assess the particularities of the brain, showing its anatomical structures, topographic description and morphometric analysis.

The study was approved by the Animal Use Ethics Committee (CEUA – FMVZ) under CEUAx No. 7614220520.

## RESULTS AND DISCUSSION

During dissection, an important characteristic was observed in relation to the shape and position of the eyes of the specimens, since the sight of birds is one of the most developed senses of these animals, being essential for their survival, acting in activities such as flying, foraging, escape and reproduction (Cuthill, 2000; Candioto, 2011; Tyrrell & Fernández-Juricic, 2017), being the eyeball of the owl (Fig. 1A), positioned rostrally in relation to the skull and brain and presenting a tubular shape, with large eyes (Fig. 1C), while the eyeball of the macaw (Fig. 1B), is positioned laterally in relation to the skull and brain and presents a flat shape, with small eyes (Fig. 1D).

Thus, the owl's type of vision is characterized by covering a field of up to 180°, and by a front binocular field of approximately 50° (Fig. 1C), for greater visual accuracy for the use of claws for predation. While in the macaw, vision is associated with the visual accuracy of the beak, for feeding itself and the offspring, and for a greater visual field amplitude of the environment, reaching up to 240° in horizontal axis, being mostly monocular with relatively short binocular field, reaching a maximum of 30° (Fig. 1D), corroborating the findings described by Martin & Osorio (2010).

The perception of ultraviolet light is a common ability in diurnal birds, which plays a very important role in communication, camouflage and orientation (Bayon *et al*., 2007), as in the case of the macaw, which has predominantly cones in the retina (Detwiler, 1955; Reese *et al*., 2009), while the owl's retina has high light sensitivity, due to the large concentration of rods, corresponding to up to 90 % of photoreceptors (Detwiler; Reese *et al*.), responsible for colorless night vision (Detwiler; Kolb, 2003; Reese *et al*.) and is extremely important for the flight and pursuit of prey (Martin *et al*., 2004; Gumpenberger & Kolm, 2006; Korbel, 2009).

In nocturnal birds such as owls and some hawks, the longitudinal axis is as long as its diameter or even a little larger, giving the eyeball a tubular shape (Walls & Cranbrook Institute of Science, 1963). The flat type occurs in diurnal birds with a narrow head, such as birds of the order Columbiformes (Korbel). The class of birds is present in a wide variety of habitats such as land, water and air, which reflect in adaptations and variability in optical design (Zeigler *et al*., 1993; Candioto; Martin, 2017), possibly be globose, tubular or flat. These adaptations are related to the way of life of these organisms and allowed some groups of birds to have a significant increase in visual acuity, when compared to other vertebrates, being able to see 2 to 8 times more than a mammal (Zeigler *et al*.; Candioto; Martin; Tyrrell & Fernández-Juricic).

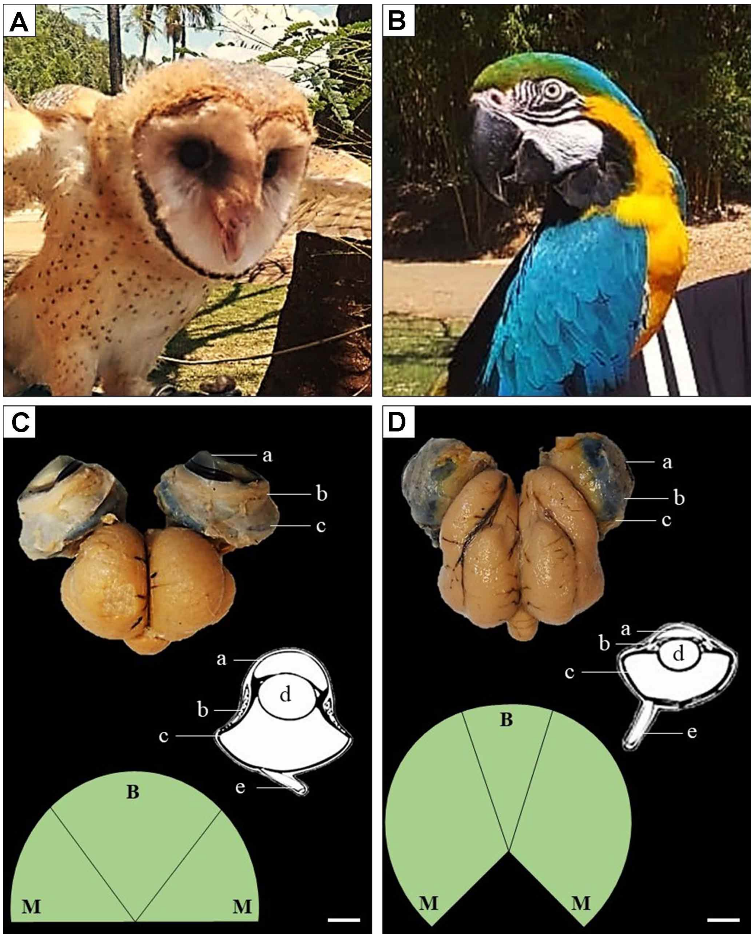


Fig. 1. Photomacrography of specimens and the relationship between the shape of the eyeball and vision and behavior. Photomacrography of specimens and the relationship between the shape of the eyeball and vision and behavior. In A – Owl (*Tyto furcata*), in B – Macaw (*Ara ararauna*). In C – rostral position of the owl's eyeball with a tubular eye morphology scheme and a 180º field of view, with a monocular (M) and binocular (B) field of up to 50º. In D – lateral position of the macaw's eyeball with a flat ocular morphology scheme and a field of view of up to 240º with a monocular and binocular field of up to 30°. Cornea (a), scleral ring (b), sclera (c), lens (d), optic nerve (e). 1cm bar. Source: Scheme adapted from Candioto (2011).

Table I. Division of the Central Nervous System (CNS) of the owl Tyto furcata and macaw *Ara ararauna*. Source: Adapted from Machado, 2009.

| Central Nervous System - CNS | | | |
|---|---|---|---|
| | Encephalon | Brain | Telencephalon |
| | | Brain stem | Diencephalon |
| Central Nervous | | | Midbrain |
| System - CNS | Spinal Cord | Cerebellum | Pons |
| | | | Bulb |
| | | | ---------------- |

The central nervous system (CNS) of macaw and owl was divided into brain and spinal cord. The encephalon is subdivided into the brain (telencephalon and diencephalon). Brain stem (midbrain, pons and bulb), and cerebellum (Table I).

After the division of the central nervous system, its anatomical structures and topography were identified, and like the mammalian brains, the brain of *Ara ararauna* and *Tyto furcata* is divided into telencephalon and diencephalon, positioned dorsally to the brainstem, composed of the midbrain, pons and medulla, and positioned cranially to the cerebellum. The diencephalon is positioned between the cerebral hemispheres, being better visualized in a sagittal view, with limited visualization in a ventral view, and a larger visual field in the owl in relation to the macaw (Fig. 2).

The telencephalon is composed of two prominent cerebral hemispheres and they are separated by the cerebral interhemispheric longitudinal fissure and cover the diencephalon and midbrain in dorsal view (Fig. 3 AB). However, there is an absence of turns, with a smooth surface and rounded ends, as described by Costa *et al*. (2018) in rhea telencephalons, with a rounded shape and of the lisencephalic type. The classification of the brain regarding the presence or absence of gyri is a characteristic associated with evolutionary aspects among vertebrates, with the brain being considered lisencephalon or gyrecephalon, when it does not present or presents convolutions, respectively (Martin *et al*., 2007; Marques *et al*., 2013).

The telencephalon only presents a depression recognized as the vallecula, evidencing the sagittal eminence present between the vallecula and the inter-hemispheric longitudinal cerebral fissure, the vallecula being deeper in the owl in relation to the macaw, highlighting the owl's sagittal eminence, presenting itself, qualitatively, with greater prominence (Fig. 3 ABEF).

We can verify that the Emu, the Ostrich, the Owl and the Pigeon have these structures, whereas in the Kiwi both the eminence and the vallecula are absent (Martin *et al*., 2007) and

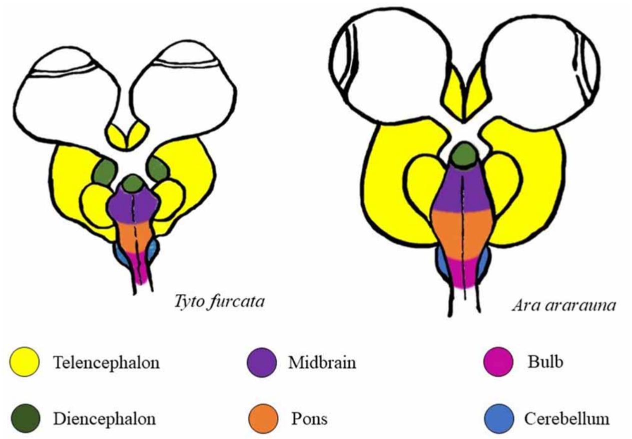


Fig. 2. Scheme of the brain of the Owl and Macaw. Scheme in ventral view of the brain of the Owl (*Tyto furcata*) and Macaw (*Ara ararauna*) comparative topographic anatomy.

these two structures are more prominent in the ostrich and in the emu than in the macaw. The sagittal eminence is a structure that receives information via ascending visual pathways in its caudal portion and information via ascending somatosensory pathways in its cranial portion (Costa *et al*.).

The cerebellum is located in the caudal portion of the brain, has a structure called cerebellar vermis and although the telencephalon is larger in the macaw, the cerebellum is qualitatively presented with the same proportion in both species (Fig. 3 ABGH). However, when comparing the relative size of the cerebellum of birds with that of mammals and reptiles, it can be seen that the cerebellum of birds is larger, even though mammals have comparatively larger brains. This is because the increase in the cerebellum in birds is related to specific behaviors and not to the general increase in brain size, as birds depend on an evolved motor control to carry out their daily activities, such as flight, vocalization, searching for food, construction of nests and also the control of the beak (Clayton & Emery). The cerebellum receives sensory and cerebral cortex information, allowing it to perform a modulatory function in movements as they are performed. The cerebellum, therefore, is directly related to procedural learning, motor planning, balance and muscle rigor (Sultan & Glickstein, 2007). Therefore, the cerebellum performs vital functions for birds, being essential for their survival.

In a ventral view, at the caudolateral end of the cerebral hemispheres, the optic lobes (Fig. 3 CD) were shown, which were well developed, similar to that observed in emus (Costa *et al*.), ostriches (Peng *et al*., 2010) and chickens (Gupta *et al*., 2016). This result is different from that found in research with owls and kiwis (Martin *et al*., 2007), where they described the optical lobe in reduced and very reduced size, respectively, justifying that it is due to the fact that these animals are from nocturnal habitats, which implied in regression of this structure driven by low light levels.

The optic nerve was well developed, positioned cranially to the optic chiasm (Fig. 3 CD), which refers to the great development of vision in birds, being large in falcons and crows and relatively small in nocturnal birds (King & Mclelland, 1984).

The medulla oblongata, pons and spinal cord have a smooth surface and their entire length is covered by the ventral median fissure, without a clear boundary between the structures (Fig. 3 CD). Between the telencephalon and the cerebellum we verified the presence of the transverse subemispheric fissure of the brain in both species (Fig. 3 GH).

When comparing the telencephalon size of the specimens, a significant difference can be seen in relation to the size of their structures, such as the telencephalon brain, eyeball and cerebellum (Fig. 4).

Thus, the morphometric analysis of its structures was performed, where significant differences can be observed in relation to the size and weight of the brain, where the macaw is larger than the owl, however, the eyeball and cerebellum are not showed significant differences in quantitative analysis (Table II).

When comparing the volume of the eyeball in relation to the volume of the brain, in birds the relationship is greater than in mammals (Bayon *et al*.). In birds, about 50 % or more of the skull volume is occupied by the eyes, while in humans, they occupy less than 5 % (Jones *et al*., 2007). In steppe eagles (*Aquila rapax*), ostrich (*Struthio camelus*), giant bustard (*Choriotis kori*) and European nightjar (*Caprimulgus europaeus*) each eyeball is larger than the brain (Burton, 2008).

It is important to demonstrate the anatomical differences between the various classes of birds, since they vary greatly in size, knowledge of the various anatomical and structural differences of these birds allows a better understanding of the evolution of birds so that we can understand possible differences. Martin *et al*. (2007) emphasize that the basic structures of the brain of birds are phylogenetically old, with changes taking place as a result of the development of some structures.

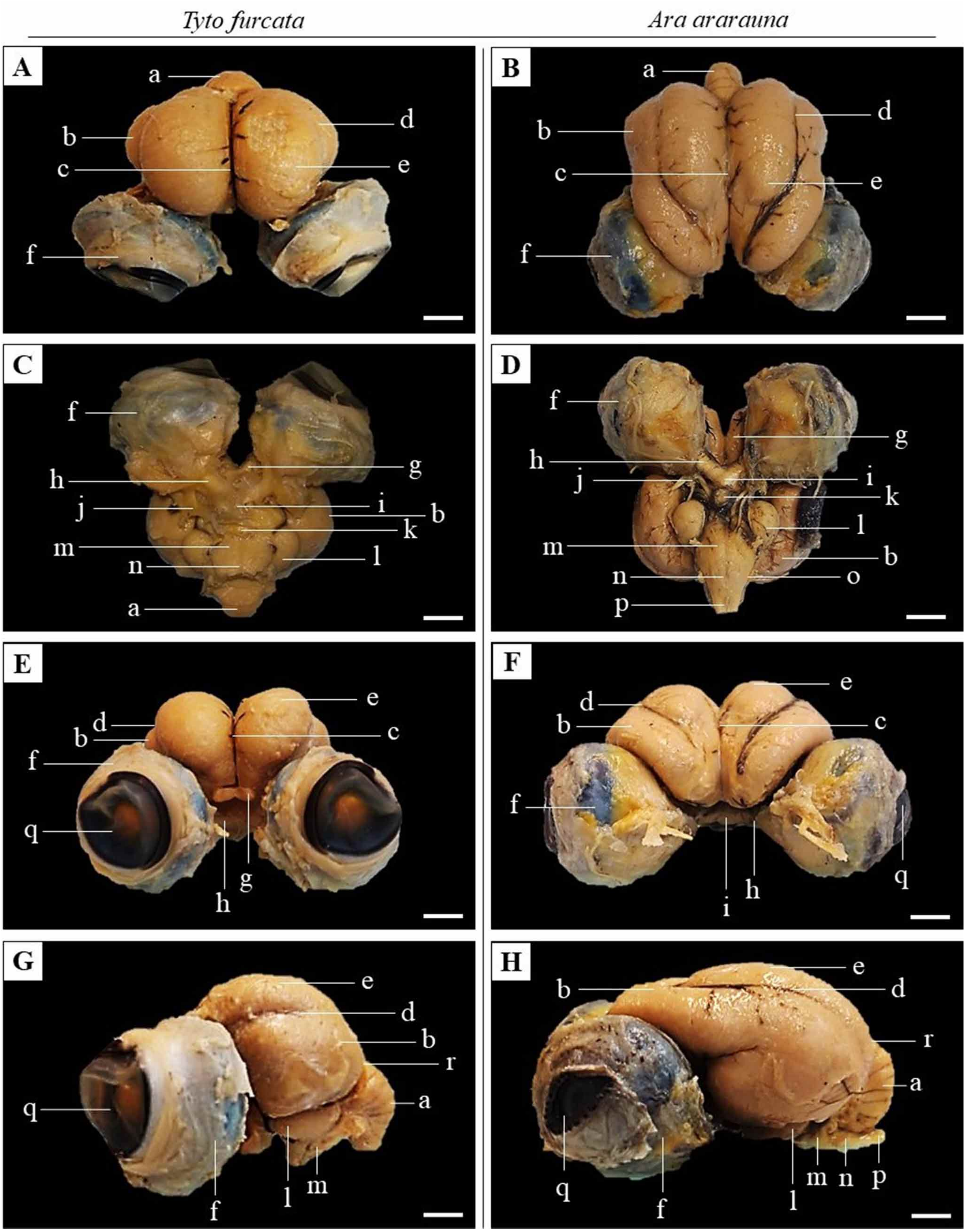


Fig. 3. Photomacrographs of the brain of the Owl (*Tyto furcata*) and the Macaw (*Ara ararauna*) and their attachments in the different anatomical planes. Photomacrographs of the brain of the Owl (*Tyto furcata*) and the Macaw (*Ara ararauna*) and their attachments in the different anatomical planes: A and B - dorsal view, C and D - ventral view, E and F - cranial view, G and H – left side view. Thus, the cerebellum (a), cerebral hemispheres (b), cerebral inter-hemispheric longitudinal fissure (c), telencephalic vallecula (d), sagittal eminence (e), eyeball (f), olfactory bulb (g) were observed, optic nerve (h), optic chiasm (i), trigeminal nerve (j), pituitary gland (k), optic lobe (l), pons (m), medulla (n), floccules - atrium of cerebellum (o), spinal cord (p), cornea (q), transverse cerebral subemispheric fissure (r). 1cm bar.

Table II. Comparative morphometric analysis of the *Tyto furcata* and *Ara ararauna*.

| | | Compared Morphometry | | |
|---|---|---|---|---|
| Species | | Eyeball | Brain | Cerebellum |
| *Ara ararauna* | Length | 2.2 cm | 5.2 cm | 1.3 cm |
| | Width | 1.5 cm | 3.5 cm | 1.1 cm |
| | Height | 1.9 cm | 2.4 cm | 1.3 cm |
| | Weight | 7.8 g | 26.6 g | 0.9 g |
| *Tyto furcata* | Length | 1.5 cm | 1.9 cm | 1.0 cm |
| | Width | 1.7 cm | 2.2 cm | 0.9 cm |
| | Height | 2.1 cm | 2.6 cm | 1.1 cm |
| | Weight | 6.9 g | 21.5 g | 0.6 g |

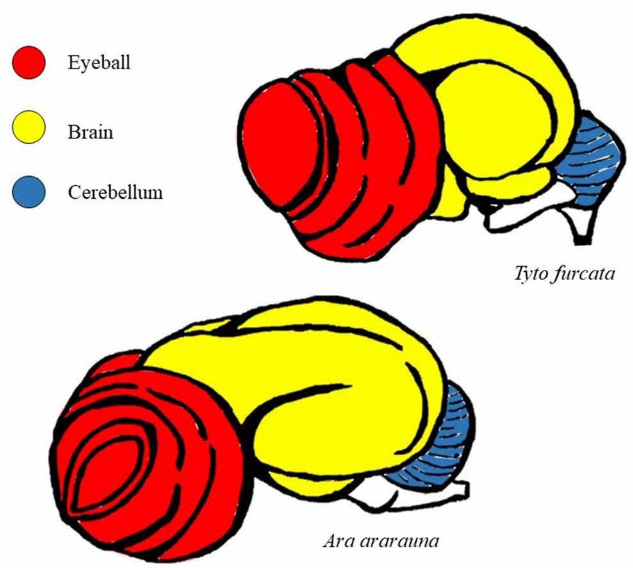


Fig. 4. Schematic of the brain of the owl and macaw comparing the analyzed morphometrically. Schematic in left lateral view of the brain of the Owl (*Tyto furcata*) and Macaw (*Ara ararauna*) comparing the topographic anatomy of the regions analyzed morphometrically.

## CONCLUSION

It was possible to observe and compare anatomical differences between the two species that ensure their survival and good functioning of their body for their respective functions in relation to their behavior, such as the position and shape of the eyes, brain and cerebellum size, and lisencephalon aspect. Anatomical structures that are not present in mammals, reptiles and in some birds were noted, such as the case of the sagittal eminence and the vallecula, which even showed differences between the two specimens studied.

Despite the smaller relative size of their brains when compared to mammals and the inexistence of some adaptations that increase the surface of the brain, such as turns, birds have some morphological changes that ensure their survival, such as the position and shape of the eyeball, reduced size of the extremities of the body, such as the head, being an evolutionary requirement for adaptations for flight, reducing the brain, which is compensated by the sagittal eminence and well-developed cerebellum, which allows a high procedural capacity.

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**RESUMEN:** El estudio de la neurología animal se ha centrado históricamente en los descendientes más cercanos de los humanos, como los monos y los chimpancés. Debido a esto, la neurología de las aves sigue siendo poco estudiada y comprendida, en comparación con la de otros grupos de animales. Así, el objetivo fue describir el sistema nervioso central para comprender mejor su funcionamiento, correlacionando los hallazgos con el rol que juega en la fisiología y biología de las aves, comparando especies con diferentes comportamientos entre herbívoros y carnívoros y llenando vacíos en la literatura que sirvan como base para futuras investigaciones.

**PALABRAS CLAVE: Aves; Cerebro; Sistema nervioso.**

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