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Review Article

Histo-Morphometrical Study of the Central Nervous System of Rose-Ringed Parakeet (*Psittacula krameria*) In Breeding and Non-Breeding Seasons

Urooj Azmat[1*], Hajra Nisar[1], Syed Mohsin Raza Shah[1], Hina Aziz[1], Mnahil Baig[2], Amna Irshad[3], Rehmat[3], Muhammad Sikandar[4]

[1]Department of Zoology, Wildlife and Fisheries, University of Agriculture, Faisalabad, Pakistan
[2]Department of Zoology, Lahore College for Women University (Lcwu), Lahore, Pakistan
[3]Department of Zoology, the Islamia University of Bahawalpur, Punjab, Pakistan
[4]Institute of Life Sciences, Shanxi University, China

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***Corresponding author:** Urooj Azmat
Department of Zoology, Wildlife and Fisheries, University of Agriculture, Faisalabad, Pakistan

Abstract

This review presents a study on the anatomical and histological features of the central nervous system in rose-ringed parakeets. The study involved nine healthy pairs of parakeets divided into three groups: Juvenile, Breeding Adults, and Non-Breeding Adults. Macroscopic and microscopic analyses were conducted on the brain, spinal cord, and optic lobes, along with measurements of body weight and dimensions. The results showed that adult parakeets during the non-breeding season exhibited the highest weights and dimensions in the body, brain, cerebrum, cerebellum, and eyes, while these parameters were lowest in juveniles. The study also highlighted the extensive optic tracts in parakeets, suggesting their high visual activity. Moreover, these findings provide major contribution into the central nervous system characteristics of rose-ringed parakeets and their developmental changes throughout different life stages. In addition, this study conducted to investigate the anatomical and histological features of the central nervous system in rose-ringed parakeets. The research involved nine pairs of healthy parakeets, categorized as Juvenile, Breeding Adults, and Non-Breeding Adults. The brain, spinal cord, and optic lobes were examined through macroscopic and microscopic analyses, while body weight and dimensions were recorded. The study found that adult parakeets during the non-breeding season exhibited the highest weights and dimensions in various anatomical structures including the body, brain, cerebrum, cerebellum, and eyes. Conversely, juveniles showed the lowest measurements. Additionally, the parakeets displayed extensive optic tracts, indicating their heightened visual activity.

Keywords: Rose-ringed parakeet, Central nervous system, Anatomical and histological features, Brain morphology, Avian neuroscience.

INTRODUCTION

The Rose-Ringed Parakeet (*Psittacula krameri*) is also called a Ringed-Neck Parakeet, in South Asian countries (Pakistan, Bangladesh, and India). It belongs to the family *"Psittacidae*". It is a medium-sized parrot from the genus "Psittacula". Wilhelm Heinrich Kramer, an Austrian scientist, was the first to describe the nomenclature of this parrot, naming it "*Psittacula krameria*". The Latin term "Psittacus," which means "parrot," was shortened to "*Psittacula,*" and the species "*krameri"* was named after the scientist (Jobling 2010). There are around 360 species of primarily brightly colored birds in the order "*Psittaciformes*." (Schirtzinger 2011). This order of birds was noisy overall, and some species are vocal mimics. Birds are typically described as "parrots" in this order. This order's species are all members of the superfamilies*; Psittacoidea* and *Cacatuoidea* (Garrett, Shuford *et al*., 2018). Three families comprise the superfamily *Psittacoidea*further; Psittacidae (Largest family), *Psittrichasiidae* (Shortest family) *Psittaculidae* (Smith, Merwin *et al*., 2023)

The family Psittacidae includes lorikeets (including lories), Along with the kea and kakapo, other bird species include parakeets (including budgerigars, rosellas, and conures), lovebirds, amazons, macaws, and parrotlets (or parrolets) (McDonald Kinkaid 2015). The first two parrot species, which are endangered, are found only in New Zealand. It belongs to the species of genuine parrots. This family includes numerous species that had recently gone extinct, as well as the 157 species of subfamily Arinae (New World or Neotropical parrots) and the about 10 species of subfamily Psittacinae (Old World or Afrotropical parrots) (Joseph, Toon *et al*., 2012).The *Psittaculidae* family was home to the rose-ringed parakeet. Old World parrots belong to the *Psittaculidae* family of parrots. *Agapornithinae, Loriinae, Platycercinae, Psittacellinae,* and *Psittaculinae* are its five subfamilies (Schweizer, Seehausen *et al*., 2010). There are 54 genera and 196 species within this family. The Psittaculinae subfamily includes the Rose-ringed parakeet. There are 13 genera and 55 species in this subfamily (Kiziroğlu 2022).

Rose-ringed parakeets are parrots of medium size, fully developed parrots have a body length of 38-42 (cm) on average, and a wingspan of about 42-48 (cm). It has a body mass of an average of about 95-140 (g). Their average lifespan was 30-40 years. The tail was much longer than half of the parrot's body length and its spans were up to 25 (cm) long. They feature zygodactyl feet with two toes pointed in the front and two in the rear, as well as broad, hooked bills. The baby's upper mandible was attached to its skull by hinges (Srivastava, Singh *et al*., 2011).The rose-ringed parakeets are sexually dimorphic. Both sexes, male and female hold distinctive colors of greenish shades in the wild and in captivity. Various color breeds of this parakeet species have been introduced such as; turquoise, white, sky-blue, purplish-blue, and beige. When increasing age, the male parrots develop a red ring around their neck, which becomes thicker with time, and above it, a black ring begins to appear (Shiels and Kalodimos 2019). Due to this feature, this parrot gets its name ringed-neck parakeet. A mature hen or female parrot has a neck ring that ranges from shadow-pale to dark grey. While juvenile parrots of both sexes do not have neck rings (Le Gros, Samadi *et al*., 2016).

Rose-ringed parakeets were native to the Indian and African continents, but feral populations had established themselves in many other countries across the world, where they are raised for the exotic pet trade (Vall-llosera, Woolnough *et al*., 2017). This parrot is an invasive species, that finds a suitable environment, in terms of influencing native birds of that habitat, just as in Belgium. These parakeets can survive in a wide range of climates beyond their native ranges, even in low winter temperatures, such as in Northern Europe. A rose-ringed parakeet was one among such parrots that could efficaciously adapt to live in habitats that had been disturbed by urbanization and deforestation (McGrath 2015)Four subspecies of rose-ringed parakeet have been recognized, based on their occurrence including African Rose-Ringed Parakeet (*Psittacula k. krameri*), Abyssinian Rose-Ringed Parakeet (*Psittacula k. parvirostris*), Indian Rose-Ringed Parakeet (*Psittacula k. manillensis*), Boreal Rose-Ringed Parakeet (*Psittacula krameri borealis* (Menchetti, Mori *et al*., 2016):

In the avian nervous system, the spinal cord does not remain the same throughout the vertebral column length. The spinal cord grows and contracts gradually across numerous vertebral segments (Rashid, Bradley *et al*., 2020). Major and prominent enlargement was lumbosacral expansion, which houses the additional afferent neurons required to gather sensory inputs from the limbs, the additional efferent neurons required to provide motor control to the limbs, and the additional interneurons required for sensory and motor integration. This differential expansion and contraction befall all vertebrates (Harrow-Mortelliti, Reddy *et al*., 2019).

The rose-ringed parakeet needs its vision to perceive the environment. Its retina is well-developed and contains two main visual components. The first was a pigmented retina, which was located next to the eye's choroid layer (Olsson 2016). This layer was a rather straightforward layer with many melanin-rich cells. The neural retina, which was located next to the vitreous body of the eye, was the second important component of the retina. This component had seven more layers as well as rods and cones (Hunt, Carvalho *et al*., 2009).

The anatomy and histology of the central nervous system of rose-ringed parakeets have not been studied yet; therefore, this research will provide a thorough examination of many areas of the brain and spinal cord to comprehend rose-ringed parrot behavior. The current study aimed to investigate the physical and morphometric characteristics of the brain of the rose-ringed parakeet, as well as to correlate its structural pattern with that of birds. Avian brains can be used as a comparative bio-model better to understand the fundamental principles of brain structure and function. As neuroscience progressed swiftly, deriving quantified data from avian brain morphology was an important field of study. There was scant documentation on the structure of parrot brains (Kuenzel 2014).

The central nervous system plays a vital role in bird's movements; flying and perching. The brain and spinal cord make up the central nervous system. It also controls the growth and function of the brain. The avian brain was further compartmentalized into various regions such as; the pallium, striatum, cerebellum, olfactory lobe, optic lobe & chiasma, hypothalamus, hypophysis, and medulla oblongata. The anatomical study of the brain had been studied in Wild African parrots, but the most focus was on the vallecula, cerebellum, and olfactory lobe in that research. Later on, research was made on the anatomical study of the chicken's brain, which reveals different kinds of cells present in various brain regions. Very little literature was available on the histological study of the central nervous system of a rose-ringed parakeet (*Psittacula krameri*) (Kuenzel, Medina *et al*., 2011, Sikandar, Shah *et al*., 2024).

The Anatomical and Histological Features of Avian Brain"The anatomical gene expression of brain regions is different in song-learning birds (songbirds, parrots, hummingbirds, etc.) and non-learning birds (quail, dove, etc.). The research evaluates that in song-learning birds there was an area in a striatal region called Area which X, was necessary for vocal learning. The Robust nucleus of Arcopalliuman (RA) was analog in song-learning birds and this region was necessary for the production of sound in birds (Pfenning, Hara *et al*., 2014).

2.1 Research Advances in Avian Brain

Through the evidence on the sagittal sections of the brain of zebra finch and pigeons. It was estimated that the portion of the brain above or adjacent to the BG (basal ganglia) accounts for approximately 75% of the telencephalon (Lovell, Wirthlin *et al*., 2020). The immunohistochemistry also indicates that the neuronal structures over and parallel to the BG in the avian brain must be cortical. The valuation of approximately 75% telencephalon region was forebrain in avian brain, this assessment was rather comparable with the mammalian cortex that occupied forebrain volume (Eugen 2021).

This forebrain area was referred to as the cortex in mammalian descriptions. But according to avian accounts, this area could not be referred to as the cortex, since the cortex was a structure made up of six cell layers. In the avian brain, the regions that are dorsal and lateral to BG display no indication of several layers, rather shows that the neurons are layered out in groups (Marzluff and Angell 2013). Therefore, another term used to describe the cortical-like structure in avians was “pallium”, which means “an outside covering”. The pallium is the structure in the avian brain, that covers the brain from the dorsal and ventral sides and also provides protection to the avian brain (Moorman, Gobes *et al*., 2012).

Such spatial memory must be stored and retrieved by cortical-like structures. Other types of learning have also been shown in chickens, such as the capacity to play tic-tac-toe against a human opponent and win. However, there had been worries that during certain events at county fairs, birds may be "coached" using secretly projected lights (Norman, Adriaense *et al*., 2019). Caledonian crows were capable of creating tools, a capacity previously believed to be exclusive to mammals. With intensive training, African gray parrots and Rose-ringed parakeets were demonstrated to be able to pick up human words and use them to interact with a human (Gruber, Schiestl *et al*., 2019).

Rather than cell layers of the cortex, the pallium constitutes columns of cells. Two recent documents estimate that functional column cells of pallium are also present in auditory and visual pathways in the avian brain. Comparatively, the cells of the functional column which are characteristics of the mammalian neocortex, in the avian auditory pathway the Field L region of the forebrain also shows in detail the existence of columns of cells that are functional (Spool, Macedo-Lima *et al*., 2021). The auditory route in the pallial area begins with the cochlea, then projects to the medulla nucleus and midbrain region, then to the thalamus nucleus, and finally to Field L (Wang, Brzozowska-Prechtl *et al*., 2010).

The auditory pallium had functional columns that are identical to those seen in the human neocortex, according to solid evidence provided by a close investigation of Field L (Medina, Abellán *et al*., 2022). Similar to this, tract-tracing methods revealed that the tectofugal and thalamofugal pathways comprised the two main parallel networks that made up the bird's visual pathways. Regarding the former, the route was composed of a tract that began in the retina, proceeded down the optic nerve to the optic lobe's outer layers in the midbrain, passed via a large thalamic nucleus, and eventually came to an end in a specific region of the pallium (Güntürkün 2000).

The entopallium, a deep pallial area, was shown to have columns of linked neurons facing the pallium's more superficial regions. These ground-breaking anatomical findings support the earlier theory that there was cell-to-cell homology between the cells of the avian pallium and specific numbered cells identified in one of the six layers typical of the mammalian neocortex and show the existence of functional columns within the avian pallium (Dugas-Ford, Rowell *et al*., 2012).

2.2 Characteristics of Avian Pallium

The avian pallium was further compartmentalized into four catalogs; hyperpallium, nidopallium, mesopallium, and arcopallium. At the medial of the arcopallium, a structure called sub-pallium was present. An investigation shows that the avian sub-pallium comprises five neural systems which include dorsal somatomotor BG, ventral visceral-limbic BG, extended amygdala, basal telencephalic system, and septal neuroendocrine system respectively. All of these neural systems vary in functions (Puelles 2001).

Voluntary motor movements are governed by the dorsal somatomotor BG. Dopamine neurons in the substantia nigra form a terminal field that sends dopaminergic input to the lateral and medial striatum of the dorsal BG. Numerous tract-tracing and immunohistochemistry studies revealed that the BG structure was highly conserved among vertebrates (Sonne, Reddy *et al*., 2022). Importantly, the comparison of the BG's structures, neurotransmitters, and neuropeptides indicated that both mammals and birds had an indirect channel that inhibits undesirable bodily motions in addition to a direct pathway that promotes movement (Rocha, Freire *et al.*, 2023).

Data show that this neuronal system was significantly comparable in both groups of vertebrates. Parkinson's disease had been linked to the degeneration of dopaminergic neurons in the substantia nigra in humans. Due to the significant similarity of dopaminergic inputs into the dorsal somatomotor BG of birds and the same 2 pathways that had been identified as governing body movement, avian species continue to be effective models for investigating Parkinson's disease (Menegas, Bergan *et al*., 2015).

In both birds and mammals, the ventral visceral-limbic BG serves a purpose known as "reward and reward-motivated learning." Similar to the dorsal somatomotor BG, the ventral visceral-limbic BG receives important neurotransmitters from the ventral tegmental nucleus of the midbrain (VTA). A major neuropeptide known as substance P was released into the ventral visceral-limbic BG's target tissues (Kuenzel, Medina *et al*., 2011).

This neural system's core component was the nucleus accumbens (NAc). It may be distinguished in birds using antibodies to substance P, tyrosine hydroxylase, dopamine, cyclic adenosine monophosphate-regulated phosphoprotein, and neuropeptide Y (Bálint and Csillag 2007). Animal studies using microdialysis have shown that feeding triggers the extracellular release of dopamine in the nucleus accumbens (NAc), which was detectable. This suggests that dopamine and the NAc are related to behavior that seeks rewards (Willuhn, Wanat *et al*., 2010).

The central and medial nuclei, which together make up the amygdaloid complex, are the two major nuclei found in mammals (Bellver 2017). Neuronal pathways ran medially and toward the midline in each of these nuclei. In birds, the globus pallidus was ventral to both channels. The central and medial amygdaloid nuclei, either directly or indirectly the bed nuclei of the stria terminalis, are the principal output nuclei of the amygdala (Paré *et al.*, 2004).

The central extended amygdala contains both the central amygdaloid nucleus and the corridor leading to the lateral bed nucleus of the stria terminalis (CEA) (Chaves, Fazekas *et al*., 2021). The CEA has been shown to communicate with several brainstem areas that regulate the autonomic nervous system. Thus, the mammalian CEA has been often associated with the regulation of appetite, fear, and stress/anxiety (Swanson 2000).

The visceral forebrain system was a neurological system suggested before the CEA was formed in mammals. It's noteworthy to notice that the visceral forebrain system and the CEA, which regulate the autonomic nervous system, had almost comparable neuronal architectures (VFS). The VFS function was thought to collaborate with the CEA during stressful or emotional situations by interfering with or overriding brainstem homeostatic mechanisms (Kuenzel and Jurkevich 2022).

It had been hypothesized that birds had a VFS similar to humans since the same group of brain areas in them showed positive for vasoactive intestinal polypeptide (VIP) in the immunohistochemistry described below. Because VIP affects behavioral changes related to the care of the young and has several functions related to energy metabolism, metabolic aspects of circadian rhythms, and circadian rhythms, VIP or a VIP-like neuropeptide may function in a neural network similar to the VFS or CEA and may be a useful marker of these neural systems (De Olmos, Beltramino *et al*., 2004).

Sub-pallial medial amygdala and a pathway of neurons leading to the medial bed nucleus of the stria terminals make up the medial extended amygdala (MEA) (Tromp 2018). In animals, it had a role in aggressive, protective, and reproductive behavior. The central extended amygdala was immediately ventral to the MEA (Choi, Dong *et al*., 2005).

Recently, the name medial amygdala for birds' nucleus taeniae amygdala was used (MeA). Since the MEA was made up of a neuronal corridor, it extends medially to two subnuclei of the medial bed nucleus of the stria terminalis (Vicario, Mendoza *et al.*, 2017). The BSTM of birds exhibits sexual dimorphism. Using the neuropeptide marker arginine vasotocin, the BSTM in chickens was recognized in the embryo and after hatching birds. However, females' BSTM was no longer detectable when it came to immunoreactivity to arginine vasotocin. According to studies, the BSTM of birds plays roles that are comparable to those of mammals (Abellán and Medina 2009).

The nucleus basalis of Meynert, which had sizable cholinergic neurons, was a significant component of the basal telencephalic system (Koulousakis, Andrade *et al*., 2019). The globus pallidus and the ventral pallidal area of the BG are partially occupied by cholinergic neurons. The regulation of cortical activity as well as attentional and arousal processes that impact learning and memory are crucial functions of the corticospinal cholinergic neurons. Neurons in this system are known to suffer detrimental effects from Alzheimer's disease in animals. It was believed that the cholinergic neurons in and around the nucleus basalis magnocellularis in birds are analogs of the Meynert nucleus in mammals (Gibbs, Maksel *et al*., 2010).

The septum and septal neuroendocrine systems are connected to ingestive, defensive, and reproductive functions. Using a variety of songbird species and antibodies against 10 neuropeptides and enzymes, the avian septum had also been divided into 4 major divisions (Abellán and Medina 2009). Functional studies on black-capped chickadees show that the septum and hippocampus, in addition to being involved in food storage, are essential for aggressive behavior and courtship (Sherry and Hoshooley 2010).

Gonadotropin-releasing hormone, type 1 (GnRH-1) neurons are part of a neuropeptide system that affects septal shape and function. It has been established that the GnRH-1 neurons, which are in charge of growing and controlling the reproductive system in vertebrates, do not begin in the brain but rather develop first in the olfactory placode/epithelium of frogs, chicks, and mammals Near the olfactory bulbs, the neurons enter the brain and proceed caudally until they reach the septal-preoptic-hypothalamic area (Wray 2010).

2.3 Anatomical Investigation of the Brain of Wild African Grey Parrot

In the brain of a wild African grey parrot, the olfactory bulb was relatively larger. This indicates that the wild parrots possess qualify sense of olfaction. This ability of parrots helps them to survive in the wild very effectively by keeping them alert from predators and aiding in locating their prey and food. The olfactory sense of all birds was not similar, some birds possess a high degree of olfaction such as the kiwi, canaries, and vultures, all these birds are very efficient in finding prey. Comparatively, some birds had a poor olfactory sense (Wanmi, Samuel *et al*., 2018).

The vallecula was a slightly convex, curved super-sulcus that bends posterior-medially on each side of the cerebrum in birds to aid in visual acuity. This statement was consistent with that of the African ostrich, but not in the case of domestic pigeons, in which vallecula is present on the lateral sides of the cerebral hemisphere. These physical characteristics may be important in species distinction, and birds with superiorly situated vallecula had good eye acuity. This signal enables the parrots to have good visions and to locate prey in the wild (Gupta, Behera *et al*., 2016).

The quantitative study of the body and brain indicated mean weights to be 163 ± 4.36 g and 4.78 ± 0.21 g, with the whole brain having length and width measuring 3.66 ± 0.19 cm and 2.06 ± 0.07 cm respectively. Similarly, the mean weight of the cerebellum in a wild African grey parrot was recorded to be 0.97 ± 0.13 g and the length of the cerebellum was 1.01 ± 0.07 cm (Adam, Onyeanusi *et al*., 2018). The wild African grey parrot's cerebellum was a little open. Because cerebellar folding influences posture, dexterity, and balance with the display of many types of flight, and motor behavior. This implies that before attacking its victim, the wild African parrot must stabilize its motor system (Wylie, Gutiérrez-Ibáñez *et al*., 2018).

The mean brain weights of most bird species were lower than their body weights, and as a result, they may vary among birds of the same body weight. The source of the brain's expanding nature may be the forward-protruding skull and elongation of the cervical region, which may have an impact on brain length and weight (Rushton and Ankney 2009).

Additionally, the cerebellum was discovered to be small, rounded to oval, and similar to that of pigeons and chickens. The band owl, vultures, and eagle all had spherical cerebelli that were inclined upward and backward (Stingo-Hirmas, Cunha *et al*., 2022). These variations explain why a bird's posture and size are connected to its cerebellum's size and location, and why most big birds have smaller cerebellum and are mostly flightless or short-distance fliers (Rehkämper, Frahm *et al*., 2008).

Moreover, the wild African grey parrot's cerebellum was not very folded. The cerebellum's folding affects posture, dexterity, and balance with the exhibition of various types of flight, and motor behavior. This suggests that before attacking its victim, the wild African grey parrot must first stabilize its motor system. Additionally, it was noted that the cerebellum was diminutive, rounded to oval, and comparable to those of chickens and pigeons (Ocklenburg and Güntürkün 2012).

The anterior dorsal region of the cerebral hemispheres contains the Wulst or hyperpallium. The complicated cognitive processes associated with higher-level awareness in mammals correspond to the West in birds. The Wulst was found anterior-most on the cerebral cortex in helmeted guinea fowls and posterior-dorsally in ducks. The domestic pigeon had a well-developed Wulst, indicating that it had a high level of consciousness and that it was a crucial sensory organ (Iwaniuk and Wylie 2006). The optic lobe of a wild African grey parrot had an oval-like shape and was rather tiny (Martin, Wilson *et al*., 2007). This discovery contradicts accounts that pigeons are huge and round and was in accord with observations on kiwi, band owls, and hummingbirds. Typically, it was believed that parrots had relatively tiny optic lobes (Iwaniuk, Nelson *et al*., 2004).

2.4 Anatomical Study of Chicken's Brain

The brain anatomy of the locally-bred chicken was studied in Basra, Iraq. According to this study, the brain of the locally-breed chicken was irregular in shape. Mainly the three major brain parts known as; the cerebrum, cerebellum, and medulla oblongata are present in this chicken breed. Ten individuals of locally-breed chicken were used in his research. At first, the mean of all chicken brains was calculated and evaluated as 23.73 ± 1.38 g. Due to the gyrus and sulcus being absent, the cerebrum was triangular and had a smooth surface during the macroscopic examination (Batah, Ghaje *et al*., 2012). The olfactory bulb was not fully formed. The average cerebral length and breadth were 17.45mm and 20.74mm, respectively. The vermis, which was positioned in the center of the cerebellum and had an oval form, was behind the transverse fissure. The average cerebellum measured 11.669mm in length and 8.6mm in width. The optic lobe looked to be big and oval, while the medulla oblongata measured an average of 4.134 mm and 6.4 mm in length and breadth, respectively (Gill, Wadas *et al*., 2008).

The molecular layer, the external granular layer, the pyramidal or external pyramidal layer, the internal granular layer, the internal pyramidal layer, and the multiform layer are the six layers of gray matter that make up the cerebral cortex, according to histological research. The medulla, which was composed of glial nerve cells and thick bundles of nerve fibers, makes up the white matter. The cerebellar cortex is made up of three layers: the molecular layer, the Purkinje cell layer, and the internal granular layer (Miyashita 2022). The three longitudinal pillars of the medulla oblongata's histological cellular structure consist of a nucleus and reticular fibers. A group of middle-sized neurons makes up the first pillar, which is situated at the median level of the medulla oblongata. A large neuron makes up the second pillar, which is situated on the medial side of the medulla oblongata. The third pillar was situated on the ventral side of the medulla oblongata (Pal, Chowdhury *et al*., 2003).

The central nervous systems of birds and animals are not significantly different. Birds' brain hemispheres had a shape like a pear. The right and left cerebral hemispheres are split by a median fissure, while the cerebral hemispheres and cerebellum are divided by a transverse fissure. The two olfactory bulbs are situated in the anterior portion of the cerebral hemispheres. This discovery confirms earlier findings that the cerebellum of swifts and falcons is small. The olfactory lobes are smaller in birds because they have poor senses of smell, while the optic lobe is very large since most birds rely on vision. The two halves of the avian brain are called grey matter and white matter. The gray matter was outside, while the white matter was within (Hussain and Al-taee 2022).

The cerebral cortex of the chicken brain according to histology studies, the brain was made up of grey matter. Following are the six layers that make up the cortex: molecular, external granular, pyramidal, internal granular, internal pyramidal, and multiform layers. Each layer performs its functions in terms of protecting the cerebrum. The white matter contains bundles of nerve fibers and glial cells which altogether establish the medulla oblongata (Sultan 2005). The medulla oblongata had a distinct cellular structure consisting of the reticular fibers and nucleus that create three longitudinal pillars. The location and composition of neurons are different in each pillar. The first, second, and third pillars were situated at the median level, medial level, and lateral sides of the medulla; which comprise a group of intermediate-size neurons, large-size neurons, and small-size neurons respectively. The molecular, Purkinje cell, and internal granular layers are all present in the cerebellum, which also has three layers (Rolls 2016).

2.5 The Wulst and Corticoid Areas of the Avian Cerebral Hemisphere

Additionally, intelligent, birds could create concepts and employ abstraction. This function was connected to the sub-cortical or cerebral cortex in birds. Since birds lack a neocortex in contrast to mammals, they have sub-cortical structures such as the hyperstriatum and wulst. The forebrain's hemispheres house the machinery required for intelligence (Güntürkün, Pusch *et al*., 2024). A major measure that runs quite similarly across various orders and families of birds may be estimated by comparing the weight of the cerebral hemisphere to the weight of the brainstem (midbrain + hindbrain - optical lobes and cerebellum). Parrots, passerine birds (crows, starlings, sparrows, etc.), woodpeckers, and owls had a high index, suggesting a large globe. Grebes, loons, swifts, doves, hens, and ostriches all had low indices. Hawks, cuckoos, rails, ducks, and herons perished between these two groups (Vincze, Vágási *et al*., 2015).

A sparrow, a crow, a parakeet, and a woodpecker all had quite big hemispheres. The remaining species' hemispheres are considerably smaller than those of the brainstem. The cerebral hemisphere covers substantially more of the midbrain and hindbrain in the first group of birds. When one contrasts the parakeet with the loon, this becomes clear (Rogers 2012). Therefore, it suggests that a big hemisphere positively corresponds with a high level of adaptation ("intelligence"). The striatum, which was broken down into the arch-striatum, paleo-striatum, neostriatum, and hyperstriatum, makes up the majority of the avian hemisphere. The first three can be found in mammals and reptiles, but only birds have the hyperstriatum. It covers the neostriatum and makes up a sizable portion of the top (vertex) of every bird's brain. Its size varies, particularly in the wulst, its superior region, which was made up of the hyperstriatum accessories and the hyperstriatum dorsal (Reiner, Perkel *et al*., 2004).

The Wulst was a swelling that may be observed in many birds, as its name suggests. Sagittal Wulst) and was more frontal in crows, more occipital in ducks, and more extensive over the vertex in parrots. It was parallel to the mesial margin of the hemisphere. The more intellectual species tend to have a larger hyperstriatum in this area. The embryological study of the Kalléns demonstrated the homology between the mammalian neocortex and the mammalian hyperstriatum and neostriatum. Wulst alone, however, was identical to the human neocortex, according to recent studies in embryology (Bischof, Eckmeier *et al*., 2016).

2.6 Interspecific Allometry of Brain in Parrots

The Psittaciformes and passerines both had comparable relative brain and telencephalic volumes. In comparison to non-passerines, Psittaciformes had much bigger brains and telencephalons. Whether they differ from non-passerines in having non-telencephalic brain areas that are noticeably smaller. To solve some of the statistical issues (such as scaling biases and correlated changes between structures), multivariate statistics might be used, and better phylogenetic resolution would allow for a more thorough comparison analysis *(Carril, Tambussi et al*., 2016).

Cognitive capacity and brain and telencephalon size are correlated. Although the proportional brain and telencephalic volumes of primates and Psittaciformes are comparable, brain and telencephalon size may have had a significant impact on the emergence of advanced cognitive capacities. Primates and Psittaciformes both had long lifespans, relied on social learning, lived in complex social groupings, and ate comparable foods (Gutiérrez-Ibáñez, Iwaniuk *et al*., 2018). The presence of sophisticated cognitive activities in passerines, including tool production and selection, spatial memory, tactical deceit, and other behaviors, raises the possibility that passerines had cognitive capacities on par with or perhaps superior to those of Psittaciformes (Chappell and Kacelnik 2002).

Microscopical analysis reveals that the cerebrum is divided into two sections. The first region is the pallium, which contains the piriform cortex and the hippocampus complex in the dorsolateral corticoid area. The mesopallium, nidopallium, and archopallium are located in the internal corticoid area's dorsal ventricular ridge, which is the second region. The nidopallium that surrounds the crescent-shaped lateral ventricles has big pyramidal neurons in it. The striatum, which contains neuronal fibers, and the pallium, which is small and pale in color and symbolizes the deepest section of the cerebrum, make up the two parts that make up the subpallium region (Abid and Al-Bakri 2017).

2.7 Avian Cerebellum

When one order of birds' gross morphological traits is compared to those of other orders, many distinctions stand out. The forebrain, midbrain, and hindbrain are the finest phrases to explain the pattern that all birds' brains follow. The eighth (auditory and vestibular) nerve was well-developed and the hindbrain was substantial in all orders. The trigeminal nerve, which supplies sensation to the face and bill, was also prominent. The cerebellum, which differs in size from species to species, shows the most variance (Manns and Ströckens 2014). Even loons had a good-sized brain, maybe due to their agility in the water. One would think that birds with rapid and skilled flying would have much larger cerebellums than birds with monotonously straight flight (Sikandar, Shah *et al*., 2024).

The histological investigations on the cerebellum of the African grey parrot and lesser sulphur crested cockatoo signified that the cerebellum is composed cerebellar cortex and cerebellar medulla. The cerebellar medulla constitutes the white matter. The cerebellar cortex is further divided into three different layers of cells. These layers are; the molecular cell layer (ML), Purkinje cells layer (PCL), and granular cells layer (GCL). The Purkinje cell layer is very thin. both white and grey matter had significant mononuclear cell perivascular cuffing. Mostly epithelioid macrophages, these cells also contained varying amounts of lymphocytes and plasma cells. Glial cells positive for the antigen were dispersed throughout this tissue. It consists of mostly single-layer cells. The Purkinje cells are globular and are present between the granular cell layer and the molecular layer (Ouyang, Storts *et al.*, 2009, Sikandar, Shah *et al.*, 2024).

2.8 Avian Olfactory Bulbs

There have been several comparison studies on the size of the olfactory bulbs and the olfactory chambers in the nasal fossa of various bird species. The size of the olfactory bulbs in various animals varies significantly. They are large in kiwis and petrels, but tiny, fused, midline structures in sparrows and parrots. Large in swimming birds, medium in marsh birds, and small in other species are the olfactory lobes. A bird's ability to smell and a well-developed olfactory system were connected to its ability to eat and reproduce. The size of the olfactory bulb was often correlated with eating behavior. The olfactory lobes of birds with short flights and arboreal lifestyles are tiny and united. On the other hand, birds that live on land and have lengthy flights have olfactory lobes that are well-developed because they must utilize smell to find their food or prey (Ksepka, Balanoff *et al.*, 2020).

From the quarter to the twenty-first century, anatomical investigations were made on the avian olfactory bulbs. Olfactory bulbs send neural fibers to several central processing locations, which was not exactly a sign of a degenerated system, according to the first neuroanatomical study. Later, as a result of microscopic examinations of the olfactory bulbs of the pigeon and the amazing size of the olfactory bulb of the northern fulmar (Fulmarus glacialis). Both bulbs had the cell kinds and layers that are typically observed in other vertebrate phyla (Helwany and Bordoni 2020). The pigeon was equivalent to the mouse, but the fulmar contains around twice as many mitral cells as the rat and rabbit. Pigeons and mice, as well as fulmar and rats, may have different functional characteristics based on certain variations in intra-bulbar cellular interactions.

2.9 Avian Optic Lobes

The shape of the optic lobe is a relatively small and oval-like structure. This finding agrees with reports on kiwis, band owls, and hummingbirds, but disagrees with reports on pigeons which are large and circular. Generally, parrots are said to possess a very small optic lobe (Martin, Wilson *et al*., 2007).

Birds have a well-developed optic lobe, which is a component of the midbrain and processes sensory data from the visual, auditory, and somatosensory axes. In birds, the intricately laminated supraventricular portion of the lobe known as the optic tectum is a retinorecipient brain area that receives up to 90% of visual information (Gignac 2020). The optic tectum's functions also include head and eye alignment toward auditory and visual inputs, visual discrimination, spatial placement of stimuli, and motion processing. Therefore, even though there isn't any proof of this association, the optic lobe might be crucial to navigation (Vincze, Vágási *et al*., 2015).

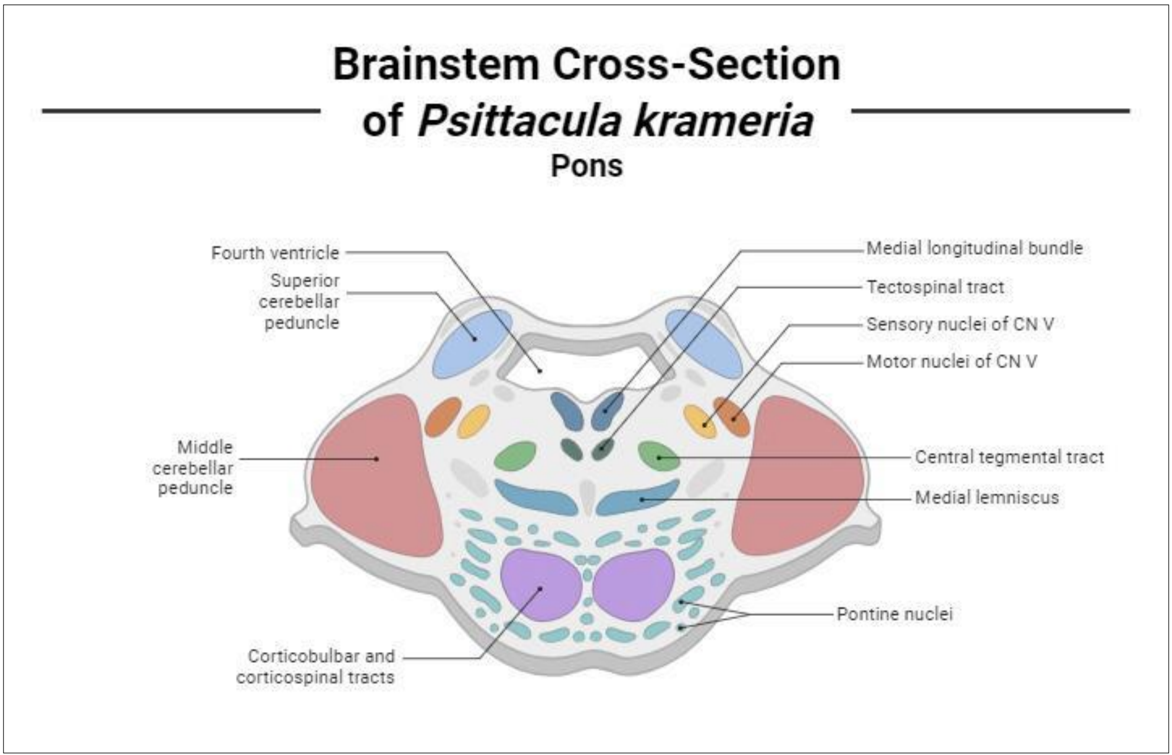

Figure 1: Illustrates a cross-section of the brainstem of Psittacula krameria. The medulla oblongata, located at the base of the brainstem, controls autonomic functions such as respiration and heart rate. The pons, situated above the medulla, plays a vital role in relaying sensory and motor information between the cerebrum and cerebellum. Additionally, the midbrain, the most superior region, coordinates visual and auditory processing. This cross-section provides insight into the anatomical structures and functional organization of the Psittacula krameria brainstem.

CONCLUSION AND FUTURE PERSPECTIVE

Future research in avian neurobiology, with a specific emphasis on rose-ringed parakeets, holds great promise for advancing our understanding of the central nervous system and unraveling the intricacies of avian brain structure and function. One area of investigation involves exploring the functional implications of the extensive optic tracts observed in rose-ringed parakeets. By conducting experiments and behavioral studies, researchers can delve into how these anatomical features contribute to visual processing, perception, and behavior in parrots. Comparative studies with other avian species can shed light on the unique adaptations and cognitive abilities of parrots, providing a broader understanding of avian neurobiology. Furthermore, investigating the relationship between the observed anatomical variations and parakeets' vocal communication skills can deepen our understanding of the neural mechanisms underlying their exceptional chattering abilities. This line of research may involve studying the connections between brain regions involved in vocalization, such as the syrinx and associated motor areas, and examining the role of learning, memory, and social interactions in parrots' vocal communication. Incorporating advanced imaging techniques, such as functional magnetic resonance imaging (fMRI), can provide valuable insights into the neural networks and connectivity patterns associated with the parakeets' remarkable cognitive and communicative abilities. By mapping brain activity during specific tasks or social interactions, researchers can identify the underlying neural processes and gain a clearer understanding of the brain regions involved. Additionally, exploring the neuroplasticity and developmental changes in the central nervous system of rose-ringed parakeets can provide valuable information about the malleability of their brain structures. By studying how the brain of parakeets changes and adapts in response to environmental factors, social interactions, and learning experiences, researchers can deepen our understanding of avian cognition, brain plasticity, and the mechanisms that underlie adaptive behaviors. Overall, future research in avian neurobiology, particularly focusing on rose-ringed parakeets, holds the potential to expand our knowledge of the avian brain, its functional implications, and the fascinating cognitive and communicative abilities observed in parrots.

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- Avihepadnavirus is a genus of the Hepadnaviridae family. It primarily infects birds, including species of duck, geese, cranes, storks, and herons etc. To understand the genetic relatedness and evolutionary diversity among avihepadnavirus strains, a comprehensive analysis of the available 136 full-length viral genomes (n = 136) was conducted. The genomes were classified into two major genotypes, i.e., GI and GII. GI viruses were further classified into 8 sub-genotypes including DHBV-I (duck hepatitis B virus-I), DHBV-II (Snow goose Hepatitis B, SGHBV), DHBV-III, RGHBV (rossgoose hepatitis B virus), CHBV (crane hepatitis B virus), THBV (Tinamou hepatitis B virus), STHBV (stork hepatitis B virus), and HHBV (Heron hepatitis B virus). DHBV-I contains two sub-clades DHBV-Ia and DHBV-Ib. Parrot hepatitis B virus (PHBV) stains fall into GII which appeared as a separate phylogenetic branch/clade. All the subtypes of viruses in GI and GII seem to be genetically connected with viruses of DHBV-I by multiple mutational steps in phylogeographic analysis. Furthermore, 16 potential recombination events among different sub-genotypes in GI and one in GII were identified, but none of which is inter-genotypic between GI and GII. Overall, the results provide a whole picture of the genetic relatedness of avihepadnavirus strains, which may assist in the surveillance of virus spreading.
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