

Neuroscience of elephant intelligence and communication

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doi.org/10.5281/VeterinaryToday.22684636

Abstract

Elephants possess one of the most remarkable nervous systems in the animal kingdom, surpassing only by certain marine mammals and primates in terms of complexity and cognitive capabilities. Renowned for their intelligence, memory and strong social bonds, elephants possess one of the most advanced nervous systems among terrestrial animals. Their massive brain and highly specialized sensory organs allow them to experience the world in ways that continue to fascinate scientists. From detecting faint scents carried by the wind to sensing distant vibrations through the ground, elephants rely on an impressive array of neural adaptations to survive and thrive. Understanding these remarkable abilities reveals not only how elephants perceive their environment but also why they are considered among the most intelligent and socially complex creatures on Earth.

Introduction

The nervous system of an elephant is a masterpiece of evolution, shaped by millions of years of adaptation to a life of social cooperation, environmental awareness and longevity. Although elephants have the largest brain of any terrestrial animal, their remarkable cognitive and sensory abilities are driven not simply by brain size, but by the sophisticated architecture and functional specialization of their nervous system. This neural complexity allows them to remember, communicate, solve problems and perceive the world with extraordinary sensitivity.

Anatomy of elephant brain

The core of an elephant's remarkable intelligence is its enormous brain, weighing between 4.5 and 5.5 kilograms, the largest of any land animal. Much of this mass is concentrated in the cerebrum, particularly in the frontal and temporal lobes, associated with learning, memory, communication and decision making among the herds. Their

cerebral cortex is highly folded, creating a vast surface area packed with billions of neural connections. This intricate network enables sophisticated information processing and supports the animal's impressive cognitive abilities.

The temporal lobes in elephants are especially well developed and play a central role in memory and hearing. These neural specialisations, helps them to remember the locations of water sources during droughts, recognize individuals after years of separation and retain memories of important places or potential dangers for decades. These regions also help elephant's to process infrasonic sounds as low-frequency calls that can travel several kilometres, allowing elephants to communicate with distant herd members and coordinate their movements across vast landscapes. Together, these adaptations make the elephant brain one of the most extraordinary examples of neural evolution in the animal kingdom.



Elephants also possess extensive association areas within the cerebrum, including regions comparable to the frontal and prefrontal cortex of other highly intelligent mammals. These areas are involved in decision-making, problem-solving, emotional regulation and social interaction. Their advanced development is reflected in the remarkable behaviours observed in elephant societies, including cooperation, empathy, caregiving and even behaviours resembling mourning for deceased herd members. Connecting the two halves of the brain is a relatively large corpus callosum, a bundle of nerve fibres that facilitates rapid communication between the cerebral hemispheres. This enhanced neural integration may contribute to the elephant's impressive coordination and precise control of its trunk, a highly versatile organ capable of performing both delicate tasks, such as picking up a single blade of grass and powerful actions, such as lifting heavy objects.

Another key feature of the elephant brain is its exceptionally large hippocampus, a structure within the limbic system that is essential for learning and spatial memory. This specialized region allows elephants to create detailed mental maps of their environment, helping them locate water sources, feeding grounds and migration routes across vast landscapes, even after many years. The limbic system, which governs memory, emotions and social behaviour, is highly developed in elephants. This neural sophistication underpins their legendary long-term memory, enabling them to remember the locations of critical resources through changing seasons, recognize individuals after long periods of separation, and recall potentially dangerous places or experiences decades later. Such abilities are particularly important for survival in the challenging environments where elephants live.

The elephant's cerebellum, responsible for coordinating movement and balance is exceptionally large and accounts for nearly one-fifth of the total brain volume. Compared with many other mammals, it contains an enormous number of neurons and is characterized by a highly folded surface that

greatly increases its processing capacity. This remarkable neural architecture enables the precise control and coordination required for an animal of such immense size. One of the most impressive functions of cerebellum is its role in controlling the elephant's trunk, an extraordinary muscular organ capable of performing both delicate and powerful tasks. Whether gently plucking a leaf, exploring objects through touch or lifting heavy loads, the trunk's versatility depends on continuous communication between sensory inputs and motor commands coordinated by the cerebellum. The cerebellum also helps maintain balance, posture and smooth movement as elephants navigate diverse and often challenging terrains. Emerging research further suggests that this region contributes to the integration of sensory information, cognition and behaviour, helping elephants to interact effectively with their social and physical environment.

Like all mammals, elephants possess twelve pairs of cranial nerves that connect the brain to the head and sensory organs. Among these, the trigeminal nerve (cranial nerve V) and facial nerve (cranial nerve VII) are particularly well developed, reflecting the trunk's extraordinary sensitivity and precise motor control. The optic nerve (cranial nerve II) carries visual information from the eyes, while the auditory nerve (cranial nerve VIII) transmits signals related to hearing and balance. The prominence of these nerves highlights the importance of touch, vision and sound in the elephant's world of perception.

Special sensory processing and perception in elephants

Sense of Olfaction:

Among all their sensory abilities, the sense of smell is perhaps the most remarkable one. Elephants possess one of the most highly developed olfactory systems in the animal kingdom, enabling them to detect and interpret an extraordinary range of scents. Their olfactory bulbs, the brain structures responsible for processing smells are exceptionally large and are supported by a greater number of functional olfactory receptor genes than those found in humans.

This powerful sense of smell allows elephants to locate water sources from several kilometres away, an ability that is crucial for survival in dry and unpredictable environments. It also helps them recognize individual elephants, identify family members, detect predators and interpret chemical signals associated with reproductive status and social interactions.

Sense of Touch:

Elephants are often referred to as *pachyderms*, a term meaning "thick-skinned," owing to their tough skin, which can range from approximately 1.9 to 3.2 centimetres in thickness. Despite its thickness, elephant skin is remarkably sensitive and serves as an important interface with the environment. One of the most extraordinary features of an elephant is its trunk, a versatile organ that plays a central role in daily life. Elephants use their trunks for a wide range of activities, including social interactions, environmental exploration, feeding, drinking and the precise manipulation of objects. Containing more than 40,000 individual muscles and supported by an extensive network of nerves, the trunk functions both as powerful motor organ and a highly sensitive tactile structure. This unique combination allows elephants to perform delicate tasks, such as picking up a single blade of grass, while also carrying out powerful actions like lifting heavy branches.

Auditory sense:

Hearing is one of the elephant's most remarkable sensory abilities. These animals can detect a broad range of sounds, including infrasonic frequencies between 1 and 20 Hz, which are far below the threshold of human hearing. This unique capability allows elephants to communicate over distances of up to 10 kilometres, helping herd members remain connected even when separated by vast landscapes. A characteristic feature of elephant communication is the production of low-frequency "rumbles." These powerful vocalizations serve a variety of purposes, including maintaining social bonds, coordinating group movements, attracting mates, providing reassurance, and warning others of potential threats. The elephant's

auditory system is specially adapted for receiving and processing such low-frequency signals. Large middle-ear structures, a highly specialized cochlea, and an expansive tympanic membrane enhance their sensitivity to deep sounds. These adaptations enable elephants to detect, process and respond to acoustic information with remarkable precision, making sound a vital component of their social and environmental awareness.

Seismic Signalling:

In addition to their remarkable sense of hearing, elephants possess the extraordinary ability to detect vibrations travelling through the ground. Specialized touch-sensitive receptors in their feet enable them to perceive subtle seismic signals, while the trunk may also assist in detecting these vibrations when it is placed against the ground. This unique sensory adaptation allows elephants to gather information from their environment in ways that are largely inaccessible to other animals. Many of these ground-borne vibrations are generated by the movements of other elephants, such as foot stomps or by low-frequency infrasonic calls that travel efficiently through the soil. This ability to "listen" through the ground plays a vital role in maintaining social cohesion and coordinating activities across vast landscapes.

Cognitive functions:

The elephant brain is characterized by a highly folded cerebral cortex, a feature that greatly increases the surface area available for neural processing. Certain regions of the elephant brain are thought to support complex cognitive abilities such as decision-making, planning, learning and problem solving. Elephants are capable of recognizing themselves in mirrors, displaying empathy toward injured or distressed companions and using objects in their environment as tools to accomplish specific tasks. Such behaviours highlight the remarkable integration and processing capacity of their neural networks. Among non-primate mammals, elephants possess one of the highest encephalisation quotients (EQ), a measure that compares brain size relative to body size. With an EQ ranging from approximately 1.8 to 2.3, elephants rank

among the most cognitively advanced animals, reflecting the exceptional development of their nervous system and their capacity for complex social and environmental interactions.

Conclusions:

The elephant nervous system is a remarkable example of evolutionary sophistication, combining a massive and highly specialized brain with an extensive network of sensory and motor pathways. These adaptations provide elephants with exceptional cognitive abilities and a keen awareness of their surroundings, enabling them to navigate complex environments, maintain intricate social relationships and communicate across great distances. Their highly developed senses of smell, hearing, touch and vibration detection play a vital role in both survival and social cohesion.

Understanding how the elephant nervous system functions is important not only from a neuroscientific perspective but also for the conservation and welfare of these extraordinary animals. Insights into their sensory perception, cognition, and behaviour can help improve veterinary care, enhance welfare standards in managed populations, and guide more compassionate conservation practices. As human activities continue to alter natural habitats, a deeper understanding of elephant neurobiology can also provide valuable clues to how these animals respond to environmental challenges. Continued research into the elephant nervous system promises to enrich our knowledge of brain evolution while contributing to the long-term protection of one of the world's most iconic and intelligent species.

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