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Article

A Multi-Chatbot Analysis: Strengths and Weaknesses in Neuroanatomy Learning

Running title: What the chatbots struggled with in neuroanatomy answers.

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Abstract

Background: The expanding interest of chatbots within the medical domain underscores the imperative for a comprehensive understanding of their capabilities and limitations, particularly in the context of anatomical education. Chatbots possess the potential to comprehend intricate anatomical concepts, deliver both advanced and contextually relevant information, and could serve as a valuable resource for medical students and educators. This study aimed to evaluate the proficiency and constraints of chatbots in the domain of neuroanatomy. **Methods**: We developed 30 questions and administered them to ChatGPT-4, Google Gemini, Microsoft Copilot, and Perplexity.ai, in their open versions. Questions were collaboratively constructed by the research team, selected through a semi-randomized process within the domain of neuroanatomy. Chatbots' responses were evaluated in a blinded manner for validity and appropriateness, utilizing a 5-point Likert scale. **Results:** The optimal performance was exhibited by ChatGPT-4 and Perplexity.ai, which achieved scores of 4.6 ± 0.5 and 4.5 ± 0.5, respectively. Microsoft Copilot (4.4 ± 0.5) and Google Gemini (4.1 ± 1.0) followed. The least successful performance was observed in the task of generating a neuroanatomical structure: only Microsoft Copilot attempted to fulfill the request, albeit with a dramatically flawed outcome. Conversely, Google Gemini and Perplexity.ai provided web links to anatomical illustrations. **Conclusions**: Despite technological advancements, AI models have not yet reached a level of sophistication sufficient to entirely supplant the role of educators or facilitators in a neuroanatomy course; however, they can serve as valuable adjunct tools for medical educators and students when utilized with careful consideration.

Keywords: neuroanatomy; artificial intelligence; chatbots; medical education

1. Introduction

Neuroanatomy has historically been regarded as a keystone of medical education, providing the essential foundation for understanding the structure and function of the nervous system [1,2]. Mastery of neuroanatomical knowledge is critical for accurate diagnosis, interpretation of imaging studies, and planning surgical interventions, particularly in neurology, neurosurgery, and radiology [3]. Despite its importance, neuroanatomy is often perceived as a challenging subject due to its complexity and the need for spatial visualization of intricate structures [4].

In recent years, artificial intelligence (AI) has emerged as a transformative force in medical education, driven by the development of large language models (LLMs) capable of generating human-like responses to complex queries [5,6]. AI-based chatbots such as ChatGPT-4, Google Gemini, Microsoft Copilot, and Perplexity.ai leverage vast datasets to provide rapid, contextually

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relevant information, offering opportunities for personalized learning, interactive question-answering, and real-time feedback [7,8]. These tools have been explored in various educational contexts, including anatomy, where they promise to complement traditional teaching methods and enhance student engagement [9,10]. The integration of AI technologies has the potential to significantly alleviate the substantial workload associated with anatomy departments worldwide, where cadaveric dissection would be a cornerstone of teaching and learning. However, it is crucial to exercise caution and rigorously evaluate the credibility of information provided by AI-powered tools [3, 6, 7, 9-17].

Recent comparative studies have highlighted the strong performance of AI-based large language models (LLMs) in anatomy-related multiple-choice questions, reporting accuracy rates exceeding 95% across platforms such as Google Gemini, ChatGPT-4, and DeepSeek, while also emphasizing the need for expert oversight to mitigate occasional errors [17].

However, significant limitations persist. Current AI models struggle to generate accurate visual content, a critical component of anatomy education, and may produce incomplete or inaccurate textual responses [3, 6, 7, 9-17]. These shortcomings raise concerns about their reliability as standalone educational tools. Ethical considerations, including academic integrity and the risk of over-reliance on AI, further underscore the need for cautious implementation [18, 19]. Previous studies have reported variable performance of AI platforms in anatomy-related tasks, with accuracy rates ranging from moderate to high depending on question type and complexity [3, 6, 7, 9-17]. While some investigations demonstrated ChatGPT-4's ability to outperform students in multiple-choice assessments [20], others highlighted its inconsistency and inability to provide detailed explanations or accurate diagrams [21-23].

Against this backdrop, the present study aims to evaluate the performance of four widely used AI-based chatbots in answering neuroanatomy questions. By systematically comparing their accuracy, consistency, and explanatory capabilities, this research seeks to clarify their current strengths and limitations. To our knowledge, this is the first study to conduct a multi-rater, blinded assessment of chatbot responses in neuroanatomy, showing images generated by AI offering insights into their potential role as adjunct resources in medical education.

2. Materials and Methods

2.1. Study Design and Chatbot Selection

This study employed a comparative evaluation of four freely accessible AI chatbots, ChatGPT-4**,** Google Gemini**,** Microsoft Copilot, and Perplexity.ai**,** to assess their performance in answering neuroanatomy-related questions. Each chatbot was tested using the same set of prompts to ensure consistency.

2.2. Question Development

A total of 30 questions were designed by a team of neuroanatomy experts. These questions were semi-randomly selected to cover diverse aspects of neuroanatomy and were categorized into four formats**:** multiple-choice questions (MCQs), questions Q1–Q10; fill-in-the-blank questions, questions Q11–Q20; descriptive questions, questions Q21–Q30, requiring concise and accurate explanations; illustration-based prompts – Embedded within descriptive questions (e.g., Q21, Q22, Q23, Q25, Q28), requesting diagrams or visual aids (Table 1).

Table 1. Questions asked to Chatbots.

Question number	Questions
1	Most neurons in the central nervous system belong to the category of: a. pseudounipolar; b. bipolar; c. multipolar; d. unipolar

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2	Which of the following is a mechanoreceptor for touch? a. Meissner's corpuscles; b. Golgi tendon organs; c. muscle spindles; d. free nerve endings
3	Where are muscle spindles located? a. in smooth muscles; b. in striated muscles; c. in the heart; d. a+b
4	Match the following nerves to their correct spinal nerve root origin (L1, L2, L3, or L4): a. Ilioinguinal nerve; b. Genitofemoral nerve; c. Lateral femoral cutaneous nerve; d. Iliohypogastric nerve
5	The trapezoid body is formed by fibers coming from: a. the red nucleus; b. The trapezoid body is formed by fibers coming from the facial nerve nucleus; c. The trapezoid body is formed by fibers coming from the ventral cochlear nucleus; d. The trapezoid body is formed by fibers coming from the vestibular nucleus; e. The trapezoid body is formed by fibers coming from the inferior olivary nucleus.
6	The inferior horn of the lateral ventricle is located in the lobe: a: frontal; b: parietal; c: temporal, d: occipital; e: all wrong
7	Superiorly, the superior colliculi are in relation with: a. the pituitary gland; b. the cerebellar tonsil; c. the mammillary bodies; d. the tuber cinereum; e. the pineal gland
8	Which of the following statements about the trigeminal nerve (V pair) is correct? a. Sensory afferents derive from the I and II branches (ophthalmic and maxillary) and are directed to the principal sensory nucleus (mesencephalic); b. Sensory afferents derive from the 3 branches (ophthalmic, maxillary, mandibular) and are directed only to the principal sensory nucleus (bulbar); c. Sensory afferents derive from the 3 branches and are directed to the principal sensory nucleus (pontine), the mesencephalic nucleus and the nucleus of the descending root; d. The V pair of cranial nerves has no sensory afferents; e. None of the answers is correct.
9	The fibers of the hypothalamic-pituitary tract originate from: a: the medial geniculate bodies; b: the mammillary bodies; c: the tuber cinereum and the mammillary bodies; d: the tuber cinereum and the supraoptic and paraventricular nuclei; e: all of the above statements are correct
10	Of the following fiber systems, only one runs through the genu of the internal capsule. Which one? a: the fibers of the corpus callosum; b: the fibers of the inferior thalamic peduncle; c: the corticospinal fibers; d: the fronto-pontine bundle; e: The corticobulbar tract
11	The "basal ganglia" encompass a group of …… that play a pivotal role in ……., as well as other functions including motor learning, executive functions, and ……..
12	The limbic lobe is a ring of ..... on the medial aspect of each hemisphere that surrounds the ..... The limbic lobe is composed of the ....., ..., and ..... gyri. The larger limbic system is involved in ..... and ..... expression.
13	....., ..., ..., ..., ... are the typical cells in the cerebrum cortex.
14	The spinocerebellar tracts convey information from ....., ..., and ..... receptors.
15	Lesions affecting the second motor neuron ..... the signal communication between the central nervous system and the muscle, resulting in ..... of the affected muscle.
16	The cochlear nuclei contain **……** of the vestibulocochlear nerve, and the ventral cochlear nucleus in humans constitutes the main relay nucleus between first-order and second-order neurons of the **……..**

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17	The ……... part of the red nucleus is more important in humans and, like the ……..…… part, is involved—though in a different way—in the …….. exerted by the cerebellum.
18	The …….. can be bilaterally affected in degenerative diseases such as …….. or in ……..; this results in difficulty swallowing due to muscle paralysis, and consequently ingested material risks entering the trachea.
19	The ……. of the thalamus receive afferents from the …….. of the hypothalamus and project to the cerebral cortex of the cingulate gyrus, forming part of a complex loop that also involves limbic lobe structures, known as the ……..
20	The …….. occupies Brodmann's area 17. It is located on the lips of the …….. and is characterized by a very ……. layer IV, crossed by a stripe of myelinated fibers, the stripe of the ……. or external Baillargerstripe or ……., which runs parallel to the cortical surface and therefore defines the striate cortex.
21	Describe the spino-bulbo-thalamo-cortical pathway and draw a diagram
22	Describe the origin and course of the median nerve. Draw a diagram.
23	Describe the morphology of the cerebellum. Then draw a diagram.
24	Which cutaneous area is innervated by the lateral femoral cutaneous nerve?
25	Describe the morphology of the internal ear. Then draw a diagram.
26	Describe the extrapyramidal system.
27	Give a description of the cortical regions of Broca's area.
28	Describe and draw a diagram illustrated the cerebellum cortex.
29	Describe the differences between neocortex and paleocortex.
30	Describe the ultrastructure of the retina.

2.3. Response Collection

Each question was submitted to all four chatbots in their open-access versions. Responses were recorded verbatim without any modification.

2.4. Evaluation Process

To ensure objectivity, three independent raters with expertise in neuroanatomy conducted a blind evaluation of all responses. The evaluation focused on: accuracy**:** Correctness of the information provided; comprehensiveness: Depth and completeness of the explanation; relevance: Alignment of the response with the question asked; clarity: Ease of understanding and logical structure.

2.5. Scoring System: 5-Point Likert Scale

Responses were rated using a 5-point Likert scale (see Table 2). Each response was evaluated on a 5-point Likert scale, ranging from "Extremely High" to "Very Poor," based on criteria such as comprehensiveness, accuracy, and relevance (Table 2). Inter-rater reliability was deemed acceptable when the scores among the raters differed by no more than one point on the Likert scale. On the other side, difference of 2 or more points was considered as unreliable (event that has never occurred). To minimize potential bias, a panel of three independent experts conducted a blind assessment of each response obtained from the application.

Table 2. 5 -point Likert Scale.

Likert point	Quality	Description
5	Extremely High quality	Totally correct, comprehensive description.
4	High quality	Mostly correct, not comprehensive description, no mistakes.
3	Moderate quality	Mostly correct, not comprehensive description, a few or minor mistakes.

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2	Poor quality	Mostly wrong, poor description, manyor significant mistakes.
1	Very poor quality	Totally wrong.

2.6. Statistical Analysis

Data analysis was performed using GraphPad Prism version 10 (GraphPad Software, San Diego, CA, USA). Non-parametric tests (Kruskal–Wallis with Dunn's post hoc correction) were applied to compare median Likert scores between chatbots, as these tests are appropriate for ordinal data without assuming normal distribution.

3. Results

A total of 30 neuroanatomy questions were evaluated across four categories: multiple-choice, fill-in-the-blank, descriptive, and illustration-based prompts embedded within descriptive questions. Responses from ChatGPT-4, Google Gemini, Microsoft Copilot, and Perplexity.ai were assessed by three independent raters using a 5-point Likert scale (1 = Very Poor Quality, 5 = Extremely High Quality). Evaluation criteria included accuracy, comprehensiveness, relevance, and clarity.

Overall, chatbots demonstrated a fair knowledge of human neuroanatomy. However, differences in response capabilities were highlighted not only between the different chatbots used but, even more interestingly, in relation to the type of question being asked (Tables 3–6).

Table 3. ChatGPT-generated responses.

Question number	Response
1	The correct answer is: multipolar. Most neurons in the central nervous system (CNS) are multipolar neurons. These neurons have one axon and multiple dendrites, which allows them to integrate a large amount of information from various sources. Multipolar neurons are the most common type in the CNS and include many types of motor neurons and interneurons.
2	The correct answer is: a. Meissner's corpuscles. Meissner's corpuscles are mechanoreceptors that respond to light touch and are sensitive to vibration. They are located in the dermis of the skin, especially in areas like the fingertips and lips, where tactile sensitivity is high.
3	The correct answer is: b. in striated muscles. Muscle spindles are sensory receptors located within striated (skeletal) muscles, not in smooth muscles or the heart. They are specialized to detect changes in the length of the muscle and play a key role in proprioception, helping to maintain posture and coordinate movement by sending information about muscle stretch to the central nervous system.
4	a. Ilioinguinal nerve: L1 The ilioinguinal nerve originates from the L1 spinal nerve. It provides sensory innervation to the inguinal region, labia majora (in females), scrotum (in males), and part of the medial thigh. b. Genitofemoral nerve: L1 and L2 The genitofemoral nerve originates from both the L1 and L2 spinal nerves. It splits into two branches: the genital branch, which innervates the cremaster muscle and provides sensory innervation to the scrotum (in males) and labia majora (in females); the femoral branch, which provides sensory innervation to the anterior thigh near the inguinal ligament. c. Lateral femoral cutaneous nerve: L2 and L3

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	The lateral femoral cutaneous nerve originates from the L2 and L3 spinal nerves. It provides sensoryinnervation to the lateral thigh. d. Iliohypogastric nerve: L1 The iliohypogastric nerve arises from the L1 spinal nerve. It provides sensory innervation to the suprapubic area, the lateral gluteal region, and part of the lower abdomen. It also supplies motor fibers to the abdominal muscles.
5	The correct answer is: c. The trapezoid body is formed by fibers coming from the ventral cochlear nucleus. The trapezoid body is a structure in the brainstem that contains decussating (crossing) fibers from the ventral cochlear nucleus. These fibers play a crucial role in the auditory pathway, specifically in the processing of sound localization and sound processing in the brainstem. The fibers from the ventral cochlear nucleus project bilaterally to the superior olivary complex, which is important for sound localization.
6	The correct answer is: c: Temporal. The inferior horn of the lateral ventricle is located in the temporal lobe of the brain. The lateral ventricle consists of several horns, including the anterior horn (in the frontal lobe), the posterior horn (in the occipital lobe), the body (in the parietal lobe), and the inferior horn (in the temporal lobe). The inferior horn is also known as the temporal horn and it extends into the temporal lobe, adjacent to structures such as the hippocampus.
7	The correct answer is: e: The pineal gland. The superior colliculi are located on the dorsal aspect of the midbrain. Superiorly, they are in close relation with the pineal gland, which lies just behind them, in the epithalamus. The pineal gland is a small endocrine gland responsible for melatonin production and is located at the midline of the brain, just above the superior colliculi.
8	The correct answer is: c. Sensory afferents derive from the 3 branches and are directed to the principal sensory nucleus (pontine), the mesencephalic nucleus, and the nucleus of the descending root. The trigeminal nerve (CN V) is responsible for both sensory and motor functions, with its sensory fibers carrying information from the face, including touch, pain, and temperature sensations. These sensory afferents come from the three branches of the trigeminal nerve: 1. Ophthalmic (V1); 2. Maxillary (V2); 3. Mandibular (V3). These sensory afferents are directed to three main nuclei: - Principal sensory nucleus (pontine): This nucleus processes fine touch and proprioception sensations from the face. - Mesencephalic nucleus: This nucleus is involved in proprioception, specifically for the muscles of mastication and the jaw. - Nucleus of the descending root: This nucleus processes pain and temperature sensations from the face (similar to the spinal cord's dorsal horn). Each of these nuclei plays a distinct role in processing different types of sensory input, and the afferents from all three branches of the trigeminal nerve are involved in transmitting these signals to the corresponding nuclei.
9	The correct answer is: d: The tuber cinereum and the supraoptic and paraventricular nuclei. The hypothalamic-pituitary tract (also known as the hypothalamo-hypophyseal tract) is a bundle of fibers that connects the hypothalamus to the posterior pituitary gland (neurohypophysis), and it is primarily involved in the release of hormones such as oxytocin and vasopressin (antidiuretic hormone, ADH). - The fibers of the hypothalamic-pituitary tract originate from the supraoptic and paraventricular nuclei of the hypothalamus, which are responsible for the synthesis of oxytocin and vasopressin.

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	- The tuber cinereum is also an important region of the hypothalamus, located near the base of the third ventricle, and it contains neurons that are involved in regulating the release of hormones from the pituitary gland. Thus, the fibers that form the hypothalamic-pituitary tract originate from the tuber cinereum and the supraoptic and paraventricular nuclei.
10	The correct answer is: e: The corticobulbar tract. The genu of the internal capsule is a region in the brain where several important fiber systems pass through as they travel between the cerebral cortex and various subcortical structures, including the brainstem and spinal cord. The corticobulbar tract runs through the genu of the internal capsule. This tract carries motor fibers from the cerebral cortex to the brainstem, particularly for the control of facial muscles and muscles of the head and neck (for cranial nerve nuclei).
11	The "basal ganglia" encompass a group of **nuclei** that play a pivotal role in **the regulation of voluntary movement**, as well as other functions including motor learning, executive functions, and **emotional processing**.
12	The limbic lobe is a ring of **cortex** on the medial aspect of each hemisphere that surrounds the **corpus callosum**. The limbic lobe is composed of the **cingulate**, **parahippocampal**, and **subcallosal** gyri. The larger limbic system is involved in **emotional processing** and **behavioral** expression.
13	**Pyramidal cells**, **granule cells**, **stellate cells**, **basket cells**, and **Martinotti cells** are the typical cells in the cerebral cortex.
14	The spinocerebellar tracts convey information from **proprioceptors**, **tactile receptors**, and **pressure receptors**.
15	Lesions affecting the second motor neuron **disrupt** the signal communication between the central nervous system and the muscle, resulting in **flaccid paralysis** of the affected muscle.
16	The cochlear nuclei contain **the central processes (primary afferent fibers) of the spiral ganglion neurons** of the vestibulocochlear nerve, and the ventral cochlear nucleus in humans constitutes the main relay nucleus between first-order and second-order neurons of the **auditory pathway**.
17	The **parvocellular** part of the red nucleus is more important in humans and, like the **magnocellular** part, is involved—though in a different way—in the **motor influence** exerted by the cerebellum.
18	The **nucleus ambiguus** can be bilaterally affected in degenerative diseases such as **amyotrophic lateral sclerosis (ALS)** or in **bulbar poliomyelitis**; this results in difficulty swallowing due to muscle paralysis, and consequently ingested material risks entering the trachea.
19	The **anterior nuclei** of the thalamus receive afferents from the **mammillary bodies** of the hypothalamus and project to the cerebral cortex of the cingulate gyrus, forming part of a complex loop that also involves limbic lobe structures, known as the **Papez circuit**.
20	• The **primary visual cortex (striate cortex)** occupies Brodmann's area 17. It is located on the lips of the **calcarine sulcus**and is characterized by a very **thick** layer IV, crossed by a stripe of myelinated fibers, the stripe of **Gennari** or external Baillarger stripe or **Gennari line**, which runs parallel to the cortical surface and therefore defines the striate cortex.
21	The spino-bulbo-thalamo-cortical pathway is part of the sensory pathway responsible for transmitting somatosensory information from the periphery to the somatosensory cortex of the brain. This pathway is primarily involved in the transmission of touch, pain, temperature, and proprioception from the body to the brain for processing. Overview of the Pathway: The spino-bulbo-thalamo-cortical pathway includes several key relays:

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	1. First-order neurons (in the spinal cord): The sensory receptors in the skin, muscles, and joints detect stimuli (such as touch, temperature, and pain). The sensory information is relayed by primary afferent neurons, which enter the spinal cord via the dorsal root and synapse at various levels of the spinal cord. 2. Second-order neurons (in the brainstem): The second-order neurons, which are located in the medulla oblongata (specifically in the gracile and cuneate nuclei for touch and proprioception), receive sensory input from the first-order neurons and decussate (cross over) to the opposite side. These second-order neurons then ascend through the medial lemniscus to the thalamus. • Third-order neurons (in the thalamus): The second-order neurons synapse with third-order neurons in the ventral posterolateral nucleus (VPL) of the thalamus. The third-order neurons then send the sensory information to the somatosensory cortex of the parietal lobe, where the sensory information is consciously perceived and interpreted.
22	• The **spino-bulbo-thalamo-cortical pathway** is a major ascending sensory pathway that transmits information from the spinal cord to the cerebral cortex, passing through the brainstem and thalamus. It plays a key role in processing somatosensory inputs such as pain, temperature, and crude touch. Here's a breakdown: 1. Spinal Component (Spino-) • Sensory neurons in the **dorsal root ganglia** receive input from peripheral receptors (e.g., nociceptors, thermoreceptors). • These neurons send axons into the **dorsal horn** of the spinal cord. • Second-order neurons in the dorsal horn project their axons upward, often crossing to the contralateral side (decussation) via the **anterior white commissure**. 2. Bulbar Component (Bulbo-) • After crossing, these fibers ascend in the **anterolateral system** (including the spinothalamic tract) through the **medulla oblongata**(bulb). • Here, they may give off collaterals to brainstem nuclei involved in autonomic and arousal responses. 3. Thalamic Component (Thalamo-) • Fibers reach the **ventral posterolateral (VPL) nucleus** of the thalamus. • The thalamus acts as a relay and integration center, modulating sensory signals before sending them to the cortex. 4. Cortical Component (Cortical-) • Third-order neurons project from the VPL to the **primary somatosensory cortex (S1)** in the postcentral gyrus. 3. This is where conscious perception of pain, temperature, and crude touch occurs.
23	The median nerve is a mixed (sensory and motor) nerve that arises from the brachial plexus, which is a network of nerves formed by the anterior rami of the C5 to T1 spinal nerves. It plays a crucial role in the motor and sensory innervation of the forearm and hand. • The median nerve is formed from the lateral cord and the medial cord of the brachial plexus.
24	The cerebellum is a crucial part of the brain involved in the coordination of voluntary movements, motor control, balance, and some cognitive functions. It has a characteristic "butterfly-like" or "tree-like structure", often referred to as the "arbor vitae" due to its appearance. Below is a detailed description of the cerebellum's morphology: General Structure: 1. Location:

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- The cerebellum is located at the posterior part of the brain, underneath the occipital lobes of the cerebrum, and above the brainstem.
- It is separated from the cerebrum by the tentorium cerebelli (a membrane structure).
2. Overall Shape:
- The cerebellum has a lobulated (lobe-like) structure, divided into several parts.
- It is roughly divided into two hemispheres (right and left), with a vermis (a narrow, central region) that connects them.
3. Surface:
- The surface of the cerebellum is highly folded, creating a series of gyri (called folia) and sulci (grooves), which increase the surface area for neural processing.
- This highly folded structure is essential for the cerebellum's function of integrating large amounts of sensory and motor information.
4. Arbor Vitae:
- Beneath the surface, the white matter of the cerebellum is arranged in a branching pattern, resembling the shape of a tree. This structure is known as the arbor vitae, meaning "tree of life."
- The white matter carries nerve fibers that transmit signals between different parts of the cerebellum and the rest of the brain.
5. Cerebellar Peduncles:
- The cerebellum communicates with other parts of the brain via three paired cerebellar peduncles:
- Superior peduncle (brachium conjunctivum) – connects the cerebellum to the midbrain.
- Middle peduncle (brachium pontis) – connects the cerebellum to the pons.
- Inferior peduncle (restiform body) – connects the cerebellum to the medulla oblongata.
6. Fissures:
- The cerebellum is divided into lobes by several deep fissures:
- The primary fissure divides the cerebellum into the anterior and posterior lobes.
- The posterolateral fissure separates the posterior lobe from the flocculonodular lobe.
7. Cerebellar Lobes:
- Anterior lobe: Located in the superior part of the cerebellum, it is involved in regulating muscle tone and coordinating voluntary movements.
- Posterior lobe: The largest lobe, which plays a major role in fine motor control and motor learning.
- Flocculonodular lobe: A small lobe that is involved in balance and eye movements.

Internal Structure of the Cerebellum:
1. Gray Matter:
- The outer surface of the cerebellum is composed of gray matter, known as the cerebellar cortex. This is where processing of motor information occurs.
- The cerebellar cortex contains three main layers:
- Molecular layer (outermost): Contains granule cells and Purkinje cell dendrites.
- Purkinje cell layer: This is a single layer of large, inhibitory Purkinje cells that play a crucial role in motor coordination.
- Granular layer (innermost): Contains densely packed granule cells, which are excitatory and receive input from other areas of the brain.
2. White Matter:
- Beneath the cerebellar cortex is the white matter, which contains the fibers of cerebellar neurons. It is where information is transmitted to and from the cerebellum.

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	- The white matter forms the arbor vitae and is organized into the deep cerebellar nuclei (e.g., dentate nucleus, emboliform nucleus, globose nucleus, and fastigial nucleus), which relay processed signals to other parts of the brain and spinal cord. --- Functional Regions of the Cerebellum: 1. Vestibulocerebellum (Flocculonodular Lobe): - Involved in balance and eye movements. It receives input from the vestibular system and coordinates balance and posture. 2. Spinocerebellum (Anterior Lobe and Vermis): - Regulates muscle tone and coordinates voluntary movements, particularly those related to posture and locomotion. 3. Cerebrocerebellum (Posterior Lobe): - Involved in planning and fine-tuning voluntary movements, especially learned motor skills. It communicates with the motor cortex to help refine motor commands. --- I cannot draw diagrams directly in this text-based format.
25	The lateral femoral cutaneous nerve primarily innervates the skin on the anterolateral and lateral aspects of the thigh. This nerve provides sensory (cutaneous) innervation and does not have motor functions. Specific Cutaneous Area Innervated: • Anterolateral thigh: This includes the skin on the outer (lateral) part of the thigh, from the hip to about the knee. • Lateral thigh: The area on the lateral side of the thigh is typically more sensitive to touch and temperature sensations, which are transmitted by the lateral femoral cutaneous nerve. Pathway: • The lateral femoral cutaneous nerve arises from the lumbar plexus, specifically from the L2 and L3 spinal nerve roots. • It travels through the pelvis and passes under the inguinal ligament near the anterior superior iliac spine (ASIS), where it emerges and supplies the skin of the lateral thigh. Clinical Note: The lateral femoral cutaneous nerve is often associated with meralgia paresthetica, a condition where compression of the nerve (often at the inguinal ligament) leads to symptoms such as numbness, tingling, or pain in the lateral thigh.
25	The inner ear, a complex labyrinthine structure nestled within the temporal bone, is the sensory organ responsible for both hearing and balance. Its intricate architecture reflects the multifaceted nature of its functions. Morphology of the Inner Ear The inner ear is divided into two primary components: • Bony Labyrinth: A system of interconnected, fluid-filled cavities within the temporal bone. It consists of: ○ Vestibule: The central cavity, housing the utricle and saccule. ○ Semicircular Canals: Three bony tubes (superior, posterior, and lateral) arranged in perpendicular planes. ○ Cochlea: A spiral-shaped cavity resembling a snail shell. • Membranous Labyrinth: A series of interconnected membranous sacs and ducts nestled within the bony labyrinth. It contains the sensory receptors for hearing and balance: ○ Utricle and Saccule: Located within the vestibule, these sacs house the otolith organs, responsible for detecting linear acceleration and head position.

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	○ Semicircular Ducts: Membranous tubes within the bony semicircular canals, containing the crista ampullaris, which detects rotational movements of the head. ○ Cochlear Duct: A spiral-shaped tube within the cochlea, containing the organ of Corti, the sensory organ for hearing. • The fluid within the bony labyrinth is called perilymph, while the fluid within the membranous labyrinth is called endolymph. These fluids play a crucial role in the transduction of sound waves into neural signals and the detection of head movements.
26	The extrapyramidal system is a complex network of neural pathways that play a crucial role in modulating and regulating movement. Unlike the pyramidal system, which directly innervates motor neurons, the extrapyramidal system exerts more indirect control over movement. Key Components: • Basal Ganglia: A group of nuclei deep within the cerebrum, including the caudate nucleus, putamen, globus pallidus, substantia nigra, and subthalamic nucleus. These structures play a critical role in planning, initiating, and executing smooth, coordinated movements. • Cerebellum: This highly convoluted structure located at the back of the brain plays a vital role in coordinating movement, maintaining balance, and regulating muscle tone. • Brainstem Nuclei: Various nuclei within the brainstem, such as the red nucleus and reticular formation, contribute to the extrapyramidal system. Key Functions: • Movement Initiation and Planning: The extrapyramidal system helps initiate and plan voluntary movements, ensuring smooth and coordinated muscle activity. • Posture and Balance: It plays a crucial role in maintaining posture, balance, and equilibrium. • Muscle Tone: The system helps regulate muscle tone and prevent excessive muscle rigidity. • Learning and Adaptation: The extrapyramidal system contributes to motor learning and the ability to adapt movements based on feedback from the environment. Key Differences from the Pyramidal System: • Direct vs. Indirect: The pyramidal system directly innervates motor neurons, while the extrapyramidal system exerts more indirect control. • Function: The pyramidal system primarily controls voluntary movements, while the extrapyramidal system focuses on movement modulation, coordination, and regulation. Disorders of the Extrapyramidal System: Damage to any component of the extrapyramidal system can result in various movement disorders, including: • Parkinson's disease: Characterized by tremors, rigidity, slowness of movement (bradykinesia), and postural instability. • Huntington's disease: Characterized by involuntary movements (chorea), cognitive decline, and psychiatric symptoms. • Dystonia: Characterized by sustained muscle contractions that cause abnormal postures or repetitive movements. This is a simplified overview of the extrapyramidal system. It is a complex network with intricate connections and functions that are still being actively researched.
27	Broca's area is a region in the frontal lobe of the brain that is primarily involved in speech production and language processing. It is typically located in the left

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	hemisphere in right-handed individuals, though it can be found in the right hemisphere in some left-handed individuals. Broca's area is situated in two main regions within the lateral frontal cortex, namely Broca's area proper and the posterior part of the prefrontal cortex, which are associated with different aspects of language functions. 1. Broca's Area Proper (BA 44 and BA 45): - Location: This region is found in the posterior part of the frontal lobe, specifically in the inferior frontal gyrus (IFG). - Functions: - Speech Production: It plays a critical role in the motor aspects of speech production. This includes the planning and execution of movements required for articulation. - Syntax Processing: It is involved in the grammatical structuring of speech, particularly in the construction of complex sentences and sentence formation. - Motor Planning for Speech: It has strong connections with motor areas of the brain that control the mouth, lips, and tongue, which are necessary for speech. The two main subdivisions of Broca's area are: - BA 44: Often considered to be more involved with the motor aspects of language (articulation). - BA 45: Associated with more complex language processing, particularly the syntactic structure of sentences. 2. Premotor Area (BA 6) : - Location : This area lies just anterior to the primary motor cortex, adjacent to Broca's area. - Functions : - This region works in concert with Broca's area to coordinate the motor planning necessary for speech. It helps in the execution of the precise and coordinated movements involved in speaking. 3. Right Hemisphere Contributions : While Broca's area is typically dominant in the left hemisphere, there is also some degree of involvement from the right hemisphere, particularly in aspects of prosody (the rhythm, tone, and intonation of speech) and non-verbal communication. Clinical Implications: - Broca's Aphasia: Damage to Broca's area, particularly in the left hemisphere, can result in Broca's aphasia (non-fluent aphasia). This condition is characterized by difficulty in producing speech, where individuals may have slow, labored speech with poor grammatical structure but retain relatively intact comprehension. - Motor Speech Disorders: Damage can also affect the motor control of speech muscles, leading to disorders like apraxia of speech.
28	I currently cannot draw images, but I can describe the structure of the cerebellum cortex for you and guide you through creating a diagram yourself. How to draw a diagram of the cerebellum cortex: 1. Draw the Cerebellum Shape: - Start by sketching an oval shape. This represents the entire cerebellum, which is located at the back of the brain under the occipital lobe. 2. Label the Lobes: - Divide the cerebellum into three main lobes: - The Anterior lobe (front part), - The Posterior lobe (back part),

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- The Flocculonodular lobe (which is located near the bottom and connects to the brainstem).

3. Draw the Cortex:
- The outer part of the cerebellum is the cerebellar cortex. Draw a series of parallel curved lines along the outer edge of the oval (these represent the folds or gyri of the cortex). This surface is highly folded to increase surface area.

4. Add Layers:
- The cerebellar cortex has three layers:
- Molecular layer (outermost layer, you can label it as "Molecular Layer").
- Purkinje cell layer (middle layer, a thin line inside the molecular layer).
- Granular layer (innermost layer, under the Purkinje cell layer).

5. Label the Cells:
- In the molecular layer, draw some parallel fibers (lines parallel to the surface) and label them as parallel fibers .
- The Purkinje cell layer consists of Purkinje cells (tree-like branching structures), which you can represent by small branching lines within the middle layer.
- The granular layer contains granule cells (tiny round dots) that you can draw scattered in this region.

6. Add the Deep Cerebellar Nuclei :
- Inside the cerebellum, draw and label the deep cerebellar nuclei . These include the dentate nucleus , interposed nuclei , and fastigial nucleus . These are typically located in the central region of the cerebellum, below the cortex.

Optional:
- You can add the arbor vitae (tree-like white matter inside the cerebellum) as branching structures beneath the cortical layers.

The neocortex and paleocortex are both parts of the cerebral cortex in the brain, but they differ significantly in their structure, function, and evolutionary development. Here's a detailed comparison of the two:

1. Evolutionary Origin:

- Neocortex :
- The neocortex is the more evolutionarily recent structure. It is considered the "new" part of the cortex, and it evolved primarily in mammals, particularly in humans, primates, and some other mammals with higher cognitive abilities.
- It is a characteristic feature of the mammalian brain and represents the latest stage of cerebral evolution in terms of complexity.

29

- Paleocortex :
- The paleocortex is an older structure, evolutionarily speaking, and is found in all vertebrates, including mammals. It is part of the evolutionary “old” cortical areas that preceded the neocortex.
- It is considered part of the limbic system and is involved more with basic, primal functions related to emotion, memory, and olfaction (sense of smell).

2. Anatomical Structure:

- Neocortex :

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- The neocortex is the largest part of the cerebral cortex in humans and other mammals, particularly primates.
- It is highly convoluted, meaning it has many folds and grooves (gyri and sulci) that increase its surface area. This allows for more neurons and higher cognitive function.
- The neocortex consists of six layers (hence the term "isocortex"), each with distinct types of neurons and connections. The layers are numbered I to VI, starting from the outermost layer.

- Paleocortex :
- The paleocortex is much smaller in size compared to the neocortex. It typically consists of three to five layers , which is fewer than the neocortex.
- The paleocortex is less convoluted, and its structure is simpler.
- It is generally associated with specific regions like the olfactory cortex (involved in the sense of smell) and parts of the limbic system (important for emotional processing and memory).

3. Functional Roles:

- Neocortex :
- The neocortex is involved in higher-order functions like sensory perception, voluntary movement, language, problem-solving, abstract thinking, and complex motor planning.
- It is responsible for processing information from the senses (vision, hearing, touch, etc.) and integrating this information to make decisions or produce appropriate responses.
- The neocortex plays a central role in cognitive functions such as reasoning, planning, memory, and social behaviors.

- Paleocortex :
- The paleocortex is associated with more primitive functions related to survival and emotion.
- It is heavily involved in olfaction (smell) , as it includes the olfactory bulb and olfactory cortex, which process olfactory signals.
- The paleocortex also plays a role in the limbic system , which governs emotions, motivation, and memory. This includes areas like the amygdala and hippocampus, which are involved in emotional processing and the formation of long-term memories.

4. Location:

- Neocortex :
- The neocortex is found in the outermost layers of the cerebral hemispheres and covers much of the brain's surface.
- It is the most prominent and expansive region of the brain in humans, occupying much of the frontal, parietal, temporal, and occipital lobes.

- Paleocortex :
- The paleocortex is primarily located in areas like the olfactory bulb , the olfactory cortex (which is part of the temporal lobe), and the limbic system , which is located deep within the brain (e.g., the hippocampus and amygdala).

5. Cell Types and Organization:

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- Neocortex :
- The neocortex has a more complex cellular organization with six distinct layers, each made up of different types of neurons (e.g., pyramidal cells, interneurons).
- It has a high degree of columnar organization , where similar types of neurons are arranged in vertical columns that process related types of information.

- Paleocortex :
- The paleocortex has a simpler arrangement with only three to five layers.
- It has fewer specialized neurons compared to the neocortex, and the cells are generally less varied in shape and function.

6. Involvement in Cognitive Function:

- Neocortex :
- The neocortex is crucial for advanced cognitive functions like perception, voluntary motor control, abstract reasoning, language, and conscious thought. It is considered the seat of intelligence in humans.
- It is involved in integration of sensory input , decision-making, and planning complex behaviors.

- Paleocortex :
- The paleocortex is more involved in basic, instinctive behaviors . It plays a central role in processing information related to emotion, memory , and the olfactory sense .
- It is important for survival-related behaviors and emotional reactions, which are less cognitive and more automatic.

The ultrastructure of the retina refers to the fine, microscopic organization of cells, tissues, and structures within the retina, which is the light-sensitive layer of tissue at the back of the eye. The retina plays a crucial role in visual perception by converting light into neural signals, which are then sent to the brain for processing.

The retina is composed of multiple layers, each with specialized cells responsible for different functions, and its ultrastructure can be understood in terms of both its cellular composition and the organization of these components . Let's break it down into the key components.

1. Layers of the Retina

30 The retina is organized into ten distinct layers , from the innermost (next to the vitreous body) to the outermost (next to the choroid). These layers are as follows:

1. Inner Limiting Membrane (ILM) :
- The innermost layer, just above the vitreous body.
- Composed of the endfeet of Müller cells , which are glial cells that span the entire retina and provide structural support.

2. Nerve Fiber Layer (NFL) :
- Made up of the axons of ganglion cells that form the optic nerve.
- These axons are unmyelinated in the retina and are responsible for transmitting visual information from the retina to the brain.
- The NFL is thicker around the macula and thinner at the periphery of the retina.

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3. Ganglion Cell Layer (GCL) :
- Contains the cell bodies of ganglion cells .
- These neurons receive input from the bipolar cells (which themselves are connected to photoreceptor cells) and send visual information to the brain through their axons, which form the optic nerve.

4. Inner Plexiform Layer (IPL) :
- This layer consists of synapses between the axons of bipolar cells and the dendrites of ganglion cells .
- It also contains synaptic connections between amacrine cells , which modulate the signals between bipolar and ganglion cells.
- The IPL is important for processing visual information, particularly the integration and refinement of signals.

5. Inner Nuclear Layer (INL) :
- This layer contains the cell bodies of bipolar cells , amacrine cells , and horizontal cells .
- Bipolar cells transmit signals from photoreceptors to ganglion cells.
- Horizontal cells connect photoreceptor cells and modulate the signal flow by providing lateral inhibition, important for contrast and edge detection.
- Amacrine cells are involved in further processing of visual signals and help regulate the output to the ganglion cells.

6. Outer Plexiform Layer (OPL) :
- This layer contains synaptic connections between the axons of photoreceptor cells (rods and cones) and the dendrites of bipolar cells .
- It also includes synapses between horizontal cells and photoreceptors, which helps in the lateral inhibition important for contrast perception.

7. Outer Nuclear Layer (ONL) :
- Contains the cell bodies of photoreceptors (rods and cones).
- The rods are more numerous and are responsible for vision in low light, while cones provide high-resolution color vision in bright light.

8. Outer Segments of Photoreceptors :
- The outer segments of rods and cones are specialized for light detection.
- Rods contain the pigment rhodopsin , which is sensitive to low light levels.
- Cones contain three types of photopigments (opsins) sensitive to different wavelengths of light, enabling color vision.
- These segments contain stacks of membrane discs, which increase the surface area available for photopigments.

9. Retinal Pigment Epithelium (RPE) :
- The RPE is a single layer of pigmented cells located just outside the retina, adjacent to the choroid.
- The RPE plays critical roles in:
- Absorbing light that passes through the retina, reducing light scattering.
- Phagocytosing the outer segments of photoreceptors that are shed and replaced periodically.
- Providing nutrients to photoreceptors and maintaining the blood-retinal barrier.
- Transporting ions and recycling retinal (vitamin A derivatives) for phototransduction.

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10. Bruch's Membrane (Part of Choroid) :
- Located beneath the RPE, Bruch's membrane separates the retina from the choroid , a vascular layer that provides oxygen and nutrients to the retina.

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2. Key Cells and Organelles in the Retina

The retina contains several distinct types of cells, each with specialized functions. Here's an overview of the cells and their ultrastructural features:

- Photoreceptors (Rods and Cones) :
- Rods have an elongated, cylindrical shape and contain discs in the outer segment where the light-sensitive pigment, rhodopsin , resides.
- Cones have a conical shape, and their outer segments contain cones -specific photopigments (e.g., photopsins for red, green, and blue light).
- The outer segments of both rods and cones are embedded in the retinal pigment epithelium (RPE) .

- Bipolar Cells :
- Bipolar cells have a single dendrite that connects to the photoreceptors and an axon that connects to ganglion cells in the inner retina.
- These cells are classified based on their connections and the type of neurotransmitters they release.

- Ganglion Cells :
- The cell bodies of ganglion cells are located in the ganglion cell layer (GCL), and their axons form the optic nerve. These cells are responsible for transmitting visual information from the retina to the brain.

- Horizontal Cells :
- These cells provide lateral inhibition and modify the signals from photoreceptors to bipolar cells. They have dendrites that receive inputs from photoreceptors and axons that provide feedback to the photoreceptor synapses.

- Amacrine Cells :
- Amacrine cells are involved in complex processing of visual information and synapse with both bipolar cells and ganglion cells. They play a role in motion detection , contrast enhancement , and other visual processing.

- Müller Cells :
- These are glial cells that extend throughout the entire thickness of the retina. They provide structural support, maintain the blood-retinal barrier, and help in the regulation of extracellular space and ion balance.

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3. Phototransduction in the Retina

The process by which light is converted into neural signals in the retina is called phototransduction , and it occurs in the photoreceptor cells . Here's how it works at the ultrastructural level:

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- When light enters the eye and reaches the photoreceptors, it is absorbed by the photopigments in the outer segment of rods and cones.
- This absorption causes a conformational change in the photopigment, which activates a cascade of biochemical reactions inside the photoreceptor, ultimately leading to a change in the membrane potential.
- In rods , the photopigment rhodopsin absorbs light and activates a G-protein cascade that reduces the levels of cyclic GMP , causing ion channels to close and hyperpolarizing the photoreceptor.
- In cones , the photopigments (three types: red, green, and blue opsins) are similarly involved in the light-activated signaling cascade.
- This change in membrane potential is transmitted to the bipolar cells , and the signal is processed through the inner retinal layers, ultimately reaching the ganglion cells , which transmit the information to the brain via the optic nerve.

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Table 4. Google Gemini-generated responses.

Question number	Response
1	The correct answer is multipolar. Multipolar neurons are the most common type of neuron in the central nervous system (CNS), including the brain and spinal cord. They have a single axon and multiple dendrites branching out from the cell body.
2	The correct answer is a. Meissner's corpuscles. Meissner's corpuscles are specialized sensory receptors located in the superficial layers of the skin, particularly in hairless areas like the fingertips, palms, and soles. They are highly sensitive to light touch, low-frequency vibrations, and changes in texture.
3	The correct answer is b. in striated muscles. Muscle spindles are specialized sensory receptors found within skeletal muscles, which are a type of striated muscle.
4	a. Ilioinguinal nerve: L1 - b. Genitofemoral nerve: L1-L2 - c. Lateral femoral cutaneous nerve: L2-L3 - d. ileohypogastric nerve: L1
5	The correct answer is c. The trapezoid body is formed by fibers coming from the ventral cochlear nucleus. The trapezoid body is a crucial structure in the auditory pathway. It is located in the brainstem and consists primarily of axons from the ventral cochlear nucleus. These axons cross over to the opposite side of the brainstem, allowing for the processing of auditory information from both ears in both cerebral hemispheres.
6	The correct answer is c: Temporal.
7	The correct answer is e: The pineal gland. The superior colliculi are located in the midbrain and are involved in visual reflexes and eye movements. Superiorly, they are in close proximity to the pineal gland, a small endocrine gland that produces melatonin and regulates circadian rhythms.
8	The correct answer is c. Sensory afferents derive from the 3 branches and are directed to the principal sensory nucleus (pontine), the mesencephalic nucleus and the nucleus of the descending root. The trigeminal nerve (CN V) is a mixed nerve with both sensory and motor functions. Sensory: Receives sensory information from the face, mouth, and parts of the head. These sensory fibers project to three main nuclei in the brainstem: Principal sensory nucleus (pontine): Receives information related to touch, pressure, and vibration. Mesencephalic nucleus: Receives proprioceptive input from the muscles of mastication. Spinal nucleus: Receives information related to pain and temperature.[4] Motor: Provides motor innervation to the muscles of mastication
9	The correct answer is d: The tuber cinereum and the supraoptic and paraventricular nuclei. The hypothalamic-pituitary tract is a bundle of nerve fibers that connects the hypothalamus to the posterior pituitary gland (also known as the neurohypophysis). The supraoptic and paraventricular nuclei are the primary origin of these fibers. These hypothalamic nuclei contain neurons that produce the hormones oxytocin and vasopressin (antidiuretic hormone). The tuber cinereum is a region of the hypothalamus that also contributes some fibers to the tract.
10	The correct answer is e: The corticobulbar tract.

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	The corticobulbar tract carries motor fibers from the cerebral cortex to the cranial nerve nuclei, controlling the muscles of the face and head. This tract specifically passes through the genu (knee) of the internal capsule.
11	The "basal ganglia" encompass a group of **subcortical nuclei** that play a pivotal role in **motor control**, as well as other functions including motor learning, executive functions, and **emotional regulation**.
12	The limbic lobe is a ring of **cortical tissue** on the medial aspect of each hemisphere that surrounds the **corpus callosum**. The limbic lobe is composed of the **cingulate gyrus, parahippocampal gyrus, and hippocampus gyri**. The larger limbic system is involved in **emotion and motivation expression.**
13	**Pyramidal cells, granule cells, stellate cells, Martinotti cells, and horizontal cells** are the typical cells in the cerebral cortex.
14	The spinocerebellar tracts convey information from **proprioceptive, tactile, and pressure receptors**.
15	Lesions affecting the second motor neuron **interrupt** the signal communication between the central nervous system and the muscle, resulting in **flaccid paralysis** of the affected muscle.
16	The cochlear nuclei contain **the cell bodies** of the vestibulocochlear nerve, and the ventral cochlear nucleus in humans constitutes the main relay nucleus between first-order and second-order neurons of the **auditory pathway**.
17	The **parvocellular** part of the red nucleus is more important in humans and, like the **magnocellular** part, is involved—though in a different way—in the **motor control** exerted by the cerebellum.
18	The **medulla oblongata** can be bilaterally affected in degenerative diseases such as **amyotrophic lateral sclerosis (ALS)** or in **bilateral strokes**; this results in difficulty swallowing due to muscle paralysis, and consequently ingested material risks entering the trachea.
19	The **anterior nuclei** of the thalamus receive afferents from the **mammillary bodies** of the hypothalamus and project to the cerebral cortex of the cingulate gyrus, forming part of a complex loop that also involves limbic lobe structures, known as the **Papez circuit**.
20	The **primary visual cortex** occupies Brodmann's area 17. It is located on the lips of the **calcarine sulcus** and is characterized by a very **thick** layer IV, crossed by a stripe of myelinated fibers, the stripe of the **Gennari** or external Baillarger stripe or **Vicq d'Azyr**, which runs parallel to the cortical surface and therefore defines the striate cortex.
16	The spino-bulbo-thalamo-cortical pathway is a complex series of neurons that transmit sensory information, such as fine touch, vibration, and proprioception (sense of body position), from the periphery of the body to the cerebral cortex for conscious perception. Here's a breakdown: First-order neurons: These sensory neurons have their cell bodies in the dorsal root ganglia of the spinal cord. Their peripheral processes receive sensory input from the skin, muscles, and joints. Their central axons ascend in the dorsal columns of the spinal cord (fasciculus gracilis and fasciculus cuneatus). Second-order neurons: These neurons are located in the medulla oblongata (in the nuclei gracilis and cuneatus). They receive synapses from the first-order neurons.

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	Their axons decussate (cross over) to the opposite side of the brainstem and ascend as the medial lemniscus. Third-order neurons: These neurons are located in the ventral posterolateral nucleus (VPL) of the thalamus. They receive synapses from the second-order neurons. Their axons project to the primary somatosensory cortex in the postcentral gyrus of the parietal lobe. In the primary somatosensory cortex, the brain processes the sensory information and creates a conscious perception of touch, vibration, and proprioception. This allows us to feel sensations like light touch, deep pressure, and the position of our limbs in space. Diagram: Unfortunately, I can't directly create and display a visual diagram here.
17	The median nerve arises from the lateral and medial cords of the brachial plexus, specifically from the contributions of the C5-T1 nerve roots. It emerges from the lateral border of the axilla and descends through the arm, initially located lateral to the axillary artery. In the cubital fossa, it passes between the two heads of the pronator teres muscle. In the forearm, the median nerve travels between the flexor digitorum superficialis and the flexor digitorum profundus muscles. It provides motor innervation to several muscles in the anterior compartment of the forearm, including the pronator teres, pronator quadratus, flexor carpi radialis, palmaris longus, and the lateral half of the flexor digitorum profundus. At the wrist, the median nerve passes through the carpal tunnel, a narrow passageway formed by the carpal bones and the flexor retinaculum. Within the hand, it innervates the thenar muscles (abductor pollicis brevis, flexor pollicis brevis, opponens pollicis), the lateral two lumbricals, and provides sensory innervation to the lateral palm and the palmar surfaces of the lateral three and a half fingers. **Key Points:** • **Origin:** Lateral and medial cords of the brachial plexus • **Course:** Axilla, arm (lateral to brachial artery), cubital fossa, forearm (between flexor muscles), carpal tunnel, hand • **Innervation:** Motor to forearm muscles, thenar muscles, and some lumbricals; Sensory to lateral palm and lateral three and a half fingers This description provides a general overview of the median nerve's origin and course. Remember that anatomical variations can occur, and detailed knowledge of the nerve's anatomy is crucial for clinicians and surgeons.
18	The cerebellum is a highly convoluted structure located at the back of the brain, inferior to the cerebrum and posterior to the brainstem. It is composed of two cerebellar hemispheres connected by a central vermis. The surface of the cerebellum is characterized by numerous parallel folds called **folia**, giving it a distinctive "tree-like" appearance. Internally, the cerebellum consists of an outer layer of gray matter called the **cerebellar cortex** and an inner core of white matter known as the **arbor vitae**. The arbor vitae, which resembles the branches of a tree, contains the axons of cerebellar neurons and their supporting cells. Deep within the white matter, there are four pairs of **deep cerebellar nuclei**: the dentate, emboliform, globose, and fastigial nuclei. These nuclei play a crucial role in cerebellar function by relaying information to other parts of the brain. **Functional Divisions of the Cerebellum:** The cerebellum is traditionally divided into three functional regions:

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	• **Vestibulocerebellum:** Located in the flocculonodular lobe, it plays a key role in maintaining balance and equilibrium. • **Spinocerebellum:** Located in the vermis and intermediate hemispheres, it is involved in the regulation of muscle tone, coordination of movement, and the control of posture. • **Cerebrocerebellum:** Located in the lateral hemispheres, it is involved in the planning and execution of voluntary movements, as well as cognitive functions such as attention and language. The cerebellum receives input from various sources, including the spinal cord, brainstem, and cerebral cortex, and sends output to various brain regions, including the thalamus, brainstem, and spinal cord. These connections allow the cerebellum to coordinate and fine-tune motor activity, ensuring smooth and accurate movements. In summary, the cerebellum is a complex structure with a highly folded surface, distinct internal anatomy, and multiple functional divisions. It plays a crucial role in motor control, coordination, and other important functions.
19	The lateral femoral cutaneous nerve innervates the skin on the lateral aspect of the thigh.
20	Sorry, there was a problem generating images. The inner ear is a complex structure located within the temporal bone of the skull. It's responsible for both hearing and balance. Here's a breakdown of its key components: 1. **Cochlea:** This is a spiral-shaped structure that resembles a snail shell. It's filled with fluid and lined with tiny hair cells. When sound waves enter the ear, they cause vibrations in the fluid, which in turn stimulate the hair cells. These hair cells then convert the mechanical energy of the vibrations into electrical signals that are sent to the brain, where they are interpreted as sound. 2. **Vestibular System:** This system is responsible for maintaining balance and spatial orientation. It consists of two main parts: ○ **Semicircular canals:** These are three fluid-filled tubes that are arranged in different planes. They detect rotational movements of the head. ○ **Otolith organs (utricle and saccule):** These organs contain tiny crystals that respond to linear acceleration and gravity. They help us sense changes in head position and linear movement. The inner ear is a delicate and intricate structure that plays a vital role in our ability to hear and maintain balance.
21	he extrapyramidal system is a complex network of neural pathways that plays a crucial role in **modulating and regulating movement**. Unlike the pyramidal system, which directly innervates motor neurons, the extrapyramidal system exerts more indirect control over movement. **Key Components:** • **Basal Ganglia:** A group of nuclei deep within the cerebrum, including the caudate nucleus, putamen, globus pallidus, substantia nigra, and subthalamic nucleus. These structures play a critical role in planning, initiating, and executing smooth, coordinated movements. • **Cerebellum:** This highly convoluted structure located at the back of the brain plays a vital role in coordinating movement, maintaining balance, and regulating muscle tone. • **Brainstem Nuclei:** Various nuclei within the brainstem, such as the red nucleus and reticular formation, contribute to the extrapyramidal system. **Key Functions:** • **Movement Initiation and Planning:** The extrapyramidal system helps initiate and plan voluntary movements, ensuring smooth and coordinated muscle activity.

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	• **Posture and Balance:** It plays a crucial role in maintaining posture, balance, and equilibrium. • **Muscle Tone:** The system helps regulate muscle tone and prevent excessive muscle rigidity. • **Learning and Adaptation:** The extrapyramidal system contributes to motor learning and the ability to adapt movements based on feedback from the environment. **Key Differences from the Pyramidal System:** • **Direct vs. Indirect:** The pyramidal system directly innervates motor neurons, while the extrapyramidal system exerts more indirect control. • **Function:** The pyramidal system primarily controls voluntary movements, while the extrapyramidal system focuses on movement modulation, coordination, and regulation. **Disorders of the Extrapyramidal System:** Damage to any component of the extrapyramidal system can result in various movement disorders, including: • **Parkinson's disease:** Characterized by tremors, rigidity, slowness of movement (bradykinesia), and postural instability. • **Huntington's disease:** Characterized by involuntary movements (chorea), cognitive decline, and psychiatric symptoms. • **Dystonia:** Characterized by sustained muscle contractions that cause abnormal postures or repetitive movements.
22	Broca's area is not a single, clearly defined cortical region, but rather a collection of interconnected areas within the frontal lobe. Here's a breakdown: • **Location:** ○ Primarily located in the **inferior frontal gyrus**, specifically in the **pars triangularis (Brodmann area 45)**and the **pars opercularis (Brodmann area 44)**. ○ Situated in the dominant hemisphere (usually the left hemisphere) of the brain. • **Key Functions:** ○ **Speech production:** Plays a crucial role in the planning and execution of speech, including the motor movements involved in articulation. ○ **Language processing:** Involved in various aspects of language processing, such as grammar, syntax, and word retrieval. **Important Note:** • Broca's area is not the sole brain region involved in language. It interacts with other key areas like Wernicke's area (involved in language comprehension) and the arcuate fasciculus (a bundle of nerve fibers connecting Broca's and Wernicke's areas).
23	The diagram you provided illustrates the intricate layers and cellular composition of the cerebellar cortex. Let's break down the key features: **1. Molecular Layer:** • This is the outermost layer, primarily containing the dendrites of Purkinje cells, which are highly branched and form a dense network. • It also contains a few interneurons, such as stellate cells and basket cells, which modulate the activity of Purkinje cells. **2. Purkinje Cell Layer:** • This layer is characterized by a single row of large, flask-shaped Purkinje cells. • These cells are the primary output neurons of the cerebellar cortex. • Their dendrites extend into the molecular layer, forming a complex dendritic tree that receives numerous synaptic inputs. **3. Granular Layer:**

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	• The innermost layer, densely packed with granule cells, the smallest neurons in the brain. • Granule cells have numerous dendrites that receive input from mossy fibers. • Their axons ascend to the molecular layer, where they bifurcate and run parallel to the surface, forming parallel fibers. **Key Synaptic Connections:** • **Parallel Fibers:** These axons of granule cells synapse extensively with the dendrites of Purkinje cells. • **Climbing Fibers:** These are the axons of neurons from the inferior olivary nucleus. They form powerful excitatory synapses on the dendrites of Purkinje cells. **Functional Significance:** This intricate arrangement of neurons and their synaptic connections allows the cerebellar cortex to process information from various sources and coordinate complex motor functions. The Purkinje cells, with their extensive dendritic arborizations, integrate a vast amount of input from parallel fibers and climbing fibers, ultimately shaping the output of the cerebellum.
24	The neocortex and paleocortex are two distinct regions of the cerebral cortex, the outermost layer of the brain, with key differences in their evolutionary origin, structure, and function. **Neocortex:** • **Evolutionary Origin:** Considered the most recently evolved part of the cerebral cortex. • **Structure:** Characterized by six distinct layers of neurons, with a highly organized cytoarchitecture. • **Functions:** Involved in higher cognitive functions such as sensory perception, motor control, language, reasoning, and consciousness. **Paleocortex:** • **Evolutionary Origin:** More ancient part of the cerebral cortex, evolving earlier in mammalian evolution. • **Structure:** Typically has three or four layers of neurons, with a less complex cytoarchitecture compared to the neocortex. • **Functions:** Primarily involved in basic functions such as olfaction (sense of smell) and limbic system functions related to emotions and motivation.
25	The ultrastructure of the retina refers to the detailed, microscopic organization of the retinal layers and their constituent cells. The retina is a complex, multi-layered structure at the back of the eye, responsible for capturing light and converting it into electrical signals that are transmitted to the brain. Here's a description of the key features at the ultrastructural level: ### 1. Layers of the Retina (From Outer to Inner): 1. Retinal Pigment Epithelium (RPE) - The RPE is the outermost layer and consists of a single layer of cuboidal or columnar cells. These cells contain pigment granules (melanin) that absorb scattered light, preventing reflection and improving visual clarity. - The RPE plays a critical role in photoreceptor health , by phagocytosing the shed outer segments of photoreceptor cells and recycling visual pigments. 2. Photoreceptor Layer (Rods and Cones)

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- Rods : These cells are responsible for vision in low-light conditions (scotopic vision). They contain rhodopsin in their outer segments, which are composed of stacked discs embedded with the pigment.
- Cones : Responsible for color vision and high acuity in bright light (photopic vision). The outer segments of cones have invaginated discs that contain photopsin.
- The outer segment of both rods and cones is connected to the inner segment , which houses the cell's nucleus and organelles for metabolic functions.

3. Outer Plexiform Layer
- This layer contains the synapses between photoreceptors (rods and cones) and bipolar cells . It's composed of synaptic terminals from photoreceptors and dendrites from bipolar cells.

4. Bipolar Cell Layer
- Bipolar cells receive signals from photoreceptors and transmit them to ganglion cells . There are two types of bipolar cells: ON bipolar cells and OFF bipolar cells , which respond differently to light stimuli.

5. Inner Plexiform Layer
- The synapses between bipolar cells and ganglion cells occur here. The inner plexiform layer is also where horizontal and amacrine cells integrate and modulate signals from the bipolar cells.

6. Ganglion Cell Layer
- This layer contains the ganglion cells , which are the final output neurons of the retina. Their axons form the optic nerve , transmitting visual information to the brain. The axons of the ganglion cells exit the eye at the optic disc .

7. Nerve Fiber Layer
- The nerve fiber layer consists of the axons of the ganglion cells . These axons gather to form the optic nerve . The nerve fibers are arranged in a radial pattern as they converge toward the optic disc.

8. Internal Limiting Membrane
- This is the innermost boundary of the retina, composed of glial cells (such as Müller cells) and their processes. It forms a structural boundary separating the retina from the vitreous body.

Ultrastructural Features:
- Photoreceptor discs: In rods and cones, the outer segments contain stacks of membrane-bound discs . In rods, these discs are separate, while in cones, the discs are continuous with the cell membrane.

- Synaptic vesicles: Within the synaptic terminals of photoreceptors and bipolar cells, synaptic vesicles contain neurotransmitters (e.g., glutamate) that are released in response to light-induced changes in membrane potential.

- Müller Cells: These are the principal glial cells in the retina and run the entire length of the retina, providing structural support, ion buffering, and helping maintain the blood-retina barrier.

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- Retinal Vascularization: The retina is supplied by two vascular systems:
- The central retinal artery , which supplies the inner retinal layers.
- The choroid , which supplies the outer layers (including the photoreceptors) via a dense network of blood vessels.

Key Cellular Components:
- Rods and Cones : The photoreceptor cells that convert light signals into electrical signals. Rods are more numerous and are sensitive to light, while cones enable color vision.
- Bipolar Cells : These cells transmit signals from photoreceptors to ganglion cells and play a role in signal processing.
- Ganglion Cells : The neurons that send the final visual information to the brain via the optic nerve.
- Horizontal Cells : These cells modulate the signals between photoreceptors and bipolar cells, playing a role in lateral inhibition.
- Amacrine Cells : Involved in modulating the synaptic connections between bipolar cells and ganglion cells.

Functionality in Vision:
- The retina's ultrastructure enables the complex processing of visual information. Light entering the eye is captured by photoreceptors in the outer layers, which convert light into electrical signals. These signals are processed by bipolar cells and modulated by horizontal and amacrine cells . Finally, ganglion cells transmit the processed visual information to the brain via the optic nerve .

The retina's sophisticated structure ensures the precise conversion of light into the neural signals necessary for vision.

Let me know if you'd like additional details on any of these components!

Table 5. Microsoft Copilot-generated responses.

Question number	Response
1	Most neurons in the central nervous system belong to the multipolar category. These neurons have one axon and multiple dendrites, allowing them to process and integrate a great deal of information from other neurons.
2	The correct answer is a. Meissner's corpuscles. These are specialized mechanoreceptors found in the skin that are sensitive to light touch and vibrations. They are primarily located in areas like the fingertips and lips.
3	Muscle spindles are located in striated muscles. So, the correct answer is b. in striated muscles. These sensory receptors are primarily involved in detecting changes in muscle length and the speed of those changes, playing a crucial role in the regulation of muscle contraction and coordination.
4	a. Ilioinguinal nerve - L1 b. Genitofemoral nerve - L1-L2 c. Lateral femoral cutaneous nerve - L2-L3 d. Iliohypogastric nerve - L1
5	The trapezoid body is formed by fibers coming from the ventral cochlear nucleus. This structure is part of the auditory pathway and plays a role in the transmission and

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	processing of auditory information from the cochlea to higher auditory centersin the brainstem and cortex.
6	The inferior horn of the lateral ventricle is located in the temporal lobe. So, the correct answer is c: Temporal.
7	The superior colliculi are in relation with the pineal gland superiorly. So, the correct answer is e: The pineal gland.
8	The correct statement about the trigeminal nerve (V pair) is: c. Sensory afferents derive from the 3 branches (ophthalmic, maxillary, mandibular) and are directed to the principal sensory nucleus (pontine), the mesencephalic nucleus and the nucleus of the descending root. The trigeminal nerve is responsible for providing sensory information from the face and head to the brain, as well as motor functions for chewing.
9	The fibers of the hypothalamic-pituitary tract originate from the tuber cinereum and the supraoptic and paraventricular nuclei. So, the correct answer is d: The tuber cinereum and the supraoptic and paraventricular nuclei.
10	The correct answer is e: The corticobulbar tract. The corticobulbar tract runs through the genu of the internal capsule, carrying motor signals from the cerebral cortex to the brainstem, specifically to the cranial nerve nuclei.
11	The "basal ganglia" encompass a group of **subcortical nuclei** that play a pivotal role in **regulating voluntary motor movements**, as well as other functions including motor learning, executive functions, and **emotional processing**.
12	The limbic lobe is a ring of **cortex** on the medial aspect of each hemisphere that surrounds the **corpus callosum**. The limbic lobe is composed of the **cingulate, parahippocampal, and subcallosal gyri**. The larger limbic system is involved in **emotion and behavioral expression**.
13	**Pyramidal cells, fusiform cells, stellate (granular) cells, horizontal cells of Cajal-Retzius, and cells of Martinotti** are the typical cells in the cerebrum cortex.
14	The spinocerebellar tracts convey information from **muscle spindles, Golgi tendon organs, and joint capsule receptors**.
15	Lesions affecting the second motor neuron **disrupt** the signal communication between the central nervous system and the muscle, resulting in **flaccid paralysis of the affected muscle**.
16	The cochlear nuclei contain **second-order neurons** of the vestibulocochlear nerve, and the ventral cochlear nucleus in humans constitutes the main relay nucleus between first-order and second-order neurons of the **auditory pathways**.
17	The **parvocellular** part of the red nucleus is more important in humans and, like the **magnocellular** part, is involved—though in a different way—in the **motor control** exerted by the cerebellum.
18	The **nucleus ambiguus** can be bilaterally affected in degenerative diseases such as **amyotrophic lateral sclerosis** or in **poliomyelitis**; this results in difficulty swallowing due to muscle paralysis, and consequently ingested material risks entering the trachea.
19	The **anterior nuclei** of the thalamus receive afferents from the **mammillary bodies** of the hypothalamus and project to the cerebral cortex of the cingulate gyrus, forming part of a complex loop that also involves limbic lobe structures, known as the **Papez circuit**.
20	The **primary visual area** occupies Brodmann's area 17. It is located on the lips of the **calcarine sulcus** and is characterized by a very **developed** layer IV, crossed by a stripe of myelinated fibers, the stripe of the **granular layer** or external Baillargerstripe or **Gennari stripe**, which runs parallel to the cortical surface and therefore defines the striate cortex.
21	The spino-bulbo-thalamo-cortical pathway is a complex neural pathway that conveys sensory information from the body to the brain. This pathway involves several key structures:

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	1. Spinal Cord: Sensory information from peripheral receptors enters the spinal cord through dorsal root ganglia. 2. Medulla Oblongata (Bulb): The sensory signals then ascend to the medulla oblongata where they synapse in the gracile and cuneate nuclei. 3. Thalamus: From the medulla, the sensory information is relayed to the thalamus, which acts as a major sensory relay station in the brain. 4. Cerebral Cortex: Finally, the sensory information is transmitted from the thalamus to the primary somatosensory cortex of the brain, where it is processed and perceived. (see Figure 1A)
22	The median nerve is a major nerve of the upper limb, playing a crucial role in the motor and sensory functions of the hand. Here's a detailed description of its origin and course: **Origin** • The median nerve originates from the brachial plexus, which is a network of nerves formed by the ventral rami of the C5 to T1 spinal nerves. • Specifically, it is formed by the merging of fibers from the lateral and medial cords of the brachial plexus. **Course** 1. **Axilla**: It begins in the axilla (armpit) and runs alongside the brachial artery. 2. **Arm**: It travels down the arm within the medial aspect of the biceps brachii muscle and brachialis muscle. 3. **Cubital Fossa**: At the elbow, it passes through the cubital fossa, locatedanteriorly to the elbow joint. 4. **Forearm**: In the forearm, it travels between the flexor digitorum superficialis and flexor digitorum profundus muscles. 5. **Wrist**: It continues to the wrist, passing through the carpal tunnel, a narrow passageway in the wrist. 6. **Hand**: Finally, in the hand, it divides into branches that supply motor and sensory functions to the thumb, index finger, middle finger, and part of the ring finger. (see Figure 1B)
23	The cerebellum, often referred to as the "little brain," is a vital structure located at the back of the brain, underneath the occipital lobes and behind the brainstem. Its morphology is characterized by the following features: **General Structure** 1. **Hemispheres**: The cerebellum consists of two lateral hemispheres that are symmetrically positioned on either side of the central vermis. 2. **Vermis**: The vermis is the narrow, central part that connects the two hemispheres and plays a crucial role in coordinating posture and locomotion. 3. **Lobes**: The cerebellum is divided into three lobes: the anterior lobe, the posterior lobe, and the flocculonodular lobe. ○ **Anterior Lobe**: Located at the front, it is primarily involved in the regulation of muscle tone and coordination of skilled voluntary movement. ○ **Posterior Lobe**: The largest lobe, it is associated with the coordination of fine motor activity and cognitive functions. ○ **Flocculonodular Lobe**: Positioned at the bottom, it is involved in maintaining balance and controlling eye movements. 4. **Folia**: The cerebellar surface is marked by thin, parallel folds called folia, which increase the surface area and allow for a greater density of neurons. **Internal Structure** 5. **Cerebellar Cortex**: The outer layer of the cerebellum, composed of graymatter, where most of the processing occurs.

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	6. **White Matter**: Beneath the cortex lies the white matter, which contains the myelinated nerve fibers that connect different parts of the cerebellum and other parts of the brain. 7. **Deep Cerebellar Nuclei**: Embedded within the white matter are the deep cerebellar nuclei (dentate, emboliform, globose, and fastigial), which are critical for sending output signals from the cerebellum to other brain regions. (see Figure 1C)
24	The lateral femoral cutaneous nerve innervates the skin on the lateral (outer) part of the thigh. This nerve is responsible for providing sensory innervation to this area, allowing you to feel sensations such as touch, pain, and temperature changes.
25	The internal ear, also known as the inner ear, is a complex structure responsible for hearing and balance. It consists of two main parts: the bony labyrinth and the membranous labyrinth. Bony Labyrinth The bony labyrinth is a series of cavities within the temporal bone and includes three main components: 1. **Cochlea**: A spiral-shaped structure responsible for converting sound vibrations into neural signals. 2. **Vestibule**: The central part of the bony labyrinth, involved in balance. It contains the utricle and saccule, which detect linear movements. 3. **Semicircular Canals**: Three looped structures (anterior, posterior, and lateral) that detect rotational movements. Membranous Labyrinth The membranous labyrinth is a series of fluid-filled tubes and sacs within the bony labyrinth: 1. **Cochlear Duct**: Located within the cochlea, it contains the organ of Corti, which houses hair cells that convert sound vibrations into electrical signals. 2. **Utricle and Saccule**: Located within the vestibule, these structures containhair cells that detect linear acceleration and head position. 3. **Semicircular Ducts**: Located within the semicircular canals, these ducts contain hair cells that detect rotational movements. Fluids • **Perilymph**: Fluid found between the bony and membranous labyrinths. • **Endolymph**: Fluid within the membranous labyrinth. Nerve Supply • **Vestibulocochlear Nerve (CN VIII)**: This nerve transmits auditory and balance information from the inner ear to the brain. (see Figure 1D)
26	The extrapyramidal system is a network of neurons in the brain that is involved in the coordination of movement and control of motor functions. It is separate from the pyramidal system, which is responsible for voluntary movement. The extrapyramidal system is primarily responsible for involuntary movement and motor control. **Key Components** 1. **Basal Ganglia**: A group of nuclei in the brain that play a crucial role in movement regulation. This includes the caudate nucleus, putamen, globus pallidus, subthalamic nucleus, and substantia nigra. 2. **Substantia Nigra**: Located in the midbrain, it produces dopamine, a neurotransmitter important for movement regulation. Degeneration of neurons in this area is associated with Parkinson's disease. 3. **Red Nucleus**: Located in the midbrain, it is involved in motor coordination. 4. **Reticular Formation**: A network of neurons in the brainstem that play a role in regulating muscle tone and reflexes.

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5. **Thalamus**: Acts as a relay station for motor and sensory signals to the cerebral cortex.
6. **Cerebellum**: While often associated with the pyramidal system, it also has connections to the extrapyramidal system and plays a role in movement coordination and balance.

Functions

- **Regulating Muscle Tone**: The extrapyramidal system helps to maintainmuscle tone and posture.
- **Coordinating Movement**: It coordinates involuntary and automatic movements, such as walking and other repetitive activities.
- **Modulating Reflexes**: It modulates reflex actions to maintain smooth and coordinated movements.
- **Suppressing Involuntary Movements**: It helps to suppress unwanted involuntary movements.

Disorders

- **Parkinson's Disease**: A disorder resulting from the degeneration of dopamine-producing neurons in the substantia nigra, leading to tremors, rigidity, and bradykinesia (slowness of movement).
- **Huntington's Disease**: A genetic disorder causing degeneration of neurons in the basal ganglia, leading to involuntary jerking movements and cognitive decline.
- **Tardive Dyskinesia**: A disorder characterized by repetitive, involuntary movements, often as a side effect of long-term use of certain medications.

Broca's area is a region in the frontal lobe of the brain that is crucial for language production and processing. It is typically located in the left hemisphere, specifically in the posterior part of the inferior frontal gyrus. Here are the key aspects of Broca's area:

Cortical Regions of Broca's Area

1. Pars Opercularis
   - Location : This region is located in the posterior part of the inferior frontal gyrus.
   - Function : It is involved in the motor aspects of speech production, including the coordination of mouth movements necessary for speaking.

2. Pars Triangularis
   - Location : This region is located anteriorly to the pars opercularis, also within the

27 inferior frontal gyrus.
   - Function : It plays a role in the cognitive processes related to language, such as syntactic processing and the organization of grammatical structure in speech and writing.

Functionality

- Speech Production : Broca's area is responsible for producing articulate speech. Damage to this area can result in Broca's aphasia, characterized by slow, effortful speech with good comprehension but poor grammar and syntax.
- Language Processing : It is also involved in the comprehension of complex sentences, particularly those requiring the understanding of grammatical relationships.
- Motor Planning : This area coordinates the movements required for speaking, ensuring that speech sounds are produced accurately and fluently.

Let's describe the ultrastructure of the cerebellar cortex and visualize it through a diagram:

28 **Ultrastructure of the Cerebellar Cortex**

The cerebellar cortex is organized into three distinct layers from superficial to deep:

1. **Molecular Layer**: This outermost layer contains:

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	○ **Stellate Cells**: Inhibitory interneurons that interact with the dendrites of Purkinje cells. ○ **Basket Cells**: Another type of inhibitory interneuron that forms basket-like connections around Purkinje cell bodies. ○ **Dendrites of Purkinje Cells**: Extensive dendritic trees of Purkinje cells extending into this layer. ○ **Parallel Fibers**: Axons of granule cells running parallel to the surface, synapsing with Purkinje cell dendrites. 2. **Purkinje Cell Layer**: This middle layer contains: ○ **Purkinje Cells**: Large, flask-shaped neurons with extensive dendritic arbors extending into the molecular layer. They are the sole output neurons of the cerebellar cortex, projecting inhibitory signals to the deep cerebellar nuclei. 3. **Granular Layer**: This innermost layer contains: ○ **Granule Cells**: Small neurons whose axons form the parallel fibers in the molecular layer. ○ **Golgi Cells**: Inhibitory interneurons that regulate the activity of granule cells. ○ **Glomeruli**: Synaptic complexes involving the dendrites of granule cells, axon terminals of mossy fibers, and Golgi cell processes. (see Figure 1E)
29	The brain's cortex is divided into different regions based on its evolutionary development and structural characteristics. The neocortex and paleocortex are two such regions with distinct differences: Neocortex 1. Structure: The neocortex is the most recently evolved part of the cerebral cortex and is characterized by its six-layered structure. It is the largest part of the human brain's cortex, making up about 90% of the cerebral cortex. 2. Function: The neocortex is responsible for higher-order brain functions such as sensory perception, cognition, generation of motor commands, spatial reasoning, and language. It is involved in complex processes like decision-making, problem-solving, and abstract thinking. 3. Location: It covers the surface of the cerebral hemispheres and includes regions such as the frontal, parietal, temporal, and occipital lobes. Paleocortex 1. Structure: The paleocortex is an older part of the cerebral cortex, consisting of three to five layers. It is much smaller in comparison to the neocortex and makes up a smaller portion of the cerebral cortex. 2. Function: The paleocortex is primarily involved in olfaction (sense of smell) and other basic, instinctual behaviors. It plays a role in certain autonomic functions and primitive sensory processes. 3. Location: It is found in regions such as the olfactory bulb and piriform cortex, which are associated with the sense of smell.
30	The retina is a complex, multi-layered structure responsible for converting light into electrical signals that are transmitted to the brain.[1] Here's a breakdown of its ultrastructure:

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	1. Photoreceptor Layer: This is the outermost layer of the retina, containing two types of photoreceptor cells: Rods: Sensitive to dim light, responsible for night vision and peripheral vision. Cones: Sensitive to bright light and responsible for color vision and high visual acuity. Photoreceptor cells contain photopigments that undergo chemical changes in response to light, initiating the visual transduction process. 2. Outer Nuclear Layer: This layer contains the cell bodies of photoreceptor cells (rods and cones). 3. Outer Plexiform Layer: This layer contains the synaptic connections between the photoreceptor cells and the bipolar cells. 4. Inner Nuclear Layer: This layer contains the cell bodies of bipolar cells, horizontal cells, and amacrine cells. Bipolar cells: Transmit signals from photoreceptors to ganglion cells. Horizontal cells: Modulate the signals between photoreceptors and bipolar cells. Amacrine cells: Modulate the signals between bipolar cells and ganglion cells. 5. Inner Plexiform Layer: This layer contains the synaptic connections between bipolar cells, amacrine cells, and ganglion cells. 6. Ganglion Cell Layer: This layer contains the cell bodies of ganglion cells. Ganglion cells are the output neurons of the retina, and their axons form the optic nerve. 7. Nerve Fiber Layer: This layer contains the axons of ganglion cells, which converge to form the optic nerve. Key Points: • The retina is a highly organized and layered structure with a complex network of interconnected neurons. • This intricate organization allows for the efficient processing and transmission of visual information from the environment to the brain. This is a simplified overview of the retinal ultrastructure. The retina is a complex and fascinating structure with numerous other cellular components and intricate synaptic connections that contribute to its remarkable function in vision. Let me know if you'd like to delve deeper into any specific aspect of the retinal structure or function!

Table 6. Perplexity.ai-generated responses.

Question number	Response
1	Multipolar neurons are the dominant type found in the CNS
2	The mechanoreceptor for touch among the options provided is: a. Meissner's corpuscles. Meissner's Corpuscles: These are specialized mechanoreceptors located in the upper layers of the skin, particularly in areas such as the fingertips, palms, and soles. They are sensitive to light touch and vibrations at low frequencies (30–50 Hz) and are rapidly adapting, making them particularly effective at detecting changes in texture and fine details of objects.
3	Muscle spindles are primarily located in: b. in striated muscles. Muscle spindles are sensory receptors found within the fascicles of striated (skeletal) muscles. They play a crucial role in proprioception by detecting changes in muscle length and the rate of that change, which is essential for motor control and coordination.
4	a. Ilioinguinal Nerve: origin: L1 (with occasional contributions from T12 or L2) – b. Genitofemoral Nerve: origin: L1 and L2 – c. Lateral Femoral Cutaneous Nerve:

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	origin: L2 and L3. D. Iliohypogastric Nerve: origin: L1 (with some contributions from T12)
5	The trapezoid body is formed by fibers coming from:c. The trapezoid body is formed by fibers coming from the ventral cochlear nucleus. The trapezoid body is a structure in the brainstem that contains decussating (crossing) fibers primarily from the ventral cochlear nucleus. These fibers are crucial for auditory processing, as they help relay information to the superior olivary complex, which is involved in sound localization and binaural hearing.
6	The inferior horn of the lateral ventricle is located in the: c: Temporal lobe. The inferior horn, also known as the temporal horn of the lateral ventricle, extends into the temporal lobe of the brain. It is one of the four main parts of the lateral ventricle, which also includes the anterior (frontal) horn, body, and posterior (occipital) horn. The inferior horn begins at the atrium of the lateral ventricle and projects anteroinferiorly towards the temporal lobe, terminatingnear structures such as the amygdala and hippocampus.
7	The superior colliculi are located in the midbrain and are positioned superiorly to the following structure: e: The pineal gland. The superior colliculi are paired structures that form part of the roof of the midbrain (tectum) and are situated just below the pineal gland. They play a crucial role in visual processing and coordinating eye movements. The pineal gland is located posterior to the thalamus and superior to the superior colliculi, making it the correct option in terms of anatomical relation.
8	The correct statement about the trigeminal nerve (V pair) is: c. Sensory afferents derive from the 3 branches and are directed to the principal sensory nucleus (pontine), the mesencephalic nucleus, and the nucleus of the descending root. The trigeminal nerve is responsible for sensory innervation of the face and has three major branches: the ophthalmic (V1), maxillary (V2), and mandibular (V3) nerves. Sensory afferents from these branches project to multiple nuclei: Principal Sensory Nucleus (Pontine): Processes touch and pressure sensations. Mesencephalic Nucleus: Involved in proprioception from the jaw and other structures. Nucleus of the Descending Root: Processes pain and temperature sensations.
9	The correct answer regarding the origin of the fibers of the hypothalamic-pituitary tract is: d: The tuber cinereum and the supraoptic and paraventricular nuclei. The hypothalamic-pituitary tract, specifically the hypothalamo-neurohypophysealtract, primarily consists of axons that originate from neurosecretory cells locatedin the supraoptic and paraventricular nuclei of the hypothalamus. These nuclei are responsible for producing hormones such as oxytocin and vasopressin (antidiuretic hormone), which are transported down their axons to the posterior pituitary gland (neurohypophysis) for release into the bloodstream. Tuber Cinereum: This area of the hypothalamus also plays a role in connecting various hypothalamic functions and is involved in the regulation of the pituitary gland, but it is not the primary source of fibers for the hypothalamic-pituitary tract.
10	The fiber system that runs through the genu of the internal capsule is:e: The corticobulbar tract. The internal capsule is a critical structure in the brain that contains various ascending and descending fiber tracts. It is divided into several parts: the anterior limb, genu, posterior limb, retrolenticular part, and sublenticular part. Corticobulbar Tract: The fibers of the corticobulbar tract, which originate in the motor cortex, pass through the genu of the internal capsule. These fibersare responsible for innervating cranial nerve nuclei that control muscles of the face, head, and neck.

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11	The "basal ganglia" encompass a group of **subcortical nuclei** that play a pivotal role in **motor control**, as well as other functions including motor learning, executive functions, and **emotional regulation**.
12	The limbic lobe is a ring of **cortex** on the medial aspect of each hemisphere that surrounds the **corpus callosum**. The limbic lobe is composed of the **cingulate, parahippocampal, and subcallosal gyri**. The larger limbic system is involved in **emotion and memory expression**.
13	The typical cells in the cerebral cortex are **pyramidal cells, stellate cells, fusiform cells, and basket cells**.
14	The spinocerebellar tracts convey information from **muscle spindles, Golgi tendon organs, and joint receptors**.
15	Lesions affecting the second motor neuron **disrupt** the signal communication between the central nervous system and the muscle, resulting **in weakness or atrophy of the affected muscle**.
16	The cochlear nuclei contain **central processes** of the vestibulocochlear nerve, and the ventral cochlear nucleus in humans constitutes the main relay nucleus between first-order and second-order neurons of the **auditory pathway**.
17	The **parvocellular** part of the red nucleus is more important in humans and, like the **magnocellular** part, is involved—though in a different way—in the **motor coordination** exerted by the cerebellum.
18	The **nucleus ambiguus** can be bilaterally affected in degenerative diseases such as **multiple system atrophy** or in **brainstem strokes**; this results in difficulty swallowing due to muscle paralysis, and consequently ingested material risks entering the trachea.
19	The **midline nuclei** of the thalamus receive afferents from the **mammillary bodies** of the hypothalamus and project to the cerebral cortex of the cingulate gyrus, forming part of a complex loop that also involves limbic lobe structures, known as the **Papez circuit**.
20	The **striate cortex** occupies Brodmann's area 17. It is located on the lips of the **calcarine sulcus** and is characterized by a very **thick** layer IV, crossed by a stripe of myelinated fibers, the stripe of the **Gennari** or external Baillarger stripe or line of **Gennari**, which runs parallel to the cortical surface and therefore defines the striate cortex.
21	The spino-bulbo-thalamo-cortical pathway is an important neural pathway that transmits sensory information from the spinal cord to the cerebral cortex, integrating sensory input and facilitating the perception of various stimuli. Below is a detailed description of this pathway along with a diagram. **Spino-Bulbo-Thalamo-Cortical Pathway** **Overview** The spino-bulbo-thalamo-cortical pathway consists of several key components that relay sensory information, particularly pain, temperature, and touch, from peripheral receptors to the brain: 1. **Spinal Cord**: The pathway begins in the spinal cord where first-order neurons (sensory neurons) enter and synapse with second-order neurons in the dorsal horn of the spinal cord. 2. **Bulbar Region (Medulla Oblongata)**: The axons of these second-order neurons decussate (cross over) to the opposite side and ascend through the spinal cord to the medulla oblongata. Here, they synapse with third-order neurons in specific nuclei such as the cuneate and gracile nuclei. 3. **Thalamus**: The third-order neurons then project to the thalamus, specifically targeting the ventral posterolateral (VPL) nucleus for somatosensory information. 4. **Cortex**: Finally, from the thalamus, sensory information is relayed to the primary somatosensory cortex located in the postcentral gyrus of the parietal lobe, where it is processed and perceived. **Functional Role**

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- The spino-bulbo-thalamo-cortical pathway is crucial for processing sensory modalities including nociception (pain), thermoreception (temperature), and mechanoreception (touch).

It allows for both conscious perception of these sensations as well as reflexive responses mediated by spinal circuits.

The median nerve is a crucial peripheral nerve that originates from the brachial plexus and courses through the arm, forearm, and into the hand. Below is a detailed description of its origin, course, and a diagram illustrating its pathway.

Origin of the Median Nerve

- The median nerve is formed by the union of two roots:
  - **Lateral Root**: Arises from the lateral cord of the brachial plexus, containing fibers from spinal nerves C5, C6, and C7.
  - **Medial Root**: Arises from the medial cord of the brachial plexus, containing fibers from spinal nerves C8 and T1.

This union typically occurs in the axillary region, just above the teres major muscle.

Course of the Median Nerve

1. **Axilla**: The median nerve descends in the axilla, initially lying lateral to the
22 axillary artery.
2. **Arm**: It travels down the arm, crossing anteriorly to the brachial artery as it descends. In this region, it lies between the biceps brachii and triceps brachii muscles.
3. **Cubital Fossa**: At the elbow, it enters the cubital fossa, lying medial to the brachial artery and deep to the bicipital aponeurosis. Here, it gives off several branches to muscles such as pronator teres and flexor carpi radialis.
4. **Forearm**: The median nerve passes between the two heads of the pronator teres muscle to enter the forearm. It runs deep to flexor digitorum superficialis and superficial to flexor digitorum profundus.
5. **Wrist**: As it approaches the wrist, it gives off a palmar cutaneous branch before entering the hand through the carpal tunnel beneath the flexor retinaculum.

Hand: In the hand, it divides into terminal branches that innervate thenar muscles and provide sensory innervation to parts of the palm.

The cerebellum is a critical structure in the brain responsible for coordinating voluntary movements, maintaining posture, and regulating balance. Its unique morphology contributes to its function, characterized by a highly folded surface and distinct anatomical regions. Below is a detailed description of the cerebellum's morphology along with a diagram.

Morphology of the Cerebellum

1. General Structure

- **Location**: The cerebellum is situated in the posterior cranial fossa, beneath the cerebrum and behind the brainstem.
- **Hemispheres**: It consists of two hemispheres (left and right) connected by a narrow midline structure known as the **vermis**.
23 • **Cerebellar Cortex**: The outer layer is composed of gray matter, forming the cerebellar cortex, which is highly folded into numerous ridges called **folia**. This folding increases the surface area for neuronal connections.

2. Lobes and Fissures

- The cerebellum can be divided into three main anatomical lobes:
  - **Anterior Lobe**: Located rostrally, it is involved in regulating muscle tone and coordinating postural adjustments.
  - **Posterior Lobe**: Positioned caudally, it plays a significant role in fine motor control and coordination of voluntary movements.
  - **Flocculonodular Lobe**: This small lobe is located inferiorly and is involved in balance and eye movements.
- **Fissures**: The lobes are separated by prominent fissures:

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	○ **Primary Fissure**: Divides the anterior lobe from the posterior lobe. ○ **Posterolateral Fissure**: Separates the posterior lobe from the flocculonodular lobe. **3. Internal Structure** • **White Matter**: Beneath the cerebellar cortex lies white matter, known as the **arbor vitae**, which has a tree-like appearance. This white matter containsmyelinated axons that connect different parts of the cerebellum and other brain regions. • **Deep Cerebellar Nuclei**: Embedded within the white matter are four pairs of deep nuclei (dentate, emboliform, globose, and fastigial), which serve as output structures for cerebellar signals. **4. Cellular Composition** • The cerebellar cortex contains several layers: ○ **Molecular Layer**: The outermost layer with few cell bodies but many synapses. ○ **Purkinje Cell Layer**: Contains large Purkinje cells that send inhibitory signals to the deep nuclei. ○ **Granular Layer**: The innermost layer rich in granule cells that form excitatory connections with Purkinje cells.
24	The lateral femoral cutaneous nerve (LFCN) is a sensory nerve that innervates specific cutaneous areas of the thigh. Here's a detailed description of the areas it supplies: **Innervation by the Lateral Femoral Cutaneous Nerve** • **Cutaneous Area**: The lateral femoral cutaneous nerve provides sensory innervation to the skin on the **lateral aspect of the thigh**. This includes both the anterior and posterior surfaces of the lateral thigh, extending down to approximately the level of the knee. • **Pathway**: The LFCN originates from the lumbar plexus, specifically from the dorsal branches of spinal nerves L2 and L3. It emerges from the lateral border of the psoas major muscle and travels over the iliacus muscle. The nerve passes under the inguinal ligament, typically medial to the anterior superior iliac spine (ASIS), before branching out to supply sensory innervation to the lateral thigh. **Clinical Relevance** The LFCN can be susceptible to injury, which may lead to conditions such as **meralgia paresthetica**, characterized by numbness, tingling, or pain in the lateral thigh due to nerve compression.
25	**Morphology of the Internal Ear** The internal ear, also known as the inner ear, is a complex structure embedded within the **petrous part of the temporal bone**. It consists of two main components: the **bony labyrinth** and the **membranous labyrinth**. Bony Labyrinth • **Cochlea**: A spiral structure responsible for hearing, it contains the **cochlear duct** of the membranous labyrinth. The cochlea is coiled around a central bony core called the **modiolus**. • **Vestibule**: The central part of the bony labyrinth, it houses the **saccule** and **utricle**of the membranous labyrinth. • **Semicircular Canals**: Three canals filled with fluid, they are involved in balance and equilibrium. Membranous Labyrinth • **Cochlear Duct**: Located within the cochlea, it contains the **organ of Corti**, which is crucial for sound processing. • **Saccule and Utricle**: These are located within the vestibule and are involved in balance. • **Semicircular Ducts**: These are part of the balance system and are filled with a fluid called **endolymph**.

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	The space between the bony and membranous labyrinths is filled with **perilymph**, a fluid similar in composition to extracellular fluid.
26	The extrapyramidal system (EPS) is a complex network of neural pathways and nuclei in the brain that plays a crucial role in the regulation and modulation of motor functions. It is distinct from the pyramidal system, which primarily controls voluntary movements. Below is a detailed description of the extrapyramidal system, including its components, functions, and clinical significance. **Description of the Extrapyramidal System** **1. Components** The extrapyramidal system consists of several key structures and pathways: • **Basal Ganglia**: A group of subcortical nuclei that include: ○ **Caudate Nucleus** ○ **Putamen** (together forming the striatum) ○ **Globus Pallidus** ○ **Substantia Nigra** ○ **Subthalamic Nucleus** • **Cerebellum**: Although primarily associated with coordination and balance, it interacts with the EPS to fine-tune motor activity. • **Brainstem Nuclei**: These include: ○ **Red Nucleus** ○ **Vestibular Nuclei** ○ **Reticular Formation** **2. Pathways** The EPS operates through several important tracts that connect these structures to the spinal cord and influence motor control: • **Reticulospinal Tract**: Modulates reflexes and autonomic functions. • **Vestibulospinal Tract**: Maintains balance and posture. • **Rubrospinal Tract**: Involved in motor control of flexor muscles. • **Tectospinal Tract**: Coordinates head and eye movements. **3. Functions** The primary functions of the extrapyramidal system include: • **Regulation of Involuntary Movements**: It helps control reflexes and automatic movements, such as those involved in maintaining posture. • **Fine-Tuning Voluntary Movements**: The EPS adjusts and refines voluntary movements initiated by the pyramidal system, making them more precise. • **Postural Tone Maintenance**: It plays a crucial role in maintaining muscle tone necessary for posture. • **Control of Automatic Movements**: Activities that become automatic through practice (e.g., riding a bicycle) are regulated by the EPS. • **Inhibition of Involuntary Movements**: The system helps suppress unwanted movements, contributing to smooth motor function. **4. Clinical Significance** Dysfunction in the extrapyramidal system can lead to various movement disorders. Conditions such as: • **Parkinson's Disease**: Characterized by tremors, rigidity, and bradykinesia due to degeneration of dopaminergic neurons in the substantia nigra. • **Huntington's Disease**: Involves hyperkinetic movements due to degeneration in the striatum. • Other conditions like dystonia, dyskinesia, and essential tremors are also linked to EPS dysfunction.
27	Broca's area is a critical region of the brain involved in language processing, particularly in speech production and comprehension. Below is a detailed description of its cortical regions based on the information gathered.

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Description of Broca's Area

Location

- Broca's area is located in the frontal lobe of the dominant hemisphere (usually the left hemisphere for right-handed individuals) and is specifically situated in the third frontal convolution , just anterior to the primary motor cortex that controls facial muscles and just above the Sylvian fissure (lateral sulcus).

Anatomical Components

Broca's area consists primarily of two Brodmann areas:

1. Pars Opercularis (Brodmann Area 44) :
   - This region is involved in the motor aspects of speech production, including phonation and articulation. It plays a role in coordinating the movements necessary for speech.
   - It is also associated with processing syntax and phonological aspects of language.

2. Pars Triangularis (Brodmann Area 45) :
   - This area contributes to semantic processing, which involves understanding word meanings and integrating them into coherent speech.
   - It is also implicated in higher cognitive functions related to language, such as grammar and sentence structure.

Functional Roles

- Speech Production : Broca's area is essential for generating articulate speech. Damage to this area can lead to Broca's aphasia, characterized by non-fluent speech, difficulty in forming grammatically correct sentences, and challenges with language repetition.
- Language Comprehension : While primarily associated with production, Broca's area also plays a role in understanding language, particularly in processing complex sentences.
- Motor Control : The region is involved in planning and executing the motor actions necessary for speech, linking language with motor functions.
- Integration with Other Areas : Broca's area connects with Wernicke's area (involved in language comprehension) via the arcuate fasciculus, facilitatingcommunication between language production and comprehension regions.

Connectivity

- Broca's area has extensive connections with other cortical regions:
  - It connects to the inferior parietal lobule , which integrates sensory information relevant to language.
  - There are connections to the superior and middle temporal gyri , which are important for auditory processing and comprehension of spoken language.
  - The area also interacts with medial frontal cortex regions (such as supplementary motor areas) that contribute to planning and executing complex motor tasks.

Clinical Significance

- Damage to Broca's area can result in various speech and language disorders, highlighting its importance in both production and comprehension of language. Understanding its structure and function aids in diagnosing and treating aphasia and other communication disorders.

Diagram of Broca's Area

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The cerebellar cortex is a highly structured and intricately organized layer of neurons that plays a crucial role in motor control and coordination. Below is a detailed description of the ultrastructure of the cerebellar cortex, along with a diagram to illustrate its organization.

Ultrastructure of the Cerebellar Cortex

1. Layers of the Cerebellar Cortex

The cerebellar cortex is composed of three distinct layers, each with specific types of neurons and functions:

- **Molecular Layer**:
  - This is the outermost layer and contains a sparse population of neurons, primarily **stellate cells** and **basket cells**, which are inhibitory interneurons.
  - The dendrites of **Purkinje cells** extend into this layer, forming a complex network with **parallel fibers** (the axons of granule cells) that run perpendicular to the Purkinje cell dendrites.
  - This layer is crucial for integrating sensory information and modulating Purkinje cell activity.
- **Purkinje Cell Layer**:
  - This middle layer consists of a single row of large **Purkinje cells**, which are the principal output neurons of the cerebellar cortex.
  - Purkinje cells have extensive dendritic trees that receive input from parallel fibers and climbing fibers (which originate from the inferior olivary nucleus).
  - The output from Purkinje cells is inhibitory, projecting to deep cerebellar nuclei and influencing motor control.

28

- **Granular Layer**:
  - The innermost layer is densely packed with small, tightly packed **granule cells**, which are the most numerous neurons in the brain.
  - Granule cells receive input from mossy fibers (which convey information from various sources) and send their axons into the molecular layer as parallel fibers.
  - This layer also contains **Golgi cells**, which provide inhibitory feedback to granule cells.

2. Neuronal Connections

- **Mossy Fibers**: These fibers project to granule cells and provide excitatory input, playing a critical role in conveying sensory and motor information to the cerebellum.
- **Climbing Fibers**: These fibers form powerful synapses directly onto Purkinje cell dendrites, providing strong excitatory input that is essential for motor learning and coordination.

3. Glial Cells

- The cerebellar cortex also contains various types of glial cells, including astrocytes, which support neuronal function and maintain homeostasis within the neural environment.

4. Functional Significance

The intricate organization of these layers allows for complex processing of motor information, coordination of movements, and integration of sensory feedback, making the cerebellum vital for maintaining balance and fine motor control.

The differences between the neocortex and paleocortex can be summarized based on their structure, function, evolutionary significance, and anatomical location. Below is a detailed comparison:

29

Differences Between Neocortex and Paleocortex

1. Structural Composition

- **Neocortex**:
  - Composed of **six distinct layers** (laminae) of neuronal cell bodies, which include:

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- Layer I: Molecular layer
- Layer II: Outer granular layer
- Layer III: Outer pyramidal layer
- Layer IV: Inner granular layer
- Layer V: Inner pyramidal layer
- Layer VI: Polymorphic layer

- Each layer has a specific arrangement of neurons and connections, facilitating complex processing and integration of information.

- **Paleocortex**:
- Composed of **three cortical layers** (laminae):
- Typically includes a more primitive structure compared to the neocortex.
- Lacks the complexity and distinct layering seen in the neocortex.

2. Functional Roles

- **Neocortex**:
- Involved in higher-order cognitive functions such as sensory perception, motor control, reasoning, language, and decision-making.
- It is responsible for processing information from various sensory modalities and integrating it for complex behaviors.

- **Paleocortex**:
- Primarily associated with the sense of **smell** (olfaction) and is involved in basic emotional responses.
- Plays a role in more primitive functions compared to the neocortex, reflecting its phylogenetic age.

3. Evolutionary Significance

- **Neocortex**:
- Considered the most evolutionarily advanced part of the cerebral cortex, it has expanded significantly in mammals, particularly in humans.
- Accounts for about **90%** of the human cerebral cortex and is associated with advanced cognitive functions.

- **Paleocortex**:
- Phylogenetically older than the neocortex, it is thought to represent an intermediate stage between the archicortex (which includes structures like the hippocampus) and the neocortex.
- Typically occupies a smaller area of the cerebral cortex (approximately **1%**) and is less developed in terms of cognitive processing capabilities.

4. Anatomical Location

- **Neocortex**:
- Found throughout most of the cerebral hemispheres, including areas such as the frontal, parietal, temporal, and occipital lobes.
- Examples include regions involved in sensory input (primary sensory areas) and motor output (primary motor cortex).

- **Paleocortex**:
- Located primarily in areas associated with olfactory processing, including parts of the olfactory bulb, piriform cortex, olfactory tubercle, and parts of the parahippocampal gyrus.

5. Clinical Relevance

- Damage or dysfunction in the neocortex can lead to significant impairments in cognitive functions such as language, reasoning, and sensory processing. Dysfunction in paleocortical regions may affect olfactory processing and emotional responses but typically does not lead to complex cognitive deficits.

30 The ultrastructure of the retina is a complex arrangement of various cell types and layers that contribute to its function in vision. Below is a detailed description based on the available information.

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Ultrastructure of the Retina

1. Layers of the Retina

The retina consists of several distinct layers, each with specific cellular components:

- Retinal Pigment Epithelium (RPE) :
  - A single layer of pigmented cells located just beneath the photoreceptors.
  - Functions include absorption of excess light, recycling of visual pigments, and support of photoreceptor cells.

- Photoreceptor Layer :
  - Contains rods and cones , the two types of photoreceptor cells responsible for light detection.
  - Rods are more numerous and sensitive to low light levels, while cones are responsible for color vision and function best in bright light.

- Outer Nuclear Layer (ONL) :
  - Contains the cell bodies of photoreceptors (rods and cones).

- Outer Plexiform Layer (OPL) :
  - Composed of synaptic connections between photoreceptors and bipolar cells, as well as horizontal cells that modulate signals.

- Inner Nuclear Layer (INL) :
  - Contains the cell bodies of bipolar cells, amacrine cells, and horizontal cells.

- Inner Plexiform Layer (IPL) :
  - Contains synaptic connections between bipolar cells and ganglion cells, along with processes from amacrine cells.

- Ganglion Cell Layer (GCL) :
  - Contains the cell bodies of retinal ganglion cells, which transmit visual information to the brain via their axons forming the optic nerve.

- Nerve Fiber Layer :
  - Composed of the axons of ganglion cells that converge to form the optic nerve.

2. Cellular Components

- Photoreceptors :
  - Rods contain outer segments filled with stacked disc membranes rich in rhodopsin for light absorption.
  - Cones have shorter outer segments with photopigments sensitive to different wavelengths (red, green, blue).

- Bipolar Cells :
  - Transmit signals from photoreceptors to ganglion cells; they can be classified into different types based on their connectivity and response properties.

- Ganglion Cells :
  - Their axons form the optic nerve; they integrate signals from multiple bipolar and amacrine cells.

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- Müller Cells :
  - Radial glial cells that span the entire thickness of the retina, providing structural support and maintaining homeostasis.

3. Synaptic Connections
The retina features complex synaptic networks:
- The OPL contains synapses between photoreceptors and bipolar cells, as well as horizontal cells that provide lateral inhibition.
- The IPL contains synapses between bipolar cells and ganglion cells, with amacrine cells modulating these connections.

4. Blood Supply
The retina receives its blood supply primarily from:
- The central retinal artery , which supplies the inner layers.
- The choroidal circulation , which supplies the outer layers, including the RPE and photoreceptors.

5. Functionality
The ultrastructural organization allows for efficient processing of visual information:
- Phototransduction occurs in photoreceptor outer segments.
- Signal processing involves multiple layers where lateral inhibition enhances contrast.
- Information is integrated at ganglion cell level before transmission to the brain.

Conclusion
The ultrastructure of the retina is characterized by its layered organization and specialized cell types that work together to convert light into neural signals. Understanding this structure is crucial for comprehending visual processing and addressing retinal diseases that can affect vision.

The overall performance of the four chatbots, based on the Likert scores for all the 30 questions, demonstrated a high general accuracy across all models (Table 7 and Figure 1A). In detail, ChatGPT-4 achieved the highest mean score (4.6 ± 0.5, mean ± standard deviation), closely followed by Perplexity.ai (4.5 ± 0.5). Microsoft Copilot (4.4 ± 0.5) and Google Gemini (4.1 ± 1,0) showed slightly lower. The only statistically significative differences were among ChatGPT-4 vs. Google Gemini ($p = 0.02$) and vs. Perplexity.ai ($p = 0.04$). All other comparisons were not statistically significative ($p > 0.5$).

Table 7. Evaluation of different Chatbots performances using a 5-point Likert scale.

Question	ChatGPT-4			Google Gemini			Microsoft Copilot			Perplexity.ai		
	R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3
1	5	5	5	5	5	5	5	5	5	4	5	5
2	4	5	5	4	5	5	4	5	5	5	5	5
3	5	5	5	4	5	5	5	5	5	5	5	5
4	5	5	5	4	5	4	4	5	4	4	5	4
5	5	5	5	5	5	5	5	5	5	5	5	5
6	5	5	5	4	5	4	4	5	4	5	5	5
7	4	5	5	5	5	5	4	5	4	5	5	5
8	5	5	5	5	5	5	5	5	5	5	5	5
9	5	5	5	5	5	5	4	5	4	5	5	5
10	4	5	5	4	5	5	4	5	5	4	5	5
11	4	5	5	4	5	5	5	5	5	4	5	5
12	4	5	5	4	5	4	4	5	5	4	5	4
13	4	5	4	3	4	4	4	3	4	3	4	4

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14	4	5	5	4	3	4	4	5	4	4	5	5
15	4	5	4	4	5	4	4	5	5	4	4	4
16	3	3	3	3	2	2	5	5	5	4	5	4
17	5	5	5	5	5	5	5	5	5	5	5	5
18	5	5	5	3	3	3	5	5	5	4	3	3
19	5	5	5	5	5	5	5	5	5	4	4	4
20	4	4	4	1	1	1	5	5	5	4	4	3
21	4	4	4	5	5	5	4	4	3	4	3	3
22	4	3	3	5	5	5	4	4	4	4	5	4
23	5	5	5	4	4	4	4	4	3	5	5	5
24	5	5	4	3	2	2	4	3	3	5	5	5
25	4	5	5	3	3	3	5	5	4	4	4	4
26	4	5	4	4	4	4	4	3	3	5	5	5
27	5	5	5	4	4	4	4	4	4	5	5	5
28	4	4	4	4	4	4	4	4	4	4	5	4
29	4	4	4	4	3	3	4	4	4	5	5	5
30	5	4	4	5	5	5	4	4	4	4	5	5

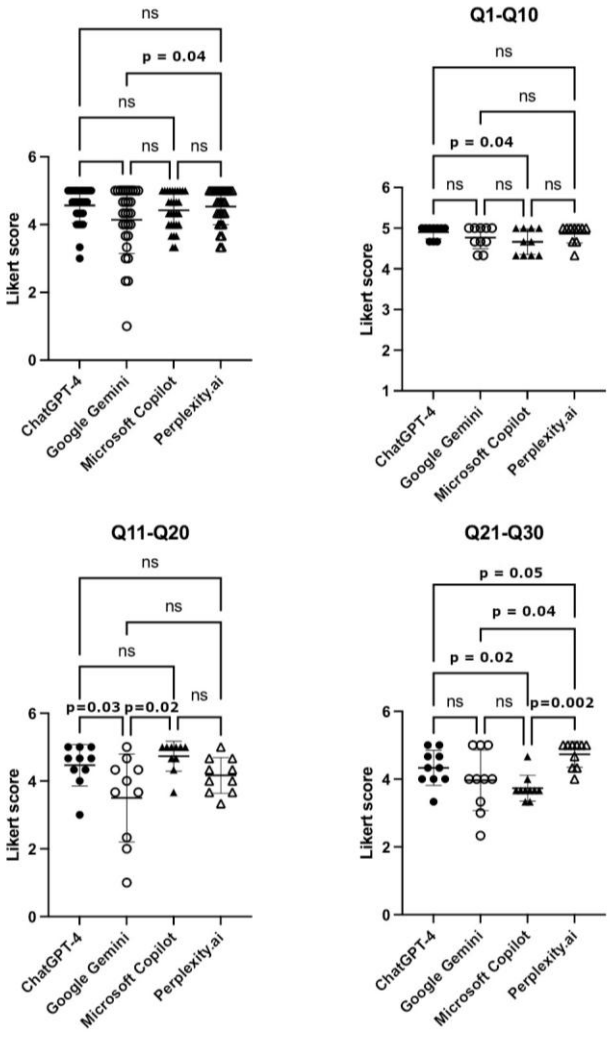

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Figure 1. Overall Chatbot Performance (Mean Likert Score). (A) Chart comparing the mean Likert scores of four AI chatbots, ChatGPT-4, Perplexity.ai, Microsoft Copilot, and Google Gemini, based on their responses to 30 neuroanatomy questions. ChatGPT-4 and Perplexity.ai achieved the highest mean scores, followed by Microsoft Copilot and Google Gemini. (B) Chart comparing the mean Likert scores of four AI chatbots, ChatGPT-4, Perplexity.ai, Microsoft Copilot, and Google Gemini, based on their responses to Q1-Q10 neuroanatomy questions. (C) Chart comparing the mean Likert scores of four AI chatbots, ChatGPT-4, Perplexity.ai, Microsoft Copilot, and Google Gemini, based on their responses to Q11-Q20 neuroanatomy questions. (D) Chart comparing the mean Likert scores of four AI chatbots, ChatGPT-4, Perplexity.ai, Microsoft Copilot, and Google Gemini, based on their responses to Q21-Q30 neuroanatomy questions. Error bars represent standard deviation, indicating variability in performance across question types. Numbers indicate p values (significative $p < 0.05$).

Indeed, the responses to the initial 10 "multiple-choice questions" received positive evaluations from the three examiners (Table 7 and Figure 1B). The mean score obtained was 4.9 ± 0.1 (mean ± standard deviation) for Chat-GPT and Perplexity.ai, 4.8 ± 0.2 for Google Gemini and Microsoft Copilot 4.7 ± 0.3. Therefore, while Chat-GPT and Perplexity.AI exhibited a marginally superior performance compared to Google Gemini and Microsoft Copilot, the overall efficacy of the analysed chatbots was notably high, demonstrating a robust capability to provide accurate and relevant information (ChatGPT-4 vs. Microsoft Copilot $p = 0.04$, for the other comparisons $p > 0.05$). The difference in evaluation is related to the completeness of the information from some chatbots that didn't just give the correct answer but went further to provide a neuroanatomical description.

The evaluation of questions 11 through 20, which were of the "fill-in-the-blank" format, revealed a similar performance pattern (Table 7 and Figure 1C). Specifically, Chat-GPT and Microsoft Copilot emerged as the most proficient, achieving a mean score of 4.4 ± 0.6 and 4.7 ±0.4, respectively. Conversely, Perplexity.ai (4.2 ± 0.5) and Google Gemini (3.5 ± 1.3) demonstrated a slightly comparatively reduced level of precision. In particular the worst performances were of Google Gemini ($p = 0.03$, and $p = 0.02$ respectively vs. ChatGPT-4 and Microsoft Copilot. The differences were not statistically significant ($p>0.05$). These findings underscore the nuanced variability in chatbot performance across different question formats, highlighting the importance of evaluating AI capabilities within specific task domains.

The comparison of the performances of the different bots in answering "describe and explain" type question (from 21 to 30), was notably poorer (Tables 4 to 6 and summarised in Table 7). This part of the study was certainly the one that put the different bots under the most stress, especially for the part concerning the "Illustrate: generate or suggest appropriate diagrams and visual aids". The results, therefore, highlighted a differential capacity among the chatbots to respond to this type of question. Perplexity.ai proved to be the best in formulating accurate neuroanatomical descriptions (score 4.7 ± 0.4), together with ChatGPT-4 (4.3 ± 0.5). On the contrary, Google Gemini (score 4.0 ± 0.9) and Microsoft Copilot (3.7 ± 0.4) provided answers that were not always consistent with the question. In certain instances, the information provided by the chatbots was suboptimal. Thus, the best performer was Perplexity.ai ($p = 0.05$, $p = 0.04$ and $p = 0.002$ respectively vs. ChatGPT-4, Google Gemini, and Microsoft Copilot). Finally, the other differences were not statistically significant ($p>0.05$).

It is widely recognized that the study of anatomy cannot be done merely from a text. Images are essential to fully understand the course of a nerve, the relationships between various structures, and so on. Thus, students could read a description, but the easier way to understand is to see a picture.

When queried about human anatomy, the chatbots provided textual information of varying quality. However, a significant limitation was the inability of the majority to generate visual representations. The absence of visual representations poses a significant challenge because the study of human anatomy fundamentally relies on the precise understanding of the morphology and spatial relationships of internal structures. In simpler terms, to truly grasp how our bodies work, we need to know not only *what* things are, but also *where* they are and *what shape* they have. That's why images are so fundamental.

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The free version of ChatGPT-4 and Google Gemini are unable to draw any type of image. Perplexity.ai, although unable to draw, often inserts links to images on the web. Finally, Microsoft Copilot proposes images that are often fanciful, with incorrect anatomical details, which can be misleading, especially in educational or medical contexts. Even the captions of the proposed images are characterized by errors. Fortunately, these errors are so evident that even a beginner student in anatomy can notice them (Figure 2).

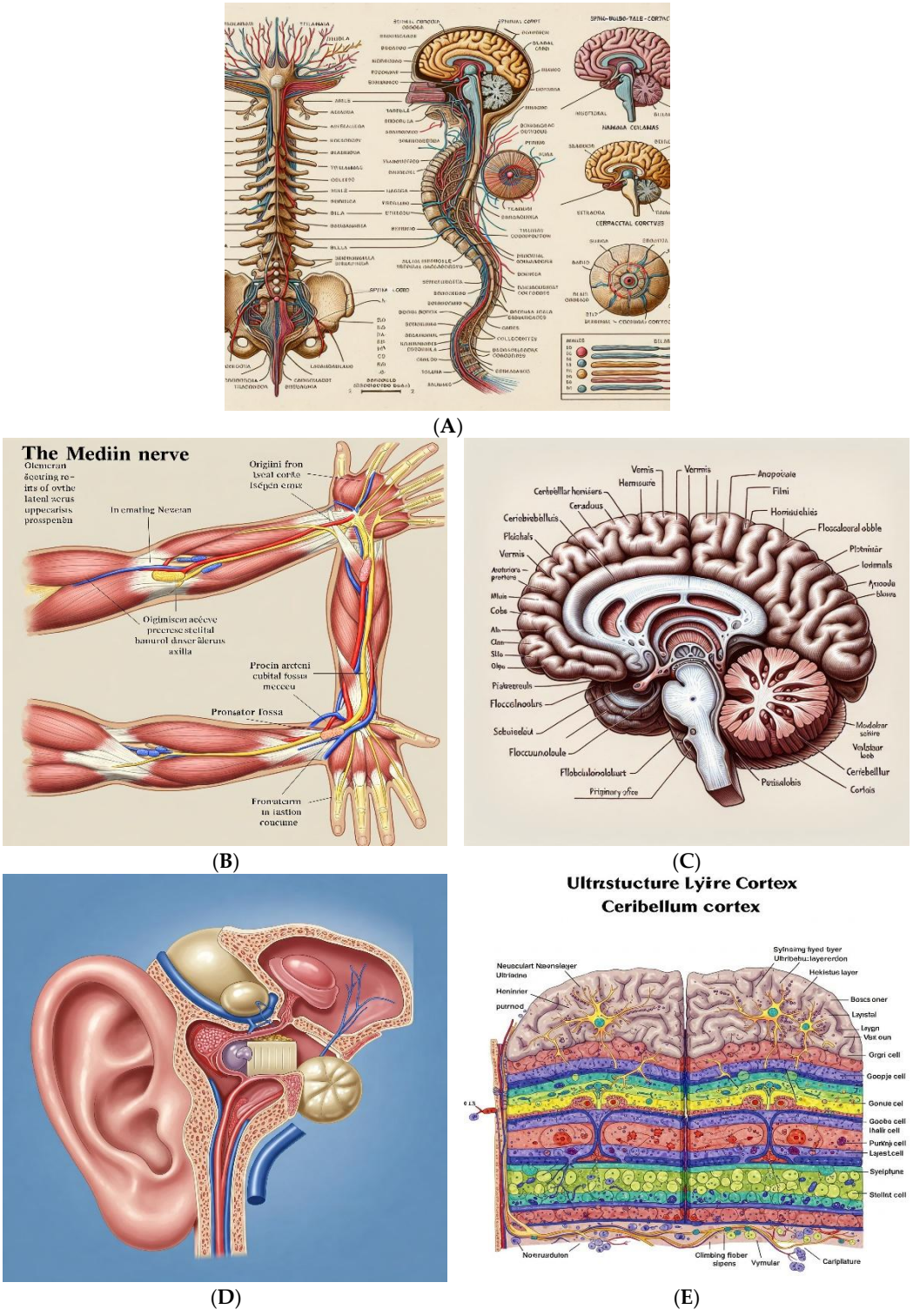

Figure 2. A graphical attempt to represent a neuroanatomical structure (April 2025). Microsoft Copilot tried to draw the spino-bulbo-thalamo-cortical pathway (A), the origin and the course of the median nerve (B), the morphology of cerebellum (C), the inner ear (D), and the microscopic morphology of the cerebellum's cortex (E). It's clear that the pictures don't make sense.

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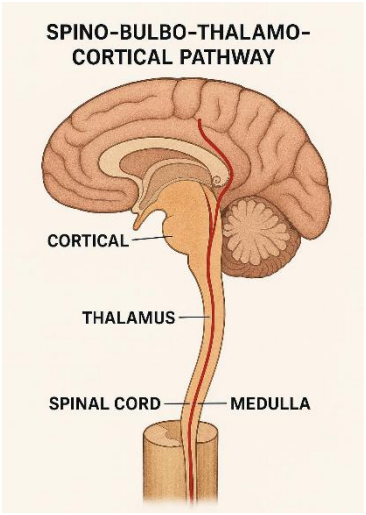
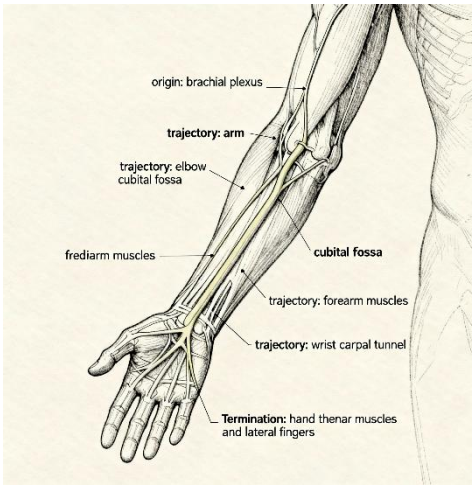
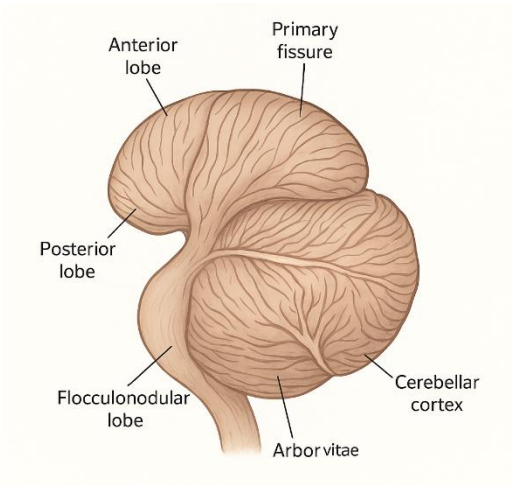
All these tests were performed during the last April. We performed recently a new evaluation on Microsoft Copilot capabilities to draw anatomical images. The aim was to verify a possible improve of this Chabot. As shown in Figure 3, Microsoft Copilot's ability to draw neuroanatomical images remains very imprecise and often "imaginative." Even after more than six months, its ability to represent anatomical images has not improved, highlighting a significant weakness in this system. Fortunately, the images are so "imaginative" and clearly incorrect that they could not lead a student to interpret them as accurate representations of reality.



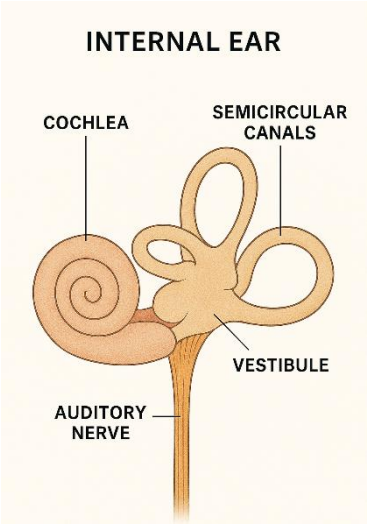
(A)



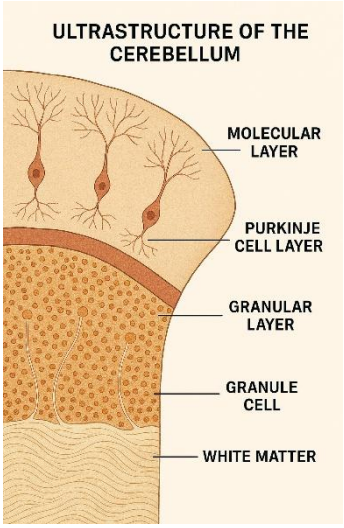
(B)



(C)



(D)



(E)

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Figure 3. A graphical attempt to represent a neuroanatomical structure (December 2025). Microsoft Copilot tried to draw the spino-bulbo-thalamo-cortical pathway (A), the origin and the course of the median nerve (B), the morphology of cerebellum (C), the inner ear (D), and the microscopic morphology of the cerebellum's cortex (E). Although the graphic results have improved, the output is still far from being acceptable and instructive for a medical student.

4. Discussion

Since its introduction at the end of 2022, ChatGPT-4 marked a significant milestone in the application of AI within higher education. Owing to its advanced natural language processing capabilities, the model rapidly gained widespread popularity among students worldwide. However, the growing adoption of ChatGPT-4 by the student population has sparked considerable global debate, eliciting both enthusiasm and scepticism [24]. These dynamics have prompted a systematic investigation aimed at assessing the effectiveness and accuracy of the system's responses to potential neuroanatomy-related questions.

The present study evaluated the performance of four widely used AI chatbots, ChatGPT-4, Google Gemini, Microsoft Copilot, and Perplexity.ai, in answering neuroanatomy questions of varying complexity. Using a structured Likert scale assessment, we observed that while all platforms demonstrated strong performance on factual and recall-based questions, significant limitations emerged in tasks requiring visual representation and comprehensive descriptive responses.

4.1. Comparison with Previous Literature

Our findings align with earlier reports emphasizing the growing role of AI-based large language models (LLMs) in medical education, particularly in anatomy, where rapid access to structured information can enhance self-directed learning and examination preparation [3, 10, 23]. Similar to the results of Singal et al. [17], who reported high accuracy rates for AI platforms in anatomy MCQs, our study confirms that LLMs excel in structured question formats. However, consistent with observations by Al-Khater [4] and Bolgova et al. [8], the inability of these models to accurately interpret or generate anatomical illustrations remains a critical shortcoming.

Finally, our results are consistent with those reported by Singal and Goyal [17], who observed near-perfect accuracy among LLMs when solving anatomy MCQs, with Google Gemini models performing slightly better than ChatGPT-4 and DeepSeek. However, similar to their findings, our study also underscores persistent limitations in handling complex or image-based tasks, reinforcing the argument that AI tools should complement rather than replace traditional anatomy teaching methods.

4.2. Performance Trends and Reliability

ChatGPT-4 and Perplexity.ai achieved the highest overall Likert scores, indicating strong reliability for text-based queries. Microsoft Copilot and Google Gemini followed closely, though Gemini exhibited greater variability, suggesting inconsistent performance across question types. These findings echo prior studies where ChatGPT-4 demonstrated superior consistency compared to other platforms in anatomy-related tasks [22, 23]. Inter-rater agreement in our study was high, reinforcing the robustness of the evaluation process.

4.3. Challenges in Visual and Applied Anatomy

Illustration-based prompts received the lowest ratings, underscoring a persistent gap in AI's ability to handle spatially complex anatomical information. This limitation has been highlighted in previous research, where LLMs struggled with radiologic anatomy and surface marking tasks [4, 23]. Although Microsoft Copilot attempted image generation, the outputs were anatomically inaccurate, raising concerns about potential misinformation if such tools are used without expert oversight.

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Of note, we observed the lack of improvement and/or learning of Chatbots over the past six months in the figurative representation abilities of neuroanatomy. This implies that students should carefully evaluate images created by Chatbots. On the other hand, the errors are so manifest that even a beginner student would hardly be misled. In conclusion, we believe that, for those approaching the study of neuroanatomy for the first time, using an atlas or textbook remains the best solution. Paradoxically, Google search and chatbots that retrieve images from the internet or from scientific articles on PubMed are more reliable.

4.4. Educational Implications

The high performance of chatbots in factual domains suggests their potential as supplementary tools for reinforcing theoretical knowledge. Their speed and accessibility can support active learning strategies, particularly for first-year medical students who often face cognitive overload in anatomy [2-4, 9-13, 16, 17, 23]. However, reliance on these tools without critical appraisal may propagate errors, especially in clinically relevant or visually dependent topics. Therefore, integration of AI into anatomy curricula should be accompanied by structured guidance and expert validation [2-4, 9-13, 16, 17, 23].

5. Conclusion

The present study highlights the growing potential of AI-based chatbots as supplementary tools in neuroanatomy education. Among the evaluated platforms, ChatGPT-4 and Perplexity.ai demonstrated the highest overall performance, achieving strong Likert ratings for accuracy, clarity, and relevance in text-based question formats. Microsoft Copilot and Google Gemini also performed well, though with slightly greater variability. These findings reinforce the capability of LLMs to support factual learning and rapid information retrieval, which can be particularly beneficial for early-stage medical learners facing extensive cognitive demands.

However, the persistent limitations observed in illustration-based and higher-order descriptive tasks underscore a critical gap in current AI technology. Neuroanatomy, as a discipline, relies heavily on spatial reasoning and visual interpretation, domains where all evaluated chatbots underperformed. This shortcoming not only restricts their role as standalone educational resources but also raises concerns about potential misinformation if such tools are used without expert oversight.

From an educational perspective, AI chatbots can complement traditional teaching by providing immediate, accessible explanations and reinforcing theoretical knowledge. Yet, their integration into curricula must be approached cautiously, with structured guidance and continuous validation by subject matter experts. Future advancements should prioritize the incorporation of validated visual resources, adaptive feedback mechanisms, and domain-specific fine-tuning to bridge the current performance gap.

In conclusion, while AI chatbots represent a promising adjunct in anatomy education, they cannot replace the irreplaceable value of hands-on dissection, interactive visualization, and expert-led instruction. Their optimal role lies in augmenting, not substituting, traditional pedagogical strategies, ensuring that technological innovation enhances, rather than compromises, the integrity of medical education.

6. Future Directions in AI-Assisted Anatomy Education

The findings of this study emphasize the need for ongoing refinement of AI-based tools in anatomy education. Future development should highlight the integration of validated, peer-reviewed visual resources to overcome current limitations in anatomical illustration. Training AI with neuroanatomy data and medical ontologies could make it more accurate and reduce errors. Reliability could be strengthened through adaptive feedback systems that allow users to flag mistakes and receive corrected explanations, promoting active learning while improving model performance.

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Evaluations should also expand to include problem-solving, clinical reasoning, and applied anatomy scenarios, offering a more comprehensive view of AI's educational potential. Comparative studies of free versus premium models are warranted to inform institutional adoption. Finally, ethical and pedagogical oversight, combined with larger question banks and image-based assessments, will be essential to ensure safe, effective, and equitable integration of AI into anatomy curricula.

References

1. Ahn, S. (2023). The impending impacts of large language models on medical education. *Korean Journal of Medical Education, 35*(1), 103–107. https://doi.org/10.3946/kjme.2023.253
2. Totlis, T., Natsis, K., Filos, D., Ediaroglou, V., Mantzou, N., Duparc, F., & Piagkou, M. (2023). The potential role of ChatGPT and artificial intelligence in anatomy education: A conversation with ChatGPT. *Surgical and Radiologic Anatomy, 45*(10), 1321–1329. https://doi.org/10.1007/s00276-023-03229-1
3. Mogali SR. Initial impressions of ChatGPT for anatomy education. Anat Sci Educ. 2024 Mar;17(2):444-447. doi: 10.1002/ase.2261.
4. Mantzou, N., Ediaroglou, V., Drakonaki, E., Syggelos, S. A., Karageorgos, F. F., & Totlis, T. (2024). ChatGPT efficacy for answering musculoskeletal anatomy questions: A study evaluating quality and consistency between raters and timepoints. *Surgical and Radiologic Anatomy, 46*(11), 1885–1890. https://doi.org/10.1007/s00276-024-03477-9
5. Sallam, M. (2023). ChatGPT utility in healthcare education, research, and practice: Systematic review on the promising perspectives and valid concerns. *Healthcare, 11*(6), 887. https://doi.org/10.3390/healthcare11060887
6. Lee H. The rise of ChatGPT: Exploring its potential in medical education. Anat Sci Educ. 2024 Jul-Aug;17(5):926-931. doi: 10.1002/ase.2270. Epub 2023 Mar 28. Erratum in: Anat Sci Educ. 2024 Dec;17(9):1779. doi: 10.1002/ase.2496.
7. Bolgova, O., Ganguly, P., & Mavrych, V. (2025). Comparative analysis of LLMs performance in medical embryology: A cross-platform study of ChatGPT, Claude, Gemini, and Copilot. *Anatomical Sciences Education, 18*, 718–726. https://doi.org/10.1002/ase.70044
8. Boscardin, C. K., Gin, B., Golde, P. B., & Hauer, K. E. (2024). ChatGPT and generative artificial intelligence for medical education: Potential impact and opportunity. *Academic Medicine, 99*(1), 22–27. https://doi.org/10.1097/ACM.0000000000005439
9. Al-Khater, K. M. K. (2025). Comparative assessment of three AI platforms in answering USMLE step 1 anatomy questions or identifying anatomical structures on radiographs. *Clinical Anatomy, 38*(2), 186–199. https://doi.org/10.1002/ca.24243
10. Mavrych, V., Ganguly, P., & Bolgova, O. (2025). Using large language models (ChatGPT, Copilot, PaLM, Bard, and Gemini) in gross anatomy course: Comparative analysis. *Clinical Anatomy, 38*(2), 200–210. https://doi.org/10.1002/ca.24244
11. Manavalan MS, Sundaramurthi I, Surapaneni KM: Assessment of the performance of ChatGPT in human anatomy of first professional MBBS Competency Based Medical Education (CBME) undergraduate. Indian J Anat. 2024, 13:17-26. doi.org/10.21088/ija.2320.0022.13124.2.
12. Saluja S, Tigga S.R. Capabilities and Limitations of ChatGPT in Anatomy Education: An Interaction With ChatGPT. Cureus 2024, 16: e69000. doi:10.7759/cureus.69000.
13. Abdellatif H, Al Mushaiqri M, Albalushi H, Al-Zaabi AA, Roychoudhury S, Das S. Teaching, Learning and Assessing Anatomy with Artificial Intelligence: The Road to a Better Future. Int J Environ Res Public Health. 2022 Oct 31;19(21):14209. doi: 10.3390/ijerph192114209.
14. Sarker IH. AI-based modeling: techniques, applications and research issues towards automation, intelligent and smart systems. SN Comput Sci. 2022, 3:158. 10.1007/s42979-022-01043-x.
15. Korteling JE, van de Boer-Visschedijk GC, Blankendaal RA, Boonekamp RC, Eikelboom AR: Human-versus artificial intelligence. Front Artif Intell. 2021, 4:622364. 10.3389/frai.2021.622364
16. Talan, T. & Kalınkara, Y. The Role of Artificial Intelligence in Higher Education: ChatGPT Assessment for Anatomy Course. Uluslararası Yönetim Bilişim Sistemleri ve Bilgisayar Bilimleri Dergisi, 7 (1), 33-40, 2023. DOI: 10.33461/ uybisbbd.1244777.

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Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 16 April 2026 doi:10.20944/preprints202604.1136.v1

17. Singal, A., & Goyal, S. (2025). Comparative evaluation of AI platforms "Google Gemini 2.5 Flash, Google Gemini 2.0 Flash, DeepSeek V3 and ChatGPT 4o" in solving multiple-choice questions from different subtopics of anatomy. *Surgical and Radiologic Anatomy, 47*, 193–202. https://doi.org/10.1007/s00276-025-03707-8
18. García-López, I. M., & Trujillo-Liñán, L. (2025). Ethical and regulatory challenges of Generative AI in education: A systematic review. *Frontiers in Education, 10,* 1565938. https://doi.org/10.3389/feduc.2025.1565938
19. Hua, S., Jin, S., & Jiang, S. (2024). *The limitations and ethical considerations of ChatGPT.* Data Intelligence, 6(1), 201–239. https://doi.org/10.1162/dint_a_00243
20. Abbas, A., Rehman, M. S., & Rehman, S. S. (2024). Comparing the performance of popular large language models on the national board of medical examiners sample questions. *Cureus, 16*(3), e55991. https://doi.org/10.7759/cureus.55991
21. Wang KD, Burkholder E, Wieman C, Salehi S and Haber N (2024) Examining the potential and pitfalls of ChatGPT in science and engineering problem-solving. *Front. Educ.*8:1330486. doi: 10.3389/feduc.2023.1330486
22. Sallam, M. (2023). ChatGPT Utility in Healthcare Education, Research, and Practice: Systematic Review on the Promising Perspectives and Valid Concerns. *Healthcare, 11*(6), 887. https://doi.org/10.3390/healthcare11060887
23. Mavrych V, Ganguly P, Bolgova O. Using large language models (ChatGPT, Copilot, PaLM, Bard, and Gemini) in Gross Anatomy course: Comparative analysis. Clin Anat. 2025 Mar;38(2):200-210. doi: 10.1002/ca.24244.
24. Aristovnik, Aleksander; Ravšelj, Dejan; Keržič, Damijana; Tomaževič, Nina; Umek, Lan; Brezovar, Nejc; al, et. (2025), "Higher Education Students' Evolving Perceptions of ChatGPT: Global Survey Data from the Academic Year 2024–2025", Mendeley Data, V1, doi: 10.17632/nv2343nwsb.1

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