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Review Article

Exploring the Complexity of the Human Brain: Cell Types, Numbers, and Lobar Functions

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Introduction

The human brain, an exquisitely intricate organ, acts as the central command center for cognition, emotion, and sensory perception. It orchestrates a remarkable array of functions, ranging from basic survival mechanisms to the most complex aspects of human thought and behavior [1]. Comprising billions of neurons alongside an equally vast number of supporting glial cells, the brain's elaborate network underpins every facet of our mental and physical experiences. Neurons serve as the primary communicators, transmitting electrical and chemical signals across complex neural circuits, enabling everything from simple reflexes to advanced problem-solving [2]. Meanwhile, glial cells, such as astrocytes, oligodendrocytes, and microglia, play critical roles in maintaining homeostasis, providing structural support, and facilitating communication within this neural framework [3].

Understanding the cellular composition of the brain, specifically the variety and quantity of its cells, has emerged as one of the most profound and elusive questions in neuroscience. This cellular diversity is not merely a matter of counting cells; it involves unraveling the distinct functional roles of various cell types and their intricate interactions. Each type of cell contributes uniquely to the overall functionality of the brain, and the balance and distribution of these cells can profoundly impact brain health and disease [4]. The quest to accurately enumerate the number of cells in the human brain extends beyond mere academic curiosity; it has signif-

icant implications for both fundamental and clinical neuroscience [3]. A precise understanding of cell numbers and types offers critical insights into brain structure and function, shaping our theories of brain development, aging, and neuroplasticity [5]. This review seeks to provide a comprehensive overview of the cell types and quantities within the human brain, illuminating the remarkable complexity that defines our most vital organ.

History of Cell Counting Methods

Brain cell counting has evolved through three distinct historical phases. Initially, data collection was limited to specific brain regions, primarily the cerebral cortex. During this period, which extended until the 1970s, some researchers expressed uncertainty about the absolute number of brain cells, while others estimated or theorized GNRs for the whole brain. The second phase saw the emergence of more comprehensive estimates for total cell counts, including glial cells, ranging from 40 to 130 billion and neurons ranging from 70 to 85 billion [6,7]. Despite these estimates suggesting a glial-to-neuron ratio (GNR) of approximately 1:1, this information was either overlooked or not effectively communicated. Consequently, the exaggerated ratios of 10:1 or even 50:1 persisted in major textbooks and reviews, with this misconception remaining largely unchallenged from the 1960s until 2009. This incorrect GNR had, unfortunately, become accepted as "common knowledge." In the third phase, *Azevedo, et al.*'s study (2009), showed that the previous textbook claims about the number of glial cells versus neurons were incorrect. This study confirmed that the earlier estimates of roughly equal numbers of neurons and glial cells previously reported by *Blinkov* and *Glezer* (1968) and *Haug* (1986) were more accurate, leading to a correction in the understanding of brain cell counts [6,8].

Overview of Cell Counting Methods

There are three different methods used to estimate the number of cells in the brain which are histology/stereology, DNA extraction and "direct enumeration" of cells in homogenized brain tissue.

Histology/stereology

The histology method for estimating the number of brain cells begins with the fixation of brain tissue using a formaldehyde-based solution. This process preserves the cellular structure and prevents decay. Once fixed, the tissue is embedded in a supportive medium and sliced into thin sections. These thin slices are then stained with specific dyes that enhance the visibility of cells or subcellular components and counted under a microscope. There are two main approaches to this counting process: the model-based approach, known as profile counting and the design-based approach, or stereology. In model-based approach, subcellular particles (usually nuclei or nucleoli) are counted in thin sections, then extrapolates to estimate total cell numbers. [9-11]. The design-based approach (stereology) takes random samples within these sections so that the samples are representative of the particle density [12-15].

DNA extraction

DNA extraction methods involve isolating the DNA contained within cells, allowing researchers to analyze genetic material for various applications [16]. This process typically begins with cell lysis, where the cell membrane is broken down to release the DNA. Following lysis, different purification techniques, such as phenol-chloroform extraction or silica-based methods, are employed to separate the DNA from proteins and other cellular components [17]. Once the DNA is extracted, researchers can calculate cell numbers by using the known average DNA content per cell nucleus, which is specific to the organism and cell type being studied. By quantifying the extracted DNA, scientists can derive the total number of cells in the sample, providing valuable insights for studies in genetics, cell biology, and molecular research [18].

Homogenization

This method was initially developed in the 1950s and involved weighing dissected chilled tissue, homogenizing it, and diluting it in a known volume of medium [19]. The tissue was then stained with methylene blue, mixed, and aliquots were counted using a hemocytometer. However, this approach had significant limitations, including the rapid degradation of unfixed cells and the inability to distinguish between different cell types [19]. Further modification of this method was introduced in 2005 and was called "isotropic fractionator" [8,20]. This include nuclei visualization using a fluorescent nuclear stain (4′,6-Diamidino-2-Phenylindole, DAPI), and neuronal and non-neuronal cell nuclei are differentiated using a neuron-specific antibody, anti-NeuN [21]. This method is advantageous because it is easy, fast, and accurate, producing cell estimates that are independent of tissue volume or cell density, and it effectively addresses the heterogeneity of brain tissues.

The Number of Lobes and Cellular Count in the Human Brain.

In the early 20th century, neuroscientist Korbinian Brodmann (1868-1918) identified 52 distinct lobes of the human brain (Figure 1), each contributing significantly to various cognitive functions. These lobes facilitate critical processes such as motor control, emotion regulation, and decision-making, illustrating how different regions collaborate to support complex behaviours (Table 1). Understanding these lobes provides valuable insights into how the brain orchestrates a wide range of functions, revealing the intricacies of its operational dynamics. By mapping these connections and examining how they interact, researchers can better understand both normal brain function and the disruptions that can lead to neurological and psychiatric disorders.

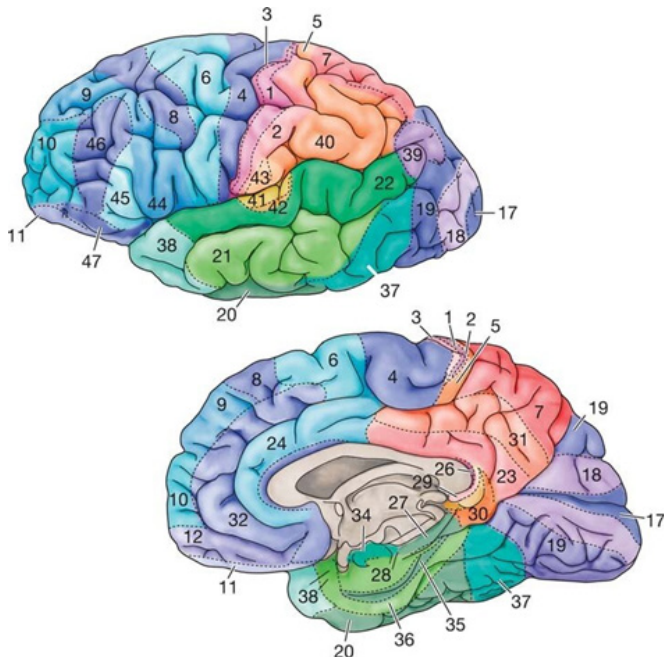

Figure 1: Types of lobes of human brain.
Source: Linda, 2016

Table 1: Types of lobes of human brain.

No	Lobes name	Function
1	Primary somatosensory cortex	Responsible for processing sensations of the body.
2	Primary somatosensory cortex	Responsible for processing sensations of the body.
3	Primary somatosensory cortex	Responsible for processing sensations of the body.
4	Primary motor cortex	Involved in initiating motor movements as well as coordinating these movements.
5	Somatosensory association cortex	An area for sensory input.
6	Premotor cortex and supplementary motor cortex	Helps to control and plan movements.
7	Visuo-motor coordination	An area for sensory input.
8	Frontal eye fields	Role in the control of visual attention and eye movements.
9	Dorsolateral prefrontal cortex	Involved in 'higher' cognitive functions such as working memory, planning, abstract reasoning, motor planning, and organization.
10	Anterior prefrontal cortex	Higher cognitive functions such as task management and planning.
11	Orbitofrontal area	Receives information about the sight of objects as well as the reward value of taste.
12	Orbitofrontal area	Receives information about the sight of objects as well as the reward value of taste.
13	Insular cortex	Sensory processing, decision-making, and motor control.
16	Insular cortex	Sensory processing, decision-making, and motor control.
17	Primary visual cortex (V1)	Interpreting and processing visual information received from the eyes.
18	Secondary visual cortex (V2)	Receives visual information for further analysis.
19	Associate visual cortex (V3, V4 & V5)	Complex processing of visual information.
20	Inferior temporal gyrus	Play a part in high-level visual processing and recognition memory.
21	Middle temporal gyrus	Involved in functions such as sound recognition and semantic retrieval, as well as semantic memory, language processing, and processing of verbal and mental arithmetic.

22	Superior temporal gyrus	Involved in auditory short-term memory and the production of speech.
23	Ventral posterior cingulate cortex	Involved in processing emotions and behavior regulation.
24	Ventral anterior cingulate cortex	Involved in processing emotions and behavior regulation..
25	Subgenual area	A limbic area rich in serotonin transporters which works with the other areas of the limbic system.
26	Ectosplenial portion of the retrosplenial region of the cerebral cortex	Related to motor learning.
27	Piriform cortex	Related to the sense of smell.
28	Ventral entorhinal cortex	Involved in processing emotions and behavior regulation.
29	Retrosplenial cortex	Related to episodic memory and navigation
30	Subdivision of retrosplenial cortex	An interface between emotional regulation, sensing and action.
31	Dorsal Posterior cingulate cortex	A central node of the default mode network (DMN), a set of brain structures with strong associations for activity during many cognitive tasks.
32	Dorsal Anterior cingulate cortex	Processing the detection and appraisal of social processes.
33	Part of anterior cingulate cortex	Involved in processing emotions and behavior regulation.
34	Dorsal entorhinal cortex	Involved in working memory.
35	Perirhinal cortex & ectorhinal area	Involved in working memory.
36	Perirhinal cortex & ectorhinal area	Involved in working memory.
37	Fusiform gyrus	Involved in higher-level visual processing.
38	Temporal pole	High-level visual area involved in visual cognition, face recognition, and visual memory.
39	Angular gyrus	Related to language and number processing, spatial cognition, memory retrieval, and attention.
40	Supramarginal gyrus	Involved in phonological processing and emotional responses.
41	Primary auditory cortex	First relay station of auditory information in the cortex.
42	Primary auditory cortex	First relay station of auditory information in the cortex.
43	Primary gustatory cortex	Responsible for the perception of taste.
44	Part of Broca area	Associated with speech production and articulation.
45	Part of Broca area	Associated with speech production and articulation.
46	Dorsolateral prefrontal cortex	Involved in cognitive functions such as working memory, attention, and executive function.
47	Pars orbitalis, part of the inferior frontal gyrus	Role in the processing of language.
48	Retrosubicular area	Processing of emotions, encoding, and navigation.
52	Parainsular area	Related to attention and salience processing

At the heart of the human brain lies the brain's cellular composition, which is essential for their functionality. Quantitative neuroscience researchers have employed histological methods to estimate the number of neurons in the human brain, providing valuable insights into its complex architecture. Estimates vary widely, with figures ranging from 30 billion to 70-80 billion, and reaching up to 85 billion [6,7,22]. More recent studies using the isotropic fractionator method have corroborated these estimates, suggesting there are between 67 and 86 billion neurons [8,20]. In terms of glial cells, early estimates by Blinkov and Glezer (1968) suggested a total of 100-130 billion glial cells in the human brain. However, Haug's own measurements indicated a lower estimate of 40-50 billion glial cells [6]. Current estimates derived from the isotropic fractionator method suggest that the total number of glial cells is likely below 85 billion, since this total includes approximately 20-25 billion endothelial cells. Thus, these findings align more closely with Haug's estimates of 40-50 billion glial cells rather than those of Blinkov and Glezer.

Factor Affecting Variation of Number of Brain Cells Among Human

Variations in the number of neurons among humans arise from a complex interplay of factors, including genetics, age, and health conditions. Each individual's genetic makeup can lead to distinct differences in brain structure and neuronal density [23]. For instance, genetic variations can influence the production of growth factors and neurotransmitters that are critical for neuron development and connectivity. This can result in differing neuronal densities in key areas such as the prefrontal cortex, responsible for decision-mak-

ing, impulse control, and higher cognitive functions, and the hippocampus, which plays a crucial role in memory formation and spatial navigation [24]. Research has shown that these variations not only affect brain structure but also correlate with cognitive abilities, emotional regulation, and learning capacity. For example, individuals with a higher density of neurons in the hippocampus may have better memory retention and spatial awareness [25]. Additionally, as individuals age, they typically experience a decline in neuron numbers due to natural aging processes, including oxidative stress, inflammation, and reduced neurogenesis. This decline can manifest as slower processing speeds, decreased memory capacity, and increased difficulty in learning new information, highlighting the critical importance of maintaining neuron health throughout life to support cognitive function and emotional well-being [26].

Health conditions play a pivotal role in neuronal variability, particularly neurodegenerative diseases such as Alzheimer's and Parkinson's. These disorders are characterized by the progressive loss of neurons, particularly in regions essential for cognitive function and motor control [27]. In Alzheimer's disease, substantial neuron loss occurs in the hippocampus, which severely impacts memory, learning, and the ability to form new memories. Additionally, the accumulation of amyloid plaques and tau tangles in the brain further contributes to neuronal damage and cognitive decline [28]. In contrast, Parkinson's disease primarily affects the substantia nigra, where the loss of dopamine-producing neurons leads to hallmark motor symptoms such as tremors, rigidity, and bradykinesia (slowness of movement). The extent of neuron loss in these critical areas serves as a vital indicator of disease severity and progression, enabling healthcare providers to tailor treatment strategies accordingly [29].

Lifestyle and environmental factors also significantly influence neuron count and overall brain health. Regular physical activity has been shown to promote neurogenesis, the process by which new neurons are created, and improve brain plasticity, which is essential for learning, memory, and recovery from injury. Exercise enhances blood flow to the brain, increases levels of neurotrophic factors like BDNF (brain-derived neurotrophic factor), and reduces inflammation, all of which contribute to neuronal health [30]. A balanced diet rich in omega-3 fatty acids, antioxidants, and essential vitamins supports neuronal integrity and can mitigate age-related cognitive decline. For example, omega-3 fatty acids found in fish have been linked to improved cognitive function and may help protect against neurodegeneration [31]. Engaging in intellectually stimulating activities, such as reading, solving puzzles, or learning new skills, has also been associated with enhanced cognitive function and resilience against decline [32]. Conversely, exposure to environmental toxins, chronic stress, and substance abuse can lead to neuronal damage and loss, heightening the risk of cognitive decline and neurodegenerative diseases [33].

Human Brain Structural Changes During Aging

The aging process significantly affects the brain, resulting in a gradual decline in both its volume and weight. Research indicates that, after reaching the age of 40, this decline occurs at an approximate rate of 5% per decade [34]. This rate of decline may accelerate further after the age of 70, leading to more pronounced changes in brain structure and function [35].

The impact of aging is not distributed evenly across the various regions of the brain [36]. The prefrontal cortex, which is crucial for executive functions such as decision-making, impulse control, and social interactions, is the area most severely affected by aging [37]. Following the prefrontal cortex, the striatum, an essential component of the brain's reward system and movement regulation, shows notable changes. Other regions experiencing decline include the temporal lobe, involved in processing auditory information and forming memories; the cerebellar vermis and cerebellar hemispheres, which are vital for coordination, balance, and motor learning; and the hippocampus, a key region for memory consolidation and spatial navigation [38].

Interestingly, the prefrontal white matter, which consists of myelinated axons that facilitate communication between different brain regions, also demonstrates deterioration, potentially affecting overall cognitive efficiency [39]. In contrast, the occipital cortex, responsible for visual processing, appears to be the least affected by age-related changes. This specific pattern of brain aging aligns closely with the cognitive alterations frequently observed in older adults, such as memory decline, slower processing speeds, and diminished executive functioning [37]. Some studies further highlight the vulnerability of the hippocampus to age-related decline, underscoring its critical role in memory and learning processes [40].

In addition to these general trends, research has identified notable gender differences in how aging impacts the brain. Men often exhibit greater declines in the frontal and temporal lobes, which can affect cognitive abilities and emotional regulation. Conversely, women tend to experience more pronounced effects in the hippocampus and parietal lobes, regions associated with memory and spatial awareness [41,42].

Types of Cells in the Human Brain

The human brain composed of a variety of cell types (Table 2) that can be broadly classified into two primary groups: neurons and glial cells. These distinct cell types share a common origin, arising from neural stem cells through a process known as neurogenesis [43]. This fundamental biological process underscores the brain's remarkable ability for development and regeneration, allowing for the formation of intricate networks that are essential for cognitive functions and effective neural communication. Neurons, the brain's primary signaling cells, are specialized for the transmission of electrical impulses throughout the nervous system. They play a pivotal role in processing and relaying information, which is crucial for everything from reflex actions to complex thought processes. The functionality of neurons depends on their ability to communicate with one another and with other types of cells, forming an extensive network that underlies all aspects of behavior and cognition [44].

Neurons can be further categorized into three main types: motor neurons, sensory neurons, and interneurons. Motor neurons are responsible for controlling muscle movements and enabling actions, making them essential for voluntary and involuntary motor functions [45]. Sensory neurons, on the other hand, transmit sensory information from various parts of the body to the brain, allowing us to perceive and interact with our environment [46]. Interneurons serve as connectors within the neural network, facilitating communication between sensory and motor neurons, as well as among other interneurons. Among interneurons, a rich diversity of subtypes exists, each with specialized functions. These various interneuron types are critical for modulating neural activity and ensuring the brain operates efficiently. Some interneurons are involved in reflex actions, rapidly processing sensory input to produce immediate responses, while others contribute to higher-order cognitive functions, such as learning and memory [47].

Table 2: Types of cells in the human brain.

No	Type of brain cell	Group	Function	References
1	Neural stem cells	Stem cell	Multipotent cells which give rise to all components of the central nervous system (CNS) during embryogenesis	[53]
2	Betz cells	Neuron	Control of leg movement.	[54]
3	Interneurone specific cell 1 (IS-1)	Interneuron	Needed for the flexible activity-dependent recruitment of OLM interneurons for feedback inhibition	[55]
4	Von Economo neuron (Spindle celss)	Neuron	Integrate inputs with emotional overtones and project to highly specific motor centers controlling vocalization, facial expression, or autonomic function.	[56]
5	Oligodendrocytes	Glial cells	Role in myelination and support of axons.	[57]
6	Hypocretin (orexin) cells	Neuron	Implicated in several neuronal systems, including sleep and wake cycles, neuroendocrine and locomotor function, autonomic regulation, feeding behaviour and energy homoeostasis, and also in the pathophysiology of narcolepsy with cateplexy.	[58]
7	Vasopressin neurons	Neuron	Regulates the time at which suprachiasmatic nucleus molecular clocks enable circadian behaviour.	[59]
8	Corticothalamic neurons	Neuron	Involved in the corticothalamic pathway, which plays a crucial role in sensory processing and the modulation of cortical activity.	[60]
9	Glucose-sensitive (GS) neurones	Neuron	Implicated in glucose homeostasis.	[61]
10	Glutamatergic relay cells	Neuron	Produce glutamate, which is one of the most common excitatory neurotransmitters in the central nervous system (CNS).	[62]
11	Transient amplifying progenitors (C cells)	Precursor cell	Highly proliferative progenitors, also known as transit amplifying Progenitors.	[63]
12	PSA-NCAM+ cells	Precursor cell	Plays a permissive role for the structural remodelling of neuronal and glial cells, particularly in the neuroendocrine system, where PSA-NCAM appears to control the retraction of the glial processes in the hypothalamo-neurohypophysial system.	[64]

13	Cholinergic cells	Neuron	In the brain processes that underlie anxiety, arousal, attention, fatigue, sleep and a number of cognitive processes.	[65]
14	Serotonergic neurons	Neuron	Release serotonin or 5-hydroxytryptamine, which plays a significant role in physiological and behavioural processes including sleep, body temperature, appetite, mood, aggression, cognition, depression, motor activity, and the circadian rhythm.	[66]
15	Tanycytes	Glial cells	Role in cerebrospinal fluid production.	[67]
16	AgRP NPY neurons	Neuron	Promote feeding behaviour and reduce energy expenditure.	[68]
17	Catecholaminergic cells	Neuron	Produce and release catecholamines, which include neurotransmitters like dopamine, norepinephrine (noradrenaline), and epinephrine (adrenaline) and plays critical roles in regulating mood, attention, arousal, and the body's stress response.	[69]
18	Cajal-Retzius cells	Interneuron	Influence the organization of the developing cortex by releasing signals that affect the underlying neurons.	[70]
19	Martinotti cells	Interneuron	Suppress pyramidal cells	[71]
20	Double-bouquet cells	Interneuron	Important element in the organization of cortical microcolumns in primates.	[72]
21	Neuroblasts	Precursor cell	The precursor of neurons, originating in the neural tube	[73]
22	Hippocampal-septal neurons	Neuron	Innervate the entire hippocampal formation and regulate hippocampal formation physiology and function	[74]
23	Medium spiny neurons	Neuron	Initiating and controlling movements of the body, limbs, and eyes.	[75]
24	Unipolar brush cells	Interneuron	Amplify inputs from the vestibular ganglia and nuclei by spreading and prolonging excitation within the granular layer.	[76]
25	Hippocampal place cells	Neuron	Encoding spatial memory and can reactivate during rest or sleep, representing distinct maps of different environments.	[77]
26	Perivascular mesenchymal stem cells	Stem cell	maintaining tissue integrity and facilitating repair mechanisms in various physiological and pathological conditions.	[78]
27	Schwann cells	Glial cell	Serve as the myelinating cell of the PNS and support cells of peripheral neurons.	[79]
28	Human Brain Pericytes	Specialized cell	Important for blood vessel formation, maintenance of the blood–brain barrier, regulation of immune cell entry to the central nervous system (CNS) and control of brain blood flow.	[80]

29	Cerebellar Golgi cells	Interneuron	Generating granular layer circuit oscillations and resonance	[81]
30	Periglomerular cells	Interneuron	Play a crucial role in modulating the activity of olfactory sensory neurons and helping to refine the sensory input before it is transmitted to other brain regions.	[82]
31	Candelabrum cells	Interneuron	Involved in modulating local circuits, influencing excitatory neuron activity, and contributing to processes such as rhythm generation and cognitive functions.	[83]
32	Basket cells	Interneuron	Make inhibitory synapses and control the overall potentials of target cells.	[84]
33	Lugaro cells	Interneuron	Samples information from the Purkinje cell axon collaterals and forwards this information to the molecular and granular layers of the cerebellum	[85]
34	Isodendritic neurons	Neuron	Play important roles in functions such as sensory perception and the coordination of neural activity across different brain regions.	[86]
35	Ivy cells	Interneuron	Known for their role in modulating the activity of nearby excitatory neurons and providing inhibitory feedback within cortical circuits.	[87]
36	Purkinje cells	Neuron	Regulate and coordinate motor movements.	[88]
37	Fork cells	Neuron	Channel neural signals from deep within the cortex to relatively distant parts of the brain.	[56]
38	Neurogliaform cells	Interneuron	Conduct feed-forward inhibition via GABAA and GABAB receptors on pyramidal cells located in several cortical areas.	[89]
39	Dopaminergic cells	Neuron	Crucial for cognitive processes, emotional responses, and motor functions.	[90]
40	Magnocellular neurosecretory cells (MNCs)	Neuron	Play a crucial role in the production and release of neurohormones, primarily oxytocin and vasopressin (also known as antidiuretic hormone or ADH).	[91]
41	Astrocytes	Glial cells	Functions and importance in neurotransmitter regulation and blood-brain barrier maintenance.	[92]
42	Cerebellar granule cells	Interneuron	Involved in functions ranging from processing visual and motor information to learning and memory.	[93]
43	Chandelier cells	Interneuron	Target the axon initial segment (AIS) of pyramidal neurons, where action potentials are generated	[94]
44	Operational hub cells	Neuron	Play a crucial role in coordinating and processing information across various networks, effectively functioning as hubs that enhance connectivity and information flow.	[95]

45	Cortical interneurons	Interneuron	Modulating the activity of excitatory pyramidal neurons and maintaining the balance between excitation and inhibition within cortical circuits.	[96]
46	Head direction cells	Neuron	Provide a sense of direction used for navigation.	[97]
47	Grid cells	Neuron	Create a "coordinate map" in the brain that enables navigation and metric (how far and in which direction) in the environment.	[98]
48	Ki67+ neural progenitor cells	Precursor cell	Play a crucial role in the generation of new neurons and glial cells during development and in the adult brain, particularly in response to certain stimuli, such as injury or environmental factors.	[99]
49	Perineural cells	Support cell	Play several important roles in the maintenance and function of neural tissue.	[100]
50	Bergmann glial cells	Glial cells	Essential for the proper functioning of the cerebellum, influencing both its structure and the activity of cerebellar neurons.	[101]
51	Rosehip cells	Interneuron	Controlling the activity of excitatory neurons, which are responsible for transmitting signals between brain cells.	[102]
52	Mossy cells	Neuron	Essential for the proper functioning of hippocampal circuits and play a significant role in cognitive processes such as memory and spatial navigation.	[103]
53	Microglial (brain-resident macrophages)	Glial cells	Immune functions and response to injury.	[104]
54	Superficial Short-Axon cells	Interneuron	Important for maintaining the overall function and stability of cortical networks, making them key players in cortical processing and integration of information.	[82]
55	Excitatory projection neurons	Neuron	Vital for the integration and processing of information in the brain, making them key components of neural circuits involved in a wide range of cognitive and motor functions.	[105]
56	A2B5+ glial precursor cells	Precursor cell	Important for the formation and maintenance of glial cells in the CNS, playing a vital role in neural development and function.	[106]
57	White matter progenitor cells (WMPCs)	Precursor cell	Important for the health and function of the white matter in the CNS, contributing to both development and repair processes.	[107]
58	Hypothalamic CART neurons	Neuron	Critical for maintaining energy balance and regulating appetite, contributing to the overall homeostasis of the body's metabolic state.	[108]
59	Pyramidal tract (PT) neurons	Neuron	Essential for higher-order brain functions, including movement, cognition, and the integration of sensory information,	[109]

60	Inferior olivary cells	Neuron	Crucial for the integration and coordination of motor functions, playing a vital role in the learning and execution of precise movements.	[110]
61	Deep cerebellar nuclei neurons	Neuron	Vital for the cerebellum's role in fine-tuning movements and learning new motor skills, making them a key component of the motor control system in the brain.	[111]
62	SOX2+ cells	Precursor cell with transcription factor	Important for stem cell maintenance and differentiation, particularly in the context of neurogenesis and development.	[112]
63	Schaffer collateral associated neurons	Neuron	Essential for excitatory communication in the hippocampus, contributing significantly to processes involved in learning and memory.	[113]
64	Calretinin-expressing (CalP+) cells	Interneuron	Important inhibitory interneurons that contribute to the regulation of neural circuit activity and play a role in cognitive processes such as learning and memory.	[114]
65	Leptomeningeal cells	Glial cells	Provide a protective barrier and structural support to the central nervous system (CNS).	[115]
66	Intratelencephalic (IT) neurons	Neuron	Vital for excitatory signaling within the telencephalon, playing essential roles in integrating information and supporting higher-order cognitive functions.	[109]
67	NG2 cells (polydendrocytes)	Precursor cell	Glial progenitor cells crucial for myelination, repair, and maintenance of the CNS.	[116]

Glial cells, often overshadowed by the more widely known neurons, are essential for supporting and maintaining the overall health of the nervous system. They can be divided into several distinct types, including astrocytes, oligodendrocytes, ependymal cells, and microglia. Each type of glial cell has unique functions that contribute to the overall functioning of the brain and spinal cord [48]. Astrocytes are the most abundant type of glial cell and provide structural support to neurons, helping to maintain the architecture of the brain. They also play a critical role in maintaining the blood-brain barrier, which protects the brain from harmful substances while allowing essential nutrients to pass through. This barrier is vital for maintaining a stable environment for neuronal function, ensuring that neurons can operate optimally [49]. Oligodendrocytes are specialized glial cells that produce myelin, a fatty substance that insulates neuronal axons. This myelination is crucial for enhancing the speed and efficiency of electrical signal transmission along the neurons. By insulating axons, oligodendrocytes facilitate rapid communication between different brain regions, which is essential for coordinated actions and cognitive processing [50]. Ependymal cells line the ventricles of the brain and are involved in the production and circulation of cerebrospinal fluid (CSF). This fluid serves multiple purposes, including cushioning the brain, removing waste, and delivering nutrients. The proper functioning of ependymal cells is critical for maintaining the brain's internal environment and protecting it from injury [51]. Microglia, the immune cells of the brain, are responsible for monitoring the health of neuronal environments. They play a crucial role in responding to injury and disease, acting as first responders to inflammation and helping to clear cellular debris. This function is vital for maintaining brain health, as microglia can protect neurons from damage and facilitate recovery following injury [52].

The human brain is a highly complex organ composed of a diverse array of cell types, each contributing to its intricate functions. Neurons are the primary signalling units, specialized for transmitting information throughout the nervous system. They can be classified into various types, with each playing unique roles in processing, integrating, and relaying signals. This diversity in neuronal architecture enables the brain to perform a vast range of cognitive and motor functions, highlighting the essential nature of neurons in maintaining brain health and functionality. In addition to neurons, glial cells play crucial supporting roles in the brain's ecosystem. Astrocytes contribute to nutrient transport, maintaining the blood-brain barrier, and modulating synaptic activity, while oligo-

dendrocytes are responsible for myelinating axons, which enhances signal transmission speed. Microglia serve as the brain's immune cells, monitoring for injury and infection, and ependymal cells help produce and circulate cerebrospinal fluid. Together, these glial cells create a supportive environment that ensures optimal neuronal function and overall brain health. The interaction between neurons and glial cells is fundamental to the brain's adaptability and resilience. Furthermore, the dynamic communication between these cell types is essential for processes such as learning and memory, underscoring the importance of their collaboration in maintaining cognitive function and homeostasis. Understanding the diverse types of brain cells and their interrelationships is vital for advancing our knowledge of brain function and developing targeted therapies for neurological disorders. As research continues to unveil the complexities of these cellular interactions, it opens new avenues for innovative treatments aimed at addressing conditions such as neurodegenerative diseases, traumatic brain injuries, and psychiatric disorders. Ultimately, a comprehensive understanding of brain cell types will enhance our ability to foster brain health and improve outcomes for individuals affected by neurological challenges.

Contributions

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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