The Origin, History and Science of Memory

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Throughout human history, much of the brain and its functioning has been unknown. At first, the theory of mind was articulated by ancient Greek philosophers. Plato, for instance, declared that the Logistikon (interpretation of consciousness at the time) was, in fact, the thinking part of the soul. Aristotle subsequently proposed that the mind was an extension of the soul that involved knowing and understanding. Outside these two major contributions, not much else of the function of the human brain had been addressed, outside of its moral reasoning and decision making. Although the studies at the time had been primitive and informal, they did tackle many of the critical concepts about consciousness, will, and memory. However, memory seemed more tangential and was treated teleologically as a means of understanding consciousness. Up until the 20th century, very few people had questioned the extent, capacity, or mechanism of memory. It was lost in the deafening roar of debate over consciousness.

However, in 1885, the first account of memory as a function of crystallized intelligence had been proposed, with the advent of the famous Ebbinghaus curve from Ebbinghaus' Über das Gedächtnis (Memory. A Contribution to Experimental Psychology, 2016). Though it seemed rather self-evident, the scientific data proving that memory decreased over time was revolutionary. As a direct result of Ebbingahus' contribution, the study of human memory was thrust to the forefront of both psychology and early neuroscience. Eventually,   Richard Semon proposed in his 1904 The Mneme that memories created an engram, a seemingly permanent change in the physical structure of the brain that can be measured (12). Later in 1949, psychology researcher Donald Hebb developed Hebb's Rule, the notion that memories were stored in connections between neurons known as synapses (65). This forms the basis of our current understanding of memory, scientifically supported by the continued efforts of modern neuroscientists from the 1950's onwards (most notably Dr. Karl Lashley, who in 1950 gave empirical evidence of engrams by eliciting episodic memories by electrically stimulating different parts of the brain with electrodes (Mastin, 2018).

Despite knowing about the nature of memory, there is little knowledge about what exactly constitutes memory, how it functions, and its relation to other cognitive processes. Currently, our understanding of memory is split between two interpretations of neural functioning: the modular approach and the holistic approach. The modular approach (first proposed by Jerry Fodor in 1983 when he published the book Modularity of Mind (2-5)) proposes that memories function differently in different parts of the brain as a result of a neural anatomical process known as functional specialization (neurons being functionally assigned different roles based upon localization and necessity (Wang, D. et al., 2014). To understand this approach, we must first understand how memories are formed.

Memories are formed by converting external stimuli into usable electrical signals. Touch, for example, uses unmyelinated dorsal root ganglia (DRG) neurons to detect pressure and proprioception (body orientation), allowing for afferent messages to be sent via the depolarization of action potentials -electrical signals created by electrochemical gradients (see figures 1.1 and 1.2)(ch1_neuronv_biov2 8-26)- once exteroreceptive (outer body) and/or interoceptive (inner body) sensations have been detected. These messages then travel to the cortex via the gracilis muscle in the thigh, ascending up the spinal cord to the cunneatus, finally making their way to the second somatosensory cortex, which includes the amygdala and hippocampus (see figure 2.1). Proponents of modular theory then propose that memories enter the hippocampus from the Cerebral Cortex through the perforant pathway, which leads to the entorhinal cortex. This data then flows to the dentate gyrus where it is transferred to the pyramidal neurons of the CA3 region of the hippocampus, which sends the information to the axons of the CA1 region. The subiculum then relays the information back to the entorhinal cortex, which pushes out the data back into the cerebral cortex, where different memories are then divided to be encoded; repressed and emotionally episodic memories are sent to the amygdala and limbic system in people with PTSD or emotional trauma, while semantic memory is stored in the neocortex. Other information is mostly kept in the synapses between neurons via complex sequences of neurotransmitters stored in synaptic vesicles waiting to be released at depolarization into the synaptic cleft in both the hippocampus and the cerebral cortexes (see figure 3.1) (Rolls, E.T., 1996).

Holists suggest the very same anatomy, however they maintain that memories are stored across the entirety of the cortex, meaning that all areas overlap with little specialization in memory storage beyond the distinction between the storage of explicit (conscious) memories in the cerebrum and implicit procedural (muscle) and episodic memories in the cerebellum and amygdala (Ramachandran, 2009). In essence, holists posit that memory storage is almost completely indeterminate and generalized across the entire brain. Both seemingly contrary theories have significant experimental support, meaning the prevailing theory is that memory is a mixture of both holism and modularity. As a result, more recent focus has been given to understanding the cellular mechanisms to better delineate between the two systems to determine their roles in very destructive disorders like Alzheimer's and PTSD.

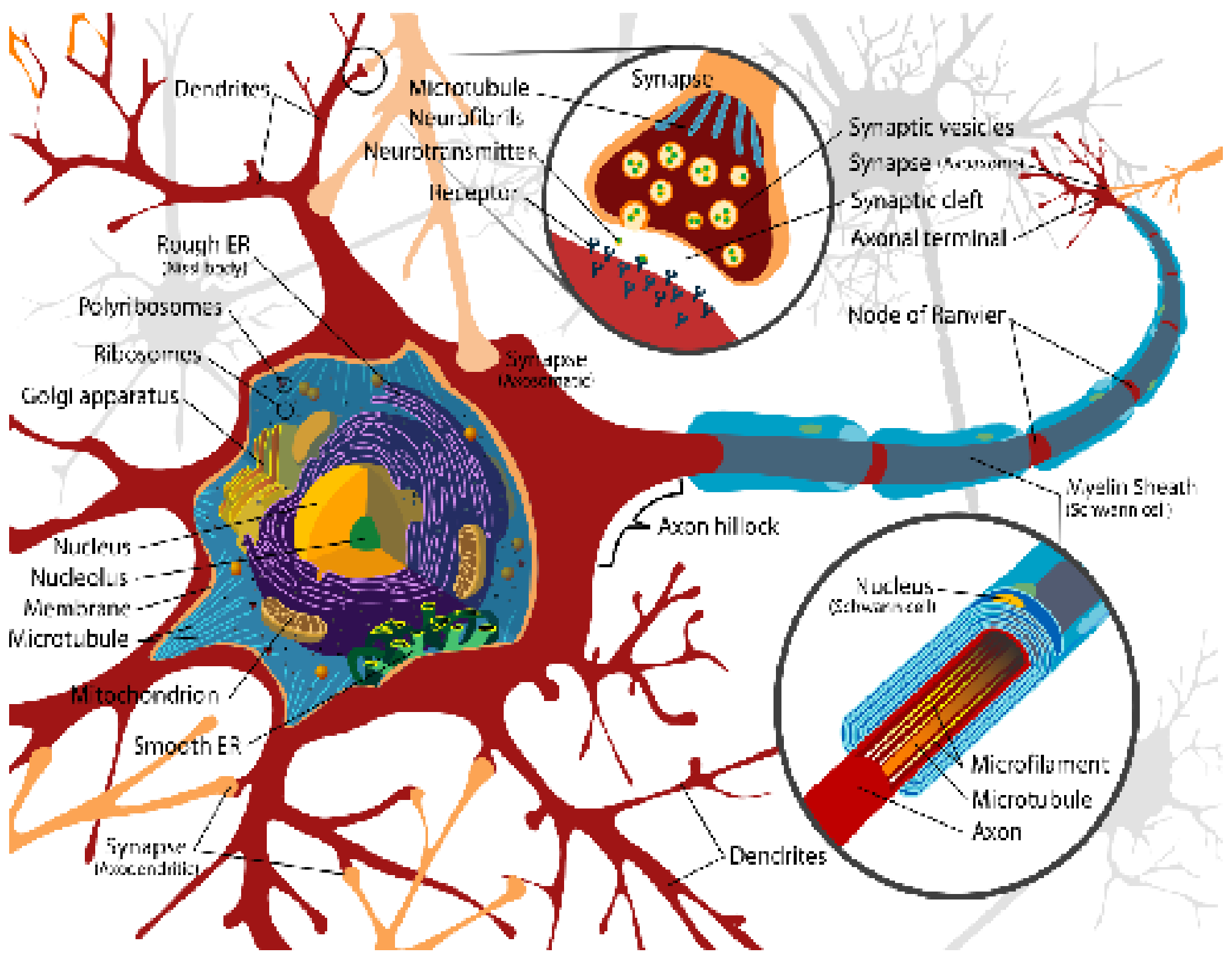

Figure 1.1 Diagram of neuron

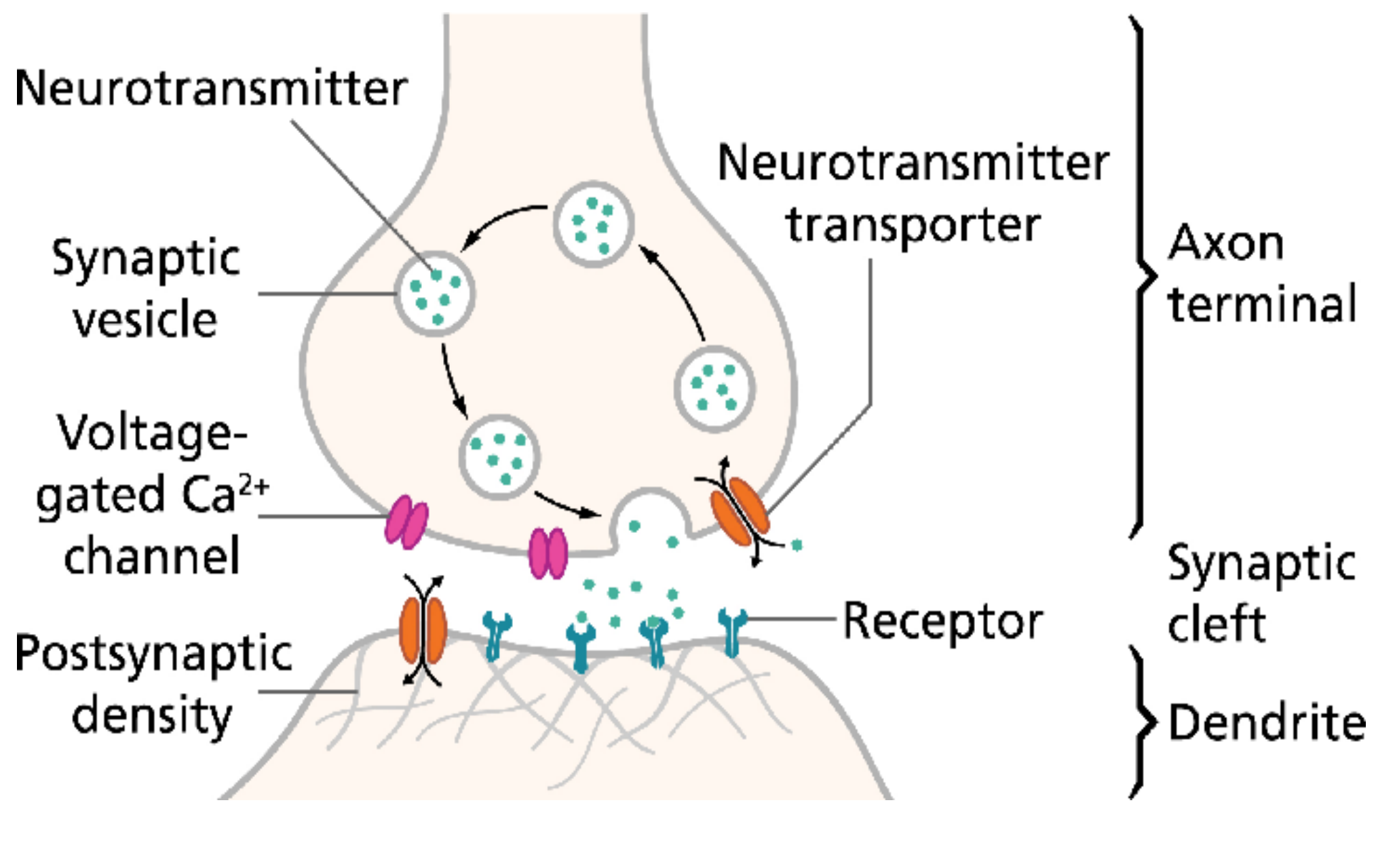

Figure 1.2: Image of the components of a synapse by which neurotransmitters are exchanged end signal transduction occurs.

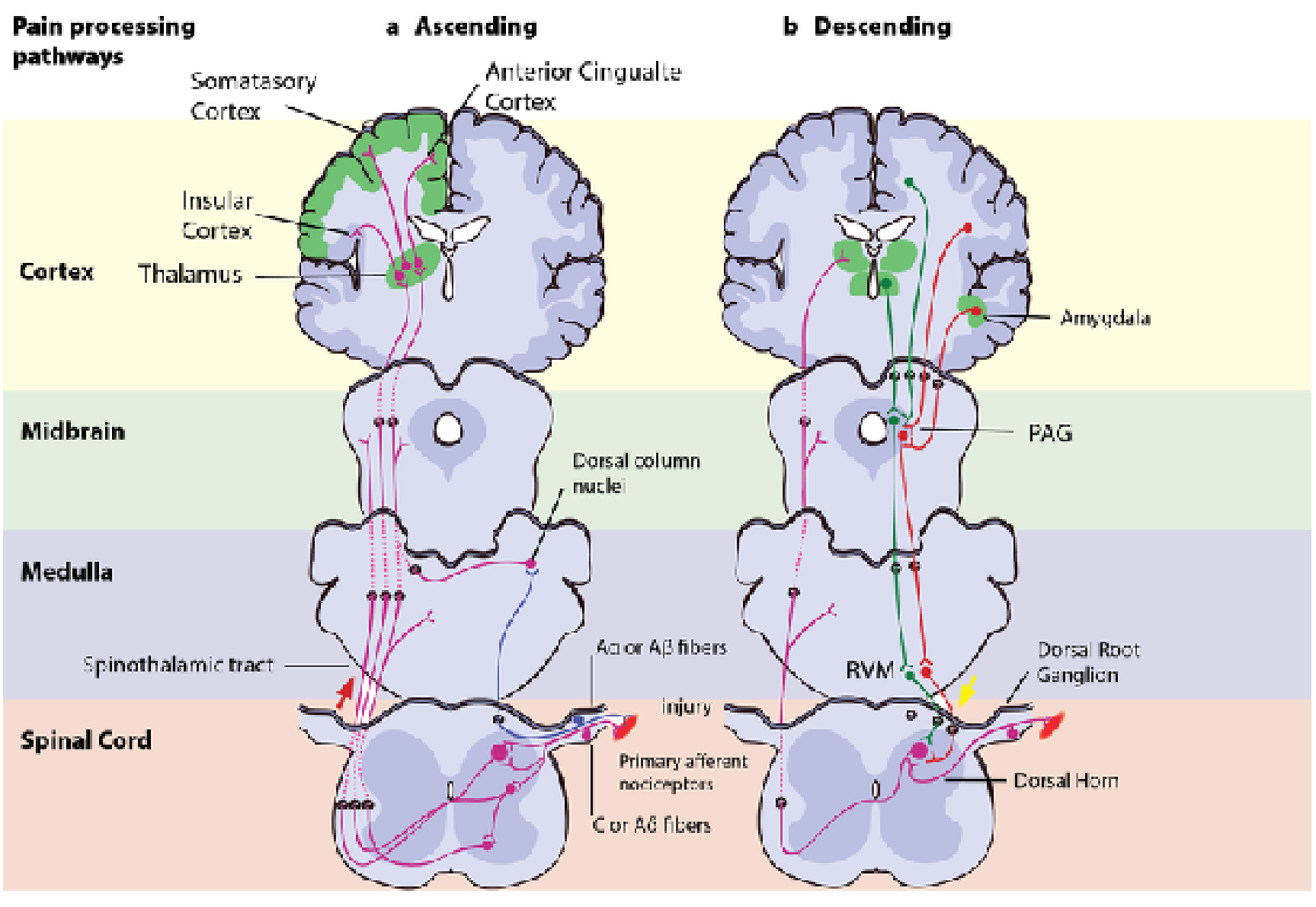

Figure 2.1: Image of the path by which sensory information is sent

After addressing the physiological distinctions for approaching memory, it's important to note that current studies on the procedure of recall have shown that memory has not been properly delineated from other cognitive processes as was originally thought. For instance, according to Tomita et al., functional Magnetic Resonance Imaging tests (fMRI) have determined that during voluntary recall, blood flow aggregation in regions of the frontal lobes associated with conscious thought increased, suggesting that feedback projections from prefrontal cortex to the posterior association cortex appear to serve the executive control of voluntary recall, not the previously believed sub-cortical regions responsible for unconscious activity. This implies that it is possible that memory and consciousness may not be separate at all. In addition, consciousness and memory have been discovered to emerge from the same cellular process. Memory is allegedly stored in complex sequences of pyramidal neurons that scientists now believe are capable of quantum computing by mechanism of tau protein synthesis in microtubules from ribosomes in the pyramidal neurons (orchestrated objective reduction theory or Orch-OR, also known as the Penrose-Hammerhoff model). The specific make up of proteases, tau proteins, and Ubiquitin proteins forms a complex system by which signaling occurs to quantum level differences, in which electron transmission is specified to particle level accuracy. This is also now considered the main mechanism of consciousness, as such neurons also associate with other high gray matter areas of the prefrontal and cerebral cortexes. This makes the data stored infinitely complex due to the extensively minute degree of error and incredibly high intensity of specificity (Atmanspacher, H., 2004). Though the Penrose-Hammerhoff model is a relatively new projection that is still being tested for validity, it does provide a possible explanation for why non-memory based conscious-driven parts of the cortex activate during voluntary recall. It should also be noted that the previously mentioned synaptic model for memory does imply that the synaptic cleft, which is associated with memory, is also responsible for signal transduction via neurotransmitters, indicating that there is some physiological correlation between the process of signal transduction and memory encoding and storage.

An interesting advancement in our current understanding of the connection between memory and consciousness can also be found in stroke victims, specifically those that suffer from cerebral ischemia -brain damage caused by lack of blood flow to the brain- (Mayo Clinic, 2018) Patients who have such debilitating strokes have the potential to develop a condition known as Capgras Syndrome, a unique disorder affecting a person's ability to relate memory to emotional experience. This rare disorder preserves the pathways for visual recognition within the posterior occipital lobe and temporal lobe, along with emotional centers of the brain such as the amygdala, parts of the diencephalon, and the basal ganglia. However, the connection between the two in the parietal lobe (now believed to be the fusiform gyrus) is damaged, producing an inability to share the processed information between the limbic system and the occipital lobe. As a result, the ailing patients are incapable of recognizing loved ones or processing emotional memories properly. Despite being able to recognize people of little significance in their lives and being able to experience emotion, these patients report being surrounded by impostors replacing their loved ones, hence the colloquial name "imposter syndrome". (Ramachandran 158-174) The problem, however, presents a surprising revelation: emotional memories are separable from conscious activity. In patients with Capgras Syndrome, there is a remarkable ability to consciously forget an individual within a short span of time; however, patients do exhibit an unconscious emotional response that is caused by an emotional "memory" of qualities of the individual. In other words, when someone with Capgras Syndrome catches up with an old friend, they fail to recognize the friend cognitively, however they unconsciously feel the typical emotions they would around said friend, indicating that emotional memory might be processed separately from conscious memory, only to interweave with consciously streamlined data in the fusiform gyrus. (Ramachandran, 2009) Similarly, people with severe anterograde amnesia who are incapable of forming new crystallized memories are reportedly able to retain unconscious emotional memory storage, sometimes even exhibiting consistent behavior in spite of not understanding why or how they started the behavior (Sacks 23-43)

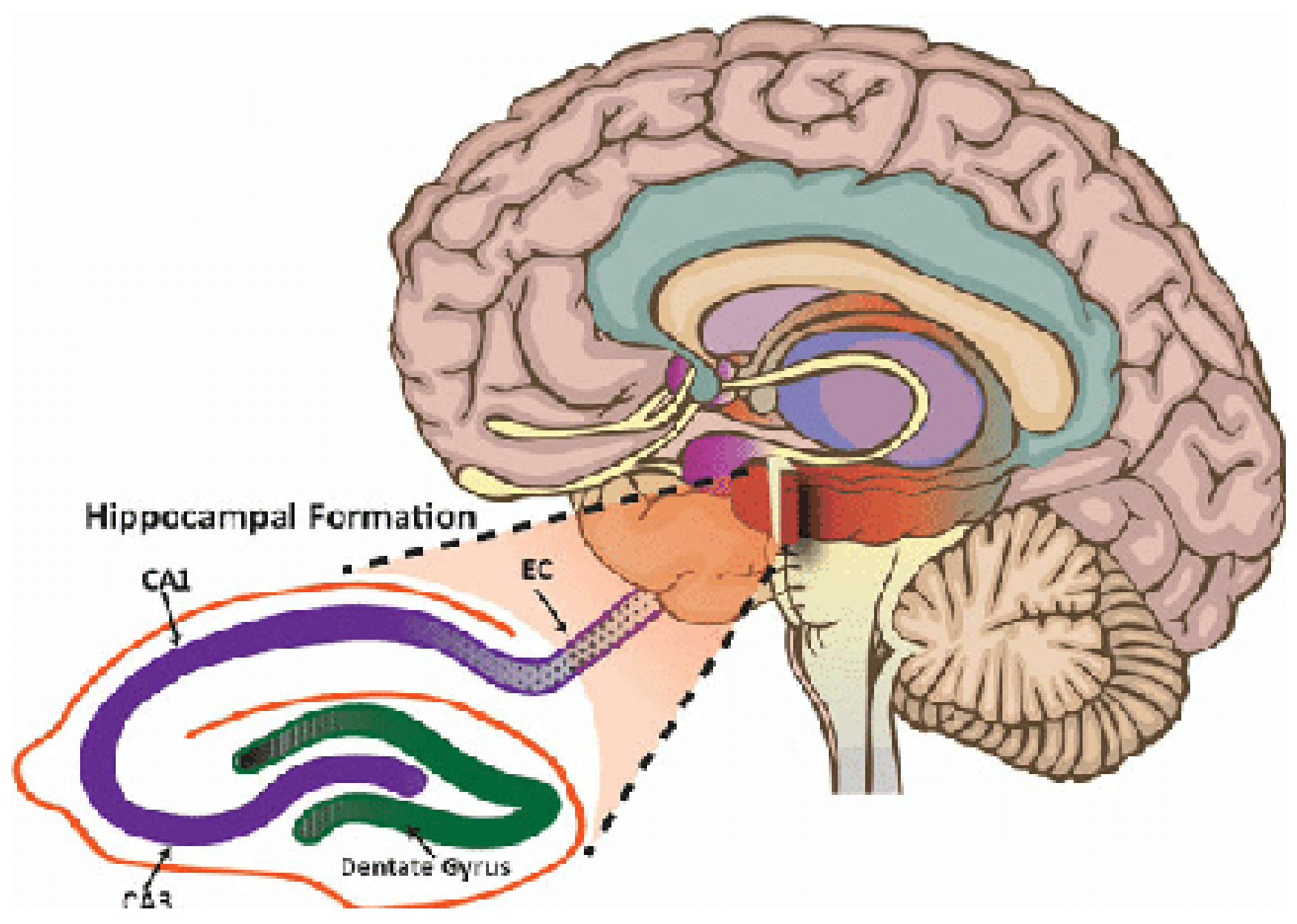

Figure 3.1: diagram of the hippocampus and position in the brain

Post Traumatic Stress Disorder, another debilitating neuropsychological condition, has revealed that the human brain is capable of altering its capacity of memory storage drastically. PTSD is a result of the overuse of corticotropin-releasing factor (CRF) in the hypothalamic-pituitary-adrenal axis system. In the brain, the thalamus circulates CRF to facilitate the release of adrenocorticotropic hormone (ACTH) from the pituitary gland, resulting in the adrenal gland releasing epinephrine. The epinephrine then operates in a negative feedback loop with norepinephrine by mechanism of auto-inhibition through presynaptic α2-adrenoceptors. This negative feedback loop prevents overproduction of cortisol and their consequent overstimulation of the pituitary gland, hypothalamus and hippocampus. (Bremner, J.D. et al., 1970)

Normally, this noradrenergic response is used to maximize utility (more blood flow, more actin filaments prepared by ionized channels, more ready action potentials, and generally faster reflexes in physiological structures) in survival circumstances, increasing activity in the sympathetic nervous system in preparation for dealing with external threats. However, people with PTSD create CRF in extreme excess due to both genetic and epigenetic influences. Some people are born with more hypothalamic corticotropin-releasing factor mRNA, meaning more glucocorticoid protein synthesis occurs (Bremner, J.D. et al, 1970). Others can have previously unexpressed genes triggered by the environmental factors causing the use of more telomeres which are responsible for cortisol production (Yang, B.Z. et al., 2013). This overabundance of CRF and cortisol has been shown to cause some impairment of intellectual ability in both crystallized and fluid intelligence. According to Dr. J. Douglas Bremner M.D et al., "Brain imaging studies have shown alterations in a circuit including medial prefrontal cortex (including anterior cingulate), hippocampus, and amygdala in PTSD… Stimulation of the noradrenergic system with yohimbine resulted in a failure of activation in dorsolateral prefrontal, temporal, parietal, and orbitofrontal cortex, and decreased function in the hippocampus."

Interestingly, these studies show that not only are memory and verbal ability reduced, but the very process of accessing memory is completely altered during triggered episodes. During post-traumatic episodes, it seems that hippocampus activity is lower than normal while most brain activity is centered in the limbic system; specifically, the amygdala, posterior cingulate, gyrus, and parahippocampal gyrus are active in these periods. The reduced brain activity in areas associated with conscious memory retrieval explain the seemingly random and uncontrollable onset of traumatic episodes and most likely occur due to overstimulation of the sympathetic nervous system. In other words, the mechanism of PTSD is most likely related to an overstimulated fight-or-flight system exercising dominance over the less developed cognitive system of the brain. The dominance occurs due to the limbic system being a far more responsive and developed brain structure, one that operates on hormonal messaging that is longer lasting than simple synaptic signaling. PTSD thus shows that memories are in fact not entirely voluntary and occur due to several diverging mechanisms rather than one (Bremner, J.D. et al., 1970).

To summarize, memory has been a relatively uninvestigated subject. However, with the advent of modern neuroscience and growing prevalence of memory disorders, it has become a scientific phenomenon worth investigating. Memory has been linked to many phenomena, branching emotion, consciousness, instinct, and genetics in a melting pot of complex neural functioning. Memory may well be the key to understanding the connection between mind and matter, consciousness, intelligence and human emotion.

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