The Brain, Biology and Cognition (ECPS5003) Damage on the Hippocampus Essay

Introduction

The brain is one of the most complex parts of the human body. The three-pound organ is in charge of a plethora of different processes including memory, vision, emotion, touch, temperature, motor skills, breathing, and hunger (Johns Hopkins Medicine, n.d.). Safe to say that whatever functions or processes the body goes through, the brain is involved somehow. According to the National Institute of Neurological Disorders and Stroke or the NIH (2022), the brain itself can be divided into three parts which are the forebrain, midbrain and hindbrain. The hindbrain is mostly responsible for the human's vital body functions such as heart rate and the respiratory system. The cerebellum, which is also located in the hindbrain alongside the brainstem and the upper part of the spinal cord, regulates movement and how one coordinates and learns movement. Travelling up to the uppermost part of the brainstem is the midbrain. The midbrain is partly responsible for vision as it is part of the circuit involved in controlling eye movement. Not to mention that it is also used to control other elective movements such as reflex actions. The biggest part of the brain however is the forebrain. It is what one might immediately glance at when looking at a picture of the brain. The cerebrum makes up the majority of the brain structure alongside other parts of the brain that are hidden beneath the cerebrum. The forebrain's properties include the storage of memory, conscious thoughts and actions, recognition and so much more. The cerebrum itself is split into two halves separated by a deep fissure. These two hemispheres communicate with each other through a thick tract of nerve fibres lying at the base of the fissure dubbed the corpus callosum. These two halves, though similar in structure, have different functions and operate differently. Inside the cerebrum or The Inner Brain, several

structures are crucial in controlling one's emotional state, perceptions, responses, and movement. These structures are also duplicated on both sides of the cerebrum. One of these structures is the hypothalamus. The hypothalamus is the mood centre. It is responsible for regulating the chemicals that can make someone feel happy, sad, or angry. It also has an effect on one's adrenaline and wakefulness in the morning. Next to it lies the thalamus. The thalamus is a major part of sending information to and from the spinal cord to the cerebrum. The information it receives and sends out is part of the cognitive functions, emotional and affective processing and motor functions of a human. Speaking of motor functions, the basal ganglia, which are clusters of neurons surrounding the thalamus, play an important role in that specific function as it is responsible for initiating and integrating movements (National Institute of Neurological Disorders and Stroke, 2022). Finally, the hippocampus acts as the memory inventory of the brain. This structure sends out memories that are appropriate for the time and space one is in, to the cerebral hemisphere to be saved for long-term storage and for retrieval whenever it is necessary.

The Hippocampus

As the highlighted area of the image is the hippocampus, the focus of this essay will be on that structure specifically. One of the brain's most studied and explored structures is the hippocampus. One of the reasons why it is so is because of the case study report done on patient H.M. who lost the ability to create new memories after getting treated for their intractable epilepsy. In the procedure itself, patient H.M. got their hippocampus surgically removed alongside nearby temporal lobe structures. This case study opened the door to the belief that the hippocampus plays a critical role in long-term memory. This alongside the discovery of place cells, head direction cells, and grid cells in the rodent hippocampal formation, led to a grasping foundation in that the hippocampus played a role in memory by giving the brain a spatiotemporal framework to bind the different sensory, emotional, and cognitive aspects of an experience together (Knierim, 2015). In rats, the hippocampus receives most of its cerebral input from the entorhinal cortex, which is made up of two distinct brain regions. The medial entorhinal cortex (MEC), especially its most caudal sections, is connected to the brain areas in charge of processing spatial information, such as the retrosplenial cortex and the dorsal presubiculum, also referred to as the postsubiculum. High-order regions involved in item recognition, like the perirhinal cortex, are linked to the lateral entorhinal cortex (LEC). Both areas send projections to one another and receive information from the olfactory cortex and prefrontal brain (Knierim, 2015).

Damage to the Hippocampus

According to Knierim (2015), the consequences of hippocampus injury on amnesia in humans have been extensively studied. The hippocampus is particularly vulnerable to injury from encephalitis, hypoxia, ischemia, and epilepsy. The entorhinal cortex is usually the first area of the brain to exhibit Alzheimer's disease-related plaques and tangles. To relieve their crippling convulsions, several epileptic patients, including the well-known H.M., had their hippocampi amputated years ago. Research conducted on both patient groups revealed that the human hippocampal and surrounding brain regions play a key role in fostering the formation of new declarative memories, or memories that can be spoken and brought into conscious awareness. Declarative memory can be further divided into two categories which are episodic memory and semantic memory. Episodic refers to recollection of a specific event that happened in the past. It might involve a specific time and place. Semantic memory on the other hand refers more to general knowledge about the world. It is knowledge stored up and that we can recollect with specific cues like “What is the capital of France?” or “How many strings are there in a guitar?”. Investigators believe that the hippocampus is important in forming episodic memories since patients who suffered from hippocampal damage in early life seem to lack in remembering specific events in their lives, but the same cannot be said about their semantic memory. However, patients with hippocampal damage have reported that they retain memories from events that happened years prior. This distinction led to the notion of the standard consolidation theory whereby one’s memories are not permanently stored in the hippocampus. The hippocampus is merely a holding place for those memories and after a certain amount of time, those memories are then moved on to other parts of the brain. Amnesic patients also seem to display a lack of ability to imagine new experiences. The incapacity to piece together a mental story of an

imagined event from its constituent parts may be connected to the incapacity to piece together a mental narrative of an autobiographical experience that happened.

Cognitive Theory (Single Consolidation Theory)

Systems consolidation is known as the process that reorganises memories through different neuronal networks. As mentioned previously, the standard consolidation theory or SCT is a belief that the hippocampus does not permanently store memories. Both semantic and episodic memories are dependent on the hippocampus at first, but as time goes on they become consolidated in their original forms to other parts of the brain (Winocur & Moscovitch, 2011). As put together by Squire and colleagues (Squire, 1992; Squire & Alvarez, 1995; Squire & Zola, 1998), the involvement of the hippocampus is time constricted. The hippocampus is only needed to form unions that are requisite for creating coherent memories. As time passes and the memory starts to take shape (consolidates), it is now able to be retrieved without the work from the hippocampus. Winocur and Moscovitch (2011) provided that much evidence supported SCT with the bulk of it coming from repeated observations of patients with severe damage to the hippocampus having trouble acquiring premorbid memories. The same cannot be said however for older memories (Marslen-Wilson & Teuber, 1975; Rempel-Clower, Zola-Morgan, Squire, & Amaral, 1996; Squire & Bayley, 2007). The reason why more recent memories are more affected by hippocampal damage according to SCT is that the process of consolidation cannot be completed as a large lesion in the hippocampus would prevent it from doing so. Thus, it is difficult for patients with such lesions to gain new memories. On the other hand, older memories should have limited issues with this as it is believed that memories which have been consolidated

are highly resistant to any form of interference as the memory has been distributed to other structures in the brain.

However, the SCT is not without its flaws. A lot of different theories have come out of the woodwork to challenge the beliefs of SCT. One of which is the multiple-trace theory or MTT. Contrary to SCT which believes that the hippocampus only stores memories temporarily, MTT is on the belief that memories in the hippocampus are permanent (Nadel & Moscovitch, 1997; Winocur et al., 2010). In SCT, the memories get transferred after a while to other parts of the brain, resulting in one remembering an event more likely. But in MMT, the memory becomes more stable over time as more hippocampus "memory traces", or functional connections, appear or become engaged. These two ideas seek to determine whether, as explicit memories become more deeply ingrained in the brain, the hippocampal function in retrieval decreases, grows, or stays constant. Tallman et al. (2022) brought up that the hippocampus does have a diminishing role in memory consolidation which supports the single consolidation theory where memories become independent of the hippocampus after some time. However, recent findings have been more varied. Tallman et al. (2022) identified three confounding variables that could explain the wide range of neuroimaging results which are fluctuations in confidence and accuracy in retrieval after a period of time, alterations in hippocampal and re-consolidation retrieval, which is more common in weaker memories and the use of only two time periods to measure the hippocampus's activity changes during retrieval. Runyan and Brooks (2022) discovered that the results of the initial Tallman et al. study fit the unified theory of the third consolidation theory almost as well as SCT, if not more so.

Neurobiochemical and engram cell investigations (Kitamura et al., 2017; Runyan et al., 2004; Stanciu et al., 2001; Vazdarjanova et al., 2002) bolster the third consolidation theory, also

known as the unified theory. The hippocampus and other brain regions involved in memory formation undergo cellular consolidation, the neuronal alterations required for memory formation, at around the same time. Memory consolidation, often referred to as systems consolidation, is the process of cell consolidation over longer functional connections required for hippocampus-independent recall, which requires continuous hippocampal activity. Modifications to these connections during reconsolidation, that is new encoding-related changes during retrieval, also need hippocampal activity. The main distinction between the unified theory and SCT is that the former holds that memory-related changes, and cellular consolidation, primarily occur in the hippocampus, while the latter suggests that similar changes occur over a comparable period in other relevant brain regions. The time course of systems consolidation is determined by cellular consolidation in longer functional links spanning these regions. This process requires time.

Nevertheless, the discovery by Tallman et al. of an extra-hippocampal network with regions with increasing activity with ageing memory and others with declining activity supports the idea that cellular changes occur concurrently with learning across various locations. After that, the connectivity between pertinent places varies with time. Here, the finding that functional connectivity between the hippocampus and many other regions decreases with memory age, while functional connectivity between the neocortex and the ventromedial prefrontal cortex, a component of long-term memory, increases, is consistent with the theory that the time course for changes in longer connections that can support hippocampal-independent retrieval is also the time course for memory consolidation. The idea that hippocampal activity is required for modifications in longer functional connections throughout networks involved in retrieval during

both systems consolidation and reconsolidation is further supported by the finding of "encoding"-related hippocampus activity.

Biological Theory (Neuroplasticity)

According to Puderbaugh and Emmady (2023), neuroplasticity is a concept that refers to both structural and functional changes made to the brain. It is also referred to as neural plasticity or brain plasticity. It is the nervous system's capacity to recognize and react to external or internal stimuli, as well as to realign its connections, structures, and functions following damage or illnesses like strokes. The first mention of plasticity in terms of connecting it to the nervous system was by William James in 1980 (Berlucchi & Buchtel, 2008). Though the term neural plasticity and the popularisation of it were done by Jerzy Konorski in 1948 (Mateos-Aparicio & Rodriguez-Moreno, 2019) and Donald Hebb in 1949 (Josselyn et al., 2017) respectively. Part of neuroplasticity is equipotentiality which is the concept that when an area of the brain is damaged, the opposing side of the brain will be able to sustain the lost function. Before equipotentiality, redundancy theory was believed for a long time. This concept stretched back to Galen to explain why the brain appeared ‘twinned’ (Puderbaugh & Emmady, 2023). That was until studies indicated that this might not be the case because unilateral injuries in the left side of the brain have been shown to impair speech even when the opposite side remains intact. The researchers hypothesised that it is simpler for a child to retrain specific abilities, like speech, than it is for an adult who has experienced such a loss. This concept then was changed into equipotentiality, to mean very early damage that can occur, the brain has the potential to compensate for its lost functions (Finger, 2010).

Vicariation is a similar concept but instead of mirroring the functions of the right side of a structure to the left side, other structures in the brain take control of the lost functions even if they are not intended to. A researcher conjured this theory after seeing his patients having sparing function despite having damage to their left hippocampus (Finer, 2010).

Graveline et al. (1998) also showed the brain can reorganise itself even after hemispherectomy. One half of the cerebral cortex is removed during a hemispherectomy, which is typically performed in response to uncontrollably violent convulsions in childhood. They demonstrated that the residual supplemental motor and sensory areas might reorganise and take over the function of the damaged area using functional magnetic resonance imaging (MRI). Similar findings were established when Jailard et al. (2005) performed serial functional MRI on four adult patients with ischemic stroke on the right side of the primary motor cortex and they found that increased activity in the bilateral premotor cortex shifted to the right hemisphere supplemental motor cortex. These findings all produced the brain's equipotentiality and vicaration.

However, it is important to highlight some of the shortcomings of neuroplasticity. For starters, most of the results for these cases seem to be more in favour of damage at a young age. It seems unlikely that adults can restore functions of the left hippocampus as they have passed the threshold to have their brains compensate for the loss. Another criticism, much with a lot of biological theories, is the inadequate understanding of the brain. Humans have been studying the brain for years and years yet we still do not have a grasp on every single function it has. The concept of brain plasticity and its practical applications are overgeneralised and its lack of reproducibility makes it a topic of concern for most people.

Conclusion

In this essay, the two theories brought up were the Single Consolidation theory and Neuroplasticity. The Single Consolidation theory (SCT) was more in the vein of understanding the function of the hippocampus in memory. At the same time, neuroplasticity looked into more of the aftermaths of damage to the brain. This essay has provided evidence for both of these theories and from said evidence, we can have an assumption on what might happen if the hippocampus is damaged. Assuming that both of these theories are true, damage to the hippocampus at an early age at first could result in trouble forming new declarative memories, but there is a possibility that other structures of the brain, or the opposing side of the hippocampus can take charge and compensate for the loss. For an adult, however, it is a bit complicated. The SCT established that memories will move onto different parts of the brain after spending some time in the hippocampus. It is to assume that memories of older events are likely not to be lost. However, new declarative memories will have trouble being formed as the hippocampus is not there to first facilitate those memories before passing them on to other parts of the brain. The effects of neuroplasticity also might not be present since the bulk of the evidence seems to imply that it can only occur at a younger age. Other than that, indeed more research needs to be done in both the cognitive and especially biological departments to better understand not just the brain, but the hippocampus as well. Lack of evidence in the biological department unfortunately plagued this research but hopefully, in time, more research can be done to avoid such a thing in the future.