

ECPS5003: The Brain, Biology and Cognition Essay Assignment

The human brain is one of the most fascinating yet complex structures, its functionality and operation still remains a large mystery until today. Our brains encompass regions that are specialised for a myriad of biological, emotional and cognitive processes from vision, emotional regulation to memory processes. Within all these different structures and their varying operations, the brain consists of a compact but crucial organ that plays a role in a number of vital functions in our body including memory formation. This structure is called the hippocampus and this essay aims to delve into the theories exploring its function in addition to examining possible cognitive and biological impacts in the case of any potential harm to that area. Before providing an in-depth exploration of the hippocampus, it is noteworthy to understand that the two hemispheres of the brain are responsible for the execution of vastly different tasks and they may respond differently to any incurred damage. For the purpose of this essay, the left hippocampus will serve as the main focus with reference to the image of the assignment.

According to Fogwe et al. (2024), the hippocampus performs complex functions in relation to memory and decision making, consequently acting as a “flash-drive” to the brain. However, comparing the hippocampus to a flash-drive often underestimates its complexity in terms of operation and organisation. In regards to its structure, the hippocampus is formed of curved brain tissues that converge into the inner surface of the temporal lobe of the brain. Within the hippocampus lies three crucial regions known as the dentate gyrus, the hippocampus proper and the subiculum. Outwardly, the hippocampus is surrounded by a protective layer, called the ependymal lining (Fogwe et al., 2024). The head, body and the tail are the different divisions of the hippocampus with the tail being slightly thin and curved while the head is the wider region. Furthermore, histological analysis segmented the hippocampus proper region in the structure into further divisions represented as CA1, CA2, CA3 and CA4 (Dhikav & Anand, 2012). After establishing the anatomy of the hippocampus, it is vital to investigate the assortment of functions associated with hippocampal functioning. Usually, the term ‘hippocampus’ evokes immediate association with processes involved in memory and that is what research has proved throughout the years. In relation to learning and memory, the hippocampus forms a connection with

other parts of the brain, namely the neocortex, which aids in consciousness of acquired information. Memory formation and learning processes are directed in a loop by two routes called the polysynaptic and direct intra-hippocampal pathways, serving critical purposes in semantic memory as well as episodic and spatial memory respectively. Other functions include spatial orientation, emotions and modulation of hypothalamic processes (Dhikav & Anand, 2012).

Essentially, it is hypothesised that the execution of these functions is distributed among the left and right hippocampus. A study conducted by Ezzati et al. (2016) brought forth evidence supporting this hypothesis which concluded the significance of the left hemisphere in episodic verbal memory while the right hemisphere is associated with spatial memory in older adults. Under the circumstance of any impairment to the hippocampal region, animal as well as human subjects who have undergone lesion examinations and functional neuroimaging techniques have consistently displayed a rather unique task of the hippocampus i.e. linking our external experiences together (Mišić et al., 2014). This signifies that the hippocampus assists in weaving coherent memories from the external stimuli encountered by the individuals. Case studies of patients with a damaged hippocampus, particularly the famous case of patient H.M, served as a critical transition in the field of cognitive neurosciences in relation to the role of the hippocampus as mentioned by Roux et al. (2021). Several theories have been proposed to facilitate understanding of hippocampal operation such as the Standard Consolidation Theory (SCT), Multiple Trace Theory and Neurogenesis. However, this essay will primarily explore the Standard Consolidation Theory and Neurogenesis Theory to highlight the cognitive as well as biological effects of an impaired left hippocampus respectively.

The Standard Model of Systems Consolidation or what is known as Standard Consolidation Theory (SCT) is one of the most distinctive concepts that were proposed to explain the hippocampal memory consolidation and various cognitive deficits that can manifest following damage to the hippocampus. This theory is derived from an initial memory consolidation model that was first proposed during 1900 by Muller and Pilzecker who discovered that learning of additional information can disrupt the memory of information that was previously acquired during an initial learning process. Therefore, this led to the hypothesis that recently learned information are originally vulnerable and are solidified

over a certain period of time (Gisquet-Verrier & Riccio, 2022). Hence, the term ‘Consolidation’ refers to how memories require a specific window of time to attain permanence in the brain according to Dudai (2004). Fundamentally, SCT suggests that declarative memories, at their initial stages, are hippocampus dependent i.e. are stored and retrieved through the hippocampus. With the passage of time, these memories become less dependent on the hippocampus and are distributed to the neocortex of the brain, where they are consolidated (Tallman et al., 2024). This denotes that the process of consolidation is a time-dependent process whereby memories are localised in the hippocampus temporarily and then encoded to other areas of the brain for permanent storage. In the paper written by Dudai (2004), the progression of system consolidation starts at the hippocampus where synaptic consolidation i.e. changes in the synaptic connections result in encoding of memories. Then, these memories become independent of the hippocampus and more reliant on the neocortex network distribution, resulting in a gradual transition of these memories onto the outer layer of the brain. This transition usually occurs and is facilitated during hours of rest. After being relocated, these memories are fixed, stored and retrieved in the neocortical region (Dudai, 2004).

Overall, it is mentioned by the author that the system consolidation process is significant to hippocampal functioning as this enables the sea-horse like structure to acquire new information instantly while preserving pre-existing knowledge and memories in another area. Not only that, but this unique yet complicated procedure also allows for the assimilation of fresh knowledge into preceding, older knowledge (Dudai, 2004). Generally speaking, this model is a complete framework that provides an exploration into how our memories might be solidified and stored in our brain while also highlighting the hippocampus’s role in the initial stages of the consolidation process. Undoubtedly, a large portion of what we know about memory, the hippocampus and consolidation processes stems from the case of patient H.M who had undergone a bilateral medial temporal lobe resection which involved his hippocampus and medial temporal lobe, to assist in mitigating his epilepsy (Pattanayak et al., 2014). Amongst the cognitive deficits noticed in H.M, he developed a profound difficulty in recalling and storing of episodic, newly learned information. Contrastingly, his ability to retrieve remote and semantic memories remained intact despite the resection (Pattanayak et al., 2014). His case aligns with the

principles of the Standard Consolidation Theory whereby the hippocampus plays a crucial part in the encoding of new knowledge and if removed or damaged, it might temper with the patient's ability to store and consolidate episodic memories. Subsequently, this observation was not unique to patient H.M only as other patients who suffered from impairments to their hippocampus demonstrated deficiencies in obtaining new experiences and knowledge, adding to the body of evidence available to reinforce SCT (Duff et al., 2020). Another rather interesting case similar to patient H.M's condition is patient K.C's memory impairment studied by Rosenbaum et al. (2005). Unfortunately, K.C encountered a motorcycle accident which rendered severe damage to his brain, specifically in the hippocampal region, resulting in intense memory loss. His memory loss was not like any other, rather it was retrograde amnesia wherein K.C finds difficulty in forming and retaining new memories (Rosenbaum et al., 2005). His case is particularly relevant to SCT's emphasis on the significant role that the hippocampus plays in the initial storage and formation of recently acquired memory. Additionally, it showcases how lesions or damage to the brain, particularly the hippocampus, can bring about cognitive deficiencies related to episodic memory consolidation.

Stark and Squire conducted an experiment in 2003 with the aim to assess the hippocampus's ability to recall information and tested a group of five individuals with hippocampal impairment as well as a control group with an intact hippocampus (Stark & Squire, 2003). Therefore, this study elaborates on the malfunction of verbal episodic memory in patients with hippocampal dysfunction, including the left hippocampus. Using a previous study as their reference, they tested the two groups with various types of memory tasks such as words, pairs of familiar objects and pairs of faces etc. Regardless of the memory tasks performed, the patients with bilateral hippocampal damage illustrated a general struggle in these tasks. This struggle involved difficulty in remembering associations of a certain stimulus or individual parts of the stimulus (Stark & Squire, 2003). Moreover, forming and retaining novel information is not the only challenge encountered by individuals with hippocampal injury, but they also experience adversity in terms of their spatial navigation skills. This point was alluded to in the beginning of the essay wherein it was mentioned that one of the many functions of the hippocampus is concerned with our spatial cognition and memory.

Accordingly, research and studies have emphasised the significant link between hippocampal functioning and sound navigational memory (Contreras et al., 2018). Amongst the evidence suggested for this is a study carried out by Laczó et al. in 2009 where they aimed to investigate the relationship between individuals with mild cognitive impairment and spatial memory. In this study, two groups of subjects with memory impairments related and unrelated to the hippocampal function were given a similar test to the Morris water maze test for rodents. Laczó et al. (2009) discovered that the former group experienced difficulty in their spatial navigation abilities in comparison to the latter group. Interestingly, this finding indicates an existing link between hippocampal dysfunction and deficits in spatial navigation.

Despite the pool of evidence in favour of the SCT, it faces a fair amount of criticism akin to any other theory to ever exist. One such criticism was discussed by Moscovitch and Gilboa (2022) related to the limitation of the concept of ‘systems consolidation’ and suggests that it is replaced with ‘memory systems reorganisation’ as the original term fails to acknowledge the dynamic nature of memories. After consolidation, memories are prone to changes through the interaction of different brain structures is essentially what ‘memory systems reorganisation’ is about and can aid researchers in understanding how human memory adapts over time (Moscovitch & Gilboa, 2022). Multiple studies conducted on animals have communicated an immediate recovery of memories after treatment which posits that consolidation blockers prevent the expression of a certain memory rather than completely prohibit their formation (Dudai, 2004). SCT recommends that memories eventually become hippocampus-independent as they are consolidated in the hippocampus. Contrastingly, theories such as Multiple Trace Theory argue that the hippocampus is constantly involved in the process of memory retrieval on the condition of the presence of adequate information related to the event (Tallman et al., 2024).

Touching on the biological impacts of hippocampal damage, the Neurogenesis theory is an intriguing explanation as it underlines the dynamic nature of the human brain and its ability to regenerate neurons in the case of harm. Additionally, the concept of neurogenesis is significant in areas such as the hippocampus as it is the centre of vital cognitive functions such as memory, learning and

our ability to navigate our surroundings. In essence, neurogenesis refers to the process of the brain's capacity to form new neurons in certain areas of the adult mammalian brain (Braun & Jessberger, 2014). The phenomenon of neurogenesis is not limited to the human brain, in fact, rodent brains undergo neurogenesis at a frequent rate and these new neurons are found to be associated in the process of remembering and learning as mentioned by Braun and Jessberger (2014). It is of general consensus now that the two principal areas of the subventricular zone and the hippocampal dentate gyrus in the adult brain is where neurogenesis occurs at a high density, deeming these areas responsible for the cell division of neurons (Gage, 2000). Consequently, this establishes a relationship between neurogenesis and the hippocampus as studies have showcased that regeneration of novel neurons occurs primarily in the hippocampal region, precisely the dentate gyrus area (DG).

A research paper by Anacker and Hen (2017) emphasises the involvement of the hippocampus in stress regulation and mood disorders such as depression, therefore, its functionality is not only limited to memory and learning. If an individual encounters an unpleasant experience, the regeneration of new neurons assists in the processes of replacing unpleasant memories with positive ones which improves cognitive flexibility. All in all, the hippocampus is responsible for mood and stress regulation which positively impacts our competence to handle stress and mood disorders (Anacker & Hen, 2017). Due to this crucial role of the hippocampus, any damage inflicted on that area might reflect adverse implications on the capability to regulate our mood and respond to stress effectively. Likewise, strong evidence between the dysfunction of neurogenesis and stress-induced psychiatric disorders have already been found (Jones et al., 2022).

Furthermore, hippocampal impairment can occur due to a variety of reasons ranging from ischemia and seizures to chronic stress exposure and Alzheimer's disease. In the aftermath of an injury, the initial period of recovery is marked by heightened activity of neurons as a result of neurogenesis in the dentate gyrus and is followed by a series of processes that gradually result in the synaptic reformation in the hippocampus (Shetty, 2014). Sometimes, the brain itself goes through alterations to compensate for the loss of certain functions. For instance, depressed individuals display certain structural modifications in the hippocampal region which consist of and exceed reduction in volume as

well as grey matter adaptations. In this case, it could be said such structural changes associated with depression occur due to neurogenesis (Kempermann & Kronenberg, 2003). Mice studies showcased that responses to various environmental stimuli can lead to increase in the neurogenesis process, resulting in a greater volume of the dentate gyrus area in the hippocampus. Despite this discovery, it is crucial to consider that results from rodent studies may not necessarily translate to human subjects (Kempermann & Kronenberg, 2003). Although neurogenesis can be used to explain the high density of new neurons in the hippocampus, it is still unclear whether this process is directly involved in any of the memory consolidation processes, from the encoding to the retrieval process (Deng et al., 2010). Another limitation of this theory is that while potential assumptions regarding the behaviour of these new neurons do exist, concrete evidence on how they behave within the brain in real life situations still remains inadequate (Snyder & Drew, 2020).

In conclusion, theories such as SCT and the Neurogenesis theory contribute beneficial insights into the field of hippocampal research and potential implications damage to that region. Nonetheless, gaps remain present within the field and call for further exploration to satisfy these questions. Researchers suggest that countless studies and ample time has been allocated towards the existence of adult neurogenesis in various mammalian species. Thus, future researchers must consider whether this process occurs within the human brain or not according to Snyder and Drew (2020). Another paper mentions that the neuropsychological field is preoccupied with studies and theories on deficit-focused studies meanwhile preservation-focused studies must receive a similar level of attention (Clark & Maguire, 2016) which can also contribute to development of treatments concerned with the improvement of cognitive functions amongst individuals suffering from brain injuries or impairments, including those with hippocampus-related disorders. Moreover, malfunctions in the hippocampus lead to different medical conditions and research has demonstrated a correlation between abnormalities caused by these disorders and the brain's ability to retain as well as acquire knowledge (von Bohlen und Halbach et al., 2018), which are both primary functions of the hippocampus. This calls for immediate attention and intervention within this field to synthesise proper treatment plans for those with brain injuries, including those with hippocampal impairments.

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