Dissecting the human brain continues to be essential for discovering novel therapeutic agents and comprehending the fundamentals of our existence (Jakovcevski et al., 2021). Among the various regions of the brain, the area known as the hippocampus is especially interesting to study. Owing to the fact that it contains a remarkable structure and significance in comprehending the functioning of the brain and cognitive processes. In the words of Anand and Dhikav (2012), hippocampus is an extension of the cerebral cortex's temporal region, which is observable from its exterior as a layer containing closely arranged neurons, curves into an S-shaped form located on the temporal lobe's border. It is made up of two layers: the dentate gyrus, which surrounds a second layer with subfields referred to as Cornu Ammonis (CA), comprising CA1, CA2, CA3, and CA4 (Sloviter & Lømo, 2012). Anan and Dhikav (2012), continue to state that memory, learning, along with navigation all depend on the hippocampus, whose connections to the neocortex facilitate conscious thought while maintaining a balance between experience retrieval and memory encoding. Furthermore, the hippocampus is considered as a key element of the limbic system of the brain of an individual, which is involved in both short- and long-term memory consolidation as well as spatial navigation. (Zhong et al., 2020). Short-term memory (STM) can be defined as processed in working memory, involving absorbing data over a brief period, while long-term memory (LTM) allows for the retention of knowledge over an extended duration, accessible either deliberately known as explicit memory or unintentionally known as implicit memory (Camina and Güell, 2017). Another point demonstrated by Sakaguchi and Sakurai (2020), tests' is that the left hippocampal region prevents the establishment of short-term memory (STM), the right hippocampal region aids in its creation and they could interact in order to increase or reduce each other's activities during the development of STMs. They also found that only the left hippocampus primarily contributes to the formation of the LTM. Despite that, any anatomical disruption within the hippocampus can impair memory formation or recall in a variety of species, including humans, nonhuman primates, together with rodents (Barry & Maguire, 2019). Various conditions can lead to hippocampal injury, including as head trauma, hemorrhagic stroke, ischemia, acute seizures, drug withdrawal, encephalitis, brain tumours, status epilepticus (SE), being exposed to chronic unexpected stress, or Alzheimer's disease (AD) (Shetty, 2014). Drawing on the highlighted image of the left hippocampus, this essay investigates its effect on biological and cognitive functioning, using a specific theory and empirical evidence enabling critical examination.

The onset of hippocampal damage manifests as a biological effect in synaptic plasticity, impeding the brain's fundamental ability to shape and create new connections between neurons. Avchalumov and Mandyam (2021), defined synaptic plasticity as a capability of neurons to change their activity in anticipation of stimuli by reorganising morphology, connections, or functioning, resulting in either a strengthening or a weakening of synaptic connections. They also state that it is a biological mechanism that helps the central nervous system acquire and store memories. Long-term potentiation (LTP) and long-term depression (LTD) are the phenomena referring to the strengthening and weakening of synaptic plasticity (Collingridge et al., 2010) which is crucial for learning and for long-term memory (Kandel & Tauc, 1965). As explained by Stampanoni et al. (2019), LTP is a form of synaptic plasticity that has been extensively investigated in relation to memory, learning and brain injury healing. Not only that, they claimed that it has also been widely studied in hippocampus neurons and includes a persistent rise in synaptic activity, as well as structural alterations on both ends of the synapse. In addition, the level of synaptic plasticity impairment that was reported throughout ageing tends to be less extreme compared to what is reported among individuals with disease-related hippocampal damage (Foster, 1999). For instance, early in the development of Alzheimer's disease, alterations in hippocampal connections become apparent in patients, particularly, it was argued that synaptic plasticity impairments could have an important part in Alzheimer's disease memory issues even in the absence of severe brain cell loss (Stampanoni et al., 2019). This impairment can hinder the coordination of brain activity between proximal or distant neurons, which could cause malfunctions in neural networks (Yener & Başar, 2013). Besides, another biological effect of hippocampus damage is memory consolidation disruption. The concept of memory consolidation was first proposed by Müller and Pilzecker (1900) where they refer to it as the procedure that converts a temporary, unstable memory into an even more long-lasting, stable one. Current theories indicate that several brain systems may work together to help consolidate memories (Nadel and Bohbot, 2001). According to Squire et al. (2015), the hippocampus is no longer essential for memory retrieval and storage once a more stable memory system emerges within the neocortex. They continue to explain that this transition is not due to the physical transfer of memories, instead referring to progressive alterations in the neocortex that increase memory complexity and communication between cortical regions. For that reason, to understand why hippocampal injury may disrupt memory consolidation, the standard consolidation theory delivers a thorough explanation.

As indicated by Alvarez and Squire (1994), in Standard Consolidation Theory (SCT), the initially weakened connections across memory pieces within the neocortex strengthen over time when the hippocampus activates them. They also highlighted that when these connections become stronger, the hippocampus is no longer required for memory recall since other areas of the brain can activate memories via newly created connections. Barry & Maguire (2019), reported that recent persuasive data in both humans and animals gives backing to the long-running premise of the SCT, which is that the hippocampus exhibits a time-limited function in storing memories. Neuroimaging studies reveal that memory stabilisation across the neocortex lasts as long as four months in humans, making it consistent with the standard consolidation theory, implying that memories rapidly move from the hippocampus towards the neocortex, turning independent of hippocampal control (Bonnici & Maguire, 2018; Barry et al., 2018). Another essential point is the memory is extremely resistant to disturbance and injury so damage to the hippocampus produces no consequence when sufficient time is given for consolidation to take place and memories are displayed throughout a distributed extra-hippocampal network which comprises the neocortex along with other structures (Winocur & Moscovitch, 2011). On the contrary, this perspective is supported by findings that individuals with hippocampal injury frequently have temporally graded retrograde amnesia (TGRA), which involves losing recent memories more than older memories, as well as severe anterograde amnesia (Squire & Bayley, 2007). This proves that hippocampal damage may impact memory consolidation, as indicated by research that reveal reduced recall of newly learnt data after lesions, although older memories are reasonably intact (Roesler & McGaugh, 2010). Indeed, SCT has persuasive strengths, which contribute to our knowledge of memory mechanisms and their complex dynamics. Firstly, it offers an extensive structure to clarify how memories are first encoded in the hippocampus then progressively consolidated in the neocortex, which develops over time. Next, Moscovitch & Gilboa (2021), emphasised that SCT led studies regarding memory consolidation in humans and rodents, providing a framework for interpretation of data. Despite providing an outline for comprehending memory development, it is important to recognise that SCT may have some limitations. Hardt et al. (2009), found that recalling consolidated memories in rodents resulted in them being exposed to disturbance for a short period after retrieval, indicating that consolidated memories might not be as stable as SCT suggests. Besides that, retrograde amnesia, regardless of whether it lasts not very long, might last for decades, showing that processes other than building neocortical connections could be relevant (Craik, 2020).

Damage that occurs in the left hippocampus region may also result in a significant impact on a number of numerous components of cognitive function, one being an impaired verbal memory. Based on the ideas of Tatsumi and Watanabe (2009) verbal memory refers to the ability to recall knowledge delivered through speech, determined by tests such as memorising word lists, narratives, or paired word sequences. This is important for the brain as a larger verbal memory capacity enables the retention of more data, the creation of more connections and conclusions, the (re)activation of pertinent knowledge, and the suppression of unimportant details (de Bree & Zee, 2021). Research on specimens from medial temporal lobe excision indicate that the left hippocampal region has a significant role in verbal capabilities (Sass, et al., 1992). In a study of adults with left temporal lobe epilepsy by Witt et al. (2019), it shows as the memory task gets increasingly dependent on long-term memory processes, there exists an increasing connection among verbal memory and the structural integrity of the left hippocampal region. They also found out that damage affecting the left hippocampal region has no effect on standard tests of working nor short-term memory, but it remains essential for quick recall for recalling lengthier sequences of words. The study by Tsalouchidou et al. (2023), concluded that the hippocampal subfields are correlated to verbal memory, which also supports the function of the left side subiculum along with left CA2/CA3 in verbal memory function. Therefore, the degree of hippocampal damage has been associated with impairments in long-term episodic memory, specifically impacting verbal memory, and is notably associated with the anatomical integrity of the left hippocampal region (Witt et al., 2014). The following matter to be discussed is the effect of hippocampus damage on episodic memory deficits. Boyle (2021) defined episodic memory as the type of declarative memory used to recall prior experiences that one has firsthand knowledge of. It is also the capability to recall particular individual experiences, including the exact location and timing as well as comprehensive details pertaining to the occurrences (Dickerson & Eichenbaum, 2010). A generally acknowledged view is that storing and retrieving new long-term episodic memories depends on the hippocampal region and the medial temporal lobe (MTL) components which encircle it (Duff et al., 2020). Complementary to this, McCormick et al. (2018) agreed that difficulties remembering prior experiences regarded as personal are commonly linked to hippocampal damage and are frequently connected to episodic or autobiographical memory. Examining the complexity of episodic memory deficits under the prism of the Multiple Trace Theory reveals further depth.

A theory proposed by Nadel and Moscovitch (1998) called Multiple Trace Theory (MTT) suggests that retrieving any episodic memory, even remote ones, is mostly dependent upon the hippocampus. Sutherland et al. (2019) concluded that the hippocampus encodes spatial context information during occurrences, which influences the specific features of the episodic memories. They also stated that according to the theory, every time a memory is retrieved or reactivated, it alters and improves a previous memory trace in the hippocampus, leading to the creation of several new traces with various triggers and contextual features. Hence the phrase “multiple trace” in the name of the theory. This clarifies the reason despite what the memory's age, the hippocampus continues to be essential to retrieve remote episodic memories (Nadel et al., 2000). Nevertheless, if the hippocampus suffers only a partial injury, current episodic memories might get erased whereas remote ones are retained, because memories that contain greater traces appear to withstand partial damage better (Sutherland et al., 2019). Evidence from studies of people with hippocampal loss shows a significant difficulty in obtaining new everyday knowledge, regardless of being capable to recall distant incidents in the past as well as acquire new skills and routines (Duff et al., 2020). Furthermore, Lee et al. (2019), have also consistently identified a negative relationship between hippocampus damage amount and memory performance which showed that as the damage increases, the memory will decrease. More importantly, the MTT is notable for its strength to provide a thorough understanding of the mechanics behind memory development and retrieval, as well as profound knowledge into the complexities of memory processes. Moscovitch et al. (2005), agreed that although new evidence might suggest modifications to MTT, the theory maintains the primary and most consistent hypothesis for remote episodic, spatial and semantic memory. Thus, given both remote and current episodic/context memories become impaired after hippocampus damage, the notion that hippocampus comprises lifetime stored data that accumulates additional traces with reactivation is strongly supported (Barry & Maguire, 2019). While the MTT offers more clarity on the function of the hippocampus in episodic memory, it also causes limitations that require additional exploration. For instance, it ignores mechanisms other than the extraction of statistical patterns in the conversion from episodic to semantic memory and does not account for the role of different brain regions in encoding, retaining, and retrieving episodic memories, both collaboratively and independently within the hippocampus (Kim et al., 2019). Lastly, MTT overlooked the dynamic character of memory, which is now becoming more relevant in modern memory theories (Schacter et al., 2012).

In brief this paper investigates the contribution of the hippocampus in brain functioning and memory processes, focusing on synaptic plasticity, memory consolidation, verbal memory, and episodic memory. It examines the effects of hippocampus injury upon these processes, using theories relating to Standard Consolidation Theory (SCT) and Multiple Trace Theory (MTT). The knowledge of human behaviour can be derived from practical real-world implications of hippocampal damage, which illuminates the complex interaction between brain architecture and cognitive activities in daily life. To give an example, individuals suffering from hippocampus damage are unable to clearly remember incidents in the past (Lah and Miller, 2008), visualise their futures (Kurczek et al., 2015), or build up imaginary scenarios (Hassabis et al., 2007). These abilities can be called mind-wandering which has a significant impact on several cognitive functions like figuring out solutions, creative thought, and planning for the future (McCormick et al., 2018). On top of that, hippocampal injury has been linked to deficiencies in a variety of linguistic and discursive capacities, though it has no impact on all areas of social conversation and language use (Gordon et al., 2014). Rubin et al. (2014), identified that individuals suffering from hippocampal damage use considerably fewer expressed speech and verbal play in interacting socially, and whenever it occurs, the result is qualitatively distinct from healthy comparison individuals. Fortunately these effects could possibly be managed using a range of treatment methods, in controlling the implications of hippocampal damage. For instance, cognitive rehabilitation seeks to improve processing of data, brain function, and interpretive abilities through personalised methods adjusted to individual needs (Barman et al., 2016). Montoya-Murillo et al. (2020), agreed that multiple meta-analyses have shown that cognitive rehabilitation has a considerable positive influence on improving attention, executive function, processing speed and different types of memory. Subsequently, Merlo et al. (2024) believed that pharmacological interventions are able to encourage memory persistence, such as cholinesterase inhibitors, medications that make use of the important function of cholinergic neurotransmitters in memory, attention, learning, and behaviour (Haake et al., 2020). All in all, studying hippocampal involvement to synaptic plasticity, memory consolidation, verbal and episodic memory, as well as the effects of hippocampal damage on biological and cognitive functions, this research indicates the complex relationship between the brain's structures and cognitive processes, providing knowledge important to medical treatment and a comprehension of human behaviour.