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Research on the role of hippocampus in memory consolidation

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Abstract. The length of time needed to recover memories in the hippocampus area varies greatly across the existing theories of system-level consolidation. These competing hypotheses do, however, have connections. The standard consolidation theory, multiple trace theory, and scene construction theory are the three existing models that are examined in this study. After reexamining their features, the authors test whether the three models can be integrated in terms of trace duration and function. It is better to think of the hippocampus's contribution to system-level consolidation as a functional transition from retention to rebuilding through time rather than just a question of persistence. The involvement of the hippocampus in memory retrieval may be fitted into a more thorough model in terms of functional transformation since the two functions, retention and reconstruction, are of equal significance and can scarcely be divided into two sections.

Keywords: hippocampus, memory consolidation, remote memory, episodic memory.

1. Introduction

The two competing theories of memory consolidation are often used to characterise hippocampal-neocortical interactions in memory. The original theory, now referred to as the standard consolidation theory, postulated that hippocampal connections to scattered neocortical storage sites were initially necessary for memory storage, but that over time this requirement diminished and the hippocampal component was rendered unnecessary. This conventional concept has been refuted by some data, leading to the numerous trace hypothesis. According to this theory, the hippocampus is always engaged in the storage and retrieval of episodic memory, whereas semantic information is believed to exist solely in the neocortex [1]. Recently, scientists presented a fresh angle to combine the first two discoveries. It has been proposed that in the absence of simple traces, the hippocampus reconstructs distant memories. This is accomplished by putting together integrated neocortical components into spatially coherent scenes that serve as the foundation for developing memory events [2]. This study provides three current theories, examines their similarities and differences, and considers if they may be combined in order to view memory from the viewpoint of a functional transformation. In order to provide a fresh, more comprehensive, and in-depth way of thinking about long-term memory, this work brings together many memory models. It offers potential new theoretical groundwork for further investigation.

2. Theories of memory consolidation

It has long been believed that the hippocampus is essential for memory encoding [2]. How the neocortex and hippocampus regions interact to create and sustain long-term memory representations is one of the primary open topics. The present controversy surrounds the hippocampus' function in distant memory retrieval. There are often three opinions on the length of distant memory retrieval due to contradicting research.

2.1. Standard consolidation theory

The "standard model" of memory consolidation gave the first description of hippocampal-cortical connections in memory. According to this hypothesis, the hippocampus serves as a transient memory structure that does little more than wait until the memory is organised somewhere else [3]. According to the classic consolidation hypothesis, the hippocampus must first link scattered neocortical storage locations in order for memory to be stored. But throughout time, this need fades, and the hippocampus component is no longer required. Hippocampal injury often results in retrograde amnesia, which is the retention of old memories after hippocampal impairment, and is considered to be caused by this shift in function over time.

2.2. Multiple trace theory

L. Nadel and M. Moscovitch assert that the conventional model still has to solve two important problems. The confusing definition of memory kinds is the first issue, since episodic and semantic memory are seen as being roughly comparable in the classic consolidation theory. The interaction between hippocampus and neocortical regions during the course of memory should also be taken into account [3].

Endel Tulving was the first to introduce the idea of episodic memory, which is the capacity to recall past experiences, including the precise time and location where information was learned [4]. In contrast, semantic memory is the general knowledge of the world that is learned through experience [5].

Contrary to conventional consolidation theory, Nadel et al. assert that hippocampus complexes are always engaged in storing and revisiting episodic memories. Also, the stability of semantic memory in the hippocampus may be impacted by long-term interactions between the two brain regions. (In the course of consolidation, semantics becomes neo-independent)

The numerous trace idea is well supported by data. Patients with localised (non-degenerative) temporal lobe lesions underwent formal testing of remote memory. Transient retrograde amnesia (RA) or practically total absence of distant memories, whether they were autobiographical or personal semantic, were both reported for lesions in the hippocampus proper (CA region and dentate gyrus). With autobiographical memory being the most severely impacted and semantic memory being nearly nonexistent, the temporal amount of distant memory loss is correlated with the magnitude of the lesion. Therefore, lesions of the hippocampal formation (proprio plus subthalamic) are linked to a ten-year or longer persistence of autobiographical memory loss.

Regardless of age, hippocampal loss impairs the ability to retain memories, particularly episodic memories. It is hypothesised that episodic memory traces are preserved in the hippocampus and have a permanent function in memory review.

2.3. Scene construction theory

A fresh angle has recently been taken in an effort to bring these two ideas into harmony. The hippocampus is capable of creating new memories from scratch. At the cellular level, there is also far more convincing evidence. In a rich natural environment, long-term potentiation (LTP) and long-term inhibition (LTD) only last seven days. The hippocampus really has a greater information turnover rate in continuous learning than it does in the supposed to be one year laboratory-controlled circumstances. In other words, until it is replaced, information in the hippocampus is only permanently present [6].

Only 15% of the cell population in neuronal ensembles fires in the same environment during a particular episode, according to observations taken after 5 and 30 days [7]. However, the sizes of the sites did not differ much and neither did the areas where individual cells were most likely to fire. According to the researchers, despite the low percentage of neuronal overlap, the information substance is kept. These findings demonstrate that old hippocampal memories are rapidly replaced by new ones, even when the same environmental settings are repeatedly visited.

Given the structural instability of hippocampal neurons, it would be almost impossible to prevent the integrity of individual engrams from deteriorating over such protracted times. LTP and learning have an impact on how dendritic spines are produced in the hippocampus. Synaptic connection is hypothesised to shift as a consequence, making it easier for new memory traces to be incorporated. Synaptic connections sustaining memory traces in the mouse hippocampus are fully erased during this time period due to the relatively short lifetime of dendritic spines (1-2 weeks) [8].

Hippocampal neurogenesis, which describes the development of new neurons in long-term memory and the integration of their function into the original circuitry, provides more proof of the transient nature of memory. Their contribution to memory is sporadic, and the new neurons seem to have a negative impact on previous memories, since greater neurogenesis after learning might actually make it harder to recall memories [9].

Hippocampal loss affects humans, who are also rodents, since a similar ability, spatial cell patterns, is pre-activated on detection of a new hippocampus activity, irrespective of subsequent route navigation [10, 11]. The hippocampus, according to researchers, is capable of activities transcending memory because it constantly generates and anticipates the representation of pictures that are not immediately evident to the senses. In this instance, the scene is a typical, egocentric, three-dimensional spatially coherent depiction of the world that is filled with objects.

Phycological research have shown evidence in support of this. Duration has a negative impact on memory accuracy but has no impact on the degree of information given. It is simple to remember experiences that never happened if they appear credible and include information about oneself. Additionally, those who had particular personal recollections were considerably more prone to being misled, indicating a process of reconstruction.

3. An integrated view of memory consolidation

3.1. Summary on these three models

The hippocampus isn't essential for memory retrial, according to the standard consolidation hypothesis; at the very least, the function is transient and only required until the memory traces are consolidated elsewhere in the long run. Multiple trace theory proponents believe that the hippocampus complex always plays a role in the storage and retrieval of episodic memories, regardless of their duration of storage, in contradiction to classic consolidation theory. The goal of scene formation theory is to reconcile the first two ideas. It was suggested that the hippocampus structures do not function in a straightforward black-or-white manner. It may vanish in a brief amount of time yet re-engage when necessary; it does not function as either existing or vanishing in a stable fashion.

3.2. Different focuses and supporting evidence

These three models vary from one another in two key ways. The first is how long memory traces may be stored in the hippocampus. A distinct perspective on the hippocampus' role is the second component. According to the conventional consolidation hypothesis, the hippocampal component ceases to be essential since it is no longer required to link the physically separated neocortical parts. According to the conventional consolidation idea, the hippocampus plays no role in memory revision. According to the multiple trace hypothesis, the hippocampus is always used in the reconsideration of episodic memory following memory acquisition. It continuously and permanently contributes to memory storage. It continuously and permanently serves as a means of memory storage. Last but not least, scene formation theory asserts that the hippocampus creates a string of cogent scenes from a recent occurrence via interactions with the cortex. These images quickly disappear from the hippocampus when the neocortex consolidates their representations. When lifetime memory review is necessary, the hippocampus performs a permanent role, but only as an autonomous actor.

3.3. Limitations on existing models

3.3.1. The scene construction theory. It seems that despite these volatility, the system in its entirety is capable of reflecting a situation steadily for at least a month. It seems that despite these volatility, the system in its entirety is capable of reflecting a situation steadily for at least a month. If this cue is sufficient, the whole network will likely agree. There could be further reasons in the minds of the researchers. Even though traces are normally "suppressed" by neurogenesis, optogenetic investigations demonstrate that they may persist in the hippocampus, be reactivated, and prompt memory manifestation in behaviour in the long term [12]. The persistence and vitality of these hippocampal traces are attested to by the fact that optogenetic suppression of these cells results in memory loss, even long periods after the acquisition. It has been shown that the hippocampus has cellular processes that might facilitate this kind of selective long-term retention [13]. Thus, neurogenesis serves to maintain and preserve the existing memories from interference and deterioration while also creating interference that may cause the loss of many distant memories. Neurogenesis and reconstruction are processes that change memory by deleting weak memories while refreshing and enhancing existing memories. There is little evidence to back up the claim that the hippocampus's apparent flow interferes with its ability to create and preserve long-term memories.

3.3.2. Multiple trace theory. As proof of a month-long stable representation, a research monitoring hippocampal markers of plasticity in mice through repeated environmental exposures was presented [14]. In fact, there was a noticeable decline comparing neuronal connections with just a small number of the cells that were active at the first exposure reappearing at the most recent instance. Every time-point in between showed a decline in representational similarity as a function of temporal distance. Only a tiny subset of all observed cells (20%) consistently returned, even with multiple temporally neighbouring environmental exposures. It is not regarded as a long-term stable neuronal representation [15].

3.4. The Interaction between HPC and neocortex under the view of functional shift

In terms of time and function, the authors contend that they may be merged into a more in-depth theory. Although they seem to have entirely opposing effects when it comes to persistence, if we define memory traces in terms of the multifunctionality, these theories really have a coherence inherent to them.

According to the author, there are just a few circumstances that evidence by itself can satisfactorily explain. The facts and the hypothesis don't match up, which results in a research that may be interpreted in several ways. For instance, Moscovitch and Nadel saw reconstruction as proof of a persisting hippocampus trace. Following contextual fear training, re-exposure to a particular setting at a later period makes memories susceptible to hippocampal lesions. Reminders, according to them, awaken latent, intangible hippocampus imprints. Reminders, according to this theory, awaken latent, inactive hippocampus traces. The rebuilding of particular memories in the hippocampus, where fresh traces are vulnerable to disturbance, might, however, equally account for the results, in Barry and Maguire's alternate theory [15].

Although the results are inconsistent and cannot be explained by current ideas, the evidence for them is also hard to disprove. These differences have received a lot of attention in recent research, which have argued in an all-or-nothing manner. However, it is more persuasive to explore the links between them than than concentrating just on the contrasts. When memory is encoded, its purpose cannot be reduced to two simple options: preservation or reconstruction. According to the authors, each hypothesis covers a different component of memory. According to the authors, each hypothesis explains a different component of memory. Both the many traces theory and the conventional consolidation theory generally presuppose that memory operates in a manner that what a person has previously encountered should be honestly and authentically kept from the start. Thus, it is anticipated that the hippocampus will continue to play a steady role in memory storage and recollection, whether permanently or temporarily.

They emphasise different things, however. Scene construction theories concentrate on the defining characteristics of memory and propose that the different components of an episode are represented as physically distinct neural clusters within the neocortex and that the hippocampus plays a key role in providing the mechanism for connecting the kept separate segments. The multiple trace theory makes a distinction between the engrams of semantic memory and episodic memory very evident. Scene building theory instead emphasises distant memory in the service of visualising future situations, while suggesting a memory reconstruction function based on transitory hippocampus traces that are expected to be unstable and alter swiftly in accordance to current and future conditions. It is challenging to separate the equally crucial processes of retention and rebuilding into two separate categories. Function is determined by structure, which serves as a cue to infer structure. In light of this and keeping these three models in mind, a more intricate computational model that rates the time of hippocampus activity by function may be created.

4. Conclusion

This study examines the contrasts and similarities between these three current models, then determines if they may be integrated in terms of time and function. These queries may provide us an idea of future routes to test the current hypotheses further and determine whether it is feasible to integrate them into a more thorough theory. The first is how long memory traces in the human hippocampus really last. Both traces at the cellular level and cognitive trials that may evaluate this topic at many levels are seen as useful techniques for providing an answer to this question. The authors suggest that the response might be influenced by several factors pertaining to the various functional elements of memory. The issue of which parts of distant memory are more prone to distortion over time arises given the function of the hippocampus in both remembering the past and creating settings for imagination. There is conflicting evidence on the electrical interactions between the hippocampus and neocortex in current and distant memory. Given the intricate and varied components that distant memory involves, the author came to the conclusion that distinctions actually exist. It is better to think of the hippocampus's contribution to system-level consolidation as a functional transition from retention to rebuilding through time rather than just a question of persistence. We may ask more useful questions concerning the hippocampus' activation during distant memory recall now that we are aware of its crucial function across a number of cognitive domains.

References

[1] Moscovitch, M., & Nadel, L. (2019). Sculpting Remote Memory: Enduring Hippocampal Traces and vmPFC Reconstructive Processes. Trends Cogn Sci, 23(8), 634-635. doi:10.1016/j.tics.2019.05.001

[2] Barry, D. N., & Maguire, E. A. (2019b). Remote Memory and the Hippocampus: A Constructive Critique. Trends Cogn Sci, 23(2), 128-142. doi:10.1016/j.tics.2018.11.005

[3] Moscovitch, M., Cabeza, R., Winocur, G., & Nadel, L. (2016). Episodic Memory and Beyond: The Hippocampus and Neocortex in Transformation. Annu Rev Psychol, 67, 105-134. doi:10.1146/annurev-psych-113011-143733

[4] Nadel, L., Samsonovich, N., Ryan, L., & Moscovitch, M. (2000). multiple trace theory of Human Memory: Computational, Neuroimaging, and Neuropsychological Results. HIPPOCAMPUS.

[5] Tulving, Endel (2002). Episodic Memory: From Mind to Brain. Annual Review of Psychology.53:1–25. doi:10.1146/annurev.psych.53.100901.135114. PMID 11752477.

[6] McRae, Ken; Jones, Michael (2013). "Semantic Memory". In Reisberg, Daniel (ed.). The Oxford Handbook of Cognitive Psychology. New York, NY: Oxford University Press. pp. 206–216. ISBN 9780195376746.

[7] Abraham, W.C. et al. (2002) Induction and experience-dependent consolidation of stable

DOI: 10.54254/2753-8818/6/20230191

long-term potentiation lasting months in the hippocampus. J. Neurosci. 22, 9626–9634
[8] Ziv, Y. et al. (2013) Long-term dynamics of CA1 hippocampal place codes. Nat. Neurosci. 16, 264–266
[9] Attardo, A. et al. (2015) Impermanence of dendritic spines in live adult CA1 hippocampus. Nature 523, 592–596
[10] Akers, K.G. et al. (2014) Hippocampal neurogenesis regulates forgetting during adulthood and infancy. Science 344, 598–602
[11] Dragoi, G. and Tonegawa, S. (2011) Preplay of future place cell sequences by hippocampal cellular assemblies. Nature 469, 397–401
[12] Gupta, A.S. et al. (2010) Hippocampal replay is not a simple function of experience. Neuron 65, 695–705 (Guskjolen and Frankland, Reinstatement of forgotten memories via environmental reminders, Personal Communication, January 27, 2019)
[13] Migues, P.V. et al. (2016) Blocking synaptic removal of GluA2containingAMPA receptors prevents the natural forgetting of long-term memories. J. Neurosci. 36, 3481–3494.
[14] Attardo, A. et al. (2018) Long-term consolidation of ensemble neural plasticity patterns in hippocampal area CA1. Cell Rep. 25, 640–650.
[15] Barry, D. N., & Maguire, E. A. (2019a). Consolidating the Case for Transient Hippocampal Memory Traces. Trends Cogn Sci, 23(8), 635-636. doi:10.1016/j.tics.2019.05.008