

Analyze the Influence of Positive Feedback to Declarative Memory Strength

Zeyu Wang^{1,a,*}

¹Wuhan University of Technology, Wuhan, 430022, China

a. zeyuwang0711@126.com

*corresponding author

Abstract: Extensive research in neuroscience and psychology has focused on memory consolidation driven by positive feedback. This paper elucidates methods to enhance memory retention. Evidence indicates that dopamine plays a crucial role in the formation of declarative memories associated with rewarding stimuli and may affect the generalization of reward value. An event-related fMRI study investigated the anticipatory mechanisms involved in reward-based memory formation during a monetary incentive encoding task, where participants were presented with cues signaling high or low-value rewards for memorizing forthcoming scenes. Following a 24-hour evaluation, participants exhibited significantly improved recall of images associated with high-value cues compared to those linked to low-value cues. Additionally, a separate monetary incentive delay task pinpointed specific brain regions involved in reward anticipation. In the encoding phase, high-reward cues that preceded recalled events activated the ventral tegmental area, nucleus accumbens, and hippocampus. Enhanced activation in these areas was predictive of stronger memory retention. The relationship between the hippocampus and ventral tegmental area was correlated with improved long-term memory retrieval. These results imply that neural activity prior to stimulus encoding can serve as a predictor for declarative memory formation, reinforcing the notion that positive feedback bolsters memory by facilitating dopamine release in the hippocampus before the learning process.

Keywords: Declarative memory, Positive feedback, Reward motivation, Dopamine, fMRI

1. Introduction

Contemporary understanding posits that memory functions as a dynamic and expansive process, intricately linked to the preexisting network of knowledge [1]. It is possible to incorporate fresh experiences into the preexisting framework of prior knowledge. This procedure makes sure that memory networks are both reactivated and refreshed through memory consolidation and retrieval functions. [2]. In the end, the representation of the memory would get increasingly abstract, encompassing data from various sensory and semantic aspects.

Memories with emotional relevance are harder to forget than neutral ones. While significant insights into aversive learning mechanisms have emerged, particularly from classical fear conditioning studies, the role of rewards in memory consolidation remains underexplored. Recent evidence suggests that positive feedback enhances memory formation and retention. The first section defines declarative memory and positive feedback, while the next discusses methodologies on

positive feedback effects. The third section presents an FMRI study identifying key brain regions involved in this process. This research aims to clarify how positive feedback boosts memory retention, potentially enhancing cognitive abilities in students through effective motivational strategies.

2. Basic terminology

2.1. Declarative memory

Declarative memory denotes the memory type that can be expressed orally; it possesses a hypothetical value for truth regarding actions or events and is generally associated with conscious remembering. This type of memory can be subdivided into episodic memory and semantic recall. It pertains to the capacity for deliberate recollection of previous experiences, facts, and principles, which in humans can be evidenced by spoken narratives [3].

The medial temporal lobe (MTL) system, encompassing the area of the hippocampus with its related structures, is well documented in scholarly literature [4].

2.2. Positive feedback

Positive feedback, often described as a reinforcement mechanism, functions as a catalyst that positively enhances behavior. Additionally, it stimulates a state of desire or energy to undertake specific actions, commonly known as motivation. Humans display two fundamental motivational orientations: approach and avoidance, which are activated in response to rewards and punishments. Although these orientations exert contrasting influences on human behavior, it is proposed that they are governed by distinct yet highly interconnected neural circuits within the limbic and mesolimbic systems [5]. This talk will focus on approach inclination. Positive feedback motivates by making incentives salient and valuable, or cue-induced "wanting."

3. Positive feedback enhances memory

Memory plays a significant role in shaping decision-making processes and guiding behavioral preferences by retrieving information related to the genesis of goals established in the past. Consequently, the retention of action outcomes becomes essential for informed decision-making in future scenarios.

Positive reinforcement or rewards can improve memory prioritisation by utilising the relative value and novelty via dopaminergic pathways originating from the VTA, which is the ventral tegmental and the amygdala, extending to the brain and hippocampal.

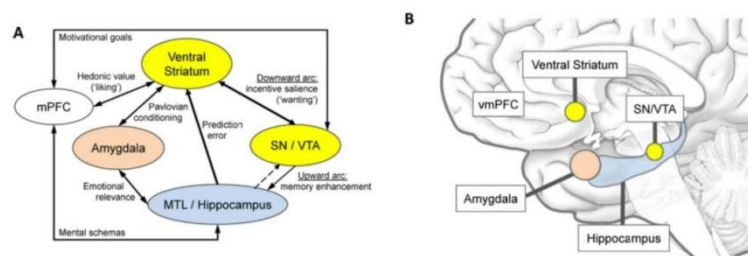


Figure 1: Schematic representation of the brain's anatomical structures associated with reward-based memory modification. (A) Functional contributions of cerebral components primarily determined through investigations in animal models. (B) Anatomical locations from section A portrayed on a human brain illustration [6].

The acronyms: SN/VTA—substantia nigra/ventral tegmental area; vmPFC—ventromedial prefrontal cortex; MTL—medial temporal lobe; BLA—basolateral amygdala.

Illustration A in Fig1 shows that dopaminergic pathways from the SN/VTA to the hippocampus, where dopamine influences plasticity, correlate with improved memory (indicated by the upward curve). The descending pathway from the hippocampus through the subiculum, nucleus accumbens, and pallidum to the VTA is activated by the motivational value of new information. There is also an indirect connection between the hippocampus and the VTA. Inputs to the VTA converge in the ventral striatum, consolidating data on current motivational goals from the mPFC (in rats) or vmPFC (in humans), sensory characteristics from the basolateral amygdala/hippocampus, and contextual memory from the hippocampus, which facilitates goal-directed behavior. The PFC assimilates new knowledge with pre-existing mental models to improve memory consolidation. Emotional arousal affects memory processing through the amygdala-hippocampus connections, with the amygdala modulating dopamine signals in the nucleus accumbens to respond to Pavlovian stimuli.

A recent optogenetic investigation conducted on rats has demonstrated that the direct activation of dopaminergic neurons in the ventral tegmental area and substantia nigra during positive reinforcement may serve as a predictive indicator of the significance of the prior stimulus [7]. Consequently, in rats, the activation of dopaminergic neurones may serve as a vital signal that renders goals "wanted." This document elucidates the specific mechanisms via which positive feedback motivation, together alertness and stimulation of the mesolimbic dopamine structure, influences the consolidation of memory.

4. Positive feedback anticipation incites arousal.

The activation of behavior is linked to the secretion of noradrenaline. [8]In rats, Locus Coeruleus (LC) neurones demonstrate phasic burst in reaction to both incentives and penalties, as well as alterations in stimulus-reinforcement contingencies, such as during extinction or reversal. Nonetheless, noradrenaline is not directly implicated in behavioural decision-making within a reinforcement learning task, in contrast to dopaminergic neurones. Noradrenergic and dopaminergic neurons simultaneously react to comparable environmental stimuli, which leads to the simultaneous release of noradrenaline and dopamine in particular brain areas, such as the frontal cortex, where they collectively influence network activity.[8]. The new study has excluded the direct role of noradrenaline in motor action selection.

The influence of arousal on human memory is inconsistent. It is both selective and modulated by adrenergic receptors located in the amygdala, which is thought to improve the recognition of relevant information and stimulate the locus coeruleus (LC). Analogous to dopamine, noradrenaline plays a crucial role in memory consolidation by facilitating long-term potentiation (LTP) via receptors found in the amygdala and hippocampus.[8]. The release of noradrenaline may affect hippocampus-dependent memory types within a restricted post-learning timeframe, including slow-wave sleep. Research indicates that variations in pupil response—an indicator of locus coeruleus (LC) activity—during the encoding phase are associated with the successful recall of emotional stimuli later on. Furthermore, there is an enhancement in the connectivity between the LC and amygdala, which offers indirect proof of the emotional drive exerted by the LC on pertinent memories. [9].

5. The function of dopamine in the processes of learning and memory consolidation

Dopaminergic neurons are predominantly situated in the ventral tegmental area (VTA) and the neighboring substantia nigra pars compacta (SNpc). The dopaminergic signaling within the VTA encapsulates the valence of feedback and conveys the expected intensity of the stimulus. The variance between these two parameters is termed "prediction error." The signaling activity of dopaminergic

neurons reflects the extent of the error. VTA neurones go to the hippocampus where dopamine enhances synaptic plasticity ultimately enhancing memory consolidation (see Figure 1). The neuromodulatory role of dopamine in the hippocampus and its promotion of improved episodic memory through a hippocampal-VTA circuit were detailed in a landmark study. [10]. Dopaminergic neurotransmission originating from the ventral tegmental area (VTA) to the ventral striatum plays a crucial role in reinforcement learning and is vital for the consolidation of memories in the hippocampus, beginning at the encoding stage. In hippocampal neurons, the stimulation of dopamine receptors lowers the threshold for long - term potentiation (LTP) and boosts protein synthesis within the dendrites of these neurons. This is crucial for maintaining late LTP in the CA1 region of the hippocampus.

Consequently, activating the substantia nigra/VTA via incentive-driven motivation is expected to improve hippocampal-dependent episodic recall of data obtained during reward anticipation. The memory-enhancing properties of dopamine are intricately associated with other information encoded in its presence, a phenomenon known as the 'penumbra hypothesis.' [11]. The 'penumbra hypothesis' suggests that an increase in dopamine availability facilitates the preferential consolidation of all encoded information, regardless of the specific stimulus that initiated the dopamine release. This assertion has been subsequently validated by both animal and human research. Enhanced dopamine levels contribute to memory stability, underscoring its vital role in the process of memory consolidation.

The density of dopamine synapses in the area of the hippocampus is significantly lower than in the regions of the striatum or prefrontal cortex. Dopaminergic neurones demonstrate significant innervation in the striatum, amygdala, and frontal cortex, with merely 15% of the neurones emanating from the ventral tegmental area/substantia nigra that project to the hippocampus being categorised as dopamine-producing, thereby suggesting that the dopamine in the hippocampus may derive from alternative sources rather than the substantia nigra [12]. Using the LC as an example, the dopaminergic and noradrenergic systems are intricately interconnected within hippocampal circuits. Dopamine, as a precursor of noradrenaline, is present in all noradrenergic fibers and can be produced at noradrenergic synapses from the locus coeruleus, which are abundant in the hippocampus.

6. Detection&experiment

Below the detection of the brain by FMRI is given and an experiment was conducted to show distinct effects from positive feedback to different types of memory.

6.1. FMRI

FMRI studies show that positive feedback and its anticipation, along with VTA co-activation, significantly enhance hippocampal memory. This is evident in real-time evaluations of visual stimuli and paired associations, as well as in delayed recognition memory assessments. Additionally, the interaction between the VTA and hippocampus during encoding may improve item association generalization.

This aligns with the framework proposed by Lisman & Grace. [10], novelty may induce dopamine release, which subsequently enhances the consolidation of memory traces associated with novel stimuli. The response to novel and rewarded things, unlike that to familiar but rewarded items, is linked to an enhanced connectivity between the SN/VTA and mesolimbic regions.

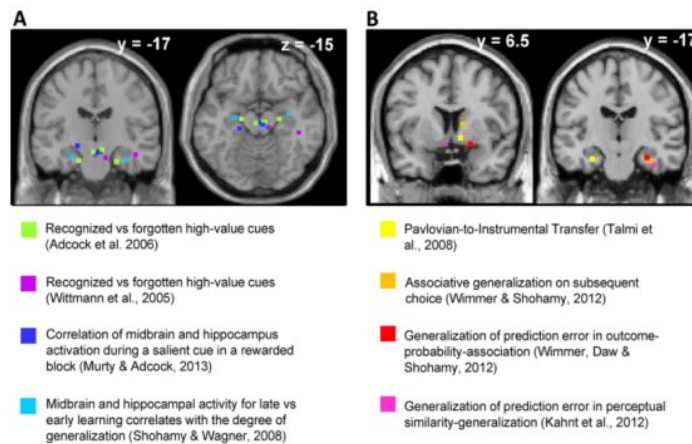


Figure 2: The underlying mechanisms of memory enhancement influenced by rewards are explored. (A) The concurrent activation of the midbrain and hippocampus during the acquisition of rewarded stimuli amplifies memory retention (indicated in green, blue, and violet) and supports associative inference (represented in turquoise). (B) The coactivation of the hippocampus and striatum plays a crucial role in the generalization of reward value. The online version of this article for a thorough comprehension of the colour allusions depicted in this image's myth.

6.2. Long-term memory versus immediate memory

Human studies found positive feedback has an influence on immediate short memory. The influence of rewards is also observed over time as memories consolidate. Wittmann illustrated that when monetary reward cues were linked to a sequence of line drawings, participants displayed markedly enhanced memory of the compensated drawings relative to the non-rewarded ones when evaluated three weeks after encoding, although this benefit was not apparent during right away evaluation. The effective identification of graphics forecasting rewards was associated with a greater stimulation in the area of the hippocampus and the lateral tegmental region during the initial encoding phase.

Murayama and Kuhbandner suggested that while rewards enhance long-term memory retention, they do not markedly influence immediate declarative memory performance.[13]. The subjects were presented with a series of trivia questions, with the provision that correct responses would yield monetary rewards. Following a 10-minute gap, no notable differences were detected between the two groups, possibly due to peak influences in memory recall, and individuals reached roughly 80% reliability. However, one week subsequently, a notable increase in average recall was observed for those answers that had been initially rewarded compared to those that had not. This study underscores the significant influence of positive reinforcement on declarative memory, indicating an improvement in long-term retention, which corresponds with the role of serotonin in regulating late LTP and consolidating of long-term memories [14].

Positive feedback may significantly influence immediate and long-term memory differently, with more notable distinctions emerging over extended retention periods that involve offline playback, which effectively safeguards reward-associated memories from decay.

7. Conclusion

This article synthesizes recent studies on memory enhancement through positive feedback, asserting that such feedback significantly influences memory formation and consolidation. It highlights that incentives activate the ventral tegmental area (VTA) and hippocampus prior to memory formation, allowing anticipations and motivations to interact with experiences, thereby impacting learning. The

anticipatory activation of this mesolimbic pathway may facilitate the conversion of motivation into memory.

Further exploration is needed on optimizing positive feedback, particularly in education. Research in U.S. primary and secondary schools suggests that financial incentives for academic success may not be effective. Researchers should explore diverse and engaging reward systems to captivate students, similar to the video game industry's use of external incentives to maintain player engagement, which is vital for educational success. However, this article overlooks individual differences in reward sensitivity, indicating that responses to rewards may vary. Future studies should examine the impact of novelty, emotional arousal, and extrinsic motivation on long-term memory consolidation, especially for content lacking intrinsic interest, to bridge current neuroscientific insights with practical applications.

References

- [1] Wang, S. H., & Morris, R. G. (2010). *Hippocampal-neocortical interactions in memory formation, consolidation, and reconsolidation. Annual review of psychology*, 61, 49–C4. <https://doi.org/10.1146/annurev.psych.093008.100523>
- [2] McKenzie, S., & Eichenbaum, H. (2011). *Consolidation and reconsolidation: two lives of memories?*. *Neuron*, 71(2), 224–233. <https://doi.org/10.1016/j.neuron.2011.06.037>
- [3] Greenberg, D. L., & Verfaellie, M. (2010). *Interdependence of episodic and semantic memory: evidence from neuropsychology. Journal of the International Neuropsychological Society : JINS*, 16(5), 748–753. <https://doi.org/10.1017/S1355617710000676>
- [4] Squire, L. R., Wixted, J. T., & Clark, R. E. (2007). *Recognition memory and the medial temporal lobe: A new perspective. Nature Reviews Neuroscience*, 8(11), 872–883. <https://doi.org/10.1038/nrn2154>
- [5] Alcaro, A., & Panksepp, J. (2011). *The SEEKING mind: primal neuro-affective substrates for appetitive incentive states and their pathological dynamics in addictions and depression. Neuroscience and biobehavioral reviews*, 35(9), 1805–1820. <https://doi.org/10.1016/j.neubiorev.2011.03.002>
- [6] Miendlarzewska, E. A., Bavelier, D., & Schwartz, S. (2016). *Influence of reward motivation on human declarative memory. Neuroscience & Biobehavioral Reviews*, 61, 156–176. <https://doi.org/10.1016/j.neubiorev.2015.11.015>
- [7] Steinberg, E. E., Keiflin, R., Boivin, J. R., Witten, I. B., Deisseroth, K., & Janak, P. H. (2013). *A causal link between prediction errors, dopamine neurons and learning. Nature neuroscience*, 16(7), 966–973. <https://doi.org/10.1038/nn.3413>
- [8] Sara S. J. (2009). *The locus coeruleus and noradrenergic modulation of cognition. Nature reviews. Neuroscience*, 10(3), 211–223. <https://doi.org/10.1038/nrn2573>
- [9] Sterpenich, V., D'Argembeau, A., Desseilles, M., Baeteau, E., Albouy, G., Vandewalle, G., Degueldre, C., Luxen, A., Collette, F., & Maquet, P. (2006). *The locus ceruleus is involved in the successful retrieval of emotional memories in humans. The Journal of neuroscience : the official journal of the Society for Neuroscience*, 26(28), 7416–7423. <https://doi.org/10.1523/JNEUROSCI.1001-06.2006>
- [10] Lisman, J. E., & Grace, A. A. (2005). *The hippocampal-VTA loop: controlling the entry of information into long-term memory. Neuron*, 46(5), 703–713. <https://doi.org/10.1016/j.neuron.2005.05.002>
- [11] Lisman, J., Grace, A. A., & Duzel, E. (2011). *A neoHebbian framework for episodic memory; role of dopamine-dependent late LTP. Trends in neurosciences*, 34(10), 536–547. <https://doi.org/10.1016/j.tins.2011.07.006>
- [12] Fields, H. L., Hjelmstad, G. O., Margolis, E. B., & Nicola, S. M. (2007). *Ventral tegmental area neurons in learned appetitive behavior and positive reinforcement. Annual review of neuroscience*, 30, 289–316. <https://doi.org/10.1146/annurev.neuro.30.051606.094341>
- [13] Murayama, K., & Kuhbandner, C. (2011). *Money enhances memory consolidation--but only for boring material. Cognition*, 119(1), 120–124. <https://doi.org/10.1016/j.cognition.2011.01.001>
- [14] Rossato, J. I., Bevilacqua, L. R., Izquierdo, I., Medina, J. H., & Cammarota, M. (2009). *Dopamine controls persistence of long-term memory storage. Science (New York, N.Y.)*, 325(5943), 1017–1020. <https://doi.org/10.1126/science.1172545>
- [15] Flannery, M. E. (2011). *Cash for grades? NEA Today*. Retrieved from <http://www.nea.org/home/42011.htm>