Brain Rhythms: Enhancing Memories

A new study shows that different processes are responsible for maintaining relevant and suppressing irrelevant information. By promoting the suppression of irrelevant information, memories may be enhanced.

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Everyday we are bombarded with information from the media, colleagues, spouses and friends. Some of this information is relevant and important, but other information is irrelevant and should have no influence on our behaviour. When listening to the weather forecast, only the weather predicted for our region is relevant to our behaviour. Adapting our behaviour to the predicted conditions — for example, driving rather than walking into work when severe rain is forecast — may depend upon us encoding the forecast in our region and ignoring the weather conditions in other regions. Distinct neural processes, as reported by Sauseng *et al.* [1] in this issue of *Current Biology,* are responsible for encoding relevant, whilst suppressing irrelevant, information.

The successful retention of relevant information depends upon the synchronization of specific brain rhythms — a coupling between theta and gamma rhythms — whereas the suppression of irrelevant information depends upon a single, distinct rhythm, the alpha rhythm. The evidence for this double dissociation comes not just from correlations: a functional link has been established between these brain rhythms and memory processing. In their work, Sauseng *et al.* [1] found that promoting the alpha rhythm increased suppression of irrelevant information and so enhanced memory performance. Thus, a simple model of memory formation in which relevant information is maintained and irrelevant information is suppressed has been shown through correlative and causative work to have a biological basis.

In the new study [1], participants were asked to learn an array of coloured squares appearing on one half of the screen, while suppressing the irrelevant coloured squares, appearing on the other half of the screen. Later, following a retention interval, participants viewed a set of 'probe' stimuli and were asked to decide whether those stimuli matched the relevant stimuli. The use of this probe tested whether learning of the relevant coloured stimuli had occurred. During the retention interval, the brain rhythms associated with learning the relevant and suppressing the irrelevant stimuli were identified by recording electrical brain activity (with an electroencephalogram).

The retention of relevant information was related to the synchronization between theta and gamma oscillations. Prior work has implicated theta oscillations and their interaction with gamma oscillations in the neuroplastic processes that underlie memory formation [2,3]. Promoting theta oscillations can also enhance memory formation [4]. Yet, to perform well on this task, it was not sufficient to recall relevant stimuli, but also necessary to suppress irrelevant stimuli. Suppression of information processing has been associated with the alpha rhythm, and consistent with those earlier observations, the alpha rhythm was found to be related to the suppression of irrelevant stimuli [1,5]. Thus, relevant information is maintained by neural processes which are distinct from those suppressing irrelevant stimuli.

Observations from this study extend beyond correlation to show a causative link between alpha rhythms and the suppression of irrelevant stimuli. Transcranial magnetic stimulation (TMS) is a technique which allows the non-invasive stimulation of the brain, and when applied at 10 Hz, it has been shown to entrain alpha rhythm [6,7]. Sauseng *et al.* [1] found that promoting alpha rhythm, by applying TMS at 10 Hz, increased participants' capacity to suppress irrelevant stimuli. Thus, the alpha rhythm is not a mere epiphenomenon of memory processing but instead seems likely to play a critical functional role in the suppression of irrelevant information.

An increasing number of studies have shown that TMS and related techniques can enhance human performance (for example, [4,8–11]). In the work of Sauseng *et al.* [1], TMS was used to enhance the alpha rhythm to increase the suppression of irrelevant information and so ultimately improve performance (Figure 1) [1]. Other studies have used non-invasive stimulation techniques to directly improve the plasticity of neural circuits and so enhance memory formation [11,12]. TMS has also been used to disrupt a brain area that was inhibiting another area, and through this disinhibition mechanism produce enhanced performance (for example, [8,9]). A challenge for future studies is to understand the relationship amongst these different descriptions of how TMS enhances performance (Figure 1).

Each description could be a distinct mechanism; alternatively, each description may offer a different perspective of the same underlying mechanism. The latter possibility of having only a single mechanism explaining all of the effects of TMS, whilst attractive from a parsimonious perspective, seems unlikely. Enhanced performance through suppressing irrelevant items was dependent upon the frequency at which TMS was applied [1]; yet TMS can disrupt a brain area at any frequency, and so rivalry between brain areas ought to be diminished, and so performance enhanced, regardless of stimulation frequency. Showing that the enhancement of memory is frequency-dependent, whilst certainly not definitive, is an important first step towards showing that rivalry between brain areas and the induction of alpha rhythms are distinct mechanisms.

Future work will deepen our understanding of the relationship between artificial and naturally occurring forms of memory enhancements [13,14]. Memories can be enhanced over sleep, and the mechanisms engaged can, at least in part, be successfully reproduced to provide memory enhancement over wakefulness [4]. Similarly, the termination of other critical processes — a disengagement between memory systems — can be successfully replicated over wakefulness to produce memory enhancements [9,15,16]. Thus, natural and artificial mechanisms of memory enhancement may have key components in common.

The apparent ease with which human performance can be enhanced implies that the brain is consistently operating below its maximum capacity. Such inefficiency may at first appear odd; after all, it would be beneficial to have the greatest possible performance at all times. However, this would be to ignore the hidden cost of improving human performance. For example, a motor skill memory can be enhanced by disrupting a declarative memory [9,15,16]. Thus, improved motor performance can occur at the cost of losing another type of knowledge. Yet retaining declarative knowledge for a motor skill would allow the motor skill to be described to other members of a group ensuring that the skill can benefit a wider society.

Redundantly encoding knowledge can also have other benefits. Finding your way around a new city involves simultaneously learning spatial landmarks and specific routes between locations. Consequently, when spatial landmarks are obscured, for example by fog, it is still possible to navigate based upon route learning. Redundant encoding therefore provides flexibility in responding to challenges from the environment; however, this comes with the cost of slowed learning due to simultaneously acquiring knowledge of both landmarks plus routes [17].

Suppressing irrelevant information and so enhancing performance may also come with a cost if initially irrelevant information becomes relevant. For instance, unbeknownst to you, your boss plans to send you out of the region that day; having maintained only the weather forecast for your region and suppressing those for other regions prevents you from responding flexibly to the new situation. So, enhanced performance may be limited to a particular context, and come with the cost of impaired performance outside of that context. Perhaps any enhanced performance comes at a cost which, in turn, implies that impaired performance may have hidden benefits. For instance, the interference between memories when they are acquired in quick succession impairs recall; but this impairment may come with benefits to memory processing [18,19].

In summary, maintaining relevant and suppressing irrelevant information are correlated with and functionally dependent upon distinct neural processes. Understanding the brain rhythms necessary for learning provides insight into memory organization, allowing the optimal conditions for encoding a specific memory to be recreated and so performance enhanced. Artificially enhancing performance may tap into mechanisms such as those engaged over sleep, which naturally enhance memories. Any enhanced performance may come with a cost — for example, a reduced capacity to respond flexibly to changing circumstances — while impaired performance may have hidden benefits for memory processing.

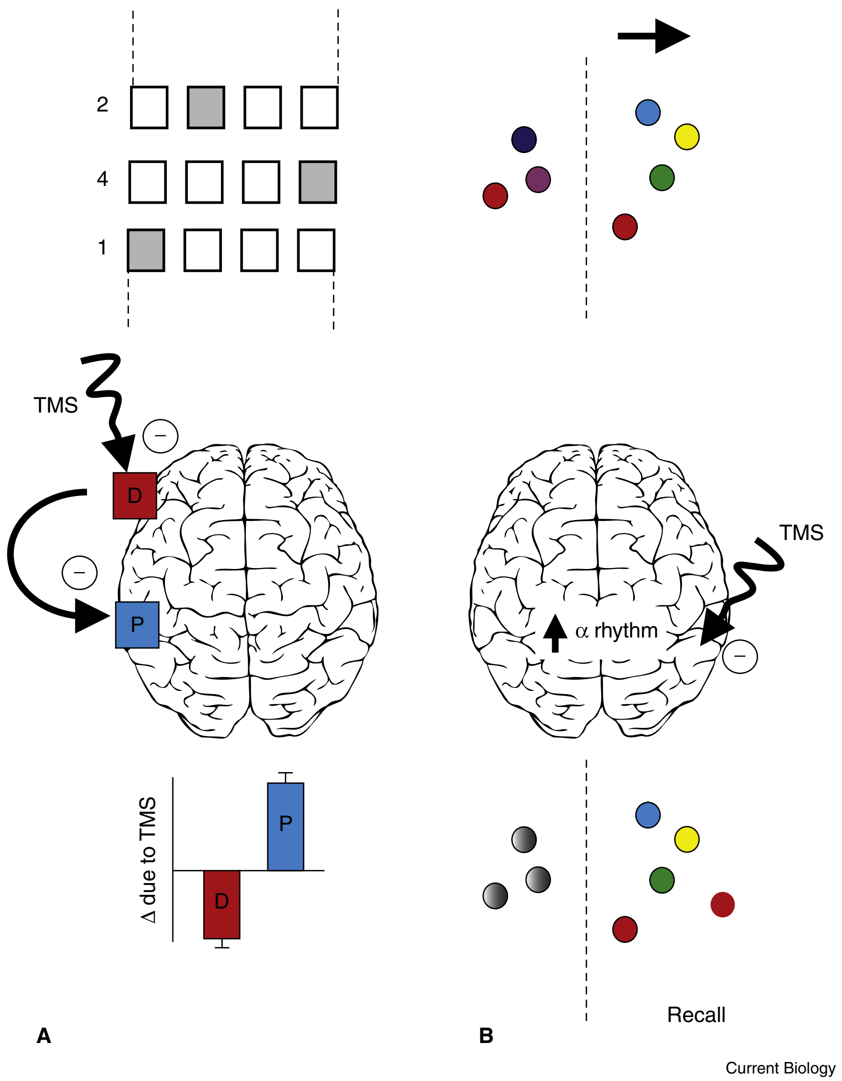

Figure 1. Possible routes to memory enhancement.

(A) A sequence can be learnt as a procedural series of movements (P; button selections, grey highlighted boxes), and as declarative knowledge (D) for the sequence (e.g., 2-4-1). Disrupting the declarative knowledge for the sequence — for example, by applying TMS to the dorsolateral prefrontal cortex — leads to an enhancement of procedural motor skill (see box graph) [9], which implies that there is a competitive interaction between different types of memory [15,16,20]. Similarly, there may be a competitive interaction between hemispheres (i.e., cerebral rivalry). By applying TMS the balance of this rivalry is altered, producing, for example, improved attention on one side [8]. (B) In contrast, a potentially distinct mechanism is to use TMS to promote the alpha rhythm and so suppress information processing within a hemisphere. Suppressing the processing of relevant information (cued to participants by an arrow; see above) will impair performance, whereas, suppressing the processing of irrelevant information will enhance performance [1]. When applied to the right hemisphere TMS will suppress the irrelevant visual cues presented on the left visual field, and so diminish their recall (recall; see above).

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