# 3. Memory enhancement and cognitive engineering

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## Key Concepts

**Deep Brain Stimulation** is an experimental surgical procedure that involves chronic implantation of stimulating wire electrodes into deep brain structures. The U.S. Food and Drug Administration approved Deep Brain Stimulation as a treatment for the motor symptoms of movement disorders in 1997, and since then the technique has been used to treat approximately 150,000 Parkinson's Disease patients. It is also being used experimentally to treat various psychiatric conditions, including major depressive disorder and obsessive-compulsive disorder.

**Optogenetics** is an experimental technique that offers by far the most sophisticated approach to manipulating memories. Developed over the past 15 years, optogenetics involves targeting specific neuronal cell types with genetic constructs containing light-sensitive algal genes. The constructs render specific, genetically targeted sub-sets of neurons sensitive to light, so that they can be activated or inhibited with light pulses delivered into the brain by means of optical fibres.

**Transcranial Magnetic Stimulation** stimulates brain activity by inducing a magnetic field that modulates the activity of neuronal populations within a targeted region of the cerebral cortex. Developed in 1985, the technique is being investigated as a treatment for various psychiatric conditions and received FDA approval as a treatment for drug-resistant major depression in 2008.

**Magnetoencephalography** is a functional neuroimaging technique that uses superconducting quantum interference devices to measure the tiny magnetic fields produced by neuronal populations. It allows for high-resolution measurement of brain activity on a millisecond-by-millisecond timescale.

## Scientific Anticipatory Brief abstract

### Current status of research and future trends

Various neurotechnologies are being used experimentally to modulate memory and other cognitive functions. These could be used to enhance memory function in healthy people, and a number of industry players are developing products aimed at the mass market for these purposes. The technologies could also have enormous clinical benefits, in the treatment of neurodegenerative disorders and psychiatric conditions that involve significant memory impairments and for which currently no therapy exists. For example, Alzheimer's Disease (AD) poses a major challenge; the incidence of AD in the developed world is predicted to increase significantly in years to come, as the Baby Boomer generation reaches retirement (Alzheimer's Association, 2019). Advances in neurotechnology may soon allow for interventions that slow the progression of the disease and, possibly, help restore memory function in Alzheimer's patients. Brain stimulation devices could potentially be used to treat patients with mild cognitive impairment, in order to delay the onset of AD, reduce its severity, or perhaps prevent onset altogether. The ability to erase specific memories could potentially be used to develop treatments for post-traumatic stress disorder (PTSD) and related conditions.

The technologies currently being used to manipulate memory function, stimulate the brain, and monitor brain activity can be broadly divided into two main categories: invasive and non-invasive. Major invasive techniques are deep brain stimulation (DBS), cortical stimulation, and opto- and chemogenetics, which are used mostly in animal research. The non-invasive techniques are transcranial direct current stimulation (tDCS), transcranial magnetic stimulation (TMS), and focused ultrasound (FUS), which can be used to modulate brain signals, and electroencephalography (EEG), magnetoencephalography (MEG), and functional magnetic resonance imaging (fMRI), which are used to record brain activity.

**Potential consequences on people, society and the planet**

Neurotechnologies that modulate human memory function will be available in the near future, for both therapeutic and enhancement purposes, but they will pose ethical issues, both for individuals and for society at large. Memory is central to human identity, so the ability to manipulate memory function could alter an individual's personhood. Beyond their potential therapeutic applications, neuromodulation devices – non-invasive devices in particular – will become available to the general public, for memory enhancement purposes in healthy people. This could increase societal inequalities by creating a 'cognitive elite' – a sub-section of the population that can afford, or has greater access to, these technologies. The widespread availability of these technologies would inevitably lead to the creation of large amounts of highly sensitive neurological data, raising the question of who should have access to the information, and why.

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Example of breakthroughs

### 5 years

**Outcomes**

- Within 3yrs, it may be possible to target and suppress the brain network activated in response to traumatic memories
- Treatment of variety of neuropsychiatric conditions, including depression (e.g. Deep Brain Stimulation is already being used as an experimental treatment for depression and several other psychiatric conditions).

**Enabling steps**

- Large electrode arrays for simultaneous recording & stimulation in multiple brain regions
- Invasive and non-invasive brain stimulation devices becoming more widely available, but mostly for medical use.
- Large clinical trials to hasten data acquisition allowing for rapid progression of the field

### 10 years

- Closed-loop devices that read and decode brain data to generate output in the form of stimulation.
- Machine learning algorithms to detect and decode mental states and stimulate the brain accordingly without requiring the intervention of a clinician.
- Non-invasive brain stimulation devices that modulate various aspects of cognitive function. They may enhance memory function by their effects on attention and the encoding and recall of information
- These devices could be used to combat age-related cognitive decline, thus reducing the risk of developing Alzheimer's Disease and other forms of dementia, and to treat psychiatric conditions such as depression.

### 25 years

- **Mini implants for use as memory aids**, that will be used pervasively to facilitate learning, transforming the learning process and the way we use our "native" cognitive functions, leading to a neuroscience based self-enhancement industry
- Optogenetics and gene therapy will advance to the point where optogenetic devices can be implanted into the brain and operated wirelessly from outside the skull.
- **Optogenetic manipulation of human memories** would have numerous therapeutic applications., such as suppress the fear memories experienced in phobias, or the intrusive memories that contribute to PTSD. The specificity of the technique could also trigger a shift from general boosting of memory function to more fine-grained suppression and enhancement of specific memories. For example, inception of false memories may help to treat self-harming behaviours.