Memory

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Memory is the faculty of the mind by which data or information is encoded, stored, and retrieved when needed. It is the retention of information over time for the purpose of influencing future action. If past events could not be remembered, it would be impossible for language, relationships, or personal identity to develop. Memory loss is usually described as forgetfulness or a disorder such as amnesia.

Memory is often understood as an information processing system with explicit and implicit functioning that is made up of a sensory processor, short-term (or working) memory, and long-term memory. This can be related to the neuron. The sensory processor allows information from the outside world to be sensed in the form of chemical and physical stimuli, and is attended to by various levels of focus and intent. Working memory serves as an encoding and retrieval processor. Information in the form of stimuli is encoded in accordance with explicit or implicit functions by the working memory processor. The working memory also retrieves information from previously stored material. Finally, the function of long-term memory is to store information through various categorical models or systems.

Declarative, or explicit memory, is the conscious storage and recollection of data. Under declarative memory resides semantic and episodic memory. Semantic memory refers to memory that is encoded with specific meaning. Meanwhile, episodic memory refers to information that is encoded along a spatial and temporal plane. Declarative memory is usually the primary process of thought when referencing memory. Non-declarative, or implicit memory, is the unconscious storage and recollection of information. An example of a non-declarative process would be the unconscious learning or retrieval of information by way of procedural memory, or a priming phenomenon. Priming is the process of subliminally arousing specific responses from memory and shows that not all memory is consciously activated, whereas procedural memory is the slow and gradual learning of skills that often occurs without conscious attention to learning.

Memory is not a perfect processor and is affected by many factors. The ways by which information is encoded, stored, and retrieved can all be corrupted. Pain, for example, has been identified as a physical condition that impairs memory, and has been noted in animal models as well as chronic

pain patients. The amount of attention given new stimuli can diminish the amount of information that becomes encoded for storage. Also, the storage process can become corrupted by physical damage to areas of the brain that are associated with memory storage, such as the hippocampus. Finally, the retrieval of information from long-term memory can be disrupted because of decay within long-term memory. Normal functioning, decay over time, and brain damage all affect the accuracy and capacity of the memory.

Sensory memory

Sensory memory holds information, derived from the senses, less than one second after an item is perceived. The ability to look at an item and remember what it looked like with just a split second of observation, or memorization, is an example of sensory memory. It is out of cognitive control and is an automatic response. With very short presentations, participants often report that they seem to "see" more than they can actually report. The first precise experiments exploring this form of sensory memory were conducted by George Sperling (1963) using the "partial report paradigm." Subjects were presented with a grid of 12 letters, arranged into three rows of four. After a brief presentation, subjects were then played either a high, medium or low tone, cuing them which of the rows to report. Based on these partial report experiments, Sperling was able to show that the capacity of sensory memory was approximately 12 items, but that it degraded very quickly (within a few hundred milliseconds). Because this form of memory degrades so quickly, participants would see the display but be unable to report all of the items (12 in the "whole report" procedure) before they decayed. This type of memory cannot be prolonged via rehearsal.

Three types of sensory memories exist. Iconic memory is a fast decaying store of visual information, a type of sensory memory that briefly stores an image that has been perceived for a small duration. Echoic memory is a fast decaying store of auditory information, also a sensory memory that briefly stores sounds that have been perceived for short durations. Haptic memory is a type of sensory memory that represents a database for touch stimuli.

Retrieval cues

How we encode information has a big impact on how well we remember it later. Research on levels of processing shows that memory is better when encoding emphasizes "deep" aspects of a stimulus (such as meaning) vs. "shallow" aspects of a stimulus (such as a place). "Deep" encoding leads to a highly distributed representation and "shallow" encoding leads to a sparse representation. Thinking about meaning creates a richer, more connected memory, while shallow processing leads to weaker, less lasting traces. Memory also works best when the cues we use to recall information match the ones present during learning which connects to the principle called encoding specificity. Similarly, context dependence shows that remembering is easier when the

environment at study matches the environment at test. For example, studying in a "wet" lab can help if the test is in the same setting. Overall, these findings show that both the way we think about information and the context in which we learn it play a major role in memory.

Short-term memory

Short-term memory, not to be confused with working memory, allows recall for a period of several seconds to a minute without rehearsal. Its capacity, however, is very limited. In 1956, George A. Miller (1920–2012), when working at Bell Laboratories, conducted experiments showing that the store of short-term memory was 7±2 items. (Hence, the title of his famous paper, "The Magical Number 7±2.") Modern perspectives estimate the capacity of short-term memory to be lower, typically on the order of 4–5 items, or argue for a more flexible limit based on information instead of items. Memory capacity can be increased through a process called chunking. For example, in recalling a ten-digit telephone number, a person could chunk the digits into three groups: first, the area code (such as 123), then a three-digit chunk (456), and, last, a four-digit chunk (7890). This method of remembering telephone numbers is far more effective than attempting to remember a string of 10 digits; this is because we are able to chunk the information into meaningful groups of numbers. This is reflected in some countries' tendencies to display telephone numbers as several chunks of two to four numbers.

Short-term memory is believed to rely mostly on an acoustic code for storing information, and to a lesser extent on a visual code. Conrad (1964) found that test subjects had more difficulty recalling collections of letters that were acoustically similar, e.g., E, P, D. Confusion with recalling acoustically similar letters rather than visually similar letters implies that the letters were encoded acoustically. Conrad's (1964) study, however, deals with the encoding of written text. Thus, while the memory of written language may rely on acoustic components, generalizations to all forms of memory cannot be made.

Long-term memory

The storage in sensory memory and short-term memory generally has a strictly limited capacity and duration. This means that information is not retained indefinitely. By contrast, while the total capacity of long-term memory has yet to be established, it can store much larger quantities of information. Furthermore, it can store this information for a much longer duration, potentially for a whole life span. For example, given a random seven-digit number, one may remember it for only a few seconds before forgetting, suggesting it was stored in short-term memory. On the other hand, one can remember telephone numbers for many years through repetition; this information is said to be stored in long-term memory. Also, our sense of self and continuity exists because of long-term memory, like what happened years ago or yesterday.

While short-term memory encodes information acoustically, long-term memory encodes it semantically: Baddeley (1966) discovered that, after 20 minutes, test subjects had the most difficulty recalling a collection of words that had similar meanings (e.g. big, large, great, huge) long-term. Another part of long-term memory is episodic memory, "which attempts to capture information such as 'what', 'when' and 'where'". With episodic memory, individuals are able to recall specific events such as birthday parties and weddings.

Short-term memory is supported by transient patterns of neuronal communication, dependent on regions of the frontal lobe (especially dorsolateral prefrontal cortex) and the parietal lobe. Long-term memory, on the other hand, is maintained by more stable and permanent changes in neural connections widely spread throughout the brain. The hippocampus is essential (for learning new information) to the consolidation of information from short-term to long-term memory, although it does not seem to store information itself. It was thought that without the hippocampus new memories were unable to be stored into long-term memory and that there would be a very short attention span, as first gleaned from patient Henry Molaison after what was thought to be the full removal of both his hippocampi. More recent examination of his brain, post-mortem, shows that the hippocampus was more intact than first thought, throwing theories drawn from the initial data into question. The hippocampus may be involved in changing neural connections for a period of three months or more after the initial learning.

Research has suggested that long-term memory storage in humans may be maintained by DNA methylation, and the 'prion' gene.

Further research investigated the molecular basis for long-term memory. By 2015 it had become clear that long-term memory requires gene transcription activation and de novo protein synthesis. Long-term memory formation depends on both the activation of memory promoting genes and the inhibition of memory suppressor genes, and DNA methylation/DNA demethylation was found to be a major mechanism for achieving this dual regulation.

Rats with a new, strong long-term memory due to contextual fear conditioning have reduced expression of about 1,000 genes and increased expression of about 500 genes in the hippocampus 24 hours after training, thus exhibiting modified expression of 9.17% of the rat hippocampal genome. Reduced gene expressions were associated with methylations of those genes.

Considerable further research into long-term memory has illuminated the molecular mechanisms by which methylations are established or removed, as reviewed in 2022. These mechanisms include, for instance, signal-responsive TOP2B-induced double-strand breaks in immediate early genes. Also the messenger RNAs of many genes that had been subjected to methylation-

controlled increases or decreases are transported by neural granules (messenger RNP) to the dendritic spines. At these locations the messenger RNAs can be translated into the proteins that control signaling at neuronal synapses.

Memory consolidation

The transition of a memory from short term to long term is called memory consolidation. Little is known about the physiological processes involved. Two propositions of how the brain achieves this task are backpropagation or backprop and positive feedback from the endocrine system. Backprop has been proposed as a mechanism the brain uses to achieve memory consolidation and has been used, for example by Geoffrey E. Hinton, Nobel Prize laureate for Physics in 2024, to build AI software. It implies a feedback to neurons consolidating a given memory to erase that information when the brain learns that that information is misleading or wrong. However, empirical evidence of its existence is not available.

On the contrary, positive feedback for consolidating a certain short-term memory registered in neurons, and considered by the neuro-endocrine systems to be useful, will make that short-term memory to consolidate into a permanent one. This has been shown to be true experimentally first in insects, which use arginine and nitric oxide levels in their brains and endorphin receptors for this task. The involvement of arginine and nitric oxide in memory consolidation has been confirmed in birds, mammals and other creatures, including humans.

Glial cells have also an important role in memory formation, although how they do their work remains to be unveiled.

Other mechanisms for memory consolidation can not be discarded.

Multi-store model

The multi-store model (also known as Atkinson–Shiffrin memory model) was first described in 1968 by Atkinson and Shiffrin.

The multi-store model has been criticised for being too simplistic. For instance, long-term memory is believed to be actually made up of multiple subcomponents, such as episodic and procedural memory. It also proposes that rehearsal is the only mechanism by which information eventually reaches long-term storage, but evidence highlights how we're capable of remembering things without rehearsal.

The model also shows all the memory stores as being a single unit whereas research into this shows differently. For example, short-term memory can be broken up into different units such as visual information and acoustic information. In a study by Zlonoga and Gerber (1986), patient 'KF' demonstrated certain deviations from the Atkinson–Shiffrin model. Patient KF was brain damaged,

displaying difficulties regarding short-term memory. Recognition of sounds such as spoken numbers, letters, words, and easily identifiable noises (such as doorbells and cats meowing) were all impacted. Visual short-term memory was unaffected, suggesting a dichotomy between visual and audial memory.

Working memory

In 1974 Baddeley and Hitch proposed a "working memory model" that replaced the general concept of short-term memory with active maintenance of information in short-term storage. In this model, working memory consists of three basic stores: the central executive, the phonological loop, and the visuo-spatial sketchpad. In 2000 this model was expanded with the multimodal episodic buffer (Baddeley's model of working memory).

The central executive essentially acts as an attention sensory store. It channels information to the three component processes: the phonological loop, the visuospatial sketchpad, and the episodic buffer.

The phonological loop stores auditory information by silently rehearsing sounds or words in a continuous loop: the articulatory process (for example the repetition of a telephone number over and over again). A short list of data is easier to remember. The phonological loop is occasionally disrupted. Irrelevant speech or background noise can impede the phonological loop. Articulatory suppression can also confuse encoding and words that sound similar can be switched or misremembered through the phonological similarity effect. the phonological loop also has a limit to how much it can hold at once which means that it is easier to remember a lot of short words rather than a lot of long words, according to the word length effect.

The visuospatial sketchpad stores visual and spatial information. It is engaged when performing spatial tasks (such as judging distances) or visual ones (such as counting the windows on a house or imagining images). Those with aphantasia will not be able to engage the visuospatial sketchpad.

The episodic buffer is dedicated to linking information across domains to form integrated units of visual, spatial, and verbal information and chronological ordering (e.g., the memory of a story or a movie scene). The episodic buffer is also assumed to have links to long-term memory and semantic meaning.

The working memory model explains many practical observations, such as why it is easier to do two different tasks, one verbal and one visual, than two similar tasks, and the aforementioned word-length effect. Working memory is also the premise for what allows us to do everyday activities involving thought. It is the section of memory where we carry out thought processes and use them to learn and reason about topics.

Types

Researchers distinguish between recognition and recall memory. Recognition memory tasks require individuals to indicate whether they have encountered a stimulus (such as a picture or a word) before. Recall memory tasks require participants to retrieve previously learned information. For example, individuals might be asked to produce a series of actions they have seen before or to say a list of words they have heard before.

By information type

Topographical memory involves the ability to orient oneself in space, to recognize and follow an itinerary, or to recognize familiar places. Getting lost when traveling alone is an example of the failure of topographic memory.

Flashbulb memories are clear episodic memories of unique and highly emotional events. People remembering what they were doing when they first heard the news of President Kennedy's assassination, the September 11 attacks, or the Sydney Siege are examples of flashbulb memories.

Long-term

Anderson (1976) divides long-term memory into declarative (explicit) and procedural (implicit) memories.

Declarative

Declarative memory requires conscious recall, in that some conscious process must call back the information. It is sometimes called explicit memory, since it consists of information that is explicitly stored and retrieved. Declarative memory can be further sub-divided into semantic memory, concerning principles and facts taken independent of context; and episodic memory, concerning information specific to a particular context, such as a time and place. Semantic memory allows the encoding of abstract knowledge about the world, such as "Paris is the capital of France". Episodic memory, on the other hand, is used for more personal memories, such as the sensations, emotions, and personal associations of a particular place or time. Episodic memories often reflect the "firsts" in life such as a first kiss, first day of school or first time winning a championship. These are key events in one's life that can be remembered clearly.

Research suggests that declarative memory is supported by several functions of the medial temporal lobe system which includes the hippocampus. Autobiographical memory – memory for particular events within one's own life – is generally viewed as either equivalent to, or a subset of, episodic memory. Visual memory is part of memory preserving some characteristics of our senses

pertaining to visual experience. One is able to place in memory information that resembles objects, places, animals or people in sort of a mental image. Visual memory can result in priming and it is assumed some kind of perceptual representational system underlies this phenomenon.

Procedural

In contrast, procedural memory (or implicit memory) is not based on the conscious recall of information, but on implicit learning. It can best be summarized as remembering how to do something. Procedural memory is primarily used in learning motor skills and can be considered a subset of implicit memory. It is revealed when one does better in a given task due only to repetition – no new explicit memories have been formed, but one is unconsciously accessing aspects of those previous experiences. Procedural memory involved in motor learning depends on the cerebellum and basal ganglia.

A characteristic of procedural memory is that the things remembered are automatically translated into actions, and thus sometimes difficult to describe. Some examples of procedural memory include the ability to ride a bike or tie shoelaces.

By temporal direction

Another major way to distinguish different memory functions is whether the content to be remembered is in the past, retrospective memory, or in the future, prospective memory. John Meacham introduced this distinction in a paper presented at the 1975 American Psychological Association annual meeting and subsequently included by Ulric Neisser in his 1982 edited volume, Memory Observed: Remembering in Natural Contexts. Thus, retrospective memory as a category includes semantic, episodic and autobiographical memory. In contrast, prospective memory is memory for future intentions, or remembering to remember (Winograd, 1988). Prospective memory can be further broken down into event- and time-based prospective remembering. Time-based prospective memories are triggered by a time-cue, such as going to the doctor (action) at 4pm (cue). Event-based prospective memories are intentions triggered by cues, such as remembering to post a letter (action) after seeing a mailbox (cue). Cues do not need to be related to the action (as the mailbox/letter example), and lists, sticky-notes, knotted handkerchiefs, or string around the finger all exemplify cues that people use as strategies to enhance prospective memory.

Failures

Transience – memories degrade with the passing of time. This occurs in the storage stage of memory, after the information has been stored and before it is retrieved. This can happen in sensory, short-term, and long-term storage. It follows a general pattern where the information is

rapidly forgotten during the first couple of days or years, followed by small losses in later days or years.

Absent-mindedness – Memory failure due to the lack of attention. Attention plays a key role in storing information into long-term memory; without proper attention, the information might not be stored, making it impossible to be retrieved later.

Physiology

Brain areas involved in the neuroanatomy of memory such as the hippocampus, the amygdala, the striatum, or the mammillary bodies are thought to be involved in specific types of memory. For example, the hippocampus is believed to be involved in spatial learning and declarative learning, while the amygdala is thought to be involved in emotional memory.

Damage to certain areas in patients and animal models and subsequent memory deficits is a primary source of information. However, rather than implicating a specific area, it could be that damage to adjacent areas, or to a pathway traveling through the area is actually responsible for the observed deficit. Further, it is not sufficient to describe memory, and its counterpart, learning, as solely dependent on specific brain regions. Learning and memory are usually attributed to changes in neuronal synapses, thought to be mediated by long-term potentiation and long-term depression.

In general, the more emotionally charged an event or experience is, the better it is remembered; this phenomenon is known as the memory enhancement effect. Patients with amygdala damage, however, do not show a memory enhancement effect.

Hebb distinguished between short-term and long-term memory. He postulated that any memory that stayed in short-term storage for a long enough time would be consolidated into a long-term memory. Later research showed this to be false. Research has shown that direct injections of cortisol or epinephrine help the storage of recent experiences. This is also true for stimulation of the amygdala. This proves that excitement enhances memory by the stimulation of hormones that affect the amygdala. Excessive or prolonged stress (with prolonged cortisol) may hurt memory storage. Patients with amygdalar damage are no more likely to remember emotionally charged words than nonemotionally charged ones. The hippocampus is important for explicit memory. The hippocampus is also important for memory consolidation. The hippocampus receives input from different parts of the cortex and sends its output out to different parts of the brain also. The input comes from secondary and tertiary sensory areas that have processed the information a lot already. Hippocampal damage may also cause memory loss and problems with memory storage. This memory loss includes retrograde amnesia which is the loss of memory for events that occurred shortly before the time of brain damage.

Cognitive neuroscience

Cognitive neuroscientists consider memory as the retention, reactivation, and reconstruction of the experience-independent internal representation. The term of internal representation implies that such a definition of memory contains two components: the expression of memory at the behavioral or conscious level, and the underpinning physical neural changes (Dudai 2007). The latter component is also called engram or memory traces (Semon 1904). Some neuroscientists and psychologists mistakenly equate the concept of engram and memory, broadly conceiving all persisting after-effects of experiences as memory; others argue against this notion that memory does not exist until it is revealed in behavior or thought (Moscovitch 2007).

One question that is crucial in cognitive neuroscience is how information and mental experiences are coded and represented in the brain. Scientists have gained much knowledge about the neuronal codes from the studies of plasticity, but most of such research has been focused on simple learning in simple neuronal circuits; it is considerably less clear about the neuronal changes involved in more complex examples of memory, particularly declarative memory that requires the storage of facts and events (Byrne 2007). Convergence-divergence zones might be the neural networks where memories are stored and retrieved. Considering that there are several kinds of memory, depending on types of represented knowledge, underlying mechanisms, processes functions and modes of acquisition, it is likely that different brain areas support different memory systems and that they are in mutual relationships in neuronal networks: "components of memory representation are distributed widely across different parts of the brain as mediated by multiple neocortical circuits".

Encoding. Encoding of working memory involves the spiking of individual neurons induced by sensory input, which persists even after the sensory input disappears (Jensen and Lisman 2005; Fransen et al. 2002). Encoding of episodic memory involves persistent changes in molecular structures that alter synaptic transmission between neurons. Examples of such structural changes include long-term potentiation (LTP) or spike-timing-dependent plasticity (STDP). The persistent spiking in working memory can enhance the synaptic and cellular changes in the encoding of episodic memory (Jensen and Lisman 2005).

Working memory. Recent functional imaging studies detected working memory signals in both medial temporal lobe (MTL), a brain area strongly associated with long-term memory, and prefrontal cortex (Ranganath et al. 2005), suggesting a strong relationship between working memory and long-term memory. However, the substantially more working memory signals seen in the prefrontal lobe suggest that this area plays a more important role in working memory than MTL (Suzuki 2007).

Consolidation and reconsolidation. Short-term memory (STM) is temporary and subject to disruption, while long-term memory (LTM), once consolidated, is persistent and stable. Consolidation of STM into LTM at the molecular level presumably involves two processes: synaptic consolidation and system consolidation. The former involves a protein synthesis process in the medial temporal lobe (MTL), whereas the latter transforms the MTL-dependent memory into an MTL-independent memory over months to years (Ledoux 2007). In recent years, such traditional consolidation dogma has been re-evaluated as a result of the studies on reconsolidation. These studies showed that prevention after retrieval affects subsequent retrieval of the memory (Sara 2000). New studies have shown that post-retrieval treatment with protein synthesis inhibitors and many other compounds can lead to an amnestic state (Nadel et al. 2000b; Alberini 2005; Dudai 2006). These findings on reconsolidation fit with the behavioral evidence that retrieved memory is not a carbon copy of the initial experiences, and memories are updated during retrieval.

Aging

One of the key concerns of older adults is the experience of memory loss, especially as it is one of the hallmark symptoms of Alzheimer's disease. However, memory loss is qualitatively different in normal aging from the kind of memory loss associated with a diagnosis of Alzheimer's (Budson & Price, 2005). Research has revealed that individuals' performance on memory tasks that rely on frontal regions declines with age. Older adults tend to exhibit deficits on tasks that involve knowing the temporal order in which they learned information, source memory tasks that require them to remember the specific circumstances or context in which they learned information, and prospective memory tasks that involve remembering to perform an act at a future time. Older adults can manage their problems with prospective memory by using appointment books, for example.

Gene transcription profiles were determined for the human frontal cortex of individuals from age 26 to 106 years. Numerous genes were identified with reduced expression after age 40, and especially after age 70. Genes that play central roles in memory and learning were among those showing the most significant reduction with age. There was also a marked increase in DNA damage, likely oxidative damage, in the promoters of those genes with reduced expression. It was suggested that DNA damage may reduce the expression of selectively vulnerable genes involved in memory and learning.

Disorders

Much of the current knowledge of memory has come from studying memory disorders, particularly loss of memory, known as amnesia. Amnesia can result from extensive damage to: (a) the regions of the medial temporal lobe, such as the hippocampus, dentate gyrus, subiculum, amygdala, the parahippocampal, entorhinal, and perirhinal cortices or the (b) midline diencephalic region,

specifically the dorsomedial nucleus of the thalamus and the mammillary bodies of the hypothalamus. There are many sorts of amnesia, and by studying their different forms, it has become possible to observe apparent defects in individual sub-systems of the brain's memory systems, and thus hypothesize their function in the normally working brain. Other neurological disorders such as Alzheimer's disease and Parkinson's disease can also affect memory and cognition.

Hyperthymesia, or hyperthymesic syndrome, is a disorder that affects an individual's autobiographical memory, essentially meaning that they cannot forget small details that otherwise would not be stored. Korsakoff's syndrome, also known as Korsakoff's psychosis, amnesic-confabulatory syndrome, is an organic brain disease that adversely affects memory by widespread loss or shrinkage of neurons within the prefrontal cortex.

While not a disorder, a common temporary failure of word retrieval from memory is the tip-of-the-tongue phenomenon. Those with anomic aphasia (also called nominal aphasia or Anomia), however, do experience the tip-of-the-tongue phenomenon on an ongoing basis due to damage to the frontal and parietal lobes of the brain.

Memory dysfunction can also occur after viral infections. Many patients recovering from COVID-19 experience memory lapses. Other viruses can also elicit memory dysfunction, including SARS-CoV-1, MERS-CoV, Ebola virus and even influenza virus.

Influencing factors

Interference

Interference can hamper memorization and retrieval. There is retroactive interference, when learning new information makes it harder to recall old information and proactive interference, where prior learning disrupts recall of new information. Although interference can lead to forgetting, it is important to keep in mind that there are situations when old information can facilitate learning of new information. Knowing Latin, for instance, can help an individual learn a related language such as French – this phenomenon is known as positive transfer.

Stress

Stress has a significant effect on memory formation and learning. In response to stressful situations, the brain releases hormones and neurotransmitters (ex. glucocorticoids and catecholamines) which affect memory encoding processes in the hippocampus. Behavioural research on animals shows that chronic stress produces adrenal hormones which impact the hippocampal structure in the brains of rats. An experimental study by German cognitive psychologists L. Schwabe and O. Wolf demonstrates how learning under stress also decreases

memory recall in humans. In this study, 48 healthy female and male university students participated in either a stress test or a control group. Those randomly assigned to the stress test group had a hand immersed in ice cold water (the reputable SECPT or 'Socially Evaluated Cold Pressor Test') for up to three minutes, while being monitored and videotaped. Both the stress and control groups were then presented with 32 words to memorize. Twenty-four hours later, both groups were tested to see how many words they could remember (free recall) as well as how many they could recognize from a larger list of words (recognition performance). The results showed a clear impairment of memory performance in the stress test group, who recalled 30% fewer words than the control group. The researchers suggest that stress experienced during learning distracts people by diverting their attention during the memory encoding process.

However, memory performance can be enhanced when material is linked to the learning context, even when learning occurs under stress. A separate study by cognitive psychologists Schwabe and Wolf shows that when retention testing is done in a context similar to or congruent with the original learning task (i.e., in the same room), memory impairment and the detrimental effects of stress on learning can be attenuated. Seventy-two healthy female and male university students, randomly assigned to the SECPT stress test or to a control group, were asked to remember the locations of 15 pairs of picture cards – a computerized version of the card game "Concentration" or "Memory". The room in which the experiment took place was infused with the scent of vanilla, as odour is a strong cue for memory. Retention testing took place the following day, either in the same room with the vanilla scent again present, or in a different room without the fragrance. The memory performance of subjects who experienced stress during the object-location task decreased significantly when they were tested in an unfamiliar room without the vanilla scent (an incongruent context); however, the memory performance of stressed subjects showed no impairment when they were tested in the original room with the vanilla scent (a congruent context). All participants in the experiment, both stressed and unstressed, performed faster when the learning and retrieval contexts were similar.

This research on the effects of stress on memory may have practical implications for education, for eyewitness testimony and for psychotherapy: students may perform better when tested in their regular classroom rather than an exam room, eyewitnesses may recall details better at the scene of an event than in a courtroom, and persons with post-traumatic stress may improve when helped to situate their memories of a traumatic event in an appropriate context.

Stressful life experiences may be a cause of memory loss as a person ages. Glucocorticoids that are released during stress cause damage to neurons that are located in the hippocampal region of the brain. Therefore, the more stressful situations that someone encounters, the more susceptible they are to memory loss later on. The CA1 neurons found in the hippocampus are destroyed due to glucocorticoids decreasing the release of glucose and the reuptake of glutamate. This high level of extracellular glutamate allows calcium to enter NMDA receptors which in return kills neurons.

Stressful life experiences can also cause repression of memories where a person moves an unbearable memory to the unconscious mind. This directly relates to traumatic events in one's past such as kidnappings, being prisoners of war or sexual abuse as a child.

The more long term the exposure to stress is, the more impact it may have. However, short term exposure to stress also causes impairment in memory by interfering with the function of the hippocampus. Research shows that subjects placed in a stressful situation for a short amount of time still have blood glucocorticoid levels that have increased drastically when measured after the exposure is completed. When subjects are asked to complete a learning task after short term exposure they often have difficulties. Prenatal stress also hinders the ability to learn and memorize by disrupting the development of the hippocampus and can lead to unestablished long term potentiation in the offspring of severely stressed parents. Although the stress is applied prenatally, the offspring show increased levels of glucocorticoids when they are subjected to stress later on in life. One explanation for why children from lower socioeconomic backgrounds tend to display poorer memory performance than their higher-income peers is the effects of stress accumulated over the course of the lifetime. The effects of low income on the developing hippocampus is also thought be mediated by chronic stress responses which may explain why children from lower and higher-income backgrounds differ in terms of memory performance.

Sleep

Making memories occurs through a three-step process, which can be enhanced by sleep. The three steps are as follows:

Acquisition which is the process of storage and retrieval of new information in memory

Consolidation

Recall

Sleep affects memory consolidation. During sleep, the neural connections in the brain are strengthened. This enhances the brain's abilities to stabilize and retain memories. There have been several studies which show that sleep improves the retention of memory, as memories are enhanced through active consolidation. System consolidation takes place during slow-wave sleep (SWS). This process implicates that memories are reactivated during sleep, but that the process does not enhance every memory. It also implicates that qualitative changes are made to the memories when they are transferred to long-term store during sleep. During sleep, the hippocampus replays the events of the day for the neocortex. The neocortex then reviews and processes memories, which moves them into long-term memory. When one does not get enough sleep it makes it more difficult to learn as these neural connections are not as strong, resulting in a lower retention rate of memories. Sleep deprivation makes it harder to focus, resulting in inefficient learning. Furthermore, some studies have shown that sleep deprivation can lead to false memories

as the memories are not properly transferred to long-term memory. One of the primary functions of sleep is thought to be the improvement of the consolidation of information, as several studies have demonstrated that memory depends on getting sufficient sleep between training and test. Additionally, data obtained from neuroimaging studies have shown activation patterns in the sleeping brain that mirror those recorded during the learning of tasks from the previous day, suggesting that new memories may be solidified through such rehearsal.

Improving

A UCLA research study published in the June 2008 issue of the American Journal of Geriatric Psychiatry found that people can improve cognitive function and brain efficiency through simple lifestyle changes such as incorporating memory exercises, healthy eating, physical fitness and stress reduction into their daily lives. This study examined 17 subjects, (average age 53) with normal memory performance. Eight subjects were asked to follow a "brain healthy" diet, relaxation, physical, and mental exercise (brain teasers and verbal memory training techniques). After 14 days, they showed greater word fluency (not memory) compared to their baseline performance. No long-term follow-up was conducted; it is therefore unclear if this intervention has lasting effects on memory.

Exercise, even at light intensity, significantly improves memory across all age groups, with the greatest benefits observed in children and adolescents. Even low- to moderate-intensity exercise and shorter interventions (1–3 months) can produce meaningful cognitive improvements.

There are a loosely associated group of mnemonic principles and techniques that can be used to vastly improve memory known as the art of memory.

The International Longevity Center released in 2001 a report which includes in pages 14–16 recommendations for keeping the mind in good functionality until advanced age. Some of the recommendations are:

to stay intellectually active through learning, training or reading

to keep physically active so to promote blood circulation to the brain

to socialize

to reduce stress

to keep sleep time regular

to avoid depression or emotional instability

to observe good nutrition.

Memorization is a method of learning that allows an individual to recall information verbatim. Rote learning is the method most often used. Methods of memorizing things have been the subject of much discussion over the years with some writers, such as Cosmos Rossellius using visual alphabets. The spacing effect shows that an individual is more likely to remember a list of items when rehearsal is spaced over an extended period of time. In contrast to this is cramming: an intensive memorization in a short period of time. The spacing effect is exploited to improve memory in spaced repetition flashcard training. Also relevant is the Zeigarnik effect, which states that people remember uncompleted or interrupted tasks better than completed ones. The so-called Method of loci uses spatial memory to memorize non-spatial information. Another memory improvement technique called Mnemonics is based on linking the material to be recalled with information that is organized in groups of images or words. Example VIBGYOR to remember all the rainbow colors in chronology.