

# Unsolved Problems in Neuroscience

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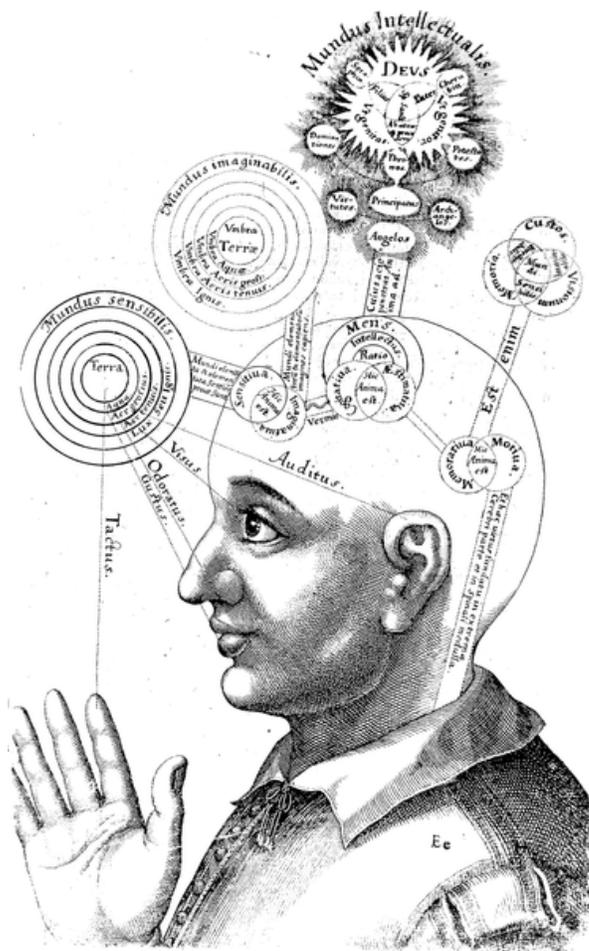
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# Chapter 1

## Consciousness



Representation of consciousness from the 17th century.

**Consciousness** is a term that has been used to refer to a variety of aspects of the relationship between the mind and the world with which it interacts. It has been defined, at one time or another, as: subjective experience; awareness; the ability to experience feelings; wakefulness; having a sense of selfhood; or as the executive control system of

the mind. Despite the difficulty of definition, many philosophers believe that there is a basic underlying intuition about consciousness that is shared by nearly all people. As Max Velmans and Susan Schneider wrote in *The Blackwell Companion to Consciousness*:

"Anything that we are aware of at a given moment forms part of our consciousness, making conscious experience at once the most familiar and most mysterious aspect of our lives."

In philosophy, consciousness is often said to imply four characteristics: subjectivity, change, continuity, and selectivity. Philosopher Franz Brentano has also suggested intentionality or aboutness (that consciousness is about something); however, there is no consensus on whether intentionality is a requirement for consciousness. Issues of practical concern in the philosophy of consciousness include whether consciousness can ever be explained mechanistically; whether non-human consciousness exists and if so how it can be recognized; at what point in fetal development consciousness begins; and whether it may ever be possible for computers to achieve a conscious state.

At one time consciousness was viewed with skepticism by many scientists and considered within the domain of philosophers and theologians, but in recent years it has been an increasingly significant topic of scientific research. In psychology and neuroscience, the focus of most research is on understanding what it means biologically and psychologically for information to be present in consciousness—that is, on determining the neural and psychological correlates of consciousness. The majority of experimental studies use human subjects and assess consciousness by asking subjects for a verbal report of their experiences (e.g., "tell me if you notice anything when I do this"). Issues of interest include phenomena such as subliminal perception, blindsight, denial of impairment, and altered states of consciousness produced by psychoactive drugs or spiritual or meditative techniques.

In medicine, consciousness is assessed by observing a patient's arousal and responsiveness, and can be seen as a continuum of states ranging from full alertness and comprehension, through disorientation, then delirium, then loss of any meaningful communication, and ending with loss of movement in response to painful stimuli. Issues of practical concern include how the presence of consciousness can be assessed in severely ill, comatose, or anesthetized people, and how to treat conditions in which consciousness is impaired or disrupted.

### ***Etymology of the word and history of the concept***

The origin of the modern concept of consciousness is often attributed to John Locke's *Essay Concerning Human Understanding*, published in 1690. Locke explicitly defined consciousness as "the perception of what passes in a man's own mind." His essay had much influence on the 18th century view of consciousness, and his definition appeared in Samuel Johnson's celebrated Dictionary (1755).

The earliest English language uses of "conscious" and "consciousness" date back, however, to the 1500s. The English word "conscious" originally derived from Latin word *consciūs* (*con-* "together" + *scire* "to know"), but the Latin version did not have the same meaning as our word — it meant *knowing with*, in other words *having joint or common knowledge with another, privy to, cognizant of*. There were, however, many occurrences in Latin writings of the phrase *consciūs sibi*, which translates literally as "knowing with oneself", or in other words *sharing knowledge with oneself about something*. Taken literally this is nonsense, but it had the figurative meaning of *knowing that one knows*, as the modern English word "conscious" does. In its earliest uses in the 1500s, the English word retained the Latin meaning. For example Thomas Hobbes in *Leviathan* wrote: "Where two, or more men, know of one and the same fact, they are said to be Conscious of it one to another." The Latin *consciūs sibi* was rendered in English as "conscious to oneself" or "conscious unto oneself". For example, Archbishop Ussher wrote in 1613 of "being so conscious unto myself of my great weakness".

A related word was *conscientia*, which primarily means moral conscience. In the literal sense, "conscientia" means knowledge-with, that is, shared knowledge. The word first appears in Latin juridical texts by writers such as Cicero. Here, *conscientia* is the knowledge that a witness has of the deed of someone else. René Descartes (1596–1650) is generally taken to be the first philosopher to use "conscientia" in a way that does not fit this traditional meaning. Descartes used "conscientia" the way modern speakers would use "conscience." In *Search after Truth* he says "conscience or internal testimony" (*conscientia vel interno testimonio*).

Shortly thereafter, in Britain, the neo-Platonist theologian Ralph Cudworth used something resembling the modern meaning of consciousness in his "True Intellectual System of the Universe" (1678), although he never explicitly defined the term.

## ***Philosophical approaches***

The philosophy of mind has given rise to many stances regarding consciousness. They differ in the answers they give to a set of fundamental questions, including:

1. Is consciousness a valid concept or a conceptual error?
2. Is it a single unified entity or a collection of distinct entities?
3. How does it relate to language?
4. Can it be explained in terms of the laws of physics?
5. Why are we convinced that other people (or even we ourselves) possess consciousness?
6. Why do we believe that some animals possess consciousness, and is there any way to test this belief?
7. What is the nature of experience, and particularly what is the nature of sensory qualities such as the color red?

The question about the relationship between consciousness and the physical realm is perhaps the most contentious of all: several schools of thought are defined mainly in terms of the answers they give to it.

### **Is it a valid concept?**

A majority of philosophers have felt that the word consciousness names a genuine entity, but some who belong to the physicalist and behaviorist schools have not been convinced; many scientists have also been dubious. The most compelling argument in favor is that the vast majority of mankind has an overwhelming intuition that there truly is such a thing. The argument against is that this intuition, however compelling it may be, is false. Gilbert Ryle, for example, argued that traditional understanding of consciousness depends on a Cartesian dualist outlook that divides into mind and body, mind and world. He proposed that we speak not of minds, bodies, and the world, but of individuals, or persons, acting in the world. Thus, by speaking of 'consciousness,' we end up misleading ourselves by thinking that there is any sort of thing as consciousness separated from behavioral and linguistic understandings.

Another problem that concerns many philosophers and scientists is the difficulty of producing a definition that does not rely on circularity or fuzziness. The neuroscientist Antonio Damasio, for example, calls consciousness "the feeling of what happens", and defines it as "an organism's awareness of its own self and its surroundings". These formulations seem intuitively reasonable, but they are difficult to apply to specific situations.

### **Is it a single thing?**

Many philosophers have argued that *consciousness* is a unitary concept that is understood intuitively by the majority of people in spite of the difficulty in defining it. Others, though, have argued that the level of disagreement about the meaning of the word indicates that it is an umbrella term meaning different things to different people.

Ned Block proposed a distinction between two types of consciousness that he called *phenomenal* (P-consciousness) and *access* (A-consciousness). P-consciousness, according to Block, is simply raw experience: it is moving, colored forms, sounds, sensations, emotions and feelings with our bodies and responses at the center. These experiences, considered independently of any impact on behavior, are called *qualia*. A-consciousness, on the other hand, is the phenomenon whereby information in our minds is accessible for verbal report, reasoning, and the control of behavior. So, when we perceive, information about what we perceive is access conscious; when we introspect, information about our thoughts is access conscious; when we remember, information about the past is access conscious, and so on. Although some philosophers, such as Daniel Dennett, have disputed the validity of this distinction, others have broadly accepted it. David Chalmers has argued that A-consciousness can in principle be understood in mechanistic terms, but that understanding P-consciousness is much more challenging: he calls this the *hard problem of consciousness*. Dennett denies that the

concept of qualia is coherent, that P-consciousness is intrinsically different from A-consciousness, and that there is anything especially hard about the "hard problem".

## **How does it relate to the physical world?**

The first influential philosopher to discuss this question specifically was Descartes, and the answer he proposed is known as Cartesian dualism. Descartes proposed that consciousness resides within an immaterial domain he called *res cogitans* (the realm of thought), in contrast to the domain of material things which he called *res extensa* (the realm of extension). He suggested that the interaction between these two domains occurs inside the brain, perhaps in a small midline structure called the pineal gland.

Although it is widely accepted that Descartes explained the problem very cogently, few later philosophers have been happy with his solution, and in particular his emphasis on the pineal gland has generally been ridiculed. Alternative solutions, however, have been extremely diverse. They can be divided broadly into two categories: dualist solutions that maintain Descartes's rigid distinction between the realm of consciousness and the realm of matter but give different answers for how the two realms relate to each other; and monist solutions that maintain that there is really only one realm of being, of which consciousness and matter are both aspects. Each of these categories itself contains numerous variants. The two main types of dualism are substance dualism (which holds that the mind is formed of a distinct type of substance not governed by the laws of physics) and property dualism (which holds that the laws of physics are universally valid but cannot be used to explain the mind). The three main types of monism are physicalism (which holds that the mind consists of matter organized in a particular way), idealism (which holds that only thought truly exists and matter is merely an illusion), and neutral monism (which holds that both mind and matter are aspects of a distinct essence that is itself identical to neither of them). There are also, however, a large number of idiosyncratic theories that cannot cleanly be assigned to any of these camps.

Some theorists hold that phenomenal consciousness in particular creates an explanatory gap. Colin McGinn takes the New Mysterianism position that it can't be solved, and David Chalmers criticizes purely physical accounts of mental experiences based on the idea that philosophical zombies are logically possible and supports property dualism.

## **How does it relate to language?**

In humans, the clearest visible indication of consciousness is the ability to use language. Medical assessments of consciousness rely heavily on an ability to respond to questions and commands, and in scientific studies of consciousness, the usual criterion for awareness is verbal report (that is, subjects are deemed to be aware if they say that they are). Thus there is a strong connection between consciousness and language. Philosophers differ, however, on whether language is essential to consciousness or merely the most powerful tool for gaining access to it.

Descartes believed that language is essential: he argued that non-human animals lack consciousness because they lack language. Others have reached the same conclusion, though sometimes for different reasons. Julian Jaynes argued in *The Origin of Consciousness in the Breakdown of the Bicameral Mind* that for consciousness to arise, language needs to have reached a fairly high level of complexity. Merlin Donald also argued for a critical dependence of consciousness on the ability to use symbols in a sophisticated way.

Those are, however, minority views. If language is essential, then speechless humans (infants, feral children, aphasics, *etc.*) could not be said to be conscious, a conclusion that the majority of philosophers have resisted. The implication that humans are the only animals capable of consciousness is also widely resisted, and often viewed as offensive.

## **Why do we believe that other people are conscious?**

Many philosophers consider experience to be the essence of consciousness, and believe that experience can only fully be known from the inside, subjectively. But if consciousness is subjective and not visible from the outside, why do the vast majority of people believe that other people are conscious? This is the problem of other minds. It is particularly acute for people who believe in the possibility of philosophical zombies, that is, people who think it is possible in principle to have an entity that is physically indistinguishable from a human being and behaves like a human being in every way but nevertheless lacks consciousness.

The most commonly given answer is that we attribute consciousness to other people because we see that they resemble us in appearance and behavior: we reason that if they look like us and act like us, they must be like us in other ways, including having experiences of the sort that we do. There are, however, a variety of problems with that explanation. For one thing, it seems to violate the principle of parsimony, by postulating an invisible entity that is not necessary to explain what we observe. Some philosophers, such as Daniel Dennett in an essay titled *The Unimaginable Preposterousness of Zombies*, argue that people who give this explanation do not really understand what they are saying. More broadly, philosophers who do not accept the possibility of zombies generally believe that consciousness is reflected in behavior (including verbal behavior), and that we attribute consciousness on the basis of behavior. A more straightforward way of saying this is that we attribute experiences to people because they tell us about their experiences.

## ***Spiritual approaches***

### ***Vedanta***

According to *Vedanta*, awareness is not a product of physical processes and can be considered under four aspects. The first is waking consciousness (*jagaritasthana*), the identification with “I” or “me” in relationship with phenomenal experiences with external objects. The second aspect is dream consciousness (*svapna-sthana*), which embodies the

same subject/object duality as the waking state. The third aspect of consciousness is deep sleep (*susupti*), which is non-dual as a result of holding in abeyance all feelings, thoughts, and sensations. The final aspect is the consciousness that underlies and transcends the first three aspects (*turiya*) also referred to as a trans-cognitive state (*anubhava*) or a state of self-realization or freedom from body-mind identification (moksha). Gaudiya Vedanta recognizes a fifth aspect of consciousness in which God becomes subordinate to *bhakti*.

## Vijñāna

In Buddhism, consciousness (*viññāṇa*) is included in the five classically defined experiential "aggregates". The aggregates are seen as empty of self-nature; that is, they arise dependent on causes and conditions. The cause for consciousness arising (*viññāṇa*) is the arising of another aggregate (physical or mental); and, consciousness arising in turn gives rise to one or more of the mental (*nāma*) aggregates. The causation chain identified in the aggregate (*khandha*) model overlaps the conditioning chain in Dependent Origination (*paticcasamuppāda*) model. Consciousness is the third link, between mind body mental formations and name & form in the traditional Twelve Causes (*nidāna*) of Dependent Origination. The six classes of consciousness are: eye-consciousness, ear-consciousness, nose-consciousness, tongue-consciousness, body-consciousness, intellect-consciousness. The following aspects are traditionally highlighted within Dependent Origination:

- consciousness is conditioned by mental fabrications (*saṅkhāra*);
- consciousness and the mind-body (*nāmarūpa*) are interdependent; and,
- consciousness acts as a "life force" by which there is a continuity across rebirths.

## Scientific approaches

Broadly speaking, scientific approaches to identifying consciousness can be divided into two categories. In one category are methods that rely on asking subjects to describe their experiences or answer questions, and therefore can only be conducted using human subjects. In the other category are methods that test for aspects of consciousness that can be manifested in nonverbal behavior, and therefore can be used in other species as well as humans. The nonverbal manifestations that have been used include arousal, responsiveness to stimulation, attention, and the ability to distinguish self from non-self.

## Cognitive psychology and cognitive neuroscience

For a long time in scientific psychology, consciousness as a research topic or explanatory concept was strongly discouraged by mainstream scholars, because of concerns about the validation of primary data. Research on topics associated with consciousness were conducted under the banner of attention. Modern investigations into consciousness are based on psychological statistical studies and case studies of consciousness states and the deficits caused by surgery, trauma or illness that disrupt the normal functioning of human senses and cognition. Another approach is experimental work on unconscious perception,

e.g., the investigation of priming effects using subliminal stimuli. These discoveries suggest that the mind is a complex structure derived from various localized functions that are bound together with a unitary awareness.

Several studies point to common mechanisms in different clinical conditions that lead to loss of consciousness. Persistent vegetative state (PVS) is a condition in which an individual loses the higher cerebral powers of the brain, but maintains sleep-wake cycles with full or partial autonomic functions. Studies comparing PVS with healthy, awake subjects consistently demonstrate an impaired connectivity between the deeper (brainstem and thalamic) and the upper (cortical) areas of the brain. In addition, it is agreed that the general brain activity in the cortex is lower in the PVS state. Some electroneurobiological interpretations of consciousness characterize this loss of consciousness as a loss of the ability to resolve time (similar to playing an old phonographic record at very slow or very rapid speed), along a continuum that starts with inattention, continues on sleep, and arrives to coma and death. It is likely that different components of consciousness can be teased apart with anesthetics, sedatives and hypnotics. These drugs appear to act differently on several brain areas to disrupt, to varying degrees, different components of consciousness. The ability to recall information, for example, may be disrupted by anesthetics acting on the hippocampal cortex. Neurons in this region are particularly sensitive to anesthetics at the time loss of recall occurs. Direct anesthetic actions on hippocampal neurons have been shown to underlie EEG effects that occur in humans and animals during loss of recall.

Brain chemistry affects human consciousness. Sleeping drugs such as midazolam (Dormicum) can bring the brain from the awake condition (conscious) to the sleep (unconscious) condition. Wake-up drugs such as flumazenil reverse this process. Many other drugs (such as alcohol, nicotine, Tetrahydrocannabinol (THC), heroin, cocaine, LSD, MDMA, caffeine), have a consciousness-changing effect.

Neurophysiological studies in awake, behaving monkeys point to advanced cortical areas in prefrontal cortex and temporal lobes as carriers of neuronal correlates of consciousness. Christof Koch and Francis Crick argue that neuronal mechanisms of consciousness are intricately related to prefrontal cortex — cortical areas involved in higher cognitive function, affect, behavioral control, and planning. Rodolfo Llinas proposes that consciousness results from recurrent thalamo-cortical resonance where the specific thalamocortical systems (content) and the non-specific (centromedial thalamus) thalamocortical systems (context) interact in the gamma band frequency via time coincidence. According to this view the "I" represents a global predictive function required for intentionality. Experimental work of Steven Wise, Mikhail Lebedev and their colleagues supports this view. They demonstrated that activity of prefrontal cortex neurons reflects illusory perceptions of movements of visual stimuli. Nikos Logothetis and colleagues made similar observations on visually responsive neurons in the temporal lobe. These neurons reflect the visual perception in the situation when conflicting visual images are presented to different eyes (i.e., bistable percepts during binocular rivalry). The studies of blindsight — vision without awareness after lesions to parts of the visual system such as the primary visual cortex — performed by Lawrence Weiskrantz and

David P. Carey provided important insights on how conscious perception arises in the brain.

The Neuroscience of free will also seems to provide relevant insights to the understanding of consciousness.

## **Measurement aspects**

Experimental research on consciousness presents special difficulties, e.g., when establishing whether an observer is unaware of a critical stimulus. Several techniques exist for dissociating the conscious visibility of stimuli from indirect effects they might have on behavior. For example, the experimental technique of Response Priming allows researchers to find conditions where the conscious visibility of a critical stimulus and the ability of that stimulus to affect a motor response develop in opposite directions, e.g., when motor effects of a stimulus become larger under conditions where its visibility is decreasing.

## **Experimental philosophy**

A new approach has attempted to combine the methodologies of cognitive psychology and traditional philosophy to understand consciousness. This research has taken place in the new field called experimental philosophy, which seeks to use empirical methods (like conducting experiments to test how ordinary non-experts think) to inform the philosophical discussion. The aim of this type of philosophical research on consciousness has been to try to get a better grasp on how exactly people ordinarily understand consciousness. For instance, work by Joshua Knobe and Jesse Prinz suggests that people may have two different ways of understanding minds generally. Another suggestion has been that there is actually no such phenomenon as consciousness, based on a criticized study by Justin Sytsma and Edouard Machery. Further, Justin Sytsma and Edouard Machery have written about the proper methodology for studying folk intuitions about consciousness.

## **Evolutionary psychology**

Consciousness can be viewed from the standpoints of **evolutionary psychology** or evolutionary biology approach as an adaptation because it is a trait that increases fitness. Consciousness also adheres to John Alcock's theory of animal behavioral adaptations because it possesses both proximate and ultimate causes.

In his paper "Evolution of consciousness," John Eccles argues that special anatomical and physical properties of the mammalian cerebral cortex gave rise to consciousness. Budsonsky, by contrast, limits consciousness to humans, proposing that human consciousness may have evolved as an adaptation to anticipate and counter social stratagems of other humans, predators, and prey. Alternatively, it has been argued that the recursive circuitry underwriting consciousness is much more primitive, having evolved initially in pre-mammalian species because it improves the capacity for interaction with

both social *and* natural environments by providing an energy-saving "neutral" gear in an otherwise energy-expensive motor output machine. Another theory, proposed by Shaun Nichols and Todd Grantham, proposes that it is unnecessary to trace the exact evolutionary or causal role of phenomenal consciousness because the complexity of phenomenal consciousness alone implies that it is an adaptation. Once in place, this recursive circuitry may well have provided a basis for the subsequent development of many of the functions that consciousness facilitates in higher organisms, as outlined by Bernard J. Baars.

## Functions of Consciousness

<b>Functions of Consciousness</b>	
<b>Function</b>	<b>Purpose</b>
Definition and context-setting	Relating global input to its contexts, thereby defining input and removing ambiguities
Adaptation and learning	Representing and adapting to novel and significant events
Editing, flagging, and debugging	Monitoring conscious content, editing it, and trying to change it if it is consciously "flagged" as an error
Recruiting and control function	Recruiting subgoals and motor systems to organize and carry out mental and physical actions
Prioritizing and access control	Control over what will become conscious
Decision-making or executive function	Recruiting unconscious knowledge sources to make proper decisions, and making goals conscious to allow widespread recruitment of conscious and unconscious "votes" for or against them
Analogy-forming function	Searching for a partial match between contents of unconscious systems and a globally displayed (conscious) message
Metacognitive or self-forming function	Reflection upon and control of our own conscious and unconscious functioning
Auto-programming and self-maintenance function	Maintenance of maximum stability in the face of changing inner and outer conditions

## Physical

Since the dawn of Newtonian science with its vision of simple mechanical principles governing the entire universe, some philosophers have been tempted by the idea that even consciousness could be explained in purely physical terms. The first influential writer to propose such an idea explicitly was Julien Offray de La Mettrie, in his book *Man a Machine* (*L'homme machine*).

The most influential modern physical theories of consciousness are based on psychology and neuroscience. Theories proposed by neuroscientists such as Gerald Edelman and António Damásio, and by philosophers such as Daniel Dennett, seek to explain access consciousness and phenomenal consciousness in terms of neural events occurring within the brain. Many other neuroscientists, such as Christof Koch, have explored the neural basis of consciousness without attempting to frame all-encompassing global theories. At the same time, computer scientists working in the field of Artificial Intelligence have pursued the goal of creating digital computer programs that can simulate or embody consciousness.

Some theorists—most of whom are physicists—have argued that classical physics is intrinsically incapable of explaining the holistic aspects of consciousness, but that quantum theory provides the missing ingredients. The most notable theories falling into this category include the Holonomic brain theory of Karl H. Pribram and David Bohm, and the Orch-OR theory formulated by Stuart Hameroff and Roger Penrose. Some of these QM theories offer descriptions of phenomenal consciousness, as well as QM interpretations of access consciousness. None of the quantum mechanical theories has been confirmed by experiment, and many scientists and philosophers consider the arguments for an important role of quantum phenomena to be unconvincing.

### ***Medical aspects***

In medicine, consciousness is measured by neuropsychological assessment. It is of concern to patients, physicians, and ethicists as well as biological scientists and biomedical engineers. Patients may suffer from disorders of consciousness and seek medical treatment. Physicians may perform medical interventions of consciousness such as instructing the patient to sleep, administering general anesthesia, or inducing medical coma. Bioethicists and neuroethicists may be concerned with the ethical implications of consciousness in medical cases of patients such as Karen Ann Quinlan and Terri Schiavo. Furthermore, biological scientists study patients with these disorders while biomedical engineers develop neuroprosthetics for them.

### **Disorders of consciousness**

Medical conditions that inhibit consciousness are considered disorders of consciousness. This category generally includes minimally conscious state and persistent vegetative state, but sometimes also includes the less severe locked-in syndrome and more severe chronic coma. Differential diagnosis of these disorders is an active area of biomedical research. Finally, brain death results in an irreversible disruption of consciousness. While other conditions may cause a moderate deterioration (e.g., dementia and delirium) or transient interruption (e.g., grand mal and petit mal seizures) of consciousness, they are not included in this category.

<b>Disorder</b>	<b>Description</b>
Locked-in syndrome	The patient has awareness, sleep-wake cycles, and meaningful behavior (viz., eye-movement), but is isolated due to

quadriplegia and pseudobulbar palsy.

Minimally conscious state	The patient has intermittent periods of awareness and wakefulness and displays some meaningful behavior.
Persistent vegetative state	The patient has sleep-wake cycles, but lacks awareness and only displays reflexive and non-purposeful behavior.
Chronic coma	The patient lacks awareness and sleep-wake cycles and only displays reflexive behavior.
Brain death	The patient lacks awareness, sleep-wake cycles, and behavior.

## **Functions**

Regarding the primary function of conscious processing, a recurring idea in recent theories is that phenomenal states somehow integrate neural activities and information-processing that would otherwise be independent. This has been called the *integration consensus*. However, it remained unspecified which kinds of information are integrated in a conscious manner and which kinds can be integrated without consciousness. Obviously not all kinds of information are capable of being disseminated consciously (e.g., neural activity related to vegetative functions, reflexes, unconscious motor programs, low-level perceptual analyses, etc.) and many kinds can be disseminated and combined with other kinds without consciousness, as in intersensory interactions such as the ventriloquism effect (cf., Morsella, 2005).

Ervin László argues that self-awareness, the ability to make observations of oneself, evolved. Émile Durkheim formulated the concept of so called collective consciousness, which is essential for organization of human, social relations. The accelerating drive of human race to explorations, cognition, understanding and technological progress can be explained by some features of collective consciousness (collective self - concepts) and collective intelligence

## **Tests**

As there is no clear definition of consciousness and no empirical measure exists to test for its presence, it has been argued that due to the nature of the problem of consciousness, empirical tests are intrinsically impossible. However, several tests have been developed that attempt an operational definition of consciousness and try to determine whether computers and non-human animals can demonstrate through behavior, by passing these tests, that they are conscious.

In medicine, several neurological and brain imaging techniques, such as EEG and fMRI, have proven useful for physical measures of brain activity associated with consciousness. This is particularly true for EEG measures during anesthesia, which can provide an indication of anesthetic depth.

## **The Turing test**

Though sometimes thought of as a test for consciousness, the Turing test (named after computer scientist Alan Turing, who proposed it) was originally presented as an operational replacement for the question "Can machines think?", which Turing regarded as too ambiguous to be meaningful. This test is commonly cited in discussion of artificial intelligence. The test is based on an "Imitation Game" in which a human experimenter converses, via computer keyboards, with two competitors, one human, the other a computer. Because all of the conversation is by keyboard, no cues such as voice, prosody, or appearance will be available to indicate which is human and which is the computer. If the human judge is unable to determine which of the conversants is the computer, the computer is said to have "passed" the test.

The Turing test has generated a great deal of philosophical debate. For example, Daniel Dennett and Douglas Hofstadter argue that anything capable of passing the Turing test is necessarily conscious, while David Chalmers, argues that a philosophical zombie could pass the test, yet fail to be conscious.

It has been argued that the question itself is excessively anthropomorphic. Edsger Dijkstra commented that "The question of whether a computer can think is no more interesting than the question of whether a submarine can swim", expressing the view that different words are appropriate for the workings of a machine to those of animals even if they produce similar results, just as submarines are not normally said to swim.

Philosopher John Searle developed a thought experiment, the Chinese room argument, which is intended to show problems with the Turing Test. Searle asks the reader to imagine a non-Chinese speaker in a room in which there are stored a very large number of Chinese symbols and rule books. Questions are passed to the person in the form of written Chinese symbols via a slot, and the person responds by looking up the symbols and the correct replies in the rule books. Based on the purely input-output operations, the "Chinese room" gives the appearance of understanding Chinese. However, the person in the room understands no Chinese at all. This argument has been the subject of intense philosophical debate since it was introduced in 1980, even leading to edited volumes on this topic alone.

The application of the Turing test to human consciousness has even led to an annual competition, the Loebner Prize, with "Grand Prize of \$100,000 and a Gold Medal for the first computer whose responses were indistinguishable from a human's."

## **Mirror**

With the mirror test, devised by Gordon Gallup in the 1970s, one is interested in whether animals are able to recognize themselves in a mirror. The classic example of the test involves placing a spot of coloring on the skin or fur near the individual's forehead and seeing if they attempt to remove it or at least touch the spot, thus indicating that they recognize that the individual they are seeing in the mirror is themselves. Humans (older

than 18 months) and other great apes, bottlenose dolphins, pigeons, elephants and magpies have all been observed to pass this test. The test is usually carried out with an identical 'spot' being placed elsewhere on the head with a non-visible material as a control, to assure the subject is not responding to the touch stimuli of the spot's presence.

## **Delay**

One problem researchers face is distinguishing nonconscious reflexes and instinctual responses from conscious responses. Neuroscientists Francis Crick and Christof Koch have proposed that by placing a delay between stimulus and execution of action, one may determine the extent of involvement of consciousness in an action of a biological organism.

For example, when psychologists Larry Squire and Robert Clark combined a tone of a specific pitch with a puff of air to the eye, test subjects came to blink their eyes in anticipation of the puff of air when the appropriate tone was played. When the puff of air followed a half of a second later, no such conditioning occurred. When subjects were asked about the experiment, only those who were asked to pay attention could consciously distinguish which tone preceded the puff of air.

Ability to delay the response to an action implies that the information must be stored in short-term memory, which is conjectured to be a closely associated prerequisite for consciousness. However, this test is only valid for biological organisms. While it is simple to create a computer program that passes, such success does not suggest anything beyond a clever programmer.

## **Merkwelt**

The merkwelt (German; English: *"way of viewing the world"*, *"peculiar individual consciousness"*) is a concept in robotics, psychology and biology that describes a creature or android's capacity to view things, manipulate information and synthesize to make meaning out of the universe.

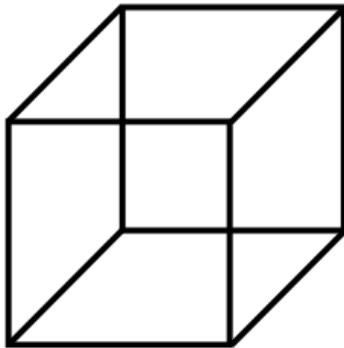
In biology, a shark's merkwelt for instance is dominated by smell due to its enlarged olfactory lobes whilst a bat's is dominated by its hearing, especially at ultrasonic frequencies. In literature, a character's merkwelt can be defined by their particular consciousness. For the collective, the plural is merkwelten. It is related to the original German meaning of zeitgeist and indeed a merkwelt can be thought of as a more general, individual zeitgeist.

To have a merkwelt, the individual must be self-aware. This "self-awareness" may involve thoughts, sensations, perceptions, moods, emotions, and dreams. This term was particularly developed by the German biologist Jakob von Uexküll who framed it as part of his theory of umwelt. This basically stated that any living 'observer' of the broader environment or umwelt through their particular werkwelt or 'mechanical viewing' (that is to say, the organs through which they view the world- their eyes, ears, mouth etc. in

humans and electrical sensors in sharks for instance) could have a merkwelt or 'perceptual universe'. In essence, his theory posits that the way each human or certain type of aware animal perceives of their environment both through their experiences, the particular way their organs perceive their environment and the way in which their consciousness processes this information (how their brain works).

## Chapter 2

# Perception



The Necker cube and Rubin vase can be perceived in more than one way.

**Perception** is the process by which an organism attains awareness or understanding of its environment by organizing and interpreting sensory information. All perception involves signals in the nervous system, which in turn result from physical stimulation of the sense organs. For example, vision involves light striking the retinas of the eyes, smell is mediated by odor molecules and hearing involves pressure waves. Perception is not the passive receipt of these signals, but can be shaped by learning, by memory and expectation. Perception involves these "top-down" effects as well as the "bottom-up" process of processing sensory input. Perception depends on complex functions of the nervous system, but subjectively seems mostly effortless because this processing happens outside conscious awareness.

Since the rise of experimental psychology in the late 19th Century, psychology's understanding of perception has progressed by combining a variety of techniques. Psychophysics measures the effect on perception of varying the physical qualities of the input. Sensory neuroscience studies the brain mechanisms underlying perception. Perceptual systems can also be studied computationally, in terms of the information they process. Perceptual issues in philosophy include the extent to which sensory qualities

such as sounds, smells or colors exist in objective reality rather than the mind of the perceiver.

Although the senses were traditionally viewed as passive receptors, the study of illusions and ambiguous images has demonstrated that the brain's perceptual systems actively and pre-consciously attempt to make sense of their input. There is still active debate about the extent to which perception is an active process of hypothesis testing, analogous to science, or whether realistic sensory information is rich enough to make this process unnecessary.

The perceptual systems of the brain enable individuals to see the world around them as stable, even though the sensory information may be incomplete and rapidly varying. Human and animal brains are structured in a modular way, with different areas processing different kinds of sensory information. Some of these modules take the form of sensory maps, mapping some aspect of the world across part of the brain's surface. These different modules are interconnected and influence each other. For instance, the taste is strongly influenced by its odor.

## Process and terminology

The process of perception begins with an object in the real world, termed the *distal stimulus* or *distal object*. By means of light, sound or another physical process, the object stimulates the body's sensory organs. These sensory organs transform the input energy into neural activity—a process called *transduction*. This raw pattern of neural activity is called the *proximal stimulus*. These neural signals are transmitted to the brain and processed. The resulting mental recreation of the distal stimulus is the *percept*. Perception is sometimes described as the process of constructing mental representations of distal stimuli using the information available in proximal stimuli.

An example would be a person looking at a shoe. The shoe itself is the distal stimulus. When light from the shoe enters a person's eye and stimulates their retina, that stimulation is the proximal stimulus. The image of the shoe reconstructed by the brain of the person is the percept. Another example would be a telephone ringing. The ringing of the telephone is the distal stimulus. The sound stimulating a person's auditory receptors is the proximal stimulus, and the brain's interpretation of this as the ringing of a telephone is the percept. The different kinds of sensation such as warmth, sound, and taste are called "sensory modalities".

Stimuli are not necessarily translated into a percept and rarely does a single stimulus translate into a percept. An ambiguous stimulus may be translated into multiple percepts, experienced randomly, one at a time, in what is called "multistable perception". And the same stimuli, or absence of them, may result in different percepts depending on subject's culture and previous experiences. Ambiguous figures demonstrate that a single stimulus can result in more than one percept; for example the Rubin vase which can be interpreted either as a vase or as two faces. The percept can bind sensations from multiple senses into a whole. A picture of a talking person on a television screen, for example, is bound to the

sound of speech from speakers to form a percept of a talking person. "Percept" is also a term used by Leibniz, Bergson, Deleuze and Guattari to define perception independent from perceivers.

## Perception and reality

In the case of visual perception, some people can actually see the percept shift in their mind's eye. Others, who are not picture thinkers, may not necessarily perceive the 'shape-shifting' as their world changes. The 'esemplastic' nature has been shown by experiment: an ambiguous image has multiple interpretations on the perceptual level.

This confusing ambiguity of perception is exploited in human technologies such as camouflage, and also in biological mimicry, for example by European Peacock butterflies, whose wings bear eye markings that birds respond to as though they were the eyes of a dangerous predator.

There is also evidence that the brain in some ways operates on a slight "delay", to allow nerve impulses from distant parts of the body to be integrated into simultaneous signals.

Perception is one of the oldest fields in psychology. The oldest quantitative law in psychology is the Weber-Fechner law, which quantifies the relationship between the intensity of physical stimuli and their perceptual effects (for example, testing how much darker a computer screen can get before the viewer actually notices). The study of perception gave rise to the Gestalt school of psychology, with its emphasis on holistic approach.

## Features

### Constancy

*Perceptual constancy* is the ability of perceptual systems to recognise the same object from widely varying sensory inputs. For example, individual people can be recognised from views, such as frontal and profile, which form very different shapes on the retina. A coin looked at face-on makes a circular image on the retina, but when held at angle it makes an elliptical image. In normal perception these are recognised as a single three-dimensional object. Without this correction process, an animal approaching from the distance would appear to gain in size. One kind of perceptual constancy is *color constancy*: for example, a white piece of paper can be recognised as such under different colors and intensities of light. Another example is *roughness constancy*: when a hand is drawn quickly across a surface, the touch nerves are stimulated more intensely. The brain compensates for this, so the speed of contact does not affect the perceived roughness. Other constancies include melody, odor, brightness and words. These constancies are not always total, but the variation in the percept is much less than the variation in the physical stimulus. The perceptual systems of the brain achieve perceptual constancy in a variety of ways, each specialized for the kind of information being processed.

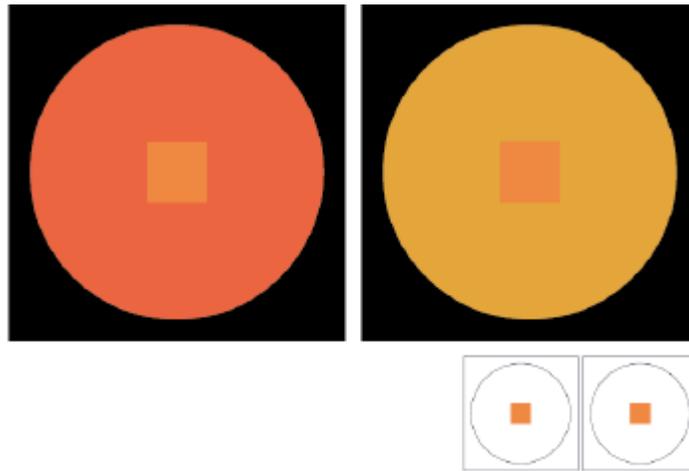
## Grouping



### Law of Closure

The *principles of grouping* (or *Gestalt laws of grouping*) are a set of principles in psychology, first proposed by Gestalt psychologists to explain how humans naturally perceive objects as organized patterns and objects. Gestalt psychologists argued that these principles exist because the mind has an innate disposition to perceive patterns in the stimulus based on certain rules. These principles are organized into five categories. The principle of *proximity* states that, all else being equal, perception tends to group stimuli that are close together as part of the same object, and stimuli that are far apart as two separate objects. The principle of *similarity* states that, all else being equal, perception lends itself to seeing stimuli that physically resemble each other as part of the same object, and stimuli that are different as part of a different object. This allows for people to distinguish between adjacent and overlapping objects based on their visual texture and resemblance. The principle of *closure* refers to the mind's tendency to see complete figures or forms even if a picture is incomplete, partially hidden by other objects, or if part of the information needed to make a complete picture in our minds is missing. For example, if part of a shape's border is missing people still tend to see the shape as completely enclosed by the border and ignore the gaps. The principle of *good continuation* makes sense of stimuli that overlap: when there is an intersection between two or more objects, people tend to perceive each as a single uninterrupted object. The principle of *common fate* groups stimuli together on the basis of their movement. When visual elements are seen moving in the same direction at the same rate, perception associates the movement as part of the same stimulus. This allows people to make out moving objects even when other details, such as color or outline, are obscured. The principle of *good form* refers to the tendency to group together forms of similar shape, pattern, color, etc. Later research has identified additional grouping principles.

## Contrast effects



Two physically identical orange squares are perceived as different subjective colors, because each has a different surrounding color.

A common finding across many different kinds of perception is that the perceived qualities of an object can be affected by the qualities of context. If one object is extreme on some dimension, then neighboring objects are perceived as further away from that extreme. "Simultaneous contrast effect" is the term used when stimuli are presented at the same time, whereas "successive contrast" applies when stimuli are presented one after another.

The contrast effect was noted by the 17th Century philosopher John Locke, who observed that lukewarm water can feel hot or cold, depending on whether the hand touching it was previously in hot or cold water. In the early 20th Century, Wilhelm Wundt identified contrast as a fundamental principle of perception, and since then the effect has been confirmed in many different areas. These effects shape not only visual qualities like color and brightness, but other kinds of perception, including how heavy an object feels. One experiment found that thinking of the name "Hitler" led to subjects rating a person as more friendly. Whether a piece of music is perceived as good or bad can depend on whether the music heard before it was unpleasant or pleasant. For the effect to work, the objects being compared need to be similar to each other: a television reporter can seem to shrink when interviewing a tall basketball player, but not when standing next to a tall building.

## Effect of motivation and expectation

A *perceptual set*, also called *perceptual expectancy* or just *set* is a predisposition to perceive things in a certain way. It is an example of how perception can be shaped by "top-down" processes such as drives and expectations. Perceptual sets occur in all the different senses. They can be long term, such as a special sensitivity to hearing one's own name in a crowded room, or short term, as in the ease with which hungry people notice

the smell of food. A simple demonstration of the effect involved very brief presentations of non-words such as "sael". Subjects who were told to expect words about animals read it as "seal", but others who were expecting boat-related words read it as "sail".

Sets can be created by motivation and so can result in people interpreting ambiguous figures so that they see what they want to see. For instance, how someone perceives what unfolds during a sports game can be biased if they strongly support one of the teams. In one experiment, students were allocated to pleasant or unpleasant tasks by a computer. They were told that either a number or a letter would flash on the screen to say whether they were going to taste an orange juice drink or an unpleasant-tasting health drink. In fact, an ambiguous figure was flashed on screen, which could either be read as the letter B or the number 13. When the letters were associated with the pleasant task, subjects were more likely to perceive a letter B, and when letters were associated with the unpleasant task they tended to perceive a number 13.

Perceptual set has been demonstrated in many social contexts. People who are primed to think of someone as "warm" are more likely to perceive a variety of positive characteristics in them, than if the word "warm" is replaced by "cold". When someone has a reputation for being funny, an audience are more likely to find them amusing. Individual's perceptual sets reflect their own personality traits. For example, people with an aggressive personality are quicker to correctly identify aggressive words or situations.

One classic psychological experiment showed slower reaction times and less accurate answers when a deck of playing cards reversed the color of the suit symbol for some cards (e.g. red spades and black hearts).

Philosopher Andy Clark explains that perception, although it occurs quickly, is not simply a bottom-up process (where minute details are put together to form larger wholes). Instead, our brains use what he calls *predictive coding*. It starts with very broad constraints and expectations for the state of the world, and as expectations are met, it makes more detailed predictions (errors lead to new predictions, or learning processes). Clark says this research has various implications; not only can there be no completely "unbiased, unfiltered" perception, but this means that there is a great deal of feedback between perception and expectation (perceptual experiences often shape our beliefs, but those perceptions were based on existing beliefs).

## Theories

### Perception as hypothesis-testing

Cognitive theories of perception assume there is a poverty of stimulus. This (with reference to perception) is the claim that sensations are, by themselves, unable to provide a unique description of the world. Sensations require 'enriching', which is the role of the mental model. A different type of theory is the perceptual ecology approach of James J. Gibson. Gibson rejected the assumption of a poverty of stimulus by rejecting the notion that perception is based in sensations – instead, he investigated what information is

actually presented to the perceptual systems. His theory "assumes the existence of stable, unbounded, and permanent stimulus-information in the ambient optic array. And it supposes that the visual system can explore and detect this information. The theory is information-based, not sensation-based." He and the psychologists who work within this paradigm detailed how the world could be specified to a mobile, exploring organism via the lawful projection of information about the world into energy arrays. Specification is a 1:1 mapping of some aspect of the world into a perceptual array; given such a mapping, no enrichment is required and perception is direct perception.

## **Perception-in-action**

An ecological understanding of perception derived from Gibson's early work is that of "perception-in-action", the notion that perception is a requisite property of animate action; that without perception action would be unguided, and without action perception would serve no purpose. Animate actions require both perception and motion, and perception and movement can be described as "two sides of the same coin, the coin is action". Gibson works from the assumption that singular entities, which he calls "invariants", already exist in the real world and that all that the perception process does is to home in upon them. A view known as constructivism (held by such philosophers as Ernst von Glasersfeld) regards the continual adjustment of perception and action to the external input as precisely what constitutes the "entity", which is therefore far from being invariant.

Glasersfeld considers an "invariant" as a target to be homed in upon, and a pragmatic necessity to allow an initial measure of understanding to be established prior to the updating that a statement aims to achieve. The invariant does not and need not represent an actuality, and Glasersfeld describes it as extremely unlikely that what is desired or feared by an organism will never suffer change as time goes on. This social constructionist theory thus allows for a needful evolutionary adjustment.

A mathematical theory of perception-in-action has been devised and investigated in many forms of controlled movement, and has been described in many different species of organism using the General Tau Theory. According to this theory, tau information, or time-to-goal information is the fundamental 'percept' in perception.

## **Evolutionary psychology and perception**

Many experts, such as Jerry Fodor, write that the purpose of perception is knowledge, but evolutionary psychologists hold that its primary purpose is to guide action. For example, they say, depth perception seems to have evolved not to help us know the distances to other objects but rather to help us move around in space. Evolutionary psychologists say that animals from fiddler crabs to humans use eyesight for collision avoidance, suggesting that vision is basically for directing action, not providing knowledge.

Building and maintaining sense organs is metabolically expensive, so these organs evolve only when they improve an organism's fitness. More than half the brain is devoted to

processing sensory information, and the brain itself consumes roughly one-fourth of one's metabolic resources, so the senses must provide exceptional benefits to fitness. Perception accurately mirrors the world; animals get useful, accurate information through their senses.

Scientists who study perception and sensation have long understood the human senses as adaptations. Depth perception consists of processing over half a dozen visual cues, each of which is based on a regularity of the physical world. Vision evolved to respond to the narrow range of electromagnetic energy that is plentiful and that does not pass through objects. Sound waves provide useful information about the sources of and distances to objects, with larger animals making and hearing lower-frequency sounds and smaller animals making and hearing higher-frequency sounds. Taste and smell respond to chemicals in the environment that were significant for fitness in the EEA. The sense of touch is actually many senses, including pressure, heat, cold, tickle, and pain. Pain, while unpleasant, is adaptive. An important adaptation for senses is range shifting, by which the organism becomes temporarily more or less sensitive to sensation. For example, one's eyes automatically adjust to dim or bright ambient light. Sensory abilities of different organisms often coevolve, as is the case with the hearing of echolocating bats and that of the moths that have evolved to respond to the sounds that the bats make.

Evolutionary psychologists claim that perception demonstrates the principle of modularity, with specialized mechanisms handling particular perception tasks. For example, people with damage to a particular part of the brain suffer from the specific defect of not being able to recognize faces (prosopagnosia). EP suggests that this indicates a so-called face-reading module.

### **Theories of visual perception**

- Empirical theories of perception
- Anne Treisman's Feature Integration Theory
- Interactive Activation and Competition
- Irving Biederman's Recognition by Components Theory

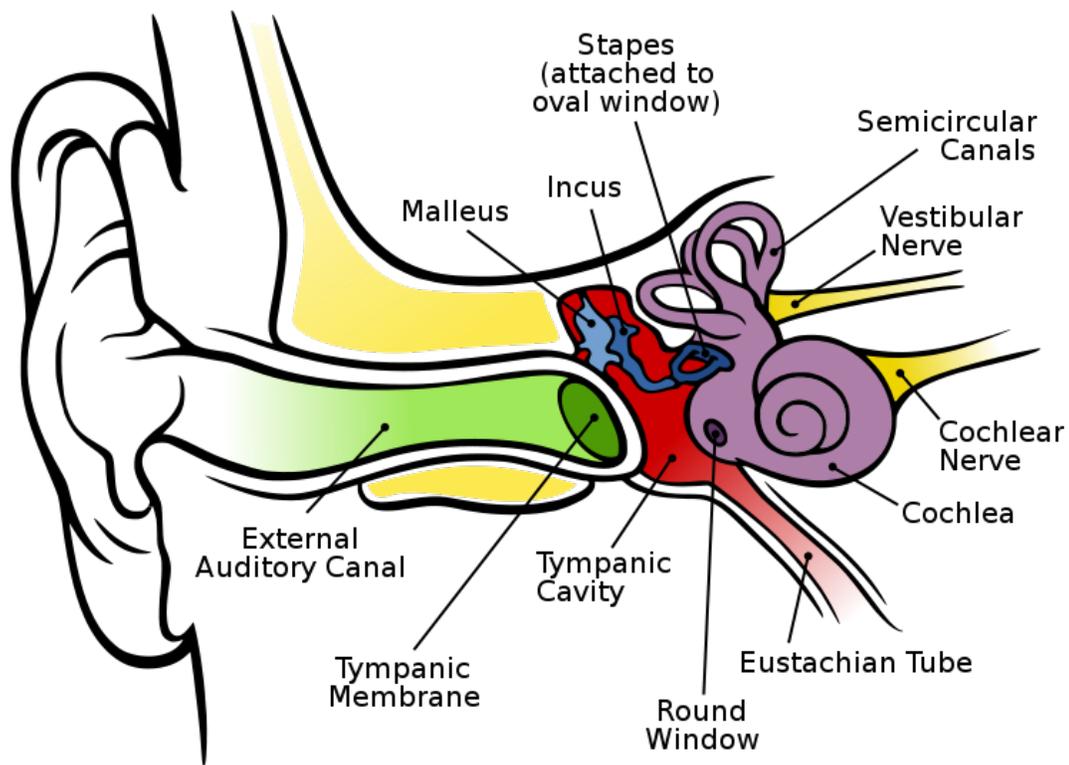
## **Physiology**

A *sensory system* is a part of the nervous system responsible for processing sensory information. A sensory system consists of sensory receptors, neural pathways, and parts of the brain involved in sensory perception. Commonly recognized sensory systems are those for vision, hearing, somatic sensation (touch), taste and olfaction (smell). In short, senses are transducers from the physical world to the realm of the mind.

The receptive field is the specific part of the world to which a receptor organ and receptor cells respond. For instance, the part of the world an eye can see, is its receptive field; the light that each rod or cone can see, is its receptive field. Receptive fields have been identified for the visual system, auditory system and somatosensory system, so far.

# Types

## Of sound

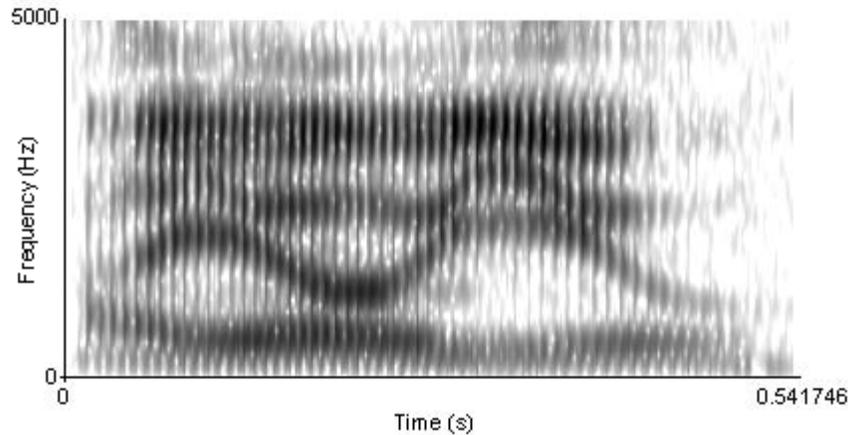


Anatomy of the human ear. (The length of the auditory canal is exaggerated in this image)

Hearing (or *audition*) is the ability to perceive sound by detecting vibrations. Frequencies capable of being heard by humans are called audio or *sonic*. The range is typically considered to be between 20 Hz and 20,000 Hz. Frequencies higher than audio are referred to as ultrasonic, while frequencies below audio are referred to as infrasonic. The auditory system includes the ears and inner structures which produce neural signals in response to the sound. The primary auditory cortex, within the temporal lobe of the human brain, is where auditory information arrives in the cerebral cortex.

Sound does not usually come from a single source: in real situations, sounds from multiple sources and directions are superimposed as they arrive at the ears. Hearing involves the computationally complex task of separating out the sources of interest, often estimating their distance and direction as well as identifying them.

## Of speech



Though the phrase "I owe you" can be heard as three distinct words, a spectrogram reveals no clear boundaries.

*Speech perception* is the process by which the sounds of language are heard, interpreted and understood. Research in speech perception seeks to understand how human listeners recognize speech sounds and use this information to understand spoken language. The sound of a word can vary widely according to words around it and the tempo of the speech, as well as the physical characteristics, accent and mood of the speaker. Listeners manage to perceive words across this wide range of different conditions. Another variation is that reverberation can make a large difference in sound between a word spoken from the far side of a room and the same word spoken up close. Experiments have shown that people automatically compensate for this effect when hearing speech.

The process of perceiving speech begins at the level of the sound signal and the process of audition. After processing the initial auditory signal, speech sounds are further processed to extract acoustic cues and phonetic information. This speech information can then be used for higher-level language processes, such as word recognition. Speech perception is not necessarily uni-directional. That is, higher-level language processes connected with morphology, syntax, or semantics may interact with basic speech perception processes to aid in recognition of speech sounds. It may be the case that it is not necessary and maybe even not possible for a listener to recognize phonemes before recognizing higher units, like words for example. In one experiment, Richard M. Warren replaced one phoneme of a word with a cough-like sound. His subjects restored the missing speech sound perceptually without any difficulty and what is more, they were not able to identify accurately which phoneme had been disturbed.

## Touch

*Haptic perception* is the process of recognizing objects through touch. It involves a combination of somatosensory perception of patterns on the skin surface (e.g., edges, curvature, and texture) and proprioception of hand position and conformation. People can

rapidly and accurately identify three-dimensional objects by touch. This involves exploratory procedures, such as moving the fingers over the outer surface of the object or holding the entire object in the hand. Haptic perception relies on the forces experienced during touch.

Gibson defined the haptic system as "The sensibility of the individual to the world adjacent to his body by use of his body". Gibson and others emphasized the close link between haptic perception and body movement: haptic perception is active exploration. The concept of haptic perception is related to the concept of extended physiological proprioception according to which, when using a tool such as a stick, perceptual experience is transparently transferred to the end of the tool.

## **Taste**

Taste (or, the more formal term, *gustation*) is the ability to perceive the flavor of substances including, but not limited to, food. Humans receive tastes through sensory organs called *taste buds*, or *gustatory calyculi*, concentrated on the upper surface of the tongue. The human tongue has 100 to 150 taste receptor cells on each of its roughly ten thousand taste buds. There are five primary tastes: sweetness, bitterness, sourness, saltiness, and umami. Other tastes can be mimicked by combining these basic tastes. The recognition and awareness of umami is a relatively recent development in Western cuisine. The basic tastes contribute only partially to the sensation and flavor of food in the mouth — other factors include smell, detected by the olfactory epithelium of the nose; texture, detected through a variety of mechanoreceptors, muscle nerves, etc.; and temperature, detected by thermoreceptors. All basic tastes are classified as either *appetitive* or *aversive*, depending upon whether the things they sense are harmful or beneficial.

## **Of the social world**

*Social perception* is the part of perception that allows people to understand the individuals and groups of their social world, and thus an element of social cognition.

## Chapter 3

# Learning

**Learning** is acquiring new or modifying existing knowledge, behaviors, skills, values, or preferences and may involve synthesizing different types of information. The ability to learn is possessed by humans, animals and some machines. Progress over time tends to follow learning curves.

Human learning may occur as part of education, personal development, or training. It may be goal-oriented and may be aided by motivation. The study of how learning occurs is part of neuropsychology, educational psychology, learning theory, and pedagogy.

Learning may occur as a result of habituation or classical conditioning, seen in many animal species, or as a result of more complex activities such as play, seen only in relatively intelligent animals. Learning may occur consciously or without conscious awareness. There is evidence for human behavioral learning prenatally, in which habituation has been observed as early as 32 weeks into gestation, indicating that the central nervous system is sufficiently developed and primed for learning and memory to occur very early on in development.

Play has been approached by several theorists as the first form of learning. Children play, experiment with the world, learn the rules, and learn to interact. Vygotsky agrees that play is pivotal for children's development, since they make meaning of their environment through play.

## Types of learning



**Training meeting** about sustainable design. The photo shows a training meeting with factory workers in a stainless steel ecodeign company from Rio de Janeiro, Brazil. This type of learning is widely used in corporations around the world.

## Simple non-associative learning

### Habituation

In psychology, habituation is an example of non-associative learning in which there is a progressive diminution of behavioral response probability with repetition stimulus. An animal first responds to a stimulus, but if it is neither rewarding nor harmful the animal reduces subsequent responses. One example of this can be seen in small song birds—if a stuffed owl (or similar predator) is put into the cage, the birds initially react to it as though it were a real predator. Soon the birds react less, showing habituation. If another stuffed owl is introduced (or the same one removed and re-introduced), the birds react to it again as though it were a predator, demonstrating that it is only a very specific stimulus that is habituated to (namely, one particular unmoving owl in one place). Habituation has been shown in essentially every species of animal, including the large protozoan *Stentor coeruleus*.

## **Sensitization**

Sensitization is an example of non-associative learning in which the progressive amplification of a response follows repeated administrations of a stimulus (Bell et al., 1995). An everyday example of this mechanism is the repeated tonic stimulation of peripheral nerves that will occur if a person rubs his arm continuously. After a while, this stimulation will create a warm sensation that will eventually turn painful. The pain is the result of the progressively amplified synaptic response of the peripheral nerves warning the person that the stimulation is harmful. Sensitization is thought to underlie both adaptive as well as maladaptive learning processes in the organism.

## **Associative learning**

Associative learning is the process by which an element is taught through association with a separate, pre-occurring element. It is also referred to as classical conditioning. Honeybees display associative learning through the proboscis extension reflex paradigm.

Operant conditioning is the use of consequences to modify the occurrence and form of behavior. *Operant conditioning* is distinguished from *Pavlovian conditioning* in that operant conditioning uses reinforcement/punishment to alter an action-outcome association. In contrast Pavlovian conditioning involves strengthening of the stimulus-outcome association.

Behaviorism is a psychological movement that seeks to alter behavior by arranging the environment to elicit successful changes and to arrange consequences to maintain or diminish a behavior. Behaviorists study behaviors that can be measured and changed by the environment. However, they do not eliminate that there are thought processes that interact with those behaviors.

Delayed discounting is the process of devaluing rewards based on the delay of time they are presented. This process is thought to be tied to impulsivity. Impulsivity is a core process for many behaviors (e.g., substance abuse, problematic gambling, OCD). Making decisions is an important part of everyday functioning. How we make those decisions is based on what we perceive to be the most valuable or worthwhile actions. This is determined by what we find to be the most reinforcing stimuli. So when teaching an individual a response, you need to find the most potent reinforcer for that person. This may be a larger reinforcer at a later time or a smaller immediate reinforcer.

## **Classical conditioning**

The typical paradigm for classical conditioning involves repeatedly pairing an unconditioned stimulus (which unfailingly evokes a reflexive response) with another previously neutral stimulus (which does not normally evoke the response). Following conditioning, the response occurs both to the unconditioned stimulus and to the other, unrelated stimulus (now referred to as the "conditioned stimulus"). The response to the conditioned stimulus is termed a *conditioned response*. The classic example is Pavlov

and his dogs. Meat powder naturally will make a dog salivate when it is put into a dog's mouth; salivating is a reflexive response to the meat powder. Meat powder is the unconditioned stimulus (US) and the salivation is the unconditioned response (UR). Then Pavlov rang a bell before presenting the meat powder. The first time Pavlov rang the bell, the neutral stimulus, the dogs did not salivate, but once he put the meat powder in their mouths they began to salivate. After numerous pairings of the bell, and then food the dogs learned that the bell was a signal that the food was about to come and began to salivate just when the bell was rang. Once this occurs the bell becomes the conditioned stimulus (CS) and the salivation to the bell is the conditioned response (CR).

Another influential person in the world of Classical Conditioning is John B. Watson. Watson's work was very influential and paved the way for B. F. Skinner's radical behaviorism. Watson's behaviorism (and philosophy of science) stood in direct contrast to Freud. Watson's view was that Freud's introspective method was too subjective, and that we should limit the study of human development to directly observable behaviors. In 1913, Watson published the article "Psychology as the Behaviorist Views," in which he argued that laboratory studies should serve psychology best as a science. Watson's most famous, and controversial, experiment, "Little Albert," where he demonstrated how psychologists can account for the learning of emotion through classical conditioning principles.

## **Imprinting**

Imprinting is the term used in psychology and ethology to describe any kind of phase-sensitive learning (learning occurring at a particular age or a particular life stage) that is rapid and apparently independent of the consequences of behavior. It was first used to describe situations in which an animal or person learns the characteristics of some stimulus, which is therefore said to be "imprinted" onto the subject.

## **Observational learning**

The learning process most characteristic of humans is imitation; one's personal repetition of an observed behavior, such as a dance. Humans can copy three types of information simultaneously: the demonstrator's goals, actions, and environmental outcomes. Through copying these types of information, (most) infants will tune into their surrounding culture.

## **Play**

Play generally describes behavior which has no particular end in itself, but improves performance in similar situations in the future. This is seen in a wide variety of vertebrates besides humans, but is mostly limited to mammals and birds. Cats are known to play with a ball of string when young, which gives them experience with catching prey. Besides inanimate objects, animals may play with other members of their own species or other animals, such as orcas playing with seals they have caught. Play involves a significant cost to animals, such as increased vulnerability to predators and the risk of

injury and possibly infection. It also consumes energy, so there must be significant benefits associated with play for it to have evolved. Play is generally seen in younger animals, suggesting a link with learning. However, it may also have other benefits not associated directly with learning, for example improving physical fitness.

## **Enculturation**

Enculturation is the process by which a person learns the requirements of their native culture by which he or she is surrounded, and acquires values and behaviors that are appropriate or necessary in that culture. The influences which as part of this process limit, direct or shape the individual, whether deliberately or not, include parents, other adults, and peers. If successful, enculturation results in competence in the language, values and rituals of the culture. (compare acculturation, where a person is within a culture different to their normal culture, and learns the requirements of this different culture).

## **Multimedia learning**

Multimedia learning is where a person uses both auditory and visual stimuli to learn information (Mayer 2001). This type of learning relies on dual-coding theory (Paivio 1971).

## **E-learning and augmented learning**

Electronic learning or e-learning is a general term used to refer to Internet-based networked computer-enhanced learning. A specific and always more diffused e-learning is mobile learning (m-learning), which uses different mobile telecommunication equipment, such as cellular phones.

When a learner interacts with the e-learning environment, it's called augmented learning. By adapting to the needs of individuals, the context-driven instruction can be dynamically tailored to the learner's natural environment. Augmented digital content may include text, images, video, audio (music and voice). By personalizing instruction, augmented learning has been shown to improve learning performance for a lifetime.

## **Rote learning**

Rote learning is a technique which avoids understanding the inner complexities and inferences of the subject that is being learned and instead focuses on memorizing the material so that it can be recalled by the learner exactly the way it was read or heard. The major practice involved in rote learning techniques is *learning by repetition*, based on the idea that one will be able to quickly recall the meaning of the material the more it is repeated. Rote learning is used in diverse areas, from mathematics to music to religion. Although it has been criticized by some schools of thought, rote learning is a necessity in many situations.

## **Informal learning**

Informal learning occurs through the experience of day-to-day situations (for example, one would learn to look ahead while walking because of the danger inherent in not paying attention to where one is going). It is learning from life, during a meal at table with parents, play, exploring, etc.

## **Formal learning**

Formal learning is learning that takes place within a teacher-student relationship, such as in a school system.

## **Nonformal learning**

Nonformal learning is organized learning outside the formal learning system. For example: learning by coming together with people with similar interests and exchanging viewpoints, in clubs or in (international) youth organizations, workshops.

## **Nonformal learning and combined approaches**

The educational system may use a combination of formal, informal, and nonformal learning methods. The UN and EU recognize these different forms of learning (cf. links below). In some schools students can get points that count in the formal-learning systems if they get work done in informal-learning circuits. They may be given time to assist international youth workshops and training courses, on the condition they prepare, contribute, share and can prove this offered valuable new insight, helped to acquire new skills, a place to get experience in organizing, teaching, etc.

In order to learn a skill, such as solving a Rubik's cube quickly, several factors come into play at once:

- Directions help one learn the patterns of solving a Rubik's cube.
- Practicing the moves repeatedly and for extended time helps with "muscle memory" and therefore speed.
- Thinking critically about moves helps find shortcuts, which in turn helps to speed up future attempts.
- The Rubik's cube's six colors help anchor solving it within the head.
- Occasionally revisiting the cube helps prevent negative learning or loss of skill.

## **Tangential learning**

Tangential learning is the process by which people will self-educate if a topic is exposed to them in a context that they already enjoy. For example, after playing a music-based video game, some people may be motivated to learn how to play a real instrument, or after watching a TV show that references Faust and Lovecraft, some people may be inspired to read the original work.

## **Dialogic learning**

Dialogic learning is a type of learning based on dialogue.

## ***Domains of learning***

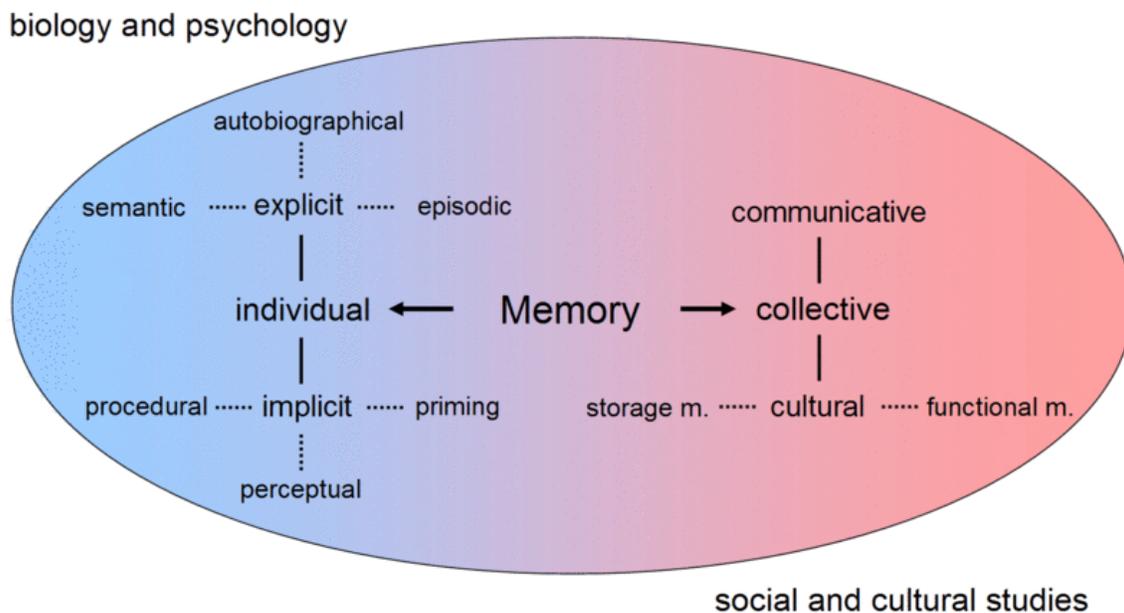
Benjamin Bloom has suggested three domains of learning:

- Cognitive – To recall, calculate, discuss, analyze, problem solve, etc.
- Psychomotor – To dance, swim, ski, dive, drive a car, ride a bike, etc.
- Affective – To like something or someone, love, appreciate, fear, hate, worship, etc.

These domains are not mutually exclusive. For example, in learning to play chess, the person will have to learn the rules of the game (cognitive domain); but he also has to learn how to set up the chess pieces on the chessboard and also how to properly hold and move a chess piece (psychomotor). Furthermore, later in the game the person may even learn to love the game itself, value its applications in life, and appreciate its history (affective domain).

## Chapter 4

# Memory



Overview of the forms and functions of memory in the sciences

In psychology, **memory** is an organism's ability to store, retain, and recall information and experiences. Traditional studies of memory began in the fields of philosophy, including techniques of artificially enhancing memory. The late nineteenth and early twentieth century put memory within the paradigms of cognitive psychology. In recent decades, it has become one of the principal pillars of a branch of science called cognitive neuroscience, an interdisciplinary link between cognitive psychology and neuroscience.

### **Processes**

From an information processing perspective there are three main stages in the formation and retrieval of memory:

- *Encoding* or registration (receiving, processing and combining of received information)
- *Storage* (creation of a permanent record of the encoded information)
- *Retrieval, recall* or *recollection* (calling back the stored information in response to some cue for use in a process or activity)

## Sensory memory

Sensory memory corresponds approximately to the initial 200–500 milliseconds after an item is perceived. The ability to look at an item, and remember what it looked like with just a second of observation, or memorisation, is an example of sensory memory. With very short presentations, participants often report that they seem to "see" more than they can actually report. The first experiments exploring this form of sensory memory were conducted by George Sperling (1960) 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.

## Short-term

Short-term memory allows recall for a period of several seconds to a minute without rehearsal. Its capacity is also very limited: George A. Miller (1956), when working at Bell Laboratories, conducted experiments showing that the store of short-term memory was  $7 \pm 2$  items (the title of his famous paper, "The magical number  $7 \pm 2$ "). Modern estimates of the capacity of short-term memory are lower, typically on the order of 4–5 items, however, 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 215), then a three-digit chunk (123) and lastly a four-digit chunk (4567). 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. Herbert Simon showed that the ideal size for chunking letters and numbers, meaningful or not, was three. This may be reflected in some countries in the tendency to remember telephone numbers as several chunks of three numbers with the final four-number groups, generally broken down into two groups of two.

Short-term memory is believed to rely mostly on an acoustic code for storing information, and to a lesser extent a visual code. Conrad (1964) found that test subjects had more difficulty recalling collections of words that were acoustically similar (e.g. dog, hog, fog, bog, log).

However, some individuals have been reported to be able to remember large amounts of information, quickly, and be able to recall that information in seconds.

## Long-term



Olin Levi Warner, *Memory* (1896). Library of Congress Thomas Jefferson Building, Washington, D.C.

The storage in sensory memory and short-term memory generally have a strictly limited capacity and duration, which means that information is available only for a certain period of time, but is not retained indefinitely. By contrast, long-term memory can store much larger quantities of information for potentially unlimited duration (sometimes a whole life span). Its capacity is immeasurably large. For example, given a random seven-digit number we may remember it for only a few seconds before forgetting, suggesting it was

stored in our short-term memory. On the other hand, we can remember telephone numbers for many years through repetition; this information is said to be stored in long-term memory.

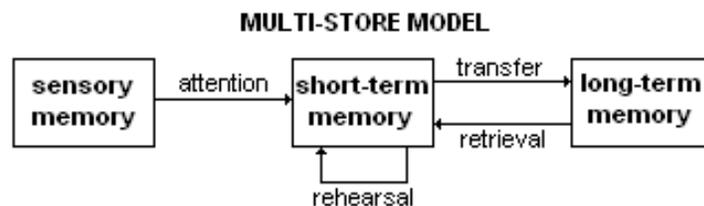
While short-term memory encodes information acoustically, long-term memory encodes it semantically: Baddeley (1966) discovered that after 20 minutes, test subjects had the most difficulty recalling a collection of words that had similar meanings (e.g. big, large, great, huge).

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 memories, on the other hand, are 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. Without the hippocampus, new memories are unable to be stored into long-term memory, and there will be a very short attention span. Furthermore, it may be involved in changing neural connections for a period of three months or more after the initial learning. One of the primary functions of sleep is thought to be improving 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 which mirror those recorded during the learning of tasks from the previous day, suggesting that new memories may be solidified through such rehearsal.

## Models

Models of memory provide abstract representations of how memory is believed to work. Below are several models proposed over the years by various psychologists. Note that there is some controversy as to whether there are several memory structures, for example, Tarnow (2005) finds that it is likely that there is only one memory structure between 6 and 600 seconds.

### Atkinson-Shiffrin model



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

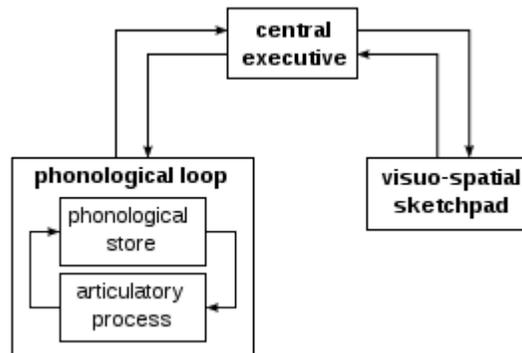
The multi-store model has been criticised for being too simplistic. For instance, long-term memory is believed to be actually made up of multiple subcomponents, such as episodic

and procedural memory. It also proposes that rehearsal is the only mechanism by which information eventually reaches long-term storage, but evidence shows us 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. Patient KF proves this. Patient KF was brain damaged and had problems with his short term memory. He had problems with things such as spoken numbers, letters and words and with significant sounds (such as doorbells and cats meowing). Other parts of short term memory were unaffected, such as visual (pictures).

It also shows the sensory store as a single unit whilst we know that the sensory store is split up into several different parts such as taste, vision, and hearing.

## Working memory



The working memory model.

In 1974 Baddeley and Hitch proposed a **working memory model** which replaced the concept of general short term memory with specific, active components. 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.

The central executive essentially acts as attention. It channels information to the three component processes: the phonological loop, the visuo-spatial 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). Then, a short list of data is easier to remember.

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).

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 semantical 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 (e.g., two visual), and the aforementioned word-length effect. However, the concept of a central executive as noted here has been criticised as inadequate and vague.

## Levels of processing

Craik and Lockhart (1972) proposed that it is the method and depth of processing that affects how an experience is stored in memory, rather than rehearsal.

- **Organization** - Mandler (1967) gave participants a pack of word cards and asked them to sort them into any number of piles using any system of categorisation they liked. When they were later asked to recall as many of the words as they could, those who used more categories remembered more words. This study suggested that the act of organising information makes it more memorable.
- **Distinctiveness** - Eysenck and Eysenck (1980) asked participants to say words in a distinctive way, e.g. spell the words out loud. Such participants recalled the words better than those who simply read them off a list.
- **Effort** - Tyler *et al.* (1979) had participants solve a series of anagrams, some easy (FAHTER) and some difficult (HREFAT). The participants recalled the difficult anagrams better, presumably because they put more effort into them.
- **Elaboration** - Palmere *et al.* (1983) gave participants descriptive paragraphs of a fictitious African nation. There were some short paragraphs and some with extra sentences elaborating the main idea. Recall was higher for the ideas in the elaborated paragraphs.

## Classification by information type

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

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, which concerns facts taken independent of context; and episodic memory, which concerns 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.

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.

In contrast, procedural memory (or *implicit memory*) is not based on the conscious recall of information, but on implicit learning. Procedural memory is primarily employed in learning motor skills and should 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.

**Topographic memory** is 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. This is often reported among elderly patients who are evaluated for dementia. The disorder could be caused by multiple impairments, including difficulties with perception, orientation, and memory.

### ***Classification by temporal direction***

A further major way to distinguish different memory functions is whether the content to be remembered is in the past, retrospective memory, or whether the content is to be remembered in the future, prospective memory. 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 example is), and lists, sticky-notes, knotted handkerchiefs, or string around the finger are all examples of cues that are produced by people as a strategy to enhance prospective memory.

### ***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 attributed to changes in neuronal synapses, thought to be mediated by long-term potentiation and long-term depression.

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.

## **Genetics**

Study of the genetics of human memory is in its infancy. A notable initial success was the association of APOE with memory dysfunction in Alzheimer's Disease. The search for genes associated with normally-varying memory continues. One of the first candidates for normal variation in memory is the gene *KIBRA*, which appears to be associated with the rate at which material is forgotten over a delay period.

## **Disorders**

Much of the current knowledge of memory has come from studying *memory disorders*. Loss of memory is known as amnesia. 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 hyperthymestic syndrome, is a disorder which 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.

While not a disorder, a common *temporary* failure of word retrieval from memory is the tip-of-the-tongue phenomenon. Sufferers of Nominal Aphasia (also called 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.

## ***Methods***

### Methods to optimize memorization

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 which is intensive memorisation in a short period of time. 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.

### Interference from previous knowledge

At the Center for Cognitive Science at Ohio State University, researchers have found that memory accuracy of adults is hurt by the fact that they know more than children and tend to apply this knowledge when learning new information. The findings appeared in the August 2004 edition of the journal Psychological Science.

Interference can hamper memorisation and retrieval. There is retroactive interference when learning new information causes forgetting of old information, and proactive interference where learning one piece of information makes it harder to learn similar new information.

### Influence of odors and emotions

In March 2007 German researchers found they could use odors to re-activate new memories in the brains of people while they slept and the volunteers remembered better later. Emotion can have a powerful impact on memory. Numerous studies have shown that the most vivid autobiographical memories tend to be of emotional events, which are likely to be recalled more often and with more clarity and detail than neutral events.

## ***Memory and 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).

## ***Improving memory***

A UCLA research study published in the June 2006 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.

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.

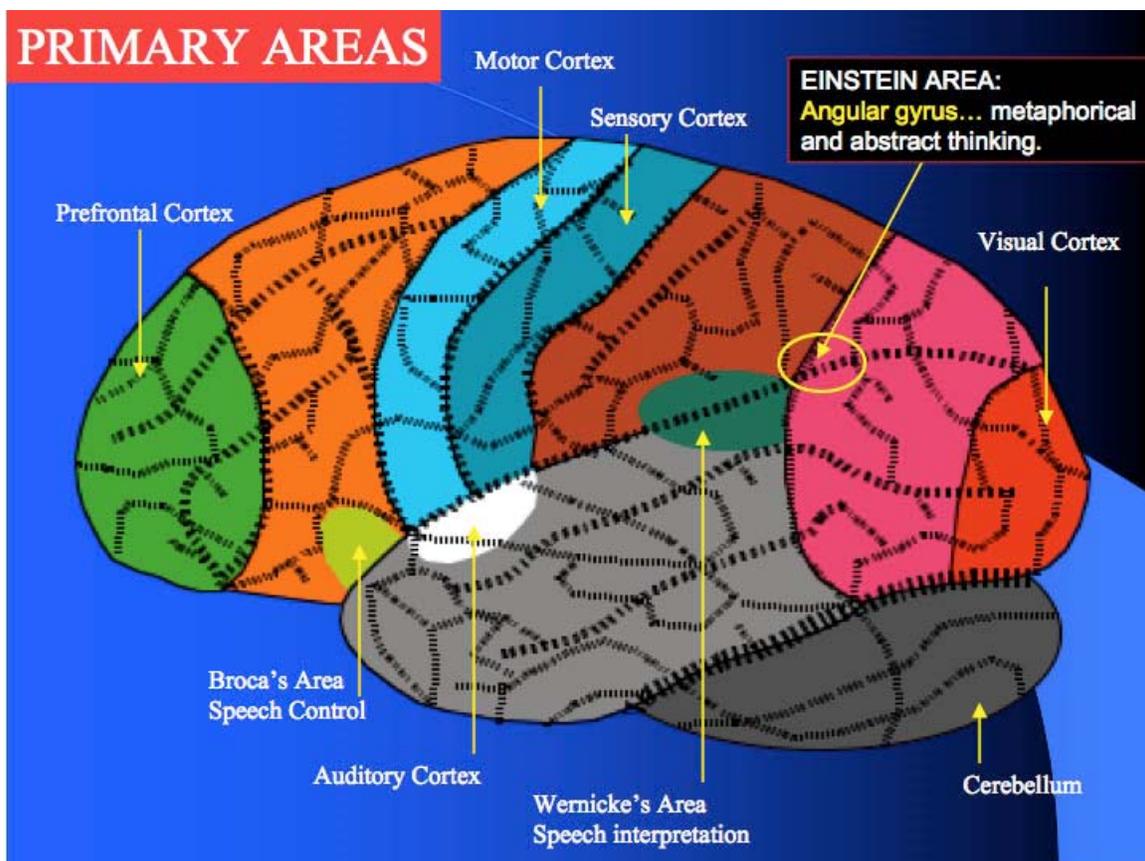
The International Longevity Center released in 2001 a report which includes in pages 14–16 recommendations for keeping the mind in good functionality until advanced age. Some of the recommendations are to stay intellectually active through learning, training or reading, to keep physically active so to promote blood circulation to the brain, to socialize, to reduce stress, to keep sleep time regular, to avoid depression or emotional instability and to observe good nutrition.

### ***Memory tasks***

- **Paired associate learning** - when one learns to associate one specific word with another. For example when given a word such as "safe" one must learn to say another specific word, such as "green". This is stimulus and response.
- **Free recall** - during this task a subject would be asked to study a list of words and then sometime later they will be asked to recall or write down as many words that they can remember.
- **Recognition** - subjects are asked to remember a list of words or pictures, after which point they are asked to identify the previously presented words or pictures from among a list of alternatives that were not presented in the original list.

## Chapter 5

# Neuroplasticity



Neuroplasticity challenges the idea that brain functions are fixed in certain locations.

**Neuroplasticity** (also known as **cortical remapping**) refers to the ability of the brain to change as a result of one's experience, that the brain is 'plastic' and 'malleable'. The discovery of this feature of the brain is rather modern; the previous belief amongst scientists was that the brain does not change after the critical period of infancy.

The brain consists of nerve cells (or "neurons") and glial cells which are interconnected, and learning may happen through change in the strength of the connections, by adding or removing connections, and by the formation of new cells. "Plasticity" relates to learning by adding or removing connections, or adding cells.

During the 20th century, the consensus was that lower brain and neocortical areas were immutable in structure after childhood, meaning learning only happens by changing of connection strength, whereas areas related to memory formation, such as the hippocampus and dentate gyrus, where new neurons continue to be produced into adulthood, were highly plastic. This belief is being challenged by new findings, suggesting all areas of the brain are plastic even after childhood.

Hubel and Wiesel had demonstrated that ocular dominance columns in the lowest neocortical visual area, V1, were largely immutable after the critical period in development. Critical periods also were studied with respect to language; the resulting data suggested that sensory pathways were fixed after the critical period. However, studies determined that environmental changes could alter behavior and cognition by modifying connections between existing neurons and via neurogenesis in the hippocampus and other parts of the brain, including the cerebellum.

Decades of research have now shown that substantial changes occur in the lowest neocortical processing areas, and that these changes can profoundly alter the pattern of neuronal activation in response to experience. According to the theory of neuroplasticity, experience can actually change both the brain's physical structure (anatomy) and functional organization (physiology) from top to bottom. Neuroscientists are presently engaged in a reconciliation of critical period studies demonstrating the immutability of the brain after development with the more recent research showing how the brain can, and does, change.

## ***Etymology***

This idea was first proposed in 1890 by William James in *The Principles of Psychology*, though the idea was largely neglected for the next fifty years. The first person to use the term *neural plasticity* appears to have been the Polish neuroscientist Jerzy Konorski.

## ***Neurobiology***

One of the fundamental principles of how neuroplasticity functions is linked to the concept of synaptic pruning, the idea that individual connections within the brain are constantly being removed or recreated, largely dependent upon how they are used. This concept is captured in the aphorism, "neurons that fire together, wire together"/"neurons that fire apart, wire apart." If there are two nearby neurons that often produce an impulse simultaneously, their cortical maps may become one. This idea also works in the opposite way, i.e. that neurons which do not regularly produce simultaneous impulses will form different maps.

## Cortical maps

Cortical organization, especially for the sensory systems, is often described in terms of maps. For example, sensory information from the foot projects to one cortical site and the projections from the hand target in another site. As the result of this somatotopic organization of sensory inputs to the cortex, cortical representation of the body resembles a map (or homunculus).

In the late 1970s and early 1980s, several groups began exploring the impacts of removing portions of the sensory inputs. Michael Merzenich and Jon Kaas and Doug Rasmusson used the cortical map as their dependent variable. They found—and this has been since corroborated by a wide range of labs—that if the cortical map is deprived of its input it will become activated at a later time in response to other, usually adjacent inputs. At least in the somatic sensory system, in which this phenomenon has been most thoroughly investigated, JT Wall and J Xu have traced the mechanisms underlying this plasticity. Re-organization is not cortically emergent, but occurs at every level in the processing hierarchy; this produces the map changes observed in the cerebral cortex.

Merzenich and William Jenkins (1990) initiated studies relating sensory experience, without pathological perturbation, to cortically observed plasticity in the primate somatosensory system, with the finding that sensory sites activated in an attended operant behavior increase in their cortical representation. Shortly thereafter, Ford Ebner and colleagues (1994) made similar efforts in the rodent whisker barrel cortex (also somatic sensory system). These two groups largely diverged over the years. The rodent whisker barrel efforts became a focus for Ebner, Matthew Diamond, Michael Armstrong-James, Robert Sachdev, Kevin Fox and great inroads were made in identifying the locus of change as being at cortical synapses expressing NMDA receptors, and in implicating cholinergic inputs as necessary for normal expression. However, the rodent studies were poorly focused on the behavioral end, and Ron Frostig and Daniel Polley (1999, 2004) identified behavioral manipulations as causing a substantial impact on the cortical plasticity in that system.

Merzenich and DT Blake (2002, 2005, 2006) went on to use cortical implants to study the evolution of plasticity in both the somatosensory and auditory systems. Both systems show similar changes with respect to behavior. When a stimulus is cognitively associated with reinforcement, its cortical representation is strengthened and enlarged. In some cases, cortical representations can increase two to threefold in 1–2 days at the time at which a new sensory motor behavior is first acquired, and changes are largely finished within at most a few weeks. Control studies show that these changes are not caused by sensory experience alone: they require learning about the sensory experience, and are strongest for the stimuli that are associated with reward, and occur with equal ease in operant and classical conditioning behaviors.

An interesting phenomenon involving cortical maps is the incidence of phantom limbs. This is most commonly described in people that have undergone amputations in hands, arms, and legs, but it is not limited to extremities. The phantom limb feeling, which is

thought to result from disorganization in the brain map and the inability to receive input from the targeted area, may be annoying or painful. Incidentally, it is more common after unexpected losses than planned amputations. There is a high correlation with the extent of physical remapping and the extent of phantom pain. As it fades, it is a fascinating functional example of new neural connections in the human adult brain.

The concept of plasticity can be applied to molecular as well as to environmental events. The phenomenon itself is complex and can involve many levels of organization. To some extent the term itself has lost its explanatory value because almost any changes in brain activity can be attributed to some sort of "plasticity". For example, the term is used prevalently in studies of axon guidance during development, short-term visual adaptation to motion or contours, maturation of cortical maps, recovery after amputation or stroke, and changes that occur in normal learning in the adult. Plasticity in more recent writing is frequently described as a property of the central nervous system with the term reorganization used to introduce the specific types of changes observed including axonal sprouting, long-term potentiation or the expression of plasticity related genomic responses Pinaud.

Norman Doidge, following the lead of Michael Merzenich, separates manifestations of neuroplasticity into adaptations that have positive or negative behavioral consequences. For example, if an organism can recover after a stroke to normal levels of performance, that adaptiveness could be considered an example of "positive plasticity". An excessive level of neuronal growth leading to spasticity or tonic paralysis, or an excessive release of neurotransmitters in response to injury which could kill nerve cells; this would have to be considered a "negative" plasticity. In addition, drug addiction and obsessive-compulsive disorder are deemed examples of "negative plasticity" by Dr. Doidge, as the synaptic rewiring resulting in these behaviors is also highly maladaptive.

A 2005 study found that the effects of neuroplasticity occur even more rapidly than previously expected. Medical students' brains were imaged during the period when they were studying for their exams. In a matter of months, the students' gray matter increased significantly in the posterior and lateral parietal cortex.

## ***History***

### **Proposal**

Until around the 1970s, an accepted idea across neuroscience was that the nervous system was essentially fixed throughout adulthood, both in terms of brain functions, as well as the idea that it was impossible for new neurones to develop after birth.

The idea that the brain and its functions are not fixed throughout adulthood was first proposed in 1890 by William James in *The Principles of Psychology*, though the idea was largely neglected.

## Research and discovery

In 1923, Karl Lashley conducted experiments on rhesus monkeys which demonstrated changes in neuronal pathways, which he concluded to be evidence of plasticity, although despite this, as well as further examples of research suggesting this, the idea of neuroplasticity was not widely accepted by neuroscientists. However, more significant evidence began to be produced in the 1960s and after, notably from scientists including Paul Bach-y-Rita, Michael Merzenich along with Jon Kaas, as well as several others.

In the 1960s, Paul Bach-y-Rita invented a device that allowed blind people to read, perceive shadows, and distinguish between close and distant objects. This “machine was one of the first and boldest applications of neuroplasticity.” The patient sat in an electrically stimulated chair that had a large camera behind it which scanned the area, sending electrical signals of the image to four hundred vibrating stimulators on the chair against the patient’s skin. The six subjects of the experiment were eventually able to recognize a picture of the supermodel Twiggy.

It must be emphasized that these people were congenitally blind and had previously not been able to see. Bach-y-Rita believed in sensory substitution; if one sense is damaged, your other senses can sometimes take over. He thought skin and its touch receptors could act as a retina (using one sense for another). In order for the brain to interpret tactile information and convert it into visual information, it has to learn something new and adapt to the new signals. The brain's capacity to adapt implied that it possessed plasticity. He thought, “We see with our brains, not with our eyes.”

A tragic stroke that left his father paralyzed inspired Bach-y-Rita to study brain rehabilitation. His brother, a physician, worked tirelessly to develop therapeutic measures which were so successful that the father recovered complete functionality by age 68 and was able to live a normal, active life which even included mountain climbing. “His father’s story was firsthand evidence that a ‘late recovery’ could occur even with a massive lesion in an elderly person.” He found more evidence of this possible brain reorganization with Shepherd Ivory Franz's work. One study involved stroke patients who were able to recover through the use of brain stimulating exercises after having been paralyzed for years. “Franz understood the importance of interesting, motivating rehabilitation: ‘Under conditions of interest, such as that of competition, the resulting movement may be much more efficiently carried out than in the dull, routine training in the laboratory’ (Franz, 1921, pg.93).” This notion has led to motivational rehabilitation programs that are used today.

Michael Merzenich is a neuroscientist who has been one of the pioneers of brain plasticity for over three decades. He has made some of “the most ambitious claims for the field - that brain exercises may be as useful as drugs to treat diseases as severe as schizophrenia - that plasticity exists from cradle to the grave, and that radical improvements in cognitive functioning - how we learn, think, perceive, and remember are possible even in the elderly.” Merzenich’s work was affected by a crucial discovery made by David Hubel and Torsten Wiesel in their work with kittens. The experiment involved

sewing one eye shut and recording the cortical brain maps. Hubel and Wiesel saw that the portion of the kitten's brain associated with the shut eye was not idle, as expected. Instead, it processed visual information from the open eye. It was "... as though the brain didn't want to waste any 'cortical real estate' and had found a way to rewire itself."

This implied brain plasticity during the critical period. However, Merzenich argued that brain plasticity could occur beyond the critical period. His first encounter with adult plasticity came when he was engaged in a postdoctoral study with Clinton Woosley. The experiment was based on observation of what occurred in the brain when one peripheral nerve was cut and subsequently regenerated. The two scientists micromapped the hand maps of monkey brains before and after cutting a peripheral nerve and sewing the ends together. Afterwards, the hand map in the brain that was expected to be jumbled was nearly normal. This was a substantial breakthrough. Merzenich asserted that "if the brain map could normalize its structure in response to abnormal input, the prevailing view that we are born with a hardwired system had to be wrong. The brain had to be plastic."

## ***Applications and examples***

### **Treatment of brain damage**

A surprising consequence of neuroplasticity is that the brain activity associated with a given function can move to a different location; this can result from normal experience and also occurs in the process of recovery from brain injury. Neuroplasticity is the fundamental issue that supports the scientific basis for treatment of acquired brain injury with goal-directed experiential therapeutic programs in the context of rehabilitation approaches to the functional consequences of the injury.

The adult brain is not "hard-wired" with fixed and immutable neuronal circuits. There are many instances of cortical and subcortical rewiring of neuronal circuits in response to training as well as in response to injury. There is solid evidence that neurogenesis (birth of brain cells) occurs in the adult, mammalian brain—and such changes can persist well into old age. The evidence for neurogenesis is mainly restricted to the hippocampus and olfactory bulb, but current research has revealed that other parts of the brain, including the cerebellum, may be involved as well.

In the rest of the brain, neurons can die, but they cannot be created. However, there is now ample evidence for the active, experience-dependent re-organization of the synaptic networks of the brain involving multiple inter-related structures including the cerebral cortex. The specific details of how this process occurs at the molecular and ultrastructural levels are topics of active neuroscience research. The manner in which experience can influence the synaptic organization of the brain is also the basis for a number of theories of brain function including the general theory of mind and epistemology referred to as Neural Darwinism and developed by immunologist Nobel laureate Gerald Edelman. The concept of neuroplasticity is also central to theories of memory and learning that are associated with experience-driven alteration of synaptic structure and function in studies of classical conditioning in invertebrate animal models such as *Aplysia*. This latter

program of neuroscience research has emanated from the ground-breaking work of another Nobel laureate, Eric Kandel, and his colleagues at Columbia University College of Physicians and Surgeons.

Paul Bach-y-Rita, deceased in 2006, was the “father of sensory substitution and brain plasticity.” In working with a patient whose vestibular system had been damaged he developed BrainPort, a machine that “replaces her vestibular apparatus and [will] send balance signals to her brain from her tongue.” After she had used this machine for some time it was no longer necessary, as she regained the ability to function normally. Her balancing act days were over.

Plasticity is the major explanation for the phenomena. Because her vestibular system was “disorganized” and sending random rather than coherent signals, the apparatus found new pathways around the damaged or blocked neural pathways, helping to reinforce the signals that were sent by remaining healthy tissues. Bach-y-Rita explained plasticity by saying, “If you are driving from here to Milwaukee and the main bridge goes out, first you are paralyzed. Then you take old secondary roads through the farmland. Then you use these roads more; you find shorter paths to use to get where you want to go, and you start to get there faster. These “secondary” neural pathways are “unmasked” or exposed and strengthened as they are used. The “unmasking” process is generally thought to be one of the principal ways in which the plastic brain reorganizes itself.”

Randy Nudo's group found that if a small stroke (an infarction) is induced by impedance of blood flow to a portion of a monkey's motor cortex, the part of the body that responds by movement will move when areas adjacent to the damaged brain area are stimulated. In one study, intracortical microstimulation (ICMS) mapping techniques were used in nine normal monkeys. Some underwent ischemic infarction procedures and the others, ICMS procedures. The monkeys with ischemic infarctions retained more finger flexion during food retrieval and after several months this deficit returned to preoperative levels. With respect to the distal forelimb representation, “postinfarction mapping procedures revealed that movement representations underwent reorganization throughout the adjacent, undamaged cortex.” Understanding of interaction between the damaged and undamaged areas provides a basis for better treatment plans in stroke patients. Current research includes the tracking of changes that occur in the motor areas of the cerebral cortex as a result of a stroke. Thus, events that occur in the reorganization process of the brain can be ascertained. Nudo is also involved in studying the treatment plans that may enhance recovery from strokes, such as physiotherapy, pharmacotherapy and electrical stimulation therapy.

Jon Kaas, a professor at Vanderbilt University, has been able to show “how somatosensory area 3b and ventroposterior (VP) nucleus of the thalamus are affected by long standing unilateral dorsal column lesions at cervical levels in macaque monkeys.” Adult brains have the ability to change as a result of injury but the extent of the reorganization depends on the extent of the injury. His recent research focuses on the somatosensory system, which involves a sense of the body and its movements using many senses. Usually when people damage the somatosensory cortex, impairment of the

body perceptions are experienced. He is trying to see how these systems (somatosensory, cognitive, motor systems) are plastic as a result of injury.

One of the most recent applications of neuroplasticity involves work done by a team of doctors and researchers at Emory University, specifically Dr. Donald Stein (who has been in the field for over three decades) and Dr. David Wright. This is the first treatment in 40 years that has significant results in treating traumatic brain injuries while also incurring no known side effects and being cheap to administer. Dr. Stein noticed that female mice seemed to recover from brain injuries better than male mice. Also in females, he noticed that at certain points in the estrus cycle females recovered even more. After lots of research, they attributed this difference due to the levels of progesterone. The highest level of progesterone present led to the fastest recovery of brain injury in these mice.

They developed a treatment that includes increased levels of progesterone injections to give to brain injured patients. “Administration of progesterone after traumatic brain injury (TBI) and stroke reduces edema, inflammation, and neuronal cell death, and enhance spatial reference memory and sensory motor recovery.” In their clinical trials, they had a group of severely injured patients that after the three days of progesterone injections there was a 60% reduction in mortality. Sam\* was in a horrific car accident that left him with marginal brain activity; according to the doctors, he was one point away from being brain dead. His parents decided to have him participate in Dr. Stein’s clinical trial and he was given the three-day progesterone treatment. Three years after the accident, he had achieved an inspiring recovery with no brain complications and the ability to live a healthy, normal life.

Stein has done some studies in which beneficial effects have been seen to be similar in aged rats to those seen in youthful rats. As there are physiological differences in the two age groups, the model was tweaked for the elderly animals by reducing their stress levels with increased physical contact. During surgery, anesthesia was kept at a higher oxygen level with lower overall isoflurane percentage and “the aged animals were give subcutaneous lactated ringers solution post-surgery to replace fluids lost through increased bleeding.” The promising results of progesterone treatments “could have a significant impact on the clinical management of TBI.” These treatments have been shown to work on human patients who receive treatment soon after the TBI. However, Dr. Stein now focuses his research on those persons who have longstanding traumatic brain injury in order to determine if progesterone treatments will assist them in the recovery of lost functions as well.

## **Treatment of learning difficulties**

Michael Merzenich developed a series of “plasticity-based computer programs known as Fast ForWord .” FastForWord offers seven brain exercises to help with the language and learning deficits of dyslexia. In a recent study, experimental training was done in adults to see if it would help to counteract the negative plasticity that results from age-related cognitive decline (ARCD). The ET design included six exercises designed to reverse the dysfunctions caused by ARCD in cognition, memory, motor control, and so on . After use

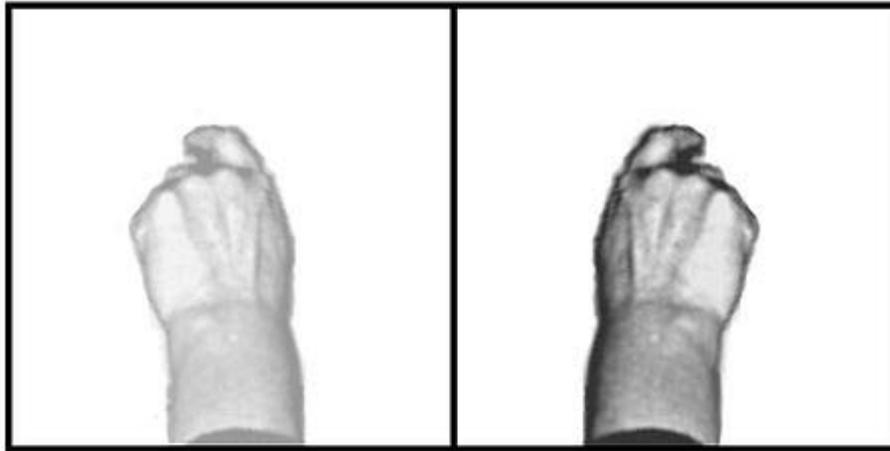
of the ET program for 8–10 weeks, there was a “significant increase in task-specific performance.” The data collected from the study indicated that a brain plasticity-based program could notably improve cognitive function and memory in adults with ARCD.

## **Brain plasticity during operation of brain-machine interfaces**

Brain-machine interface (BMI) is a rapidly developing field of neuroscience. According to the results obtained by Mikhail Lebedev, Miguel Nicolelis and their colleagues, operation of BMIs results in incorporation of artificial actuators into brain representations. The scientists showed that modifications in neuronal representation of the monkey's hand and the actuator that was controlled by the monkey brain occurred in multiple cortical areas while the monkey operated a BMI. In these single day experiments, monkeys initially moved the actuator by pushing a joystick. After mapping out the motor neuron ensembles, control of the actuator was switched to the model of the ensembles so that the brain activity, and not the hand, directly controlled the actuator. The activity of individual neurons and neuronal populations became less representative of the animal's hand movements while representing the movements of the actuator. Presumably as a result of this adaptation, the animals could eventually stop moving their hands yet continue to operate the actuator. Thus, during BMI control, cortical ensembles plastically adapt, within tens of minutes, to represent behaviorally significant motor parameters, even if these are not associated with movements of the animal's own limb.

Active laboratory groups include those of John Donoghue at Brown, Richard Andersen at Caltech, Krishna Shenoy at Stanford, Nicholas Hatsopoulos of University of Chicago, Andy Schwartz at University of Pittsburgh, Sandro Mussa-Ivaldi at Northwestern and Miguel Nicolelis at Duke. Donoghue and Nicolelis' groups have independently shown that animals can control external interfaces in tasks requiring feedback, with models based on activity of cortical neurons, and that animals can adaptively change their minds to make the models work better. Donoghue's group took the implants from Richard Normann's lab at Utah (the "Utah" array), and improved it by changing the insulation from polyimide to parylene-c, and commercialized it through the company Cyberkinetics. These efforts are the leading candidate for the first human trials on a broad scale for motor cortical implants to help quadriplegic or locked-in patients communicate with the outside world.

## Phantom limbs



A diagrammatic explanation of the mirror box. The patient places the good limb into one side of the box (in this case the right hand) and the amputated limb into the other side. Due to the mirror, the patient sees a reflection of the good hand where the missing limb would be (indicated in lower contrast). The patient thus receives artificial visual feedback that the "resurrected" limb is now moving when they move the good hand.

Phantom limbs are phenomena in which a person continues to feel pain or sensation within a part of their body which has been amputated. An explanation for this refers to the concept of neuroplasticity, as the cortical maps of the removed limbs are believed to have become engaged with the area around them in the postcentral gyrus. This results in activity within the surrounding area of the cortex being misinterpreted by the area of the cortex formerly responsible for the amputated limb. Pain is often experienced due to the

association of this area with the pain that may have been experienced by the limb before it was amputated. Much of this was discovered by neuroscientist Vilayanur S. Ramachandran, who also developed a method of treatment for it called a mirror box, again using neuroplasticity to remove the association of the limb with the surrounding cortex by providing visual feedback to make it appear that the limb is responding.

## **Meditation**

A number of studies have linked meditation practice to differences in cortical thickness or density of gray matter. One of the most well-known studies to demonstrate this was led by Sara Lazar, from Harvard University, in 2000. Richard Davidson, a neuroscientist at the University of Wisconsin, has led experiments in cooperation with the Dalai Lama on effects of meditation on the brain. His results suggest that long-term, or short-term practice of meditation results in different levels of activity in brain regions associated with such qualities as attention, anxiety, depression, fear, anger, the ability of the body to heal itself, and so on. These functional changes may be caused by changes in the physical structure of the brain.

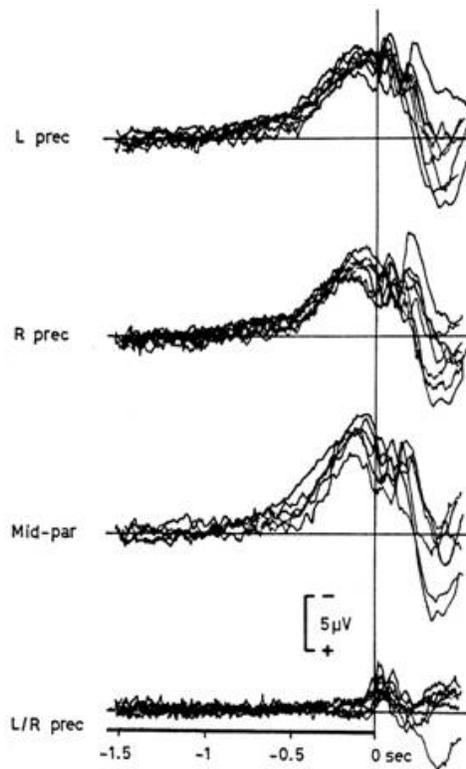
## **Fitness and Exercise**

"In the study, scientists had two groups of mice swim a water maze and in a separate trial had them endure an unpleasant stimulus to see how quickly they would learn to move away from it. For the next four weeks they allowed one group of mice to run inside their rodent wheels, an activity most mice enjoy, while requiring the other group to push harder on minitreadmills at a speed and duration controlled by the scientists. They then tested both groups again to track their learning skills and memory. Both groups of mice performed admirably in the water maze, bettering their performances from the earlier trial. But only the treadmill runners were better in the avoidance task, a skill that, according to brain scientists, demands a more complicated cognitive response.

The mice who raced on the treadmills showed evidence of molecular changes in several portions of their brains when viewed under a microscope, while the voluntary wheel-runners had changes in only one area. "Our results support the notion that different forms of exercise induce neuroplasticity changes in different brain regions," Chaoying J. Jen, a professor of physiology and an author of the study, says."

## Chapter 6

# Neuroscience of Free Will



Typical recording of the readiness potential. Benjamin Libet investigated whether this neural activity corresponded to the "felt intention" (or will) to move of experimental subjects.

**Neuroscience of free will** refers to recent neuroscientific investigations shedding light on the question of free will, which is a philosophical and scientific question as to whether, and in what sense, rational agents exercise control over their actions or decisions. As it has become possible to study the living brain, researchers have begun to watch decision-making processes at work.

The field itself remains highly controversial as there is no consensus among researchers about the significance of findings, their meaning, or what conclusions may be drawn. In the light of recent studies, there lies a possibility that the experience of "will" requires re-conceptualization. While this would carry implications for moral responsibility in general, the research below is still new enough to warrant only tentative conclusions.

## **Overview**

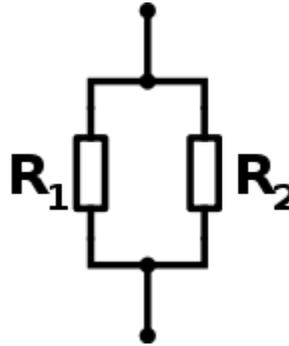


How and whether consciousness directly initiates, or even moderates behaviour remains unclear

One significant finding of these studies is that a person's brain seems to commit to certain decisions before the person becomes aware of having made them. Early studies found delays of about half a second; with contemporary brain scanning technology, scientists in 2008 were able to predict with 60% accuracy whether subjects would press a button with their left or right hand up to 10 seconds before the subject became aware of having made that choice. These findings may not be sufficient to contradict free will, as it would be quite likely that a large range of cognitive operations are necessary to freely press a button.

Another proposed explanation is a 'forward model of motor control', which is mentioned below. The idea is that our conscious self does not cause all behaviours. Instead, the conscious self is alerted (through various sensations) to behaviours that the rest of the

brain and body are already planning and performing. To be clear, this model does not deny that consciousness affects behaviour; it does not forbid conscious experience from being used as input by unconscious processes - information that might modify a behaviour in progress. The key is that the unconscious processes play a much larger role in behaviour. This model thus challenges some conceptions of free will, since self awareness may only *recognize* a feeling of will, which appears before an action.



One possibility is that both feelings of intention and actual behaviors are on a sort of parallel circuit, both emerging from brain processing outside of awareness

It may be possible, then, that our intuitions about the role of our conscious "intentions" have led us astray; it may be the case that we have confused correlation with causation by believing that conscious awareness necessarily causes the body's movement. This possibility is bolstered by various introspection illusions - studies showing that humans do not have full access to various internal processes. The discovery that humans possess a determined will would have implications for moral responsibility. Neuroscientist and writer Sam Harris believes this is the case, suggesting "*Thoughts simply arise (what else could they do?)...The illusion of free will is itself an illusion*".

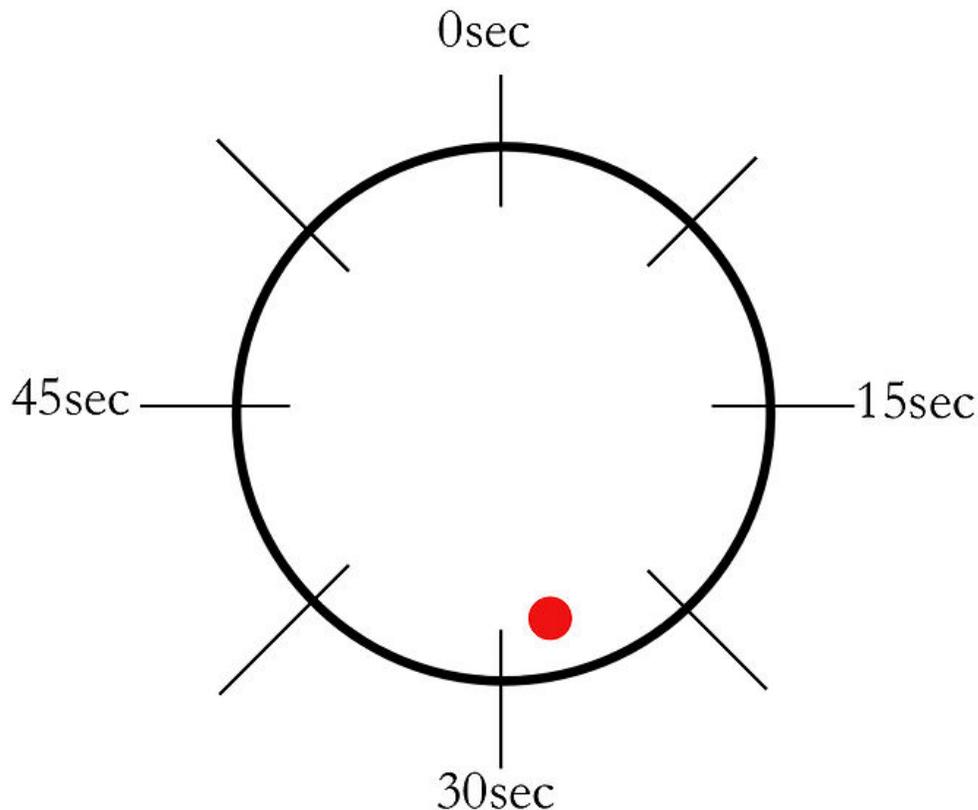
There have been a number of problems regarding studies of free will. Particularly in earlier studies, research relies too much on the introspection of the participants (other research shows that things such as introspective estimates of event timing are not accurate). The conscious decision may be made elsewhere in the brain before conscious realization, leaving room for free will even if the conscious realization comes delayed. The brain activity measures have been insufficient and primitive as there is no good independent brain-function measure of the conscious generation of intentions, choices, or decisions; the conclusions drawn from measurements that *have* been made are debatable too, as they don't necessarily tell, for example, what a sudden dip in the readings are representing. In other words, the dip might have nothing to do with unconscious decision, since many other mental processes are going on while performing the task.

These studies have therefore only just begun to shed light on the role that consciousness plays in actions and it is too early to draw very strong conclusions. It is worth noting that such experiments - so far - have dealt only with free will decisions made in short time frames (seconds) and *may* not have direct bearing on free will decisions made

("thoughtfully") by the subject over the course of *many* seconds, minutes, hours or longer.

### ***Benjamin Libet's early experiments***

A pioneering experiment in this field was conducted by Benjamin Libet in the 1980s, in which he asked each subject to choose a random moment to flick their wrist while he measured the associated activity in their brain (in particular, the build-up of electrical signal called the readiness potential). Although it was well known that the readiness potential preceded the physical action, Libet asked how the readiness potential corresponded to the felt intention to move. To determine when the subject felt the intention to move, he asked her to watch the second hand of a clock and report its position when she felt that she had felt the conscious will to move.



The "Libet Clock", used by having the subject memorize the position of the dot when something occurs (in this case, when they feel the urge to move).

Libet found that the *unconscious* brain activity leading up to the *conscious* decision by the subject to flick his or her wrist began approximately half a second *before* the subject consciously felt that she had decided to move. Libet's findings suggest that decisions made by a subject are first being made on a subconscious level and only afterward being

translated into a "conscious decision", and that the subject's belief that it occurred at the behest of her will was only due to her retrospective perspective on the event.

## Criticism

The interpretation of these findings has been criticized by Daniel Dennett, who argues that people will have to shift their attention from their intention to the clock, and that this introduces temporal mismatches between the felt experience of will and the perceived position of the clock hand. Consistent with this argument, subsequent studies have shown that the exact numerical value varies depending on attention. Despite the differences in the exact numerical value, however, the main finding has held. Philosopher Alfred Mele criticizes this design for other reasons. Having attempted the experiment himself, Mele explains that "the awareness of the intention to move" is an ambiguous feeling at best. For this reason he remained skeptical of interpreting the subjects' reported times for comparison with their 'readiness potential'.

In a variation of this task, Haggard and Eimer asked subjects to decide not only when to move their hands, but also to decide *which hand to move*. In this case, the felt intention correlated much more closely with the "lateralized readiness potential" (LRP), an ERP component which measures the difference between left and right hemisphere brain activity. Haggard and Eimer argue that the feeling of conscious will therefore must follow the decision of which hand to move, since the LRP reflects the decision to lift a particular hand.

A more direct test of the relationship between the readiness potential and the "awareness of the intention to move" was conducted by Banks and Isham (2009). In their study, participants performed a variant of the Libet's paradigm in which a delayed tone followed the button press. Subsequently, research participants reported the time of their intention to act (e.g., Libet's "W"). If W were time-locked to the readiness potential, W would remain uninfluenced by any post-action information. However, findings from this study show that W in fact shift systematically with the time of the tone presentation, implicating that W is, at least in part, retrospectively reconstructed rather than pre-determined by the readiness potential.

A study conducted by Jeff Miller and Judy Trevena (2009) suggests that the readiness potential (RP) signal in Libet's experiments doesn't represent a decision to move, but that it's merely a sign that the brain is paying attention. In this experiment the classical Libet experiment was modified by playing an audio tone indicating to volunteers to decide whether to tap a key or not. The researchers found that there was the same RP signal in both cases, regardless of whether or not volunteers actually elected to tap, which suggests that the RP signal doesn't indicate that a decision has been made. In a second experiment they asked volunteers to decide on the spot whether to use left hand or right to tap the key while monitoring their brain signals, and they found no correlation among the signals and the chosen hand. This criticism has itself been criticized by free-will researcher Patrick Haggard, who mentions literature that distinguishes two different circuits in the brain that lead to action: a "stimulus-response" circuit and a "voluntary" circuit. According to

Haggard, researchers applying external stimuli are testing neither the voluntary circuit, nor Libet's hypothesis about internally triggered actions.

## ***Unconscious actions***

### **Timing intentions compared to actions**

A recent study by Masao Matsushashi and Mark Hallett claims to have replicated Libet's findings without relying on subjective report or clock memorization on the part of participants. The authors believe that their method can identify the time (T) at which a subject becomes aware of her own movement. Matsushashi and Hallett argue that this time not only varies, but often occurs after early phases of movement genesis have already begun (as measured by the readiness potential). They conclude that a person's awareness cannot be the cause of movement, and may instead only notice the movement.

### **Summary of experiment**

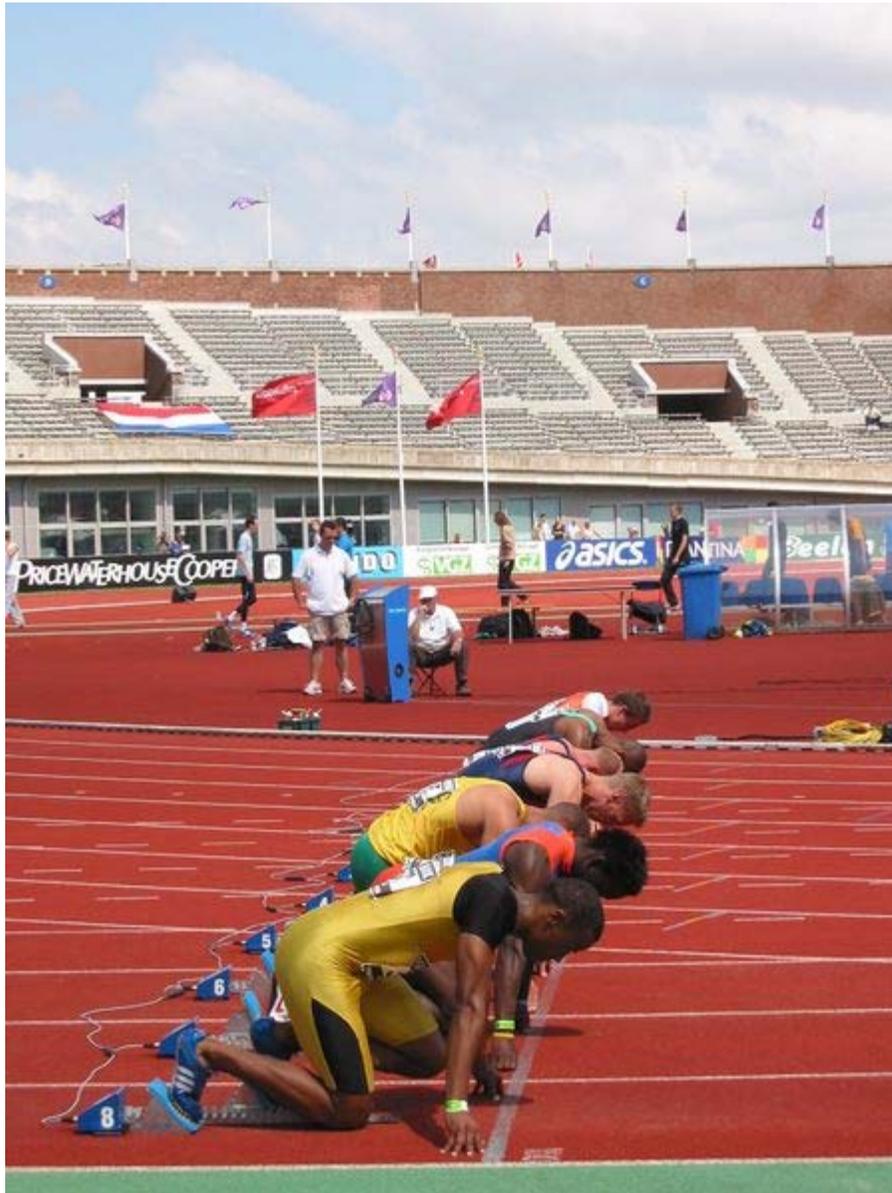


It was difficult to identify exactly when a person becomes aware of their action. Surprisingly, awareness seems to come only after actions have already begun in the brain

Matsushashi and Hallett's study can be summarized thus: *Hypothesis*: If our conscious intention is what causes movement genesis, conscious intention should always occur

before any movement has begun. This is because otherwise, if we become aware of a movement only after it has already been started, our awareness is obviously not the cause of that movement. *Experiment:* Have subjects perform self-paced finger movements while "stop-signal" sounds play randomly. The subject must stop his movement if he hears a signal while he is aware of any intention to move. Whenever there *is* an action, graph any tones that occurred before that action. The graph will show tones at only 2 points: (a) before the subject is even aware of her movement genesis (or else she would have stopped the movement), as well as (b) after it is too late to stop the action (called the point of no return - of little importance here). As seen in the histogram above, now the researchers know exactly how many seconds before most actions the subject normally becomes aware: This moment of awareness, dubbed "T", can be found by looking at the border between tones and no tones. In other words, time T is found by looking to see when tones started resulting in vetoed actions (and an empty graph, since we only graphed the tone if there *was* an action). That is how we estimate the timing of the conscious intention to move without relying on the subject's knowledge or demanding them to focus on a clock. The last step is to compare time T to ERP measures of when their finger movements begin. *Results:* The time of the conscious intention to move T normally occurred *too late* to be the cause of movement genesis (again, see the example of a subject's histogram on the right. Although it is not shown, this subject's readiness potentials tells us that his actions start at -2.8 seconds, any yet this is even before his time "T"). *Conclusion:* The feeling of the conscious intention to move does not cause movement genesis; both the feeling of intention and the movement itself are the result of unconscious processing.

## The experiment

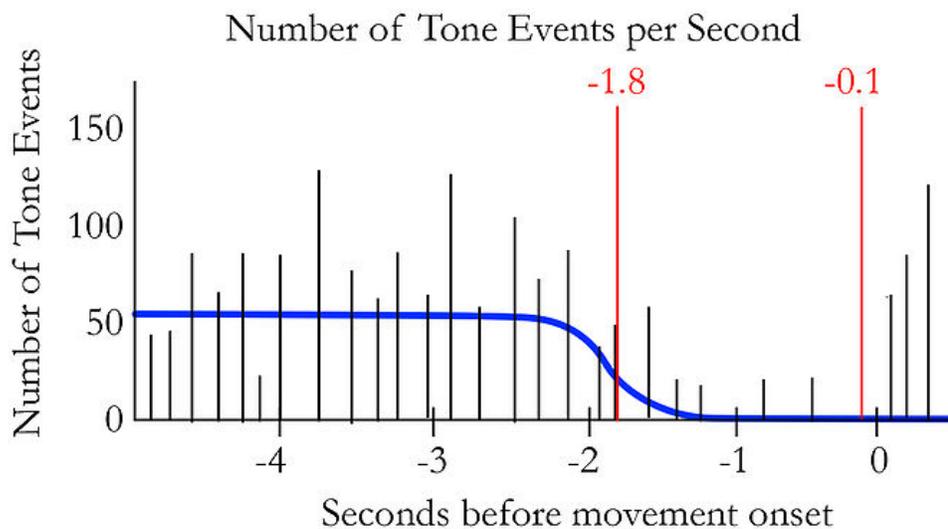


A simple "signalling noise" is used, but it is to warn participants that they must prevent any actions they are aware of

In this new study, volunteers were again asked to perform finger extensions in short, self-paced intervals. In this version of the experiment, researchers introduced randomly timed "stop tones" during the self paced movements. If participants were not conscious of any intention to move, they simply ignored the tone. On the other hand, if they were aware of their intention to move at the time of the tone, they had to try and veto the action, then relax for a bit before continuing self paced movements. This experimental design allowed Matsushashi and Hallet to see when, once the subject moved their finger, any tones

occurred. The goal was to identify their own equivalent of Libet's W, their own estimation of the timing of the conscious intention to move, which they called "T".

Testing the hypothesis that conscious intention occurs after movement genesis has already begun required the researchers to analyse the distribution of tones before actions. The idea is that, after time T, tones will lead to vetoing and thus a reduced representation in the data. There would also be a point of no return P where a tone was too close to the movement onset for the movement to be vetoed. In other words, the researchers were expecting to see many tones (when the subjects are not yet aware of their movement genesis), followed by a drop in the appearance of tones during a certain period of time (where the subjects are conscious of their intention and would stop any movement), and finally an increase again in tones (when the subjects do not have the time to process the tone and prevent an action). That is exactly what the researchers found.



Graphing tones as they appeared (or didn't) in the time before any action. In this case, researchers believe the subject becomes aware of his/her actions at about -1.769 seconds (this is time 'T'). A typical, strange example: this subject's brain scans suggest movement preparation as early as -2.8 seconds.

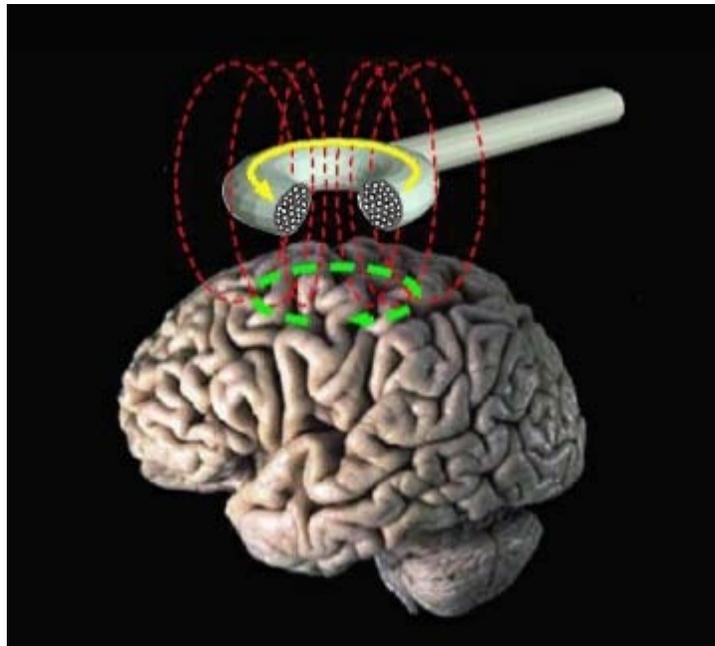
Let's look at when tones can be seen before Subject A moved, for example. He or she showed many tones on average up until 1.8 seconds before movement onset, but a significant decrease in tones immediately after that time. Presumably this is because the subject usually became aware of his or her intention to move at -1.8 seconds, which is then labelled point T. Since most actions are vetoed if a tone occurs after point T, there are very few tones represented during that range. Finally, there is a sudden increase in the number of tones appearing before an action at -0.1 seconds: meaning this subject has passed point P. Matsushashi and Hallet were thus able to establish an average time T (-1.42 seconds) and P without subjective report, and compare it to EEG measurements of

movement (which begin at about -2.8 seconds). In the end, since T — like Libet's original W — was often found after movement genesis had already begun, the authors concluded that the generation of awareness occurs afterwards or in parallel to action, but most importantly, it is probably not the cause.

## **Criticisms**

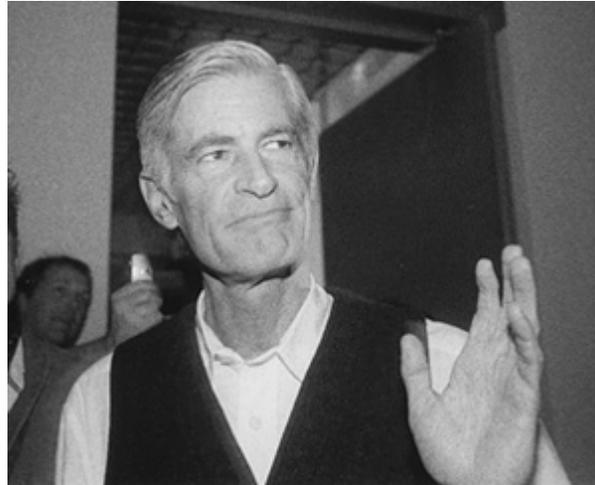
Note that these results were gathered using finger movements, and may not necessarily generalize to other actions such as thinking, or even other motor actions in different situations. Indeed, the human act of Planning has implications for free will and so this ability must also be explained by any theories of unconscious decision making. Philosopher Alfred Mele, although he has expressed views that amount to determinism, also doubts the conclusions of these studies. He explains that simply because a movement may have been initiated before our "conscious self" has become aware of it does not mean our consciousness does not still get to approve, modify, and perhaps cancel (called vetoing) the action.

## ***Manipulating the unconscious***



Transcranial Magnetic Stimulation uses magnetism to safely stimulate or inhibit parts of the brain.

Related experiments showed that neurostimulation could affect which hands people move, even though the experience of free will was intact. Ammon and Gandevia found that it was possible to influence which hand people move by stimulating frontal regions that are involved in movement planning using transcranial magnetic stimulation in either the left or right hemisphere of the brain.



Scientists were able to change which hand subjects normally chose to move without subjects noticing the influence

Right-handed people would normally choose to move their right hand 60% of the time, but when the right hemisphere was stimulated they would instead choose their left hand 80% of the time (recall that the right hemisphere of the brain is responsible for the left side of the body, and the left hemisphere for the right). Despite the external influence on their decision-making, the subjects continued to report that they believed their choice of hand had been made freely. In a follow-up experiment, Alvaro Pascual-Leone and colleagues found similar results, but also noted that the transcranial magnetic stimulation must occur within 200 milliseconds, consistent with the time-course derived from the Libet experiments.

It should be noted that, despite his findings, Libet himself did not interpret his experiment as evidence of the inefficacy of conscious free will - he points out that although the tendency to press a button may be building up for 500 milliseconds, the conscious will retains a right to veto any action at the last moment. According to this model, unconscious impulses to perform a volitional act are open to suppression by the conscious efforts of the subject (sometimes referred to as "free won't"). A comparison is made with a golfer, who may swing a club several times before striking the ball. The action simply gets a rubber stamp of approval at the last millisecond. Max Velmans argues however that "free won't" may turn out to need as much neural preparation as "free will".

### ***Unconsciously cancelling actions***

The possibility that human "free won't" is also the prerogative of the subconscious is being explored.

## Retrospective judgement of free choice



As green light switches to yellow, research seems to suggest that humans cannot tell the difference between "deciding" to keep driving, and having no time to decide at all.

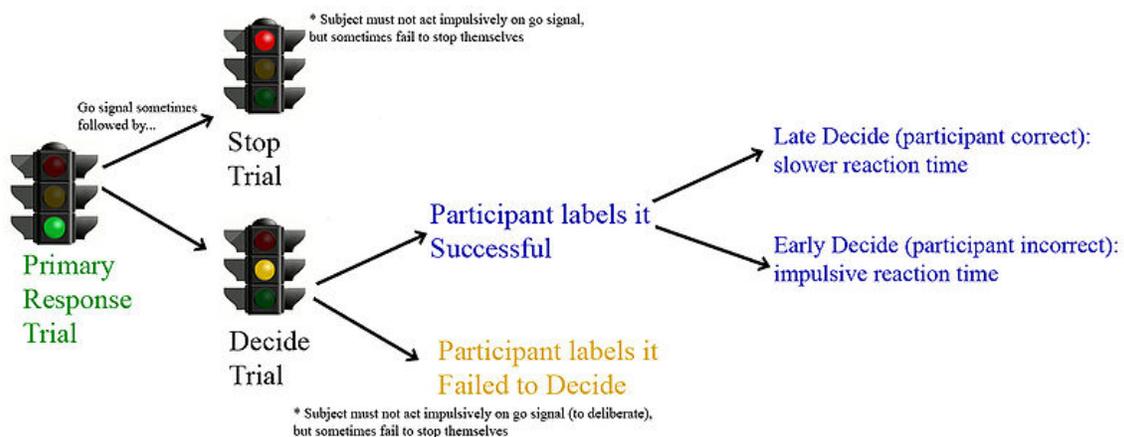
Recent research by Simone Kühn and Marcel Brass suggests that our consciousness may not be what causes some actions to be vetoed at the last moment. First of all, their experiment relies on the simple idea that we ought to know when we consciously cancel an action (i.e. we should have access to that information). Secondly, they suggest that access to this information means humans should find it *easy* to tell, just after completing an action, whether it was impulsive (there no time to decide) and when there was time to deliberate (the participant decided to allow/ not to veto the action). The study found evidence that subjects could not tell this important difference. This again leaves some conceptions of free will vulnerable to the Introspection illusion. The researchers interpret

their results to mean that the decision to "veto" an action is determined subconsciously, just as the initiation of the action may have been subconscious in the first place.

## The experiment

It started by gathering participants' reaction times (RT). In order to collect RT information, volunteers were asked to respond to a go-signal as quickly as possible in primary response trials. These baseline trials were interlaced with experimental trials in which the go-signal would be subsequently followed by either a "stop" or "decide" signal. These occasional second signals appeared with various delays. The occasional decide trials, for example, required that the participants prevent themselves from acting impulsively on the initial go-signal long enough to decide what to do. Due to the varying delays, this was sometimes impossible (e.g. some decide signals simply appeared too *late* in the movement process to be obeyed, and for the action to stop). Note that any trial where the subject does react, and where it is impulsively, shows a quick RT closer to 600ms. Any trial where they took time to decide should show a comparatively slow RT, in this case closer to 1400ms.

Kuhn and Brass wanted to test participant self-knowledge. The first step was that after every decide trial, participants were next asked whether they had actually had time to decide. Specifically, the volunteers were asked to label each decide trial as either failed-to-decide (the action was the result of acting impulsively on the initial go-signal) or successful decide (the result of a deliberated decision). See the diagram for this decide trial split: failed-to-decide and successful decide; the next split in this diagram (participant correct or incorrect) will be explained at the end of this experiment. Note also that the researchers sorted the participants' successful decide trials into "decide go" and "decide nogo", but were not concerned with the nogo trials since they did not yield any RT data (and are not featured anywhere in the diagram on the right). Note that successful stop trials did not yield RT data either.

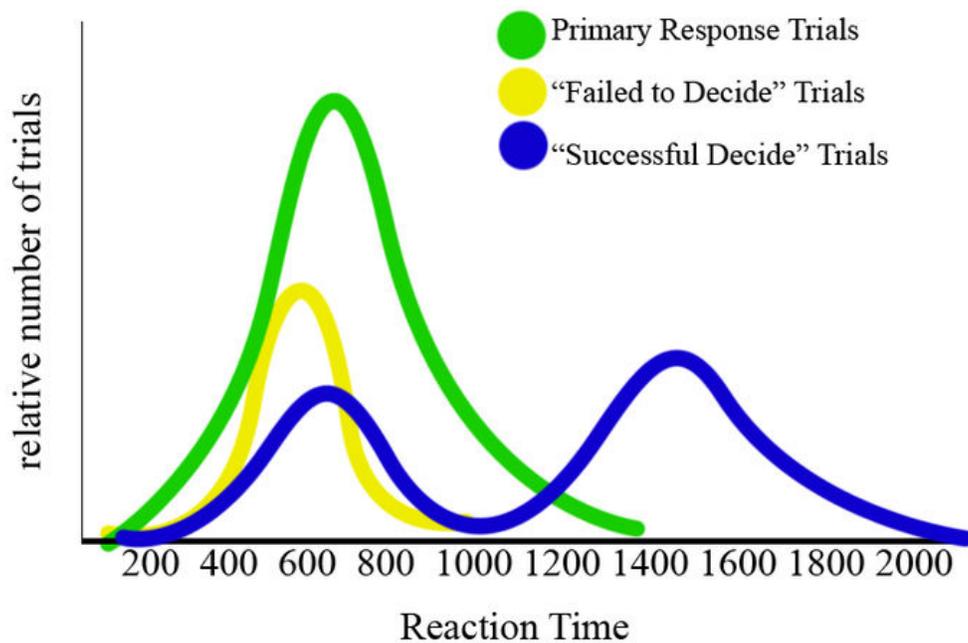


The traffic lights are metaphors - they were not the actual stimuli. The colours of the trial text corresponds to graph elsewhere.

The different types of trials and their different possible outcomes.

Kuhn and Brass now knew what to expect: primary response trials, any failed stop trials, and the “failed-to-decide” trials were all instances where the participant obviously acted impulsively – they would show the same quick RT. In contrast, the “successful *decide*” trials (where the decision was a “go” and the subject moved) should show a slower RT. Presumably, if deciding whether to veto is a conscious process, volunteers should have no trouble distinguishing impulsivity from instances of true deliberate continuation of a movement. Again, this is important since decide trials require that participants rely on self knowledge. Note that stop trials cannot test self knowledge because if the subject *does* act, it is obvious to them that they reacted impulsively.

### Results and implications



The general distribution of reaction times for the different trials. Notice the timing of the two peaks for trials labelled "successful decide".

Unsurprisingly, the recorded RTs for the primary response trials, failed stop trials, and “failed-to-decide” trials all showed similar RTs: 600ms seems to indicate an impulsive action made without time to truly deliberate. What the two researchers found next was not as easy to explain: while some “successful decide” trials did show the tell-tale slow RT of deliberation (averaging around 1400ms), participants had also labelled many impulsive actions as “successful decide”. This result is startling because participants should have had no trouble identifying which actions were the results of a conscious “I will not veto”, and which actions were un-deliberated, impulsive reactions to the initial go-signal. As the authors explain:

“ [The results of the experiment] clearly argue against Libet’s assumption that a veto process can be consciously initiated. He used the veto in order to reintroduce the possibility to control the unconsciously initiated actions. But since the subjects are not very accurate in observing when they have [acted impulsively instead of deliberately], the act of vetoing cannot be consciously initiated. ”

In decide trials the participants, it seems, were not able to reliably identify whether they had actually had time to decide – at least, not based on internal signals. The authors explain that this result is difficult to reconcile with the idea of a conscious veto, but simple to understand if the veto is considered an unconscious process. Thus it seems that the intention to move might not only arise from the subconscious, but it may only be inhibited if the subconscious says so. This conclusion would reduce the consciousness to more of narrator than direct arbiter (i.e. unconscious processing causes all thoughts, and these thoughts are again processed subconsciously).

### **Criticisms**

In this recent experiment, subjects could not reliably distinguish between "producing an action without stopping and stopping an action before voluntarily resuming". The conclusions that are drawn from this information, however - such as the assumption that only the faster decisions can be unconscious and that because the conscious ones have the same timing they must also be unconscious -, have yet to be debated properly or even replicated. It is also worth noting that Libet consistently referred to a veto of an action that was initiated endogenously. That is, a veto that occurs in the absence of external cues, instead relying on only internal cues (if any at all). This veto may be a different type of veto than the one explored by Kühn and Brass using their decide signal.

### ***Other related phenomena***

#### **Retrospective Construction**

The idea behind retrospective construction is that, while part of the "yes, I did it" feeling of agency seems to occur during action, there also seems to be processing performed after the fact - after the action is performed - to establish the full feeling of agency.

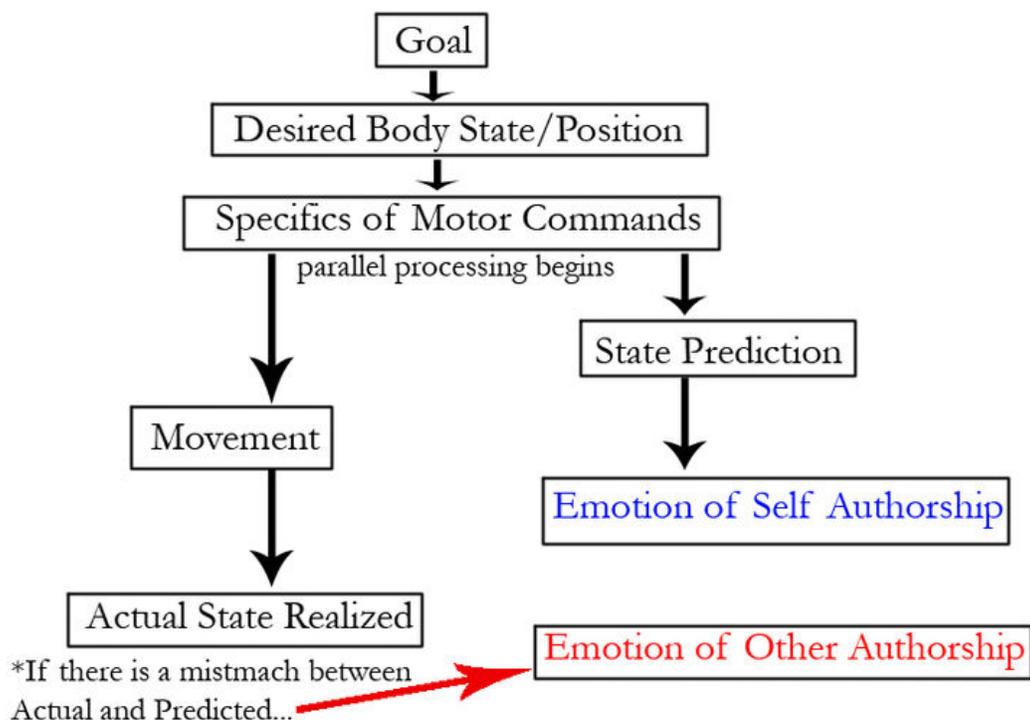
Subconscious agency processing can even alter, in the moment, how we perceive the timing of sensations or actions. Kühn and Brass apply retrospective construction to explain the two peaks in "successful decide" RT's. They suggest that the late decide trials were actually deliberated, but that the impulsive early decide trials that should have been labelled "failed to decide" were mistaken during subconscious agency processing. They explain that people may "persist in believing that they have access to their own cognitive processes" when in fact we do a great deal of automatic subconscious processing before conscious perception occurs.

## The pre-SMA and the intention to move

Scanning the brain in action, the readiness potential that indicates the beginning of movement genesis is recorded by an EEG applied to the pre-supplementary motor area (pre-SMA) of the brain. Directly stimulating the pre-SMA causes volunteers to report a feeling of intention, and sufficient stimulation of that same area causes physical movement. This suggests that awareness of an intention to move may literally be the “sensation” of the body’s early movement, but certainly not the cause. Other studies have at least suggested that “The greater activation of the SMA, SACC, and parietal areas during and after execution of internally generated actions suggests that an important feature of internal decisions is specific neural processing taking place during and after the corresponding action...Therefore, awareness of intention timing seems to be fully established only after execution of the corresponding action, in agreement with the time course of neural activity observed here.”.

## Thinking to ourselves and the forward model of motor control

### A Forward Model of Motor Control



A forward model of motor control. Notice that a prediction of the future state is made just before the movement occurs. Presumably that efference copy is used to establish agency.



Neurological disorders such as alien hand syndrome make a person lose his sense of agency.

Our ability to talk to ourself and think in words is a major part of the human experience of consciousness. From a young age, individuals are encouraged by society to introspect carefully, but also to communicate the results of that introspection . Simon Jones and Charles Fernyhough explain that our ability to talk to ourselves, “inner speech”, is essentially regular speech . This theory originates with the developmental psychologist Lev Vygotsky, who observed that children will often narrate their actions out loud before eventually replacing the habit with the adult equivalent: sub-vocal articulation. During sub-vocal articulation, no sound is made but the mouth still moves—or at least the brain might prepare the actions without executing them. Jones and Fernyhough explain that hearing words in our head is caused by sub-vocal articulation. This hypothesis has received support from evidence that schizophrenics suffering auditory hallucinations, more specifically auditory verbal hallucinations (AVH), need only to open their mouths in order to disrupt the voices in their heads. To explain exactly how inner speech works, what goes wrong with AVH patients, and how all the actions we’ve been discussing might work subconsciously, Jones and Fernyhough apply what is known as the forward model of motor control (FMMC), a model that uses the idea of efferent copies.

As the body sends the information required to generate movement, it is as though the same information is faxed to other areas of the brain. This "efferent" copy of planned-movement information is used by the brain to predict what sensations will come next, effectively predicting the upcoming position of a limb, for example. If the actual sensations match the predicted sensations, we experience the feeling of agency. If there is

a mismatch between the body and its predicted position, for example due to obstructions or other cognitive disruption, no feeling of agency occurs. The FMFC explains AVH rather easily: since inner speech is a normal action, the malfunction in schizophrenic patients is in the generation of the predictive efferent copy used to confirm and cause the feeling of agency. That is why patients suffering AVH perceive their self talk as alien. It is by the application of the FMFC that we might imagine how other consciousness processes could be the result of efferent, predictive processing. If our conscious self is the efferent copy of actions and vetos being performed, then the consciousness is a sort of narrator of what is already occurring in the body, and an incomplete narrator at that. This model helps explain how we might experience a free will even if it were determined. Only one thing is certain: correlation of a conscious "intention to move" with the actual "action" does not guarantee causation.

## **Models of consciousness**

How the brain constructs consciousness is still a mystery, and cracking it open would have a significant bearing on the question of free will. Numerous different models have been proposed, for example, the Multiple Drafts Model which argues that there is no central Cartesian theater where conscious experience would be represented, but rather that consciousness is located all across the brain. This model would explain the delay between the decision and conscious realization, as experiencing everything as a continuous 'filmstrip' comes behind the actual conscious decision. On the contrary, few models of Cartesian materialism have gained some recognition by neuroscience, implying that there actually might be special brain areas that store the contents of consciousness; this does not, however, rule out the possibility of a conscious will. Other models such as epiphenomenalism argue that conscious will is an illusion, and that consciousness is a by-product of physical states of the world. Work in this sector is still highly speculative, and there is no single model of consciousness which would be favored by the researchers.

## Chapter 7

# Sleep

**Sleep** is a naturally recurring state characterized by reduced or absent consciousness, relatively suspended sensory activity, and inactivity of nearly all voluntary muscles. It is distinguished from quiet wakefulness by a decreased ability to react to stimuli, but it is more easily reversible than hibernation or coma. Sleep is a heightened anabolic state, accentuating the growth and rejuvenation of the immune, nervous, skeletal and muscular systems. It is observed in all mammals, all birds, and many reptiles, amphibians, and fish.

The purposes and mechanisms of sleep are only partially clear and are the subject of intense research. Sleep is often thought to help conserve energy, but actually decreases metabolism only about 5–10%. Hibernating animals need to sleep despite the hypometabolism seen in hibernation, and in fact they must return from hypothermia to euthermia in order to sleep, making sleeping "energetically expensive."



Sleeping child

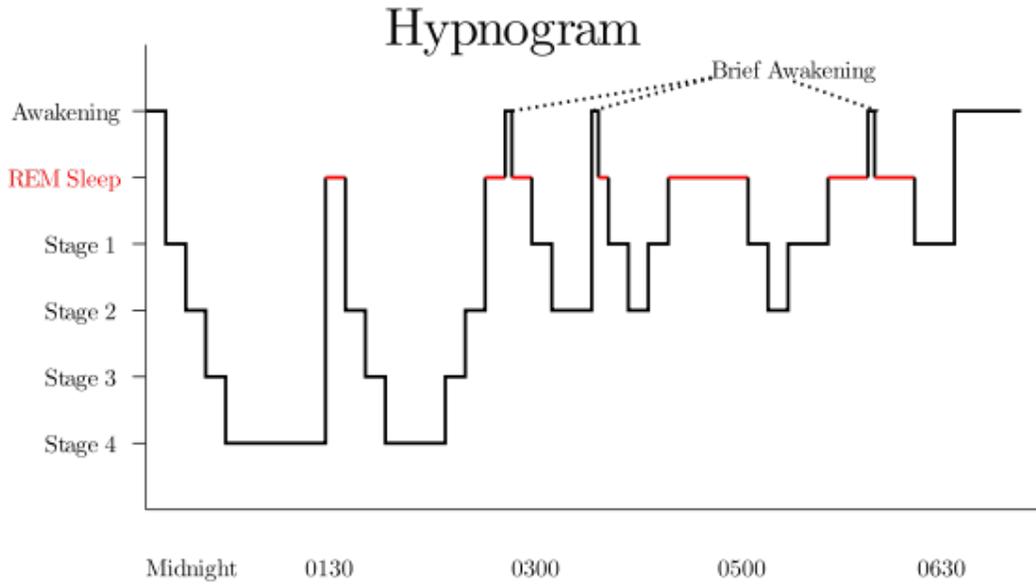


Sleeping kittens

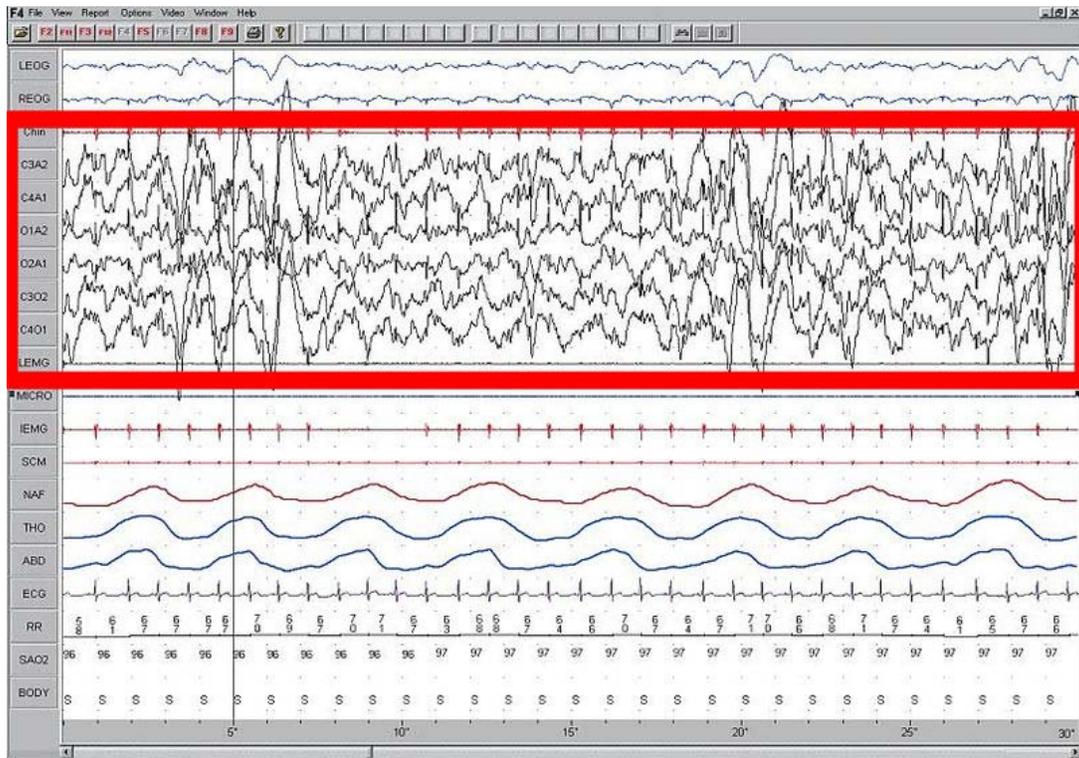
## ***Physiology***

### **Sleep stages**

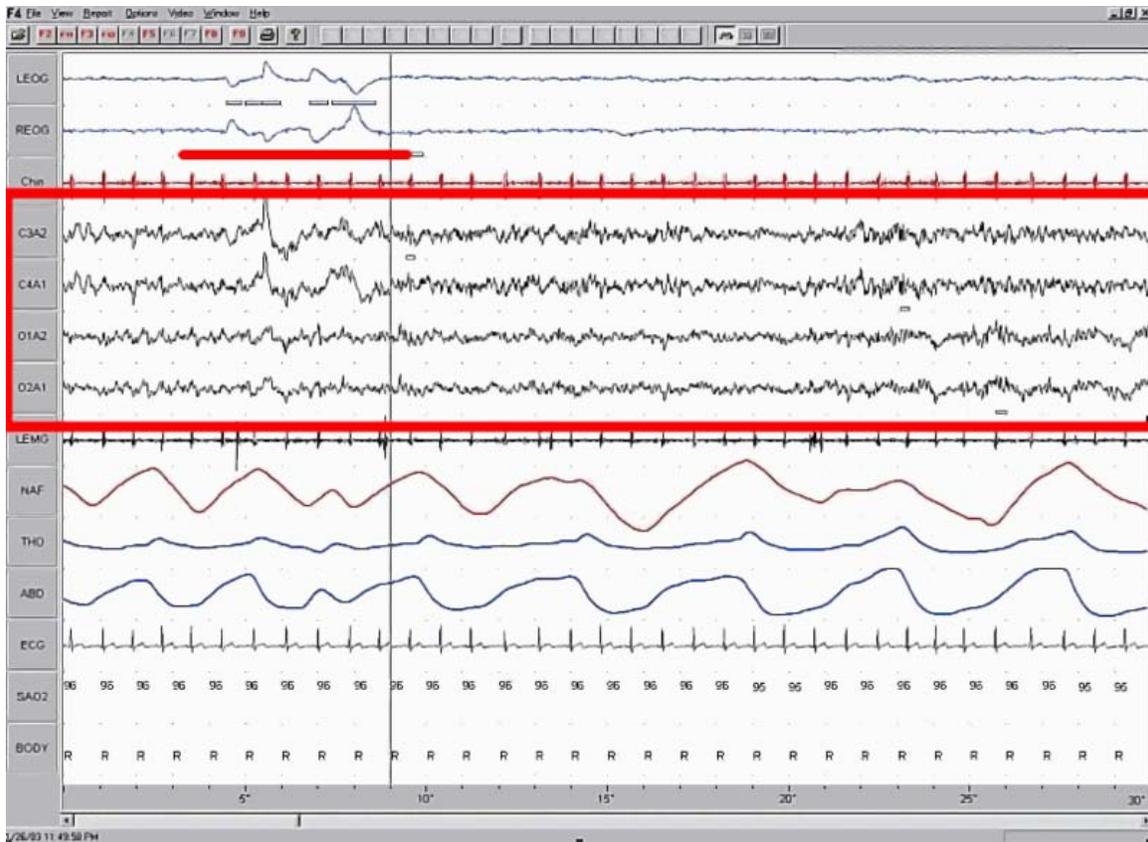
In mammals and birds, sleep is divided into two broad types: rapid eye movement (REM) and non-rapid eye movement (NREM or non-REM) sleep. Each type has a distinct set of associated physiological, neurological, and psychological features. The American Academy of Sleep Medicine (AASM) further divides NREM into three stages: N1, N2, and N3, the last of which is also called delta sleep or slow-wave sleep (SWS).



Hypnogram showing sleep cycles from midnight to 6.30 am, with deep sleep early on. There is more REM (marked red) before waking.



Stage N3 sleep; EEG highlighted by red box. Thirty seconds of deep sleep, here with greater than 50% delta waves.



REM sleep; EEG highlighted by red box; eye movements highlighted by red line. Thirty seconds of sleep.

Sleep proceeds in cycles of REM and NREM, the order normally being N1 → N2 → N3 → N2 → REM. There is a greater amount of deep sleep (stage N3) earlier in the sleep cycle, while the proportion of REM sleep increases later in the sleep cycle and just before natural awakening.

The stages of sleep were first described in 1937 by Alfred Lee Loomis and his coworkers, who separated the different electroencephalography (EEG) features of sleep into five levels (A to E), which represented the spectrum from wakefulness to deep sleep. In 1953, REM sleep was discovered as distinct, and thus William Dement and Nathaniel Kleitman reclassified sleep into four NREM stages and REM. The staging criteria were standardized in 1968 by Allan Rechtschaffen and Anthony Kales in the "R&K sleep scoring manual." In the R&K standard, NREM sleep was divided into four stages, with slow-wave sleep comprising stages 3 and 4. In stage 3, delta waves made up less than 50% of the total wave patterns, while they made up more than 50% in stage 4. Furthermore, REM sleep was sometimes referred to as stage 5.

In 2004, the AASM commissioned the AASM Visual Scoring Task Force to review the R&K scoring system. The review resulted in several changes, the most significant being the combination of stages 3 and 4 into Stage N3. The revised scoring was published in

2007 as *The AASM Manual for the Scoring of Sleep and Associated Events*. Arousals and respiratory, cardiac, and movement events were also added.

Sleep stages and other characteristics of sleep are commonly assessed by polysomnography in a specialized sleep laboratory. Measurements taken include EEG of brain waves, electrooculography (EOG) of eye movements, and electromyography (EMG) of skeletal muscle activity. In humans, each sleep cycle lasts from 90 to 110 minutes on average, and each stage may have a distinct physiological function. This can result in sleep that exhibits loss of consciousness but does not fulfill its physiological functions (i.e., one may still feel tired after apparently sufficient sleep).

Scientific studies on sleep having shown that sleep stage at awakening is an important factor in amplifying sleep inertia. Alarm clocks involving *sleep stage monitoring* appeared on the market in 2005. Using sensing technologies such as EEG electrodes or accelerometers, these alarm clocks are supposed to wake people only from light sleep.

### **NREM sleep**

According to the 2007 AASM standards, NREM consists of three stages. There is relatively little dreaming in NREM.

**Stage N1** refers to the transition of the brain from alpha waves having a frequency of 8–13 Hz (common in the awake state) to theta waves having a frequency of 4–7 Hz. This stage is sometimes referred to as somnolence or drowsy sleep. Sudden twitches and hypnic jerks, also known as positive myoclonus, may be associated with the onset of sleep during N1. Some people may also experience hypnagogic hallucinations during this stage. During N1, the subject loses some muscle tone and most conscious awareness of the external environment.

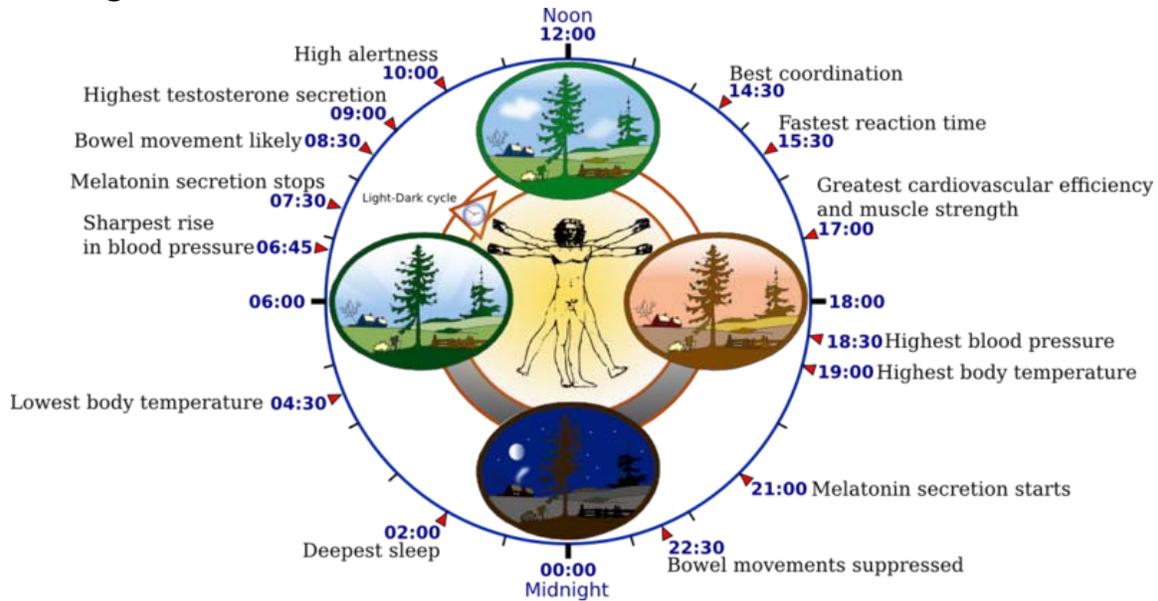
**Stage N2** is characterized by sleep spindles ranging from 11–16 Hz (most commonly 12–14 Hz) and K-complexes. During this stage, muscular activity as measured by EMG decreases, and conscious awareness of the external environment disappears. This stage occupies 45–55% of total sleep in adults.

**Stage N3** (deep or slow-wave sleep) is characterized by the presence of a minimum of 20% delta waves ranging from 0.5–2 Hz and having a peak-to-peak amplitude  $>75 \mu\text{V}$ . (EEG standards define delta waves to be from 0–4 Hz, but sleep standards in both the original R&K, as well as the new 2007 AASM guidelines have a range of 0.5–2 Hz.) This is the stage in which parasomnias such as night terrors, nocturnal enuresis, sleepwalking, and somniloquy occur. Many illustrations and descriptions still show a stage N3 with 20–50% delta waves and a stage N4 with greater than 50% delta waves; these have been combined as stage N3.

## REM sleep

Rapid eye movement sleep, or REM sleep, accounts for 20–25% of total sleep time in most human adults. The criteria for REM sleep include rapid eye movements as well as a rapid low-voltage EEG. Most memorable dreaming occurs in this stage. At least in mammals, a descending muscular atonia is seen. Such paralysis may be necessary to protect organisms from self-damage through physically acting out scenes from the often-vivid dreams that occur during this stage.

## Timing



The human biological clock

Sleep timing is controlled by the circadian clock, sleep-wake homeostasis, and in humans, within certain bounds, willed behavior. The circadian clock—an inner timekeeping, temperature-fluctuating, enzyme-controlling device—works in tandem with adenosine, a neurotransmitter that inhibits many of the bodily processes associated with wakefulness. Adenosine is created over the course of the day; high levels of adenosine lead to sleepiness. In diurnal animals, sleepiness occurs as the circadian element causes the release of the hormone melatonin and a gradual decrease in core body temperature. The timing is affected by one's chronotype. It is the circadian rhythm that determines the ideal timing of a correctly structured and restorative sleep episode.

Homeostatic sleep propensity (the need for sleep as a function of the amount of time elapsed since the last adequate sleep episode) must be balanced against the circadian element for satisfactory sleep. Along with corresponding messages from the circadian clock, this tells the body it needs to sleep. Sleep offset (awakening) is primarily determined by circadian rhythm. A person who regularly awakens at an early hour will generally not be able to sleep much later than his or her normal waking time, even if moderately sleep-deprived.

Sleep duration is affected by the gene DEC2. Some people have a mutation of this gene; they sleep two hours less than normal. Neurology professor Ying-Hui Fu and her colleagues bred mice that carried the DEC2 mutation and slept less than normal mice.

## **Optimal amount in humans**

### **Adult**

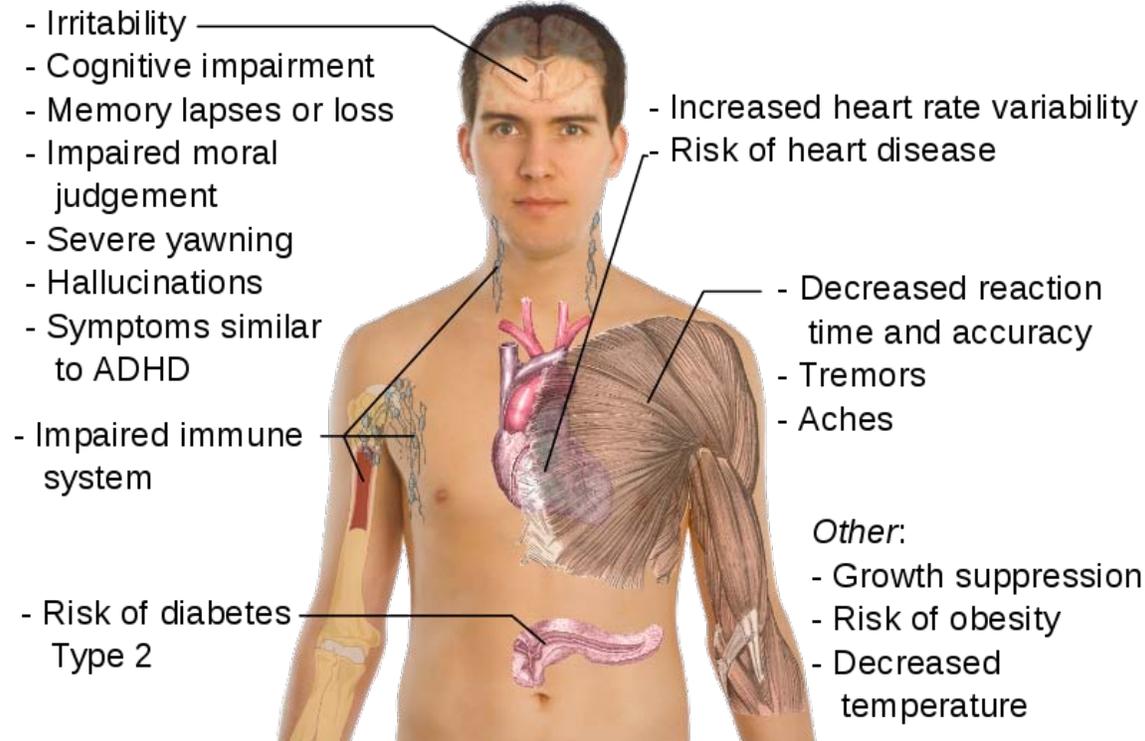
The optimal amount of sleep is not a meaningful concept unless the timing of that sleep is seen in relation to an individual's circadian rhythms. A person's major sleep episode is relatively inefficient and inadequate when it occurs at the "wrong" time of day; one should be asleep at least six hours before the lowest body temperature. The timing is correct when the following two circadian markers occur after the middle of the sleep episode and before awakening:

- maximum concentration of the hormone melatonin, and
- minimum core body temperature.

Human sleep needs can vary by age and among individuals, and sleep is considered to be adequate when there is no daytime sleepiness or dysfunction. Moreover, self-reported sleep duration is only moderately correlated with actual sleep time as measured by actigraphy, and those affected with sleep state misperception may typically report having slept only four hours despite having slept a full eight hours.

A University of California, San Diego psychiatry study of more than one million adults found that people who live the longest self-report sleeping for six to seven hours each night. Another study of sleep duration and mortality risk in women showed similar results. Other studies show that "sleeping more than 7 to 8 hours per day has been consistently associated with increased mortality," though this study suggests the cause is probably other factors such as depression and socioeconomic status, which would correlate statistically. It has been suggested that the correlation between lower sleep hours and reduced morbidity only occurs with those who wake after less sleep naturally, rather than those who use an alarm.

## Effects of Sleep deprivation



Main health effects of sleep deprivation, indicating impairment of normal maintenance by sleep

Researchers at the University of Warwick and University College London have found that lack of sleep can more than double the risk of death from cardiovascular disease, but that too much sleep can also be associated with a doubling of the risk of death, though not primarily from cardiovascular disease. Professor Francesco Cappuccio said, "Short sleep has been shown to be a risk factor for weight gain, hypertension, and Type 2 diabetes, sometimes leading to mortality; but in contrast to the short sleep-mortality association, it appears that no potential mechanisms by which long sleep could be associated with increased mortality have yet been investigated. Some candidate causes for this include depression, low socioeconomic status, and cancer-related fatigue... In terms of prevention, our findings indicate that consistently sleeping around seven hours per night is optimal for health, and a sustained reduction may predispose to ill health."

Furthermore, sleep difficulties are closely associated with psychiatric disorders such as depression, alcoholism, and bipolar disorder. Up to 90% of adults with depression are found to have sleep difficulties. Dysregulation found on EEG includes disturbances in sleep continuity, decreased delta sleep and altered REM patterns with regard to latency, distribution across the night and density of eye movements.

## Hours by age

Children need more sleep per day in order to develop and function properly: up to 18 hours for newborn babies, with a declining rate as a child ages. A newborn baby spends almost 9 hours a day in REM sleep. By the age of five or so, only slightly over two hours is spent in REM.

<b>Age and condition</b>	<b>Average amount of sleep per day</b>
Newborn	up to 18 hours
1–12 months	14–18 hours
1–3 years	12–15 hours
3–5 years	11–13 hours
5–12 years	9–11 hours
Adolescents	9–10 hours
Adults, including elderly	7–8 hours
Pregnant women	8(+) hours

## Sleep debt

Sleep debt is the effect of not getting enough rest and sleep; a large debt causes mental, emotional and physical fatigue.

Sleep debt results in diminished abilities to perform high-level cognitive functions. Neurophysiological and functional imaging studies have demonstrated that frontal regions of the brain are particularly responsive to homeostatic sleep pressure.

Scientists do not agree on how much sleep debt it is possible to accumulate; whether it is accumulated against an individual's average sleep or some other benchmark; nor on whether the prevalence of sleep debt among adults has changed appreciably in the industrialized world in recent decades. It is likely that children are sleeping less than previously in Western societies.

## Genetics

It is suspected that a considerable amount of sleep-related behavior, such as when and how long a person needs to sleep, is regulated by our genetics. Researchers have discovered some evidence that seems to support this assumption.

## Functions

The multiple theories proposed to explain the function of sleep reflect the as-yet incomplete understanding of the subject. (When asked what he knew about the reason people sleep, after 50 years of research, researcher William Dement answered, "As far as I know, the only reason we need to sleep that is really, really solid is because we get

sleepy.") It is likely that sleep evolved to fulfill some primeval function and took on multiple functions over time. (As an analogy, the larynx in all mammals controls the passage of food and air, but may have descended in humans to take on speech capabilities in addition.)

It has been pointed out that, if sleep were not essential, one would expect to find:

- Animal species that do not sleep at all
- Animals that do not need recovery sleep when they stay awake longer than usual
- Animals that suffer no serious consequences as a result of lack of sleep

Outside of a few basal animals that have no brain or a very simple one, no animals have been found to date that satisfy any of these criteria. While some varieties of shark, such as great whites and hammerheads, must remain in motion at all times to move oxygenated water over their gills, they still "sleep" by deactivating one cerebral hemisphere at a time.

Some of the many proposed functions of sleep are as follows.

## **Restoration**

Wound healing has been shown to be affected by sleep. A study conducted by Gumustekin et al. in 2004 shows sleep deprivation hindering the healing of burns on rats.

It has been shown that sleep deprivation affects the immune system. In a study by Zager et al. in 2007, rats were deprived of sleep for 24 hours. When compared with a control group, the sleep-deprived rats' blood tests indicated a 20% decrease in white blood cell count, a significant change in the immune system. It is now possible to state that "sleep loss impairs immune function and immune challenge alters sleep," and it has been suggested that mammalian species which invest in longer sleep times are investing in the immune system, as species with the longer sleep times have higher white blood cell counts.

It has yet to be proven that sleep duration affects somatic growth. One study by Jenni et al. in 2007 recorded growth, height, and weight, as correlated to parent-reported time in bed in 305 children over a period of nine years (age 1–10). It was found that "the variation of sleep duration among children does not seem to have an effect on growth." It has been shown that sleep—more specifically, slow-wave sleep (SWS)—does affect growth hormone levels in adult men. During eight hours' sleep, Van Cauter, Leproult, and Plat found that the men with a high percentage of SWS (average 24%) also had high growth hormone secretion, while subjects with a low percentage of SWS (average 9%) had low growth hormone secretion.

There are multiple arguments supporting the restorative function of sleep. The metabolic phase during sleep is anabolic; anabolic hormones such as growth hormones (as mentioned above) are secreted preferentially during sleep. The duration of sleep among

species is, in general, inversely related to animal size and directly related to basal metabolic rate. Rats with a very high basal metabolic rate sleep for up to 14 hours a day, whereas elephants and giraffes with lower BMRs sleep only 3–4 hours per day.

Energy conservation could as well have been accomplished by resting quiescent without shutting off the organism from the environment, potentially a dangerous situation. A sedentary nonsleeping animal is more likely to survive predators, while still preserving energy. Sleep, therefore, seems to serve another purpose, or other purposes, than simply conserving energy; for example, hibernating animals waking up from hibernation go into rebound sleep because of lack of sleep during the hibernation period. They are definitely well-rested and are conserving energy during hibernation, but need sleep for something else. Rats kept awake indefinitely develop skin lesions, hyperphagia, loss of body mass, hypothermia, and, eventually, fatal sepsis.

## **Ontogenesis**

According to the ontogenetic hypothesis of REM sleep, the activity occurring during neonatal REM sleep (or active sleep) seems to be particularly important to the developing organism (Marks et al., 1995). Studies investigating the effects of deprivation of active sleep have shown that deprivation early in life can result in behavioral problems, permanent sleep disruption, decreased brain mass (Mirmiran et al., 1983), and an abnormal amount of neuronal cell death (Morrissey, Duntley & Anch, 2004).

REM sleep appears to be important for development of the brain. REM sleep occupies the majority of time of sleep of infants, who spend most of their time sleeping. Among different species, the more immature the baby is born, the more time it spends in REM sleep. Proponents also suggest that REM-induced muscle inhibition in the presence of brain activation exists to allow for brain development by activating the synapses, yet without any motor consequences that may get the infant in trouble. Additionally, REM deprivation results in developmental abnormalities later in life.

However, this does not explain why older adults still need REM sleep. Aquatic mammal infants do not have REM sleep in infancy; REM sleep in those animals increases as they age.

## **Memory processing**

Scientists have shown numerous ways in which sleep is related to memory. In a study conducted by Turner, Drummond, Salamat, and Brown, working memory was shown to be affected by sleep deprivation. Working memory is important because it keeps information active for further processing and supports higher-level cognitive functions such as decision making, reasoning, and episodic memory. The study allowed 18 women and 22 men to sleep only 26 minutes per night over a four-day period. Subjects were given initial cognitive tests while well-rested, and then were tested again twice a day during the four days of sleep deprivation. On the final test, the average working memory

span of the sleep-deprived group had dropped by 38% in comparison to the control group.

Memory seems to be affected differently by certain stages of sleep such as REM and slow-wave sleep (SWS). In one study, cited in Born, Rasch, and Gais, multiple groups of human subjects were used: wake control groups and sleep test groups. Sleep and wake groups were taught a task and were then tested on it, both on early and late nights, with the order of nights balanced across participants. When the subjects' brains were scanned during sleep, hypnograms revealed that SWS was the dominant sleep stage during the early night, representing around 23% on average for sleep stage activity. The early-night test group performed 16% better on the declarative memory test than the control group. During late-night sleep, REM became the most active sleep stage at about 24%, and the late-night test group performed 25% better on the procedural memory test than the control group. This indicates that procedural memory benefits from late, REM-rich sleep, whereas declarative memory benefits from early, SWS-rich sleep.

A study conducted by Datta indirectly supports these results. The subjects chosen were 22 male rats. A box was constructed wherein a single rat could move freely from one end to the other. The bottom of the box was made of a steel grate. A light would shine in the box accompanied by a sound. After a five-second delay, an electrical shock would be applied. Once the shock commenced, the rat could move to the other end of the box, ending the shock immediately. The rat could also use the five-second delay to move to the other end of the box and avoid the shock entirely. The length of the shock never exceeded five seconds. This was repeated 30 times for half the rats. The other half, the control group, was placed in the same trial, but the rats were shocked regardless of their reaction. After each of the training sessions, the rat would be placed in a recording cage for six hours of polygraphic recordings. This process was repeated for three consecutive days. This study found that during the posttrial sleep recording session, rats spent 25.47% more time in REM sleep after learning trials than after control trials. These trials support the results of the Born et al. study, indicating an obvious correlation between REM sleep and procedural knowledge.

An observation of the Datta study is that the learning group spent 180% more time in SWS than did the control group during the post-trial sleep-recording session. This phenomenon is supported by a study performed by Kudrimoti, Barnes, and McNaughton. This study shows that after spatial exploration activity, patterns of hippocampal place cells are reactivated during SWS following the experiment. In a study by Kudrimoti et al., seven rats were run through a linear track using rewards on either end. The rats would then be placed in the track for 30 minutes to allow them to adjust (PRE), then they ran the track with reward-based training for 30 minutes (RUN), and then they were allowed to rest for 30 minutes. During each of these three periods, EEG data were collected for information on the rats' sleep stages. Kudrimoti et al. computed the mean firing rates of hippocampal place cells during prebehavior SWS (PRE) and three ten-minute intervals in postbehavior SWS (POST) by averaging across 22 track-running sessions from seven rats. The results showed that ten minutes after the trial RUN session, there was a 12% increase in the mean firing rate of hippocampal place cells from the PRE level; however,

after 20 minutes, the mean firing rate returned rapidly toward the PRE level. The elevated firing of hippocampal place cells during SWS after spatial exploration could explain why there were elevated levels of SWS sleep in Datta's study, as it also dealt with a form of spatial exploration.

A study has also been done involving direct current stimulation to the prefrontal cortex to increase the amount of slow oscillations during SWS (Marshall et al., 2006, as cited in Walker, 2009). The direct current stimulation greatly enhanced word-pair retention the following day, giving evidence that SWS plays a large role in the consolidation of episodic memories.

The different studies all suggest that there is a correlation between sleep and the complex functions of memory. Harvard sleep researchers Saper and Stickgold point out that an essential part of memory and learning consists of nerve cell dendrites' sending of information to the cell body to be organized into new neuronal connections. This process demands that no external information is presented to these dendrites, and it is suggested that this may be why it is during sleep that memories and knowledge are solidified and organized.

## **Preservation**

The "Preservation and Protection" theory holds that sleep serves an adaptive function. It protects the animal during that portion of the 24-hour day in which being awake, and hence roaming around, would place the individual at greatest risk. Organisms do not require 24 hours to feed themselves and meet other necessities. From this perspective of adaptation, organisms are safer by staying out of harm's way, where potentially they could be prey to other, stronger organisms. They sleep at times that maximize their safety, given their physical capacities and their habitats. (Allison & Cicchetti, 1976; Webb, 1982).

This theory fails to explain why the brain disengages from the external environment during normal sleep. However, the brain consumes a large proportion of the body's calories at any one time and preservation of energy could only occur by limiting its sensory inputs. Another argument against the theory is that sleep is not simply a passive consequence of removing the animal from the environment, but is a "drive"; animals alter their behaviors in order to obtain sleep. Therefore, circadian regulation is more than sufficient to explain periods of activity and quiescence that are adaptive to an organism, but the more peculiar specializations of sleep probably serve different and unknown functions. Moreover, the preservation theory needs to explain why carnivores like lions, which are on top of the food chain and thus have little to fear, sleep the most. It has been suggested that they need to minimize energy expenditure when not hunting.

Preservation also does not explain why aquatic mammals sleep while moving. Quiescence during these vulnerable hours would do the same and would be more advantageous, because the animal would still be able to respond to environmental challenges like predators, etc. Sleep rebound that occurs after a sleepless night will be

maladaptive, but obviously must occur for a reason. A zebra falling asleep the day after it spent the sleeping time running from a lion is more, not less, vulnerable to predation.

## ***Dreaming***



Bronze statue of Eros sleeping, 3rd century BC–early 1st century AD

Dreaming is the perceived experience of sensory images and sounds during sleep, in a sequence which the dreamer usually perceives more as an apparent participant than as an observer. Dreaming is stimulated by the pons and mostly occurs during the REM phase of sleep.

People have proposed many hypotheses about the functions of dreaming. Sigmund Freud postulated that dreams are the symbolic expression of frustrated desires that had been relegated to the unconscious mind, and he used dream interpretation in the form of psychoanalysis to uncover these desires.

Freud's work concerns the psychological role of dreams, which does not exclude any physiological role they may have. Recent research claims that sleep has the overall role of consolidation and organization of synaptic connections formed during learning and experience. As such, Freud's work is not ruled out. Nevertheless, Freud's research has been expanded on, especially with regard to the organization and consolidation of recent memory.

Certain processes in the cerebral cortex have been studied by John Allan Hobson and Robert McCarley. In their activation synthesis theory, for example, they propose that dreams are caused by the random firing of neurons in the cerebral cortex during the REM period. Neatly, this theory helps explain the irrationality of the mind during REM periods, as, according to this theory, the forebrain then creates a story in an attempt to reconcile and make sense of the nonsensical sensory information presented to it. Ergo, the odd nature of many dreams.

## ***Effect of food and drink on sleep***

### **Hypnotics**

- Nonbenzodiazepine hypnotics such as eszopiclone (Lunesta), zaleplon (Sonata), and zolpidem (Ambien) are commonly used as sleep aids prescribed by doctors to treat forms of insomnia. Nonbenzodiazepines are the most commonly prescribed and OTC sleep aids used worldwide and have been greatly growing in use since the 1990s. They target the GABA<sub>A</sub> receptor.
- Benzodiazepines target the GABA<sub>A</sub> receptor also, and as such, they are commonly used sleep aids as well, though benzodiazepines have been found to decrease REM sleep.
- Antihistamines, such as diphenhydramine (Benadryl) and doxylamine (found in various OTC medicines, such as NyQuil)
- Alcohol – Often, people start drinking alcohol in order to get to sleep (alcohol is initially a sedative and will cause somnolence, encouraging sleep). However, being addicted to alcohol can lead to disrupted sleep, because alcohol has a rebound effect later in the night. As a result, there is strong evidence linking alcoholism and forms of insomnia. Alcohol also reduces REM sleep.
- Barbiturates cause drowsiness and have actions similar to alcohol in that they have a rebound effect and inhibit REM sleep, so they are not used as a long-term sleep aid.
- Melatonin is a naturally occurring hormone that regulates sleepiness. It is made in the brain, where tryptophan is converted into serotonin and then into melatonin, which is released at night by the pineal gland to induce and maintain sleep. Melatonin supplementation may be used as a sleep aid, both as a hypnotic and as a chronobiotic.
- Siesta and the "post-lunch dip" – Many people have a temporary drop in alertness in the early afternoon, commonly known as the "post-lunch dip." While a large meal can make a person feel sleepy, the post-lunch dip is mostly an effect of the biological clock. People naturally feel most sleepy (have the greatest "drive for sleep") at two times of the day about 12 hours apart—for example, at 2:00 a.m. and 2:00 p.m. At those two times, the body clock "kicks in." At about 2 p.m. (14:00), it overrides the homeostatic buildup of sleep debt, allowing several more hours of wakefulness. At about 2 a.m. (02:00), with the daily sleep debt paid off, it "kicks in" again to ensure a few more hours of sleep.
- Tryptophan – The amino acid tryptophan is a building block of proteins. It has been claimed to contribute to sleepiness, since it is a precursor of the

- neurotransmitter serotonin, involved in sleep regulation. However, no solid data have ever linked modest dietary changes in tryptophan to changes in sleep.
- Marijuana – Some people use marijuana to induce sleepiness. Users often report relaxation and drowsiness.

## **Stimulants**

- Amphetamine (dextroamphetamine, and a related, more dangerous drug methamphetamine, etc.) are used to treat narcolepsy. Their most common effects are anxiety, insomnia, stimulation, increased alertness, and decreased hunger.
- Caffeine is a stimulant that works by slowing the action of the hormones in the brain that cause somnolence, particularly by acting as an antagonist at adenosine receptors. Effective dosage is individual, in part dependent on prior usage. It can cause a rapid reduction in alertness as it wears off.
- Cocaine and crack cocaine – Studies on cocaine have shown its effects to be mediated through the circadian rhythm system. This may be related to the onset of hypersomnia (oversleeping) in regard to "Cocaine-Induced Sleep Disorder."
- MDMA, including similar drugs like MDA, MMDA, or bk-MDMA – The class of drugs called empathogen-entactogens keep users awake with intense euphoria. Commonly known as "ecstasy."
- Methylphenidate – Commonly known by the brand names *Ritalin* and *Concerta*, methylphenidate is similar in action to amphetamine and cocaine; its chemical composition more closely resembles that of cocaine.
- Tobacco – Tobacco has been found not only to disrupt but also to reduce total sleep time. In studies, users have described more daytime drowsiness than nonsmokers.
- Other analeptic drugs like Modafinil and Armodafinil are prescribed to treat narcolepsy, hypersomnia, shift work sleep disorder, and other conditions causing Excessive Daytime Sleepiness. The precise mechanism of these CNS stimulants is not known, but they have been shown to increase both the release of monoamines and levels of hypothalamic histamine, thereby promoting wakefulness.

## **Sleep problems**

There are many reasons for poor sleep. For example, excessive exposure to bright light within hours of bedtime or simply resisting the urge to fall asleep can trigger a "second wind," which then can temporarily make it difficult to fall asleep afterwards. Following sleep hygienic principles may solve problems of physical or emotional discomfort. When the culprit is pain, illness, drugs, or stress, the cause must be treated. Sleep disorders (including the sleep apneas, narcolepsy, primary insomnia, periodic limb movement disorder (PLMD), restless leg syndrome (RLS), and the circadian rhythm sleep disorders) are treatable. Fatal familial insomnia, or FFI, is a genetic disease with no known treatment or cure which results in increasing insomnia until sleep is completely impossible, and eventually results in death.

Older people are more easily awoken by disturbances in the environment and may to some degree lose the ability to consolidate sleep.

## **Pharmacological treatments**

### **Other treatments**

There are various techniques and products which aim to improve sleep. These range from returning to sleep on the floor since beds are a relatively recent invention in human history, to various mattress designs.

A 2010 review of published scientific research suggested that exercise generally improves sleep for most people, and helps sleep disorders such as insomnia. The optimum time to exercise *may* be 4 to 8 hours before bedtime, though exercise at any time of day is beneficial, with the possible exception of heavy exercise taken shortly before bedtime, which may disturb sleep. However there is insufficient evidence to draw detailed conclusions about the relationship between exercise and sleep.

White noise appears to be a promising treatment for insomnia.

## ***Anthropology of sleep***

Research suggests that sleep patterns vary significantly across cultures. The most striking differences are between societies that have plentiful sources of artificial light and ones that do not. The primary difference appears to be that pre-light cultures have more broken-up sleep patterns. For example, people might go to sleep far sooner after the sun sets, but then wake up several times throughout the night, punctuating their sleep with periods of wakefulness, perhaps lasting several hours. The boundaries between sleeping and waking are blurred in these societies. Some observers believe that nighttime sleep in these societies is most often split into two main periods, the first characterized primarily by deep sleep and the second by REM sleep.

Some societies display a fragmented sleep pattern in which people sleep at all times of the day and night for shorter periods. In many nomadic or hunter-gatherer societies, people will sleep on and off throughout the day or night depending on what is happening. Plentiful artificial light has been available in the industrialized West since at least the mid-19th century, and sleep patterns have changed significantly everywhere that lighting has been introduced. In general, people sleep in a more concentrated burst through the night, going to sleep much later, although this is not always true.

In some societies, people generally sleep with at least one other person (sometimes many) or with animals. In other cultures, people rarely sleep with anyone but a most intimate relation, such as a spouse. In almost all societies, sleeping partners are strongly regulated by social standards. For example, people might only sleep with their immediate family, extended family, spouses, their children, children of a certain age, children of specific gender, peers of a certain gender, friends, peers of equal social rank, or with no one at all.

Sleep may be an actively social time, depending on the sleep groupings, with no constraints on noise or activity.

People sleep in a variety of locations. Some sleep directly on the ground; others on a skin or blanket; others sleep on platforms or beds. Some sleep with blankets, some with pillows, some with simple headrests, some with no head support. These choices are shaped by a variety of factors, such as climate, protection from predators, housing type, technology, and the incidence of pests.

### ***Sleep in non-humans***



Sleeping Japanese Macaques

Neurological sleep states can be difficult to detect in some animals. In these cases, sleep may be defined using behavioral characteristics such as minimal movement, postures typical for the species, and reduced responsiveness to external stimulation. Sleep is quickly reversible, as opposed to hibernation or coma, and sleep deprivation is followed by longer or deeper rebound sleep. Herbivores, who require a long waking period to gather and consume their diet, typically sleep less each day than similarly sized carnivores, who might well consume several days' supply of meat in a sitting.

Horses and other herbivorous ungulates can sleep while standing, but must necessarily lie down for REM sleep (which causes muscular atony) for short periods. Giraffes, for example, only need to lie down for REM sleep for a few minutes at a time. Bats sleep while hanging upside down. Some aquatic mammals and some birds can sleep with one

half of the brain while the other half is awake, so-called unihemispheric slow-wave sleep. Birds and mammals have cycles of non-REM and REM sleep (as described above for humans), though birds' cycles are much shorter and they do not lose muscle tone (go limp) to the extent that most mammals do.

Many mammals sleep for a large proportion of each 24-hour period when they are very young. However, killer whales and some dolphins do not sleep during the first month of life. Such differences may be explained by the ability of land-mammal newborns to be easily protected by parents while sleeping, while marine animals must, even while very young, be more continuously vigilant for predators.

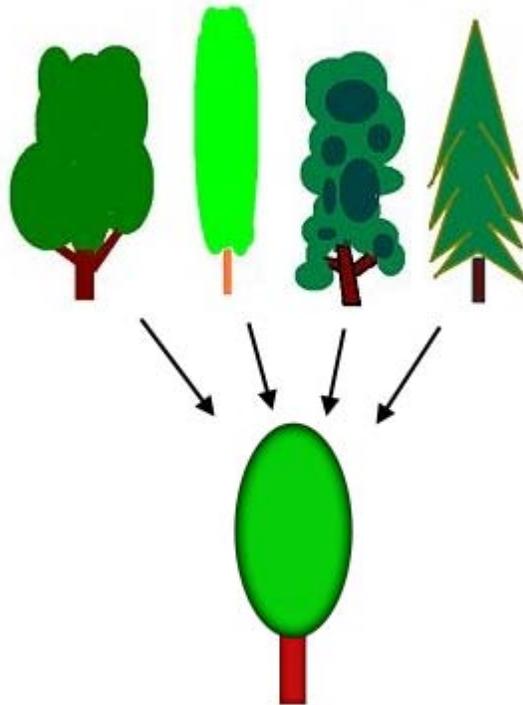
## Chapter 8

# Cognition

**Cognition** is the scientific term for "the process of thought". Usage of the term varies in different disciplines; for example in psychology and cognitive science, it usually refers to an information processing view of an individual's psychological functions. Other interpretations of the meaning of *cognition* link it to the development of *concepts*; individual minds, groups, and organizations.

The term **cognition** refers to a faculty for the processing of information, applying knowledge, and changing preferences. Cognition, or cognitive processes, can be natural or artificial, conscious or unconscious. These processes are analyzed from different perspectives within different contexts, notably in the fields of linguistics, anesthesia, neurology, psychology, philosophy, anthropology, systemics, computer science and creed. Within psychology or philosophy, the concept of cognition is closely related to abstract concepts such as mind, intelligence, cognition is used to refer to the mental functions, mental processes (thoughts) and states of intelligent entities (humans, human organizations, highly autonomous machines and artificial intelligences).

## Psychology



When the mind makes a generalization such as the concept of *tree*, it extracts similarities from numerous examples; the simplification enables higher-level thinking.

The sort of mental processes described as *cognitive* are largely influenced by research which has successfully used this paradigm in the past, likely starting with Thomas Aquinas, who divided the study of behavior into two broad categories: cognitive (how we know the world), and affective (feelings and emotions). Consequently, this description tends to apply to processes such as memory, association, concept formation, language, attention, perception, action, problem solving and mental imagery. Traditionally, emotion was not thought of as a cognitive process. This division is now regarded as largely artificial, and much research is currently being undertaken to examine the cognitive psychology of emotion; research also includes one's awareness of strategies and methods of cognition, known as metacognition.

Empirical research into cognition is usually scientific and quantitative, or involves creating models to describe or explain certain behaviors.

While few people would deny that cognitive processes are a function of the brain, a cognitive theory will not necessarily make reference to the brain or other biological process (compare neurocognitive). It may purely describe behavior in terms of information flow or function. Relatively recent fields of study such as cognitive science and neuropsychology aim to bridge this gap, using cognitive paradigms to understand

how the brain implements these information-processing functions or how pure information-processing systems (e.g., computers) can simulate cognition. The branch of psychology that studies brain injury to infer normal cognitive function is called cognitive neuropsychology. The links of cognition to evolutionary demands are studied through the investigation of animal cognition. And conversely, evolutionary-based perspectives can inform hypotheses about cognitive functional systems evolutionary psychology.

The theoretical school of thought derived from the cognitive approach is often called cognitivism.

The phenomenal success of the cognitive approach can be seen by its current dominance as the core model in contemporary psychology (usurping behaviorism in the late 1950s). Cognition is severely damaged in dementia.

### ***Cognition as social process***

It has been observed since antiquity that language acquisition in human children fails to emerge unless the children are exposed to language. Thus, language acquisition is an example of an emergent behavior. In this case, the individual is made up of a set of mechanisms "expecting" such input from the social world.

In education, for instance, which has the explicit task in society of developing child cognition, choices are made regarding the environment and permitted action that lead to a formed experience. In social cognition, face perception in human babies emerges by the age of two months. This is in turn affected by the risk or cost of providing these, for instance, those associated with a playground or swimming pool or field trip. On the other hand, the macro-choices made by the teachers are extremely influential on the micro-choices made by children.

In a large systemic perspective, cognition is considered closely related to the social and human organization functioning and constrains. Managerial decision making processes can be erroneous in politics, economy and industry for the reason of different reciprocally dependent socio-cognitive factors. This domain became the field of interest of emergent socio-cognitive engineering.